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IPCMC2022

International Project and Construction Management Conference

7TH INTERNATIONAL PROJECT AND CONSTRUCTION MANAGEMENT CONFERENCE

PROCEEDINGS BOOK

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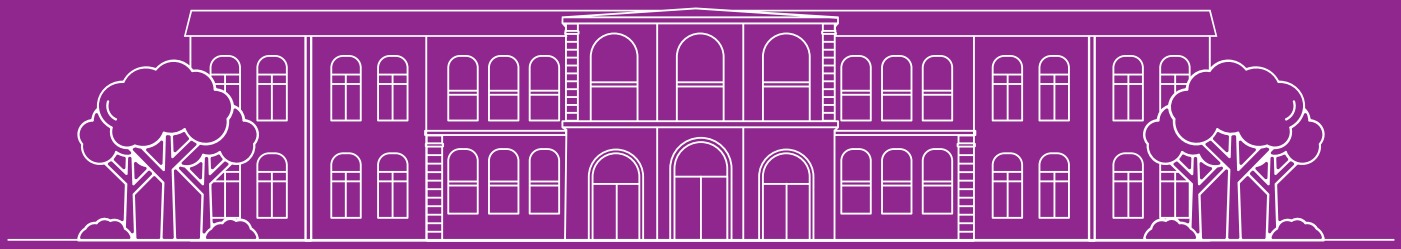


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PREFACE

Welcome to Istanbul for the 7th International Project and Construction Management Conference (IPCMC), We expect this year's conference to be hosted by Yildiz Technical University with more participation than the previous conferences. The conference aims to facilitate interdisciplinary integration and international cooperation among academicians, industry professionals and researchers in the project and construction management field to share their latest research findings, experiences, and prospects. IPCMC 2022 is expected to serve as a forum especially for the early-stage researchers to discuss their research ideas, preliminary findings of their studies and develop new academic networks. Well-known keynote speakers from academia are invited to share their experiences and foresights. As a tradition of the IPCMC conferences, rewards will be delivered to the best papers. In this way, it is aimed to provide an interaction between academia and industry.

IPCMC 2022 attracted a great attention with a total of 143 full-text papers to be presented verbally. The regular increase in the number of papers in the IPCMC to date indicates the importance of project and construction management research at the international level. It can also be considered that the popularity of this year's host city, i.e., Istanbul, may have contributed to this attention. It is Istanbul's endless variety that fascinates its visitors. Istanbul is Türkiye's most developed and largest city, with the latest discoveries indicating that the history of human habitation here goes back some 400,000 years. The museums, churches, palaces, grand mosques, bazaars, and sites of natural beauty are countless.

Looking at the main topics of the conference, the most papers were written on (1) project management, (2) organization, leadership and strategy, (3) construction methods and technology, (4) design management, (5) economics and financial management, (6) real estate development and management, (7) digital technologies, (8) disasters, risk and resilience, (9) clean energy and sustainability, (10) health and safety, (11) legal affairs and dispute resolution, (12) professional issues in education and practice, respectively. These topics are of great importance as they highlight the current needs and trends of research society and the industry. These trends are expected to significantly guide young scholars and professionals who are at the very beginning of their research and/or working lives.

We would like to express our gratitude to Honorary Chair, Rector of YTU, Prof. Tamer Yılmaz, and co-chairs Prof. M. Talat Birgönül and Assoc. Prof. Zeynep Işık for their valuable contributions to the Conference, and all the researchers who took part in the Conference Organizing, Scientific, and Reward Assessment Committees. Finally, we would like to thank 12 companies that provided financial support to the realization of the Conference. We would like to thank all the participants for their contributions to the field of project and construction management by participating in the IPCMC 2022. We sincerely hope that the academic community and industrial practitioners will continue to support us in our attempts to provide even more meaningful conferences with numerous critical idea exchanges, diverse opportunities for fruitful networking and future collaborations between the delegates.

Editors

Cenk Budayan

Serkan Kıvrak

Serdar Ulubeyli

Yildiz Technical University, Istanbul, 20-22 October 2022

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Comparison of the Benefits of CPM and PERT to Project Partners on Different Projects

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Abstract

The increase in the need for industrialization due to urbanization with the rise in the world population increases the demand for planning. Increasingly complex projects in the construction industry and the fact that each project is unique increases the importance of planning. Optimization of time, cost, and quality parameters is a vital mission of modern project management. The effect of time delays in projects on planning and budgeting is an essential problem for project partners and especially project manager. However, the work program, which is mandatory at the contract stage in the Turkish public construction sector, has not reached the desired level in the private sector. At the same time, scientific studies dealing with business programming methods such as CPM and PERT are limited. In this study, The work programming of the productions selected from the projects of the housing and school building in Kayseri was done using CPM and PERT. Thus, the benefits that different projects and methods can provide to the project manager have been compared over time and cost. Based on the data obtained, it was determined that the main difference between the CPM and PERT diagrams was in the time estimates. It was concluded that the project partners should manage the planning process by observing the time and cost together.

Keywords: *construction work planning, project management, CPM, PERT.*

Introduction

The biggest share in the growth of the country's economies; It belongs to sectors such as agriculture, industry, trade and construction. Among these sectors, the construction sector has the largest share. It is seen that the share of the construction sector in the Gross Domestic Product (GDP) is around 30% (KPMG, 2020). Completion of the projects produced in the construction sector, which has an important share in the country's economy, within the desired time, quality and cost is possible with a coordinated work. This coordinated work is provided by the concept of project management.

Project management is the art and science of coordinating people, equipment, materials, money and programs to complete a given project on time and at the desired cost (Oberlender,

2000). Project management covers all phases of the project and ensures that the investor's organization is organized and followed up with the project management team (Sorguç, 2005). The American Construction Management Association (CMMA) has defined project management as controlling time, cost, profit, and quality by applying professional management methods at all stages of a project (Gökuç, 2006). Kezner et al. (2001) defined project management as the whole system of planning, executing and controlling the resources required for a job to achieve the desired goal. Oberlender (2000) defined project management as the balance management between scope, budget and planning and stated that quality is an indispensable element in this balance (Figure 1). In project management, scope means the amount and quality of work, budget means measurable cost, and schedule means the logical sequence and timing of the work (Oberlender, 2000).

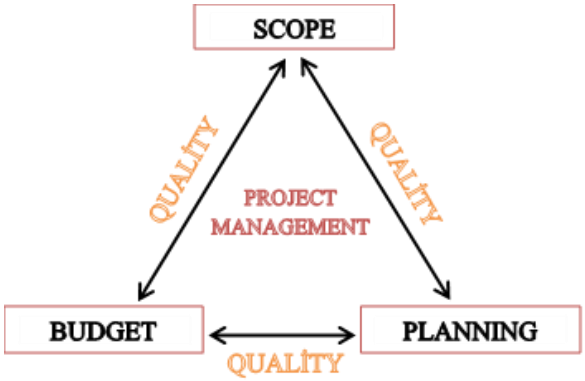


Figure 1: Balance in project management (Oberlender, 2000).

Today, the importance of project management has become an element of competition between companies, due to the coexistence of different disciplines in projects, the originality of projects and the growth of project volumes. In today's economic conditions, it has gained importance to evaluate projects in terms of time and cost, and it has become the most important goal to present the best quality work at the most appropriate time and cost. The concept that constitutes the appropriate method and strategy system to achieve this goal is project planning. Project planning is the creation of a method and strategy system in accordance with the project objectives (Taner, 2019). It continues from the beginning of the project until its closure.

Planning and Planning Techniques in Project Management

In the construction sector, which covers a significant part of the economies of developed and developing countries in the world, project planning has gained importance with the increase in technology and the volume of projects carried out in recent years. Project planning is the process of determining the actions necessary to achieve the project management objective (Gültekin, 2007). İnceoğlu (1980) defined planning as bringing together tools and directing actions to achieve goals. Oberlender (2000) stated that planning is the creation of an action plan to guide the completion of a project (Oberlender, 2000). It is a dynamic process that includes the questions of why, how, when and for whom the work in project planning will be done (Figure 2). In this dynamic process, the actions of the works are checked, and revisions are made according to possible deviations.

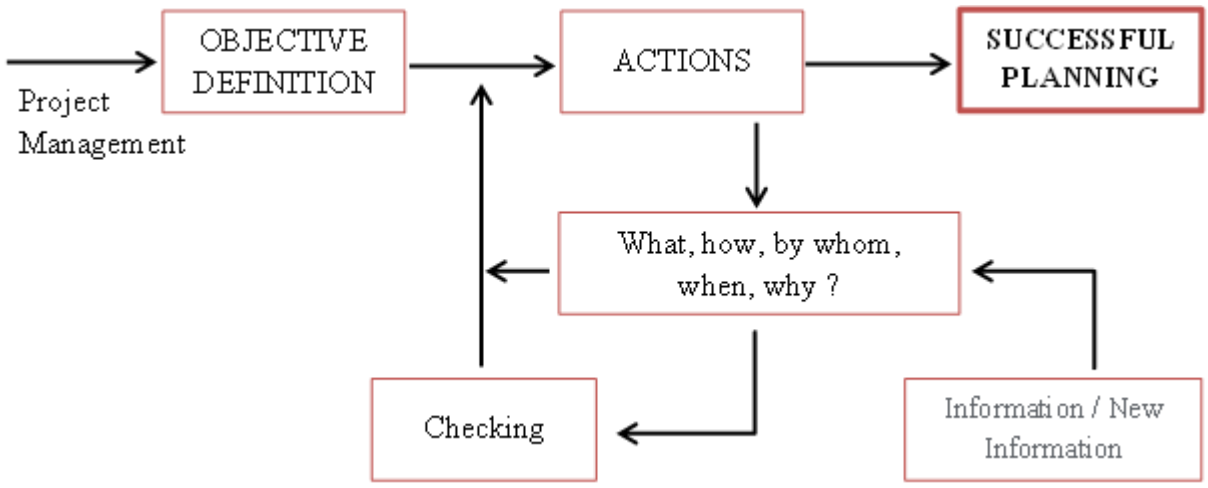


Figure 2: Project planning process cycle (Gültekin, 2007).

In order for the planning to be successful, it is very important that all parties involved in the project participate in the planning process and that constraints and critical activities are identified (Oberlender, 2000). Project planning enables taking the right decisions and carrying out and following the activities accordingly, allowing the necessary measures to be taken for the opportunities and dangers in the project process (Barutçugil, 1988). While some of these activities are independent of each other, the realization of some activities is dependent on the successful completion of another activity (Durucasu et al., 2015). Determining the relationships and durations of these activities, arranging them in line with the priority relationship, and controlling them during and after the implementation are provided by project planning techniques.

Planning Techniques

Towards the end of the 1950s, studies on the development of project planning and programming techniques began to be carried out and have reached the present day by developing. Project planning techniques include Gantt diagrams, Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), Balance Bar Method and Saddle Method (Günaydın, 2001). PERT and CPM diagrams are widely used to observe critical information such as the sequence of activities in the project, the impact and priority of activities on each other, and the effects of problems affecting the operation between activities (Seker, 2007). Based on this, in this study, PERT and CPM methods were examined and used in the field study.

CPM Technique

The Critical Path Method (CPM) was developed in 1956 by the DuPont Company as Rernington Rand consultants as a deterministic approach to planning (Oberlender, 2000). Critical Path Method: It emerged as a result of a parametric programming model developed to solve the project planning problem (Zareei, 2018). It aims to provide the relationship between the activities involved in the project and the timing of costs and resources (Oberlender, 2000). It is used to estimate the minimum project duration, respectively, of the activities with the critical path or the longest duration in the project (Hiller, 1990). Five parameters are

considered for each activity to determine the critical path, including earliest start (EEBa), earliest finish time (EEBi), latest start (EGBa), latest finish time (EGBi), and scheduling flexibility. In order to obtain the data for these five parameters, three separate calculations are performed: forward calculation, backward calculation and total delay time (Yalkı, 2019). These; 1. Forward Calculation: It is done to find the earliest start and earliest finish time of each activity in the project. This calculation is made for all activities throughout the process (Yalkı, 2019). The calculation consists of three steps. These are (Yalkı, 2019);

- Step 1: EEBa (0) =1
- Step 2: EEBi = EEBa + Activity Time (Sj) (j=1,2,3 for n (n is the last activity.))
- Step 3: EEBa = EEBi + 1 for Next Event

Backward Calculation

It is done to find the latest start time and latest finish time of each activity in the project. It consists of two steps. These are (Yalkı, 2019);

- Step 1: EGBa = EGBi - Duration of Activity (Sj)
- Step 2: Latest Start for Next Event = EGBi + 1

Total Delay (Delay) Time

Calculates the total amount of delay time (TGS) allowed for each activity in the project. If this time is equal to zero, it means that the activity must be done on time and the activity is critical activity (Zareei, 2018; Yalkı, 2019) to calculate the total delay time;

- EGBa – EEBa = EGBi - EEBi = TGS

In line with the data obtained, the CPM diagram is created according to the duration of each activity and the interdependence of the activities. In the diagram, the earliest start and end time of each project, the latest start and end time, the activity name and the activity duration are expressed as data (Figure 3) (Zareei, 2018).

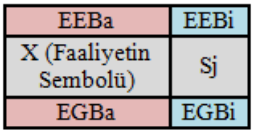


Figure 3: Activity show at CPM (Yalkı, 2019).

PERT Technique

The Program Evaluation and Review Technique (PERT) was developed by the US Navy in 1957 as a probabilistic approach to timing (Oberlender, 2000). The program evaluation and review technique is a management science for project planning and control (Siswanto et al., 2011). The purpose of PERT is not to create a program but to analyze the project network (Nicholas & Herman, 2012). The biggest difference between the PERT method and the CPM is the estimation of activity times (Oberlender, 2000). PERT addresses uncertainty in time using three-time estimates: optimistic, average, and pessimistic. Optimistic time (a) is the

shortest time the activity can be completed, assuming everything is going well. average (m); It is the time that will occur with the repetition of the activity. pessimistic time (b); assuming everything is going badly, is the longest the activity can require. PERT uses three different formulas to find the expected duration (te), variance (o2) and standard deviation (o) of each activity. These are;

- Expected Duration of Each Activity: te = (a + 4m + b) / 6
- Variance and Standard Deviation: o2 =[(b-a) / 6]2 o = (b-a) / 6

In line with the data obtained, the PERT diagram is created according to the duration of each activity and the interdependence of the activities. The diagram shows the optimistic time (a), the most likely time (m), the pessimistic time (b), the name of the activity (x), and the expected duration (te) of the activity for each activity (Figure 4).

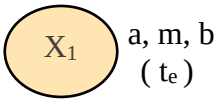


Figure 4: Activity Show at PERT (Yalkı, 2019).

In line with these data, it has been determined that temporal data of the projects are obtained with CPM and PERT methods in project management planning. Since it is aimed to obtain the best quality product with the most appropriate time and cost in project management, there is a relationship between time planning and cost. Therefore, it is necessary to make the necessary cost analysis for each activity (Gültekin, 2007; Siswanto et al., 2011). With cost analysis, if there are activities within the project that can be accelerated in the project, the effects of these activities on the whole project are examined by calculating which activities, their duration, and costs (Siswanto et al., 2011). The relationship between time and cost is calculated by accelerating cost (Siswanto et al., 2011). This calculation is;

$$\text{Acceleration cost (slope)} = \frac{\text{Accelerated Cost} - \text{Normal Cost}}{\text{Normal Time - Accelerated Time}}$$

In line with these data, within the scope of the study, time-cost analyzes were carried out in projects with different functions and volumes using CPM and PERT methods. In line with the data obtained, the effects of the time and cost problems that may arise with the changes in the programming on the project stakeholders were examined and suggestions were made to the stakeholders.

Study Area and Method

Today, in direct proportion to the growth of cities, people's needs for housing, education, public, health and sports structures have increased. Since the population density and human needs are directly proportional, the buildings selected in the study area were selected from the central districts with the highest population density. Within the scope of the study, residence and school projects located in the central districts of Kayseri were examine. Located in Talas district, the school (A) with 15 classrooms consists of three floors, a basement floor, a ground floor and a normal floor. The school, which was built by the public, has a construction area of 1,820,00 m² (Figure 5). The residence (B), which is located in Melikgazi district and consists of 44 flats and 3 shops, consists of 16 floors, including a basement, a ground floor, 13 normal

floors and an attic. Built by a private construction company, the residence has a construction area of 9,448.00 m² (Figure 6). The data of the projects are given in Table 1.



Figure 5: School project (MEB, 2020).



Figure 6: Residence project (İkonProje, 2020).

Table 1. Information on the projects.

Projeler	**School (S)**	**Residence (R)**
Location (District)	Talas	Melikgazi
Construction Area (m²)	1.820,00 m²	9.448,00 m²
Number of Floors	3	16
Number of Classrooms / Flats	15	44
Number of Shops	-	3

All activities related to each floor in the projects are carried out by separate worker groups. "Mould Activities (A), Iron Activities (B), Concrete Activities (C), Brick Wall Activities (D)" were selected among the activities to be carried out in the project. The priority relationship between these activities is expressed in Table 2 over the basement and ground floor. Activities A1, B1, C2 etc. Expressing it as the form was made to show the activities related to the floors. Durations are calculated in days.

Table 2. Priority relationship between activities.

Activities	**Priority Relationships**
A1 (Basement Floor Formwork Activities)	-
B1 (Basement Floor Iron Activities)	A1 (Basement Floor Formwork Activities)
C1 (Basement Floor Concrete Activities)	B1 (Basement Floor Iron Activities)
A2 (Ground Floor Formwork Activities)	C1 (Basement Floor Concrete Activities)
D1 (Basement Brick Wall Activities)	C1 (Basement Floor Concrete Activities)
B2 (Ground Floor Iron Activities)	A2 (Ground Floor Formwork Activities)
C2 (Ground Floor Concrete Activities)	B2 (Ground Floor Iron Activities)
D2 (Ground Floor Brick Wall Activities)	C2 (Ground Floor Concrete Activities)

Quantities of these activities were made, and the duration of the activities were analyzed according to the unit price list prepared by the Ministry of Environment and Urbanization for 2020 (Table 3). CPM and PERT diagrams were created in line with these data.

Method

Today, project planning, which will lead to success in project management, has gained importance due to the fact that project management is a competitive element. Projects with different functions and volumes were selected to examine the effects of CPM and PERT techniques, which are among the techniques that provide project planning, on project stakeholders. After the network diagram of the projects was created, the critical ways that could cause the delay of the projects were examined. Possible problems that may be encountered in terms of time were defined and alternative solutions were searched.

Since the concepts of time and cost are in a relationship in project management, cost analysis has been carried out. Since the PERT method was carried out in an environment of uncertainty, the cost analysis was examined over the PERT data. With the study, the benefits that both different projects and the methods used can provide to the project manager are compared. In line with the data obtained, the effects of the changes in programming and the cost and time problems that may arise on the project stakeholders were examined and suggestions were made to the stakeholders.

Table 3. Quantity takeoff abstract.

Quantity Takeoff Abstract							
Project	Field of Activity	Activity No	Poz Number	Activity	Quantity	Unit	Time to Perform with the Team (Days)
SCHOOL	Basement	C_1	Y.16.050/16	Concrete	278,01	m^3	6
		A_1	Y.21.001/03	Formwork	1.884,69	m²	177
		B_1	Y.23.014	Iron	24,015	Tonne	30
		D_1	Y.18.001 /C16	Wall	306,47	m²	33
	Ground floor	C_2	Y.16.050/16	Concrete	184.59	m^3	4
		A_2	Y.21.001/03	Formwork	1.258,89	m²	118
		B_2	Y.23.014	Iron	20.772	Ton	26
		D_2	Y.18.001 /C16	Wall	429.74	m²	46
	Regular Floor	C_3	Y.16.050/16	Concrete	184.59	m^3	4
		A3	Y.21.001/03	Formwork	1258.89	m²	118
		B_3	Y.23.014	Iron	20.772	Tonne	26
		D_3	Y.18.001 /C16	Wall	444.98	m²	46
	Total Days						634
RESİDENCE	Basement	C_1	Y.16.050/16	Concrete	2.018,13	m^3	31
		A_1	Y.21.001/03	Formwork	678,00	m²	74
		B_1	Y.23.014	Iron	18,20	Tonne	13
		D_1	Y.18.001 /C16	Wall	200,26	m²	22
	Ground floor	C_2	Y.16.050/16	Concrete	2.018,13	m^3	31
		A_2	Y.21.001/03	Formwork	678,00	m²	74
		B_2	Y.23.014	Iron	18,20	Ton	13
		D_2	Y.18.001 /C16	Wall	324,20	m²	35
	Regular Floor	C_3	Y.16.050/16	Concrete	26.235,69	m^3	185
		A3	Y.21.001/03	Formwork	8.825,17	m²	178
		B_3	Y.23.014	Iron	236,60	Tonne	181
		D_3	Y.18.001 /C16	Wall	2.480,21	m²	256
	Total Days						1093

Findings and Discussion

In order to plan each project with the CPM method in line with the data obtained; Five parameters were calculated for each activity: earliest start (EEBa), earliest finish time (EEBi), latest start (EGBa), latest finish time (EGBi) and total latency time (TGS) (Table 4). Afterwards, CPM diagrams were created according to the duration of each activity and the interdependence of the activities. First, the CPM diagram of the activities selected from the school project was created and it was determined that they could be completed in 83 days (Figure 7). Afterwards, a CPM diagram was created for the housing project, and it was seen that it could be completed in 418 days (Figure 8). The critical path of the projects has been determined as "A1, B1, C1, D1, A2, B2". It has been seen that any delay in these activities will cause disruption of the entire project.

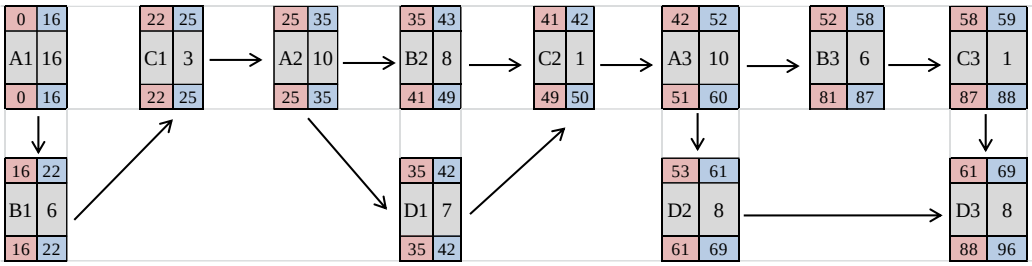


Figure 7: School project CPM diagram.

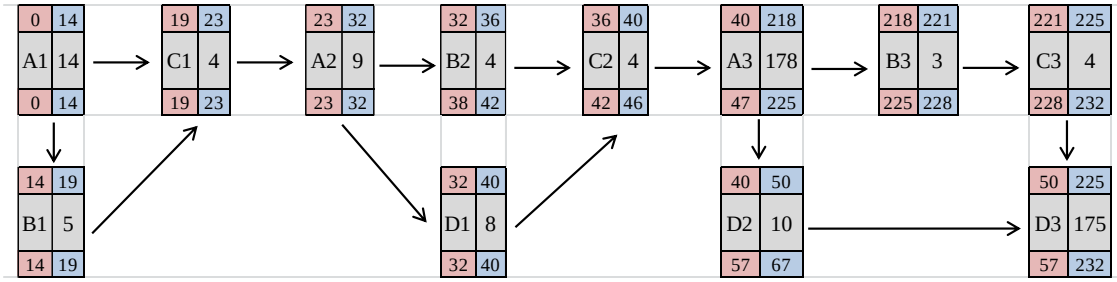


Figure 8: Residence project CPM diagram.

Table 4. CPM data of activities.

CPM VERİLERİ								
Project	Activity Area	Activity Number	EEBa	EEBi	EGBa	EGBi	TGS	Activity Duration
SCHOOL	Basement	A_1	0	16	0	16	0	16
		B_1	16	22	16	22	0	6
		C_1	22	25	22	25	0	3
		D_1	35	42	35	42	0	7
	Ground floor	A_2	25	35	25	35	0	10
		B_2	35	43	35	43	0	8
		C_2	41	42	49	50	7	1
		D_2	53	61	61	69	8	7
	Regular Floor	A_3	42	52	51	60	9	10
		B_3	52	58	81	87	29	6
		C_3	58	59	87	88	19	1
		D_3	61	69	88	96	27	8
	Total Days							83
RESİDEN VE	Basement	A_1	0	14	0	14	0	14
		B_1	14	19	14	19	0	5

		C_1	19	23	19	23	0	4
		D_1	32	40	32	40	0	8
	Ground floor	A_2	23	32	23	32	0	9
		B_2	32	36	32	36	0	4
		C_2	36	40	36	40	0	4
		D_2	40	50	57	67	17	10
	Regular Floor	A_3	40	218	47	225	7	178
		B_3	218	221	225	228	7	3
		C_3	221	225	228	232	7	4
		D_3	50	225	57	232	7	175
	Total Days							418

Afterwards, triple time estimates for each activity determined within the projects, expected durations, variances and standard deviations of these activities were calculated (Table 5). Then, according to the PERT technique, the network diagram of the project was created with the data of optimistic time (a), average (m), pessimistic time (b), expected time (te). First, the PERT diagram of the activities selected from the school project was created, and it was determined that they could be completed in a period of 97-131 days (Figure 9). Afterwards, a PERT diagram was created for the housing project, and it was seen that it could be completed in 265-412 days (Figure 10). The critical path of the projects has been determined as "A1, B1, C1, D1, A2, B2". The standard deviation of the school project is 9 days, which is obtained by adding the standard deviations of the critical activities. The standard deviation of the housing project is 16 days.

Table 5. PERT data of activities.

PERT Data								
Project	Activity Area	Activity Number	Optimistic Time (A)	Average (m)	Pessimistic Time (B)	Expected Time (te)	Variance (o^2)	Standard Deviation (o)
SCHOOL	Basement	A_1	2	4	6	4	0,44	0,66
		B_1	7	15	22	15	6,25	2,5
		C_1	2	3	5	3	0,25	0,5
		D_1	7	15	22	15	6,25	2,5
	Ground floor	A_2	2	3	4	3	0,11	0,33
		B_2	7	15	22	15	6,25	2,5
		C_2	2	3	5	3	0,11	0,33
		D_2	7	15	22	15	6,25	2,5
	Regular Floor	A_3	2	3	4	3	0,11	0,33
		B_3	7	15	22	15	6,25	2,5
		C_3	2	3	5	3	0,11	0,33
		D_3	7	15	22	15	6,25	2,5
					Total Days	114	-	17,48
RESİDENCE	Basement	A_1	10	21	31	21	3,36	1,83
		B_1	12	24	37	24	17,3	4,16
		C_1	4	8	13	8	2,25	1,5
		D_1	7	15	22	15	6,25	2,5
	Ground floor	A_2	10	21	31	21	3,36	1,83
		B_2	12	24	37	24	17,3	4,16
		C_2	4	8	13	8	2,25	1,5
		D_2	7	15	22	15	6,25	2,5
	Regular Floor	A_3	30	61	126	61	256	16
		B_3	28	56	112	56	196	14
		C_3	20	41	82	41	106,7	10,33
		D_3	25	50	75	50	69,4	8,33
					Total Days	344	-	68,64

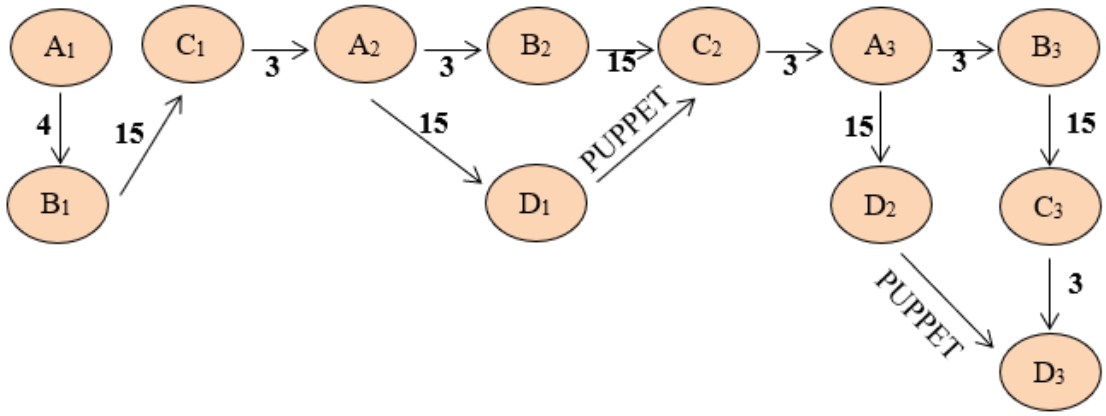


Figure 9: School project PERT diagram.

The activities with the most delay time in the school project are B1, D1, B2, D2, B3, D3 activities with 2.5 days. These activities are followed by activity A1, which has a lag time of 0.66 days. Since these activities have more delay time than other activities, it is possible to transfer resources from these activities to critical activities in the form of time and labor [22]. In this direction, it has been determined that the activities of B1, D1, B2, D2, B3, D3 can be accelerated by allocating additional worker groups to critical activities A1, C1 and A2.

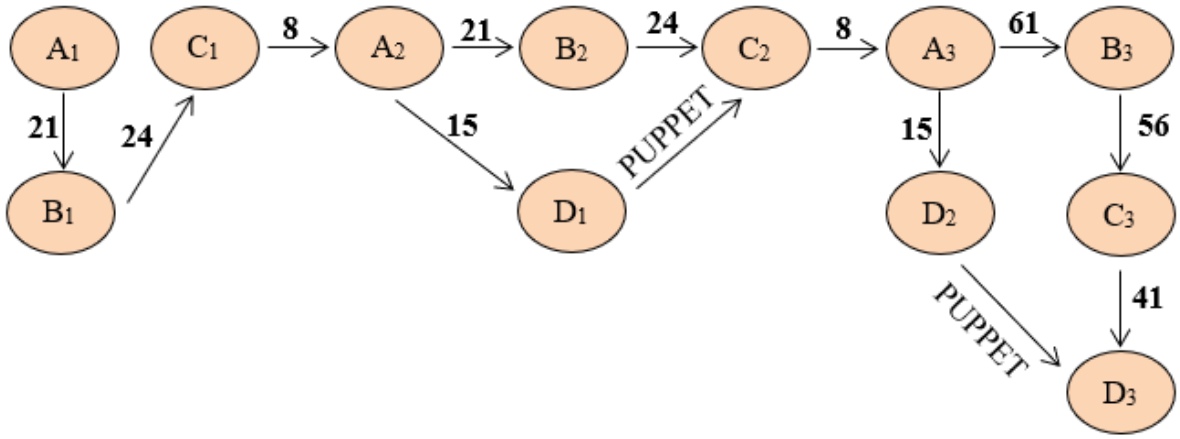


Figure 10: Residence project PERT diagram

The activity with the highest delay time in the housing project is the A3 activity with 16 days. This activity is followed by activity B3 with a latency of 14 days and activity C3 with a latency of 10.33 days. Additional worker groups can be allocated from the A3, B3, C3 activities in the project to the critical activities A1, B1, C1, D1, A2 and B2.

The completion times of the activities were determined by creating CPM and PERT diagrams of the selected activities within the projects examined in this study (Table 6). Due to the different functions and volumes of the projects, it allows the project managers to choose the optimum or near-optimal alternatives by comparing the different time combinations of the projects. It has been determined that planning the projects separately with CPM and PERT techniques provides convenience to the project managers in establishing different perspectives and problem structure. Thus, the project manager can easily decide which activities should not be interrupted and which should be emphasized.

Table 6. Architectural and planning information of the projects reviewed.

PROJECTS		SCHOOL	RESİDENCE
Architectural Information	Location (District)	Talas	Melikgazi
	Construction Area (m²)	1.820,00 m²	3.800,00 m²
	Number of Floors	3	16
	Number of Classrooms / Flats	15	44
	Number of Shops	-	3
Planning Information	CPM (Day)	83	418
	PERT (Day)	97-131	265-412

In line with these data, it has been determined that temporal data of the projects are obtained with CPM and PERT methods in project management planning. Considering that the project, which was planned with the PERT method, was carried out in an environment of uncertainty, and could be affected by some changes arising from various factors, the cost analysis was carried out over PERT. First of all, the costs of the selected activities within the housing and school project were calculated according to the unit price list prepared by the Ministry of Environment and Urbanization for 2020. Assuming that the activities are accelerated by 2 times, the accelerated durations of the activities have been determined (Table 6).

Table 7. Costs and acceleration times of activities.

Time-cost									
Project	Activity Area	A. No	Poz Number	Activity	Quantity	Unit	Time	A. Time	Cost
SCHOOL	Basement	C_1	Y.16.050/16	Concrete	278,01	m^3	4	2	72.944,26 ₺
		A_1	Y.21.001/03	Formwork	1.884,69	m²	15	7,5	126.651,168 ₺
		B_1	Y.23.014	Iron	24,015	Ton	3	1,5	106.727,70 ₺
		D_1	Y.18.001 /C16	Wall	306,47	m²	15	7,5	20.150,40 ₺
	Ground floor	C_2	Y.16.050/16	Concrete	184.59	m^3	3	1,5	48.432,72 ₺
		A_2	Y.21.001/03	Formwork	1.258,89	m²	15	7,5	84.597,40 ₺
		B_2	Y.23.014	Iron	20.772	Ton	3	1,5	92.306.24 ₺
		D_2	Y.18.001 /C16	Wall	429.74	m²	15	7,5	28.255,40 ₺
	Regular Floor	C_3	Y.16.050/16	Concrete	184.59	m^3	3	1,5	48.432,72 ₺
		A3	Y.21.001/03	Formwork	1.258.89	m²	15	7,5	84.597,40 ₺
		B_3	Y.23.014	Iron	20.772	Ton	3	1,5	92.306.24 ₺
		D_3	Y.18.001 /C16	Wall	444.98	m²	15	7,5	29.257,43 ₺
								Total Cost	**835.659,07 ₺**
RESİDENCE	Basement	C_1	Y.16.050/16	Concrete	2.018,13	m^3	21	10,5	529.516,94 ₺
		A_1	Y.21.001/03	Formwork	678,00	m²	24	12	45.561,60 ₺
		B_1	Y.23.014	Iron	18,20	Ton	8	4	80.884,62 ₺
		D_1	Y.18.001 /C16	Wall	200,26	m²	15	7,5	13.167,09 ₺
	Ground floor	C_2	Y.16.050/16	Concrete	2.018,13	m^3	21	10,5	529.516,94 ₺
		A_2	Y.21.001/03	Formwork	678,00	m²	24	12	45.561,60 ₺
		B_2	Y.23.014	Iron	18,20	Ton	8	4	80.884,62 ₺
		D_2	Y.18.001 /C16	Wall	324,20	m²	15	7,5	21.316,15 ₺
	Regular Floor	C_3	Y.16.050/16	Concrete	26.235,69	m^3	61	30,5	6.883.720,3 ₺
		A3	Y.21.001/03	Formwork	8.825,17	m²	56	28	593.051,42 ₺
		B_3	Y.23.014	Iron	236,60	Ton	41	20,5	1.051.500,08 ₺
		D_3	Y.18.001 /C16	Wall	2.480,21	m²	50	25	163.073,80 ₺
								Total Cost	**10.037.755,16 ₺**

In line with these data, acceleration costs, accelerating times and acceleration cost (slope) of the activities in the project were calculated (Table 8).

It has been determined that the costs selected within the school project can be completed to 2,506,977.21 ₺ by accelerating the activities by 2 times, and the costs selected within the housing project can be completed to 30,113,265,48 ₺. Acceleration processes can be performed with this data obtained. In this direction, while accelerating, three activities with the smallest slope were selected on the road to be accelerated.

The activity with the lowest slope in the school project is the D1 activity with 20,150,40 ₺. This activity is followed by D2 activity with 28.255.40 ₺ and D3 activity with 29.257.43 ₺. Accordingly, D1, D2 and D3 activities were selected. The activity with the lowest slope in the housing project is the D1 activity with 13,167.09 ₺. This activity is D2 activity with 21,316,15 ₺ and A1 activities with 45,561,60 ₺. Accordingly, D1, D2 and A1 activities were selected. Acceleration processes were applied to the selected activities, and as a result of this process, the completion times and costs of the activities were determined (Table 9).

Table 8. Accelerated costs and slopes of activities.

SÜRE-MALİYET								
Project	Activity Area	A. No	Activity	Time	Cost	A. Time	Accelerated Cost	Slope
SCHOOL	Basement	C_1	Concrete	4	72.944,26 ₺	2	218.832,78 ₺	72.944,26 ₺
		A_1	Formwork	15	126.651,16 ₺	7,5	379.953,48 ₺	126.651,16 ₺
		B_1	Iron	3	106.727,70 ₺	1,5	320.183,10 ₺	106.727,70 ₺
		D_1	Wall	15	20.150,40 ₺	7,5	60.451,20 ₺	20.150,40 ₺
	Ground floor	C_2	Concrete	3	48.432,72 ₺	1,5	145.298,16 ₺	48.432,72 ₺
		A_2	Formwork	15	84.597,40 ₺	7,5	253.792,20 ₺	84.597,40 ₺
		B_2	Iron	3	92.306.24 ₺	1,5	276.918,72 ₺	92.306.24 ₺
		D_2	Wall	15	28.255,40 ₺	7,5	84.766,20 ₺	28.255,40 ₺
	Regular Floor	C_3	Concrete	3	48.432,72 ₺	1,5	145.298,16 ₺	48.432,72 ₺
		A3	Formwork	15	84.597,40 ₺	7,5	253.792,20 ₺	84.597,40 ₺
		B_3	Iron	3	92.306.24 ₺	1,5	276.918,72 ₺	92.306.24 ₺
		D_3	Wall	15	29.257,43 ₺	7,5	84.766,20 ₺	29.257,43 ₺
	Total			**109**	**835.659,07 ₺**	**54,5**	**2.506,977,21 ₺**	**835.659,07 ₺**
RESİDENCE	Basement	C_1	Concrete	21	529.516,94 ₺	10,5	1.588.550,82 ₺	529.516,94 ₺
		A_1	Formwork	24	45.561,60 ₺	12	136.684,80 ₺	45.561,60 ₺
		B_1	Iron	8	80.884,62 ₺	4	242.653,86 ₺	80.884,62 ₺
		D_1	Wall	15	13.167,09 ₺	7,5	39.501,27 ₺	13.167,09 ₺
	Ground floor	C_2	Concrete	21	529.516,94 ₺	10,5	1.588.550,82 ₺	529.516,94 ₺
		A_2	Formwork	24	45.561,60 ₺	12	136.684,80 ₺	45.561,60 ₺
		B_2	Iron	8	80.884,62 ₺	4	242.653,86 ₺	80.884,62 ₺
		D_2	Wall	15	21.316,15 ₺	7,5	63.948,45 ₺	21.316,15 ₺
	Regular Floor	C_3	Concrete	61	6.883.720,3 ₺	30,5	2.066.160,90 ₺	6.883.720,3 ₺
		A_3	Formwork	56	593.051,42 ₺	28	1.779.154,26 ₺	593.051,42 ₺
		B_3	Iron	41	1.051.500,08 ₺	20,5	3.154.500,24 ₺	1.051.500,08 ₺
		D_3	Wall	50	163.073,80 ₺	25	489.221,40 ₺	163.073,80 ₺
	Total			**344**	**10.037.755,16 ₺**	**172**	**30.113.265,48 ₺**	**10.037.755,16 ₺**

Table 9. Costs and times of accelerated activities.

HIZLANDIRILMIŞ FAALİYETLER								
Project	Activity Area	A. No	Poz Number	Activty	Quantity	Unit	Accelerated Time	Accelerated Cost
SCHOOL	Basement	D_1	Y.18.001 /C16	Wall	306,47	m²	7,5	60.451,20 ₺
	Ground floor	D_2	Y.18.001 /C16	Wall	429.74	m²	7,5	84.766,20 ₺
	Regular Floor	D_3	Y.18.001 /C16	Wall	444.98	m²	7,5	84.766,20 ₺
	Total Cost							**229.983,60 ₺**
RESİDENCE	Basement	A_1	Y.21.001/03	Formwork	678,00	m²	10,5	136.684,80 ₺
		D_1	Y.18.001 /C16	Wall	200,26	m²	7,5	39.501,27 ₺
	Ground floor	D_2	Y.18.001 /C16	Wall	324,20	m²	7,5	63.948,45 ₺
							Total Cost	**240.134,52 ₺**

D1, D2 and D3 activities in the school project were accelerated and the completion time of the activities selected from the project was reduced from 114 days to 92.5 days. With the acceleration of the activities, its cost increased from 835,659.07 ₺ to 987,979.44 ₺. Accordingly, the acceleration cost (slope) of the school project was calculated and found to be 7,084.66 ₺ (Figure 11).

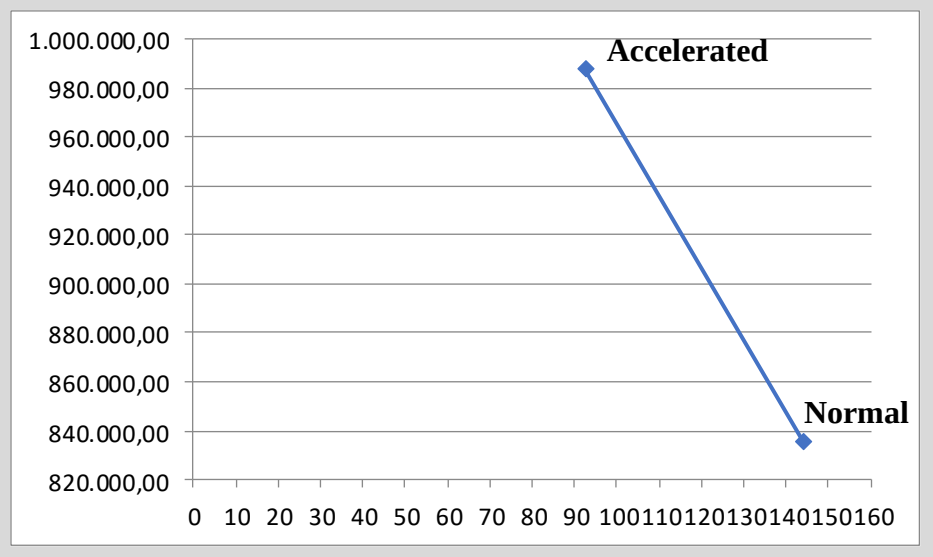


Figure 11: School project duration-cost analysis

D1, D2 and A1 activities in the housing project were accelerated and the completion time of the activities selected from the project was reduced from 344 days to 318.5 days. With the acceleration of the activities, its cost increased from 10,037,755.16 ₺ to 10,197,844.84 ₺. In this direction, the acceleration cost (slope) of the housing project was calculated and determined to be 6,278.02 ₺ (Figure 12)

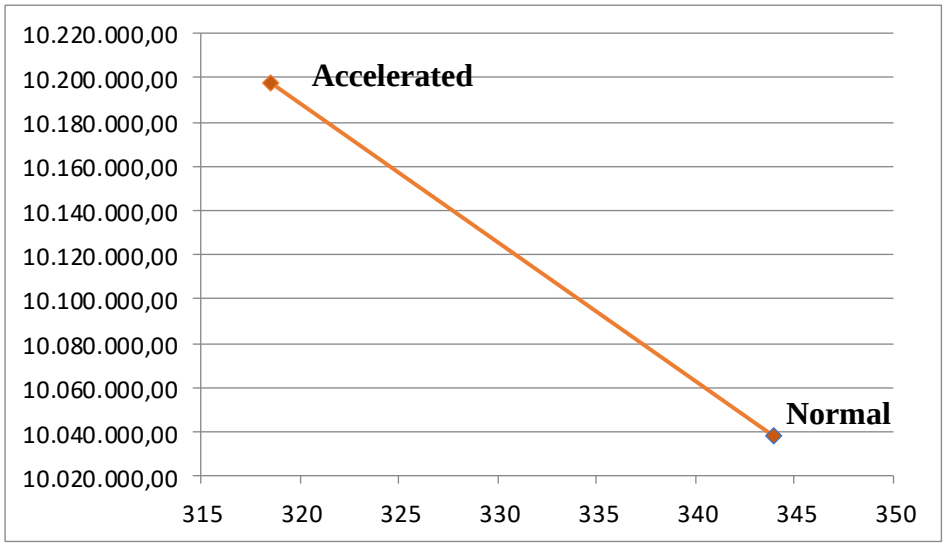


Figure 12: Residence project duration-cost analysis.

Conclusion and Recommendations

Within the scope of the study, CPM and PERT diagrams were created by selecting projects with different functions and volumes to examine the effects of CPM and PERT techniques on project stakeholders. In line with the data obtained, it has been determined that the main difference between CPM and PERT diagrams is in the time estimates (Figure 13). While the completion time of the activities in the school project was 83 days in the CPM technique, it was determined as 114 days in the PERT technique. In the housing project, while the completion time of the activities was 418 days in the CPM technique, it was determined as 339 days in the PERT technique.

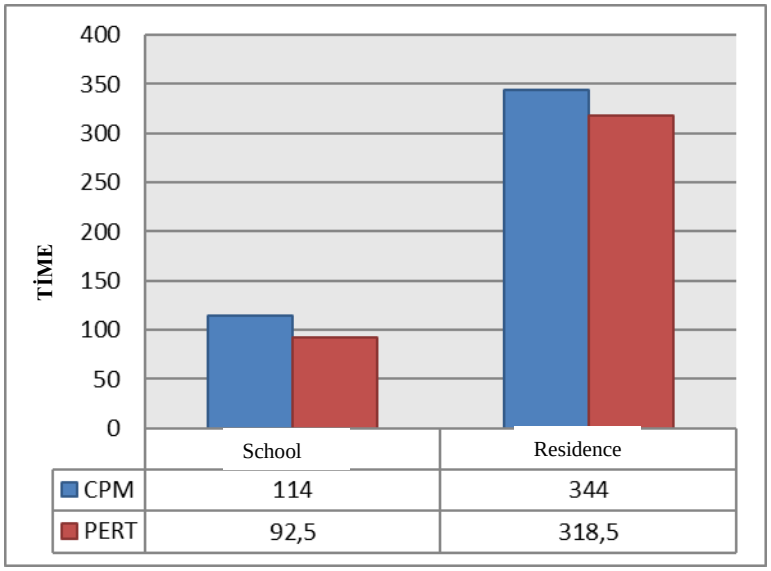


Figure 13: Comparison of projects CPM and PERT times.

Afterwards, the acceleration costs of the projects were determined by making cost analyzes with the temporal data of the projects (Figure 14). While the acceleration cost of the activities accelerated for 21.5 days in the school project was 7,084.66 ₺, the acceleration cost of the activities accelerated for 25.5 days in the housing project was determined as 6,278.02 TL.

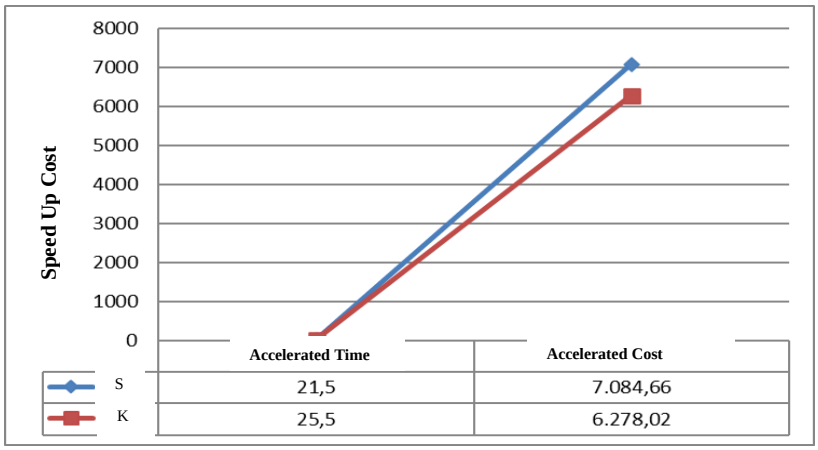


Figure 14: Comparison of acceleration costs of projects.

With the use of CPM and PERT methods in project planning by the project stakeholders, critical activities and ways that affect the realization time of the activities were determined, and it was seen that from which non-critical activities labor can be transferred to critical activities and the duration of the activities can be determined. In line with the data obtained, it has been seen that the project manager must make a time-cost analysis in order for the project management to be successful. Thus, it was emphasized that the project manager should manage the project planning process by observing the activities that can be accelerated in the projects, their duration and costs. With this type of analysis, the accuracy of which is trusted, the project management will be successful and quality products will be achieved by making time-cost analyzes of the project stakeholders in the planning process of the projects in public and private sector investments. It is aimed that this study will contribute to future academic studies and stakeholders in the building sector.

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Critical Construction Time Overruns Causes in Turkish Construction Industry

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Abstract

Time overrun is one of the most serious issues in construction industry throughout the world, which may result in many negative impacts on the construction project like budget overrun, low productivity, contract expiration, work acceleration resulting in bad quality, and disputes among construction stakeholders, and construction industry overall. Construction industry has a large share in the country's economy and in the employment of the workers in Turkey. Considering the importance of the sector for the countries, it is essential to determine the critical causes of the time overrun in order to prevent or minimize this problem. Therefore, this research aims to determine the critical time overrun causes in Turkish construction industry. To reach this aim first, time overrun causes for construction projects were determined with systematic literature review, and critical causes of time overrun were identified thereafter. Using Web of Science database, 181 articles indexed in SCI-E, SSCI, AHCI, and published last 10 years were reviewed through a systematic literature review (SLR). As a result of SLR, 60-time overrun causes were identified under eight categories. The questionnaire was designed by the obtained 60 causes with 5-point Likert scale as measuring instrument and conducted to 600 architects and engineers occupied at construction industry. A total of 127 valid questionnaire were returned, representing a 21.16 % response rate. Obtained data analyzed using reliability analysis, and mean score ranking. The findings of this research revealed that "decision change of the employer during the design and implementation phase"," shortage of supplies, delays in delivery", "poor communication and coordination among stakeholders", "price fluctuations", "delayed permits from the municipality", lack of skilled workers", "design changes", and "unpredictable weather conditions" are the most critical construction time overrun causes. Considering these critical causes, the suggestions have been developed to improve the current situation.

Keywords: *time overrun, construction management, construction industry.*

Introduction

The construction industry in Turkey considered one of the key drivers of the economy. The construction industry contributed $33 billion USD to the national GDP, with a share of 5.4% (Tekçe, 2020). Further, the industry employs as much as 10% (excluding agriculture) of the Turkish workforce (Turkish Contractors Association, 2016). A construction project is considered as successful when it is completed on time, within budget, and in accordance specified quality standards (Yılmaz, 2020), with the specifications (Olawale & Sun, 2013).

Time overrun is one of the most significant problems in construction industry which directly affect the project success, adversely.

Time overrun is often defined as delay the beyond a project completion date (Ansah & Sorooshian, 2018) that the parties agreed upon for the delivery of a project (Parchami Jalal & Shoar, 2017). Construction projects might overlay time overrun in different stages, from project start through project completion (Zaman et al., 2022). However, most time overruns occur at the construction phase (Ansah & Sorooshian, 2018). Time overruns in construction projects, affect negatively the planning and delivery dimension of operations, regardless of the socio-economic status of the country involved (Yap et al., 2021). This problem is a major phenomenon in construction industry, particularly in emerging countries (Amoatey et al., 2015). The cause and effect of the length of time spent on building in Tanzania are presented by Kikwasi (2013). According to another study conducted in Qatar, between 2000 and 2013 72 percent of public construction projects were not completed on schedule (Senouci, 2016). Similar to this, Maceda (2016) notes that time overruns occur in 70% of projects in Dubai. These studies present that construction projects are often delayed, which are demanding for both developed and developing countries. Notably, the construction holdup will result in an increase in project expenditure overall (Faridi, 2006).

Hitherto many effects of time overrun have been identified at previous studies (Amarkhil et al., 2021; Ansah & Sorooshian, 2018; Jahangoshai Rezaee et al., 2019) and the subject is still a critical topic of research among construction management researchers globally (Zaman et al. 2022). Amarkhil et al. (2021) identified frequently studied topics on the project delay to understand type and impact of delays to manage project. Kazaz et al. (2012) particularized causes of delays in construction projects in Turkey. Zidane and Andersen (2018), studied about universal delay factors in construction projects in Norway. As seen from a brief review, several obstacles were identified, all of which are important; however, it is unclear which of them are the critical and significant at the construction phase. Understanding the causes of time overrun that can affect the project at construction phase is important to recognize the mitigation measures to diminish the effect on the project performance. Hence, the objective of this study is to identify the critical causes of time overrun in the Turkish construction industry.

Research Method

This research aims to determine the critical time overruns causes in Turkish construction industry. The research methodology is divided into four phases; identification of time overrun causes with systematic literature review, organizing the questionnaire, data collection and data analyses to reach the aim of the study.

In the first stage, time overrun causes for construction projects were determined with systematic literature review (SLR). Conducting SLR, that involves “planning the review,” “conducting the review,” and “documenting the review” stages, extensive literature was examined and presented in Figure 1.

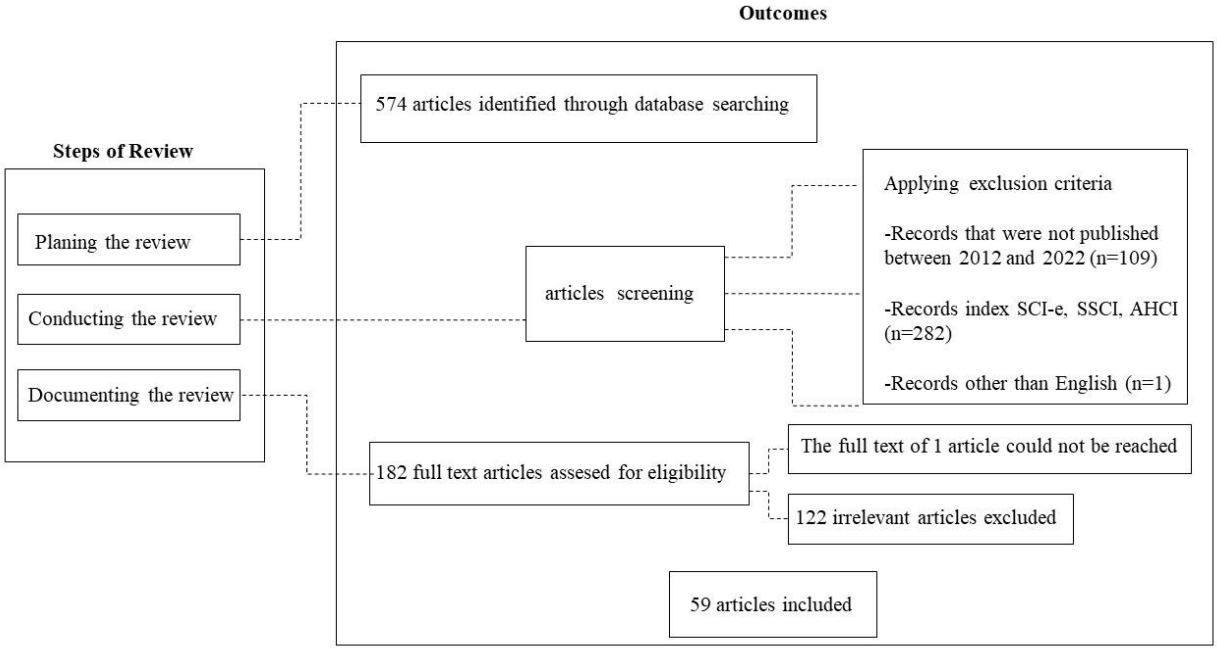


Figure 1: Stages of systematic literature review.

Web of Science (WoS) search engine was used to find scientific papers regarding time overruns at construction industry. WoS was considered for its accuracy, comprehensiveness, and skilled coverage of several study fields (Hong & Chan, 2014).

Keywords were used to set search parameters in the WoS database. The search parameters were remarked as keywords "time overrun" AND "construction" NOT "road" NOT "highway" NOT "infrastructure". In total, 574 journal articles were identified during the initial search. Based on the study topic, researchers should define inclusion and exclusion criteria (Kitchenham & Charters, 2007). The search was limited to English-language articles, and review papers published in academic journals between 2012-2022, and indexed in SCI-E, SSCI, AHCI. Among the 574 records, 392 of them extracted applying the exclusion criteria. The full text of 1 article could not be reached, therefore 181 full-text studies having full access. Due to irrelevancy, 122 studies were excluded. Finally, 59 studies were considered relevant and included selected for thorough examination to identify critical time overrun causes. Finally, 60-time overrun causes (TOCs) that were directly related to these eight categories were determined and are listed in Table 1.

At the second phase of the methodology, a questionnaire was designed for architects, and civil engineers and contractors working at construction firms in Turkey based on SLR results. Considering the time overrun causes, the questionnaire is consisted of eight sections, and total of 60 TOCs with 5-point Likert scale. The questionnaire conducted to 600 architects and engineers occupied at construction industry. A total of 127 valid questionnaire were returned, representing a 21.16 % response rate.

Table 1. Construction time overruns causes.

Cause category	Codes of causes	Time overrun causes (TOCs)	Sources
Contractor and Employer (CE)	CE1	Contractor's financial problems	[1-5], [7], [9], [11], [12], [16], [17], [24], [37]
	CE2	Contractor's experience and skills training	[1-7], [9], [11], [12], [15], [16], [22-24], [27], [59]
	CE3	Slow decision making by the employer	[1], [2], [6], [7], [9], [12], [13], [23]
	CE4	Employer's shortage of funds	[1], [9], [15], [16]
	CE5	Contractor origin/quality	[1], [4], [9], [11], [30]
	CE6	Decision change of the employer during the design and implementation phase	[1], [4-7], [9], [12], [13], [15], [18]
Equipment and Material (EM)	EM1	Frequent equipment malfunctions	[12], [15], [16]
	EM2	Insufficient modern equipment	[3], [4], [6], [7], [12], [15], [18], [24]
	EM3	Low equipment efficiency	[2], [12], [15], [16]
	EM4	Lack of equipment	[5-7], [15], [16], [23]
	EM5	Inappropriate equipment	[1-3], [5], [15]
	EM6	Shortage of materials	[4-9], [12], [13], [15], [16]
	EM7	Late supply of material	[1], [2], [5-8], [12], [15], [16], [37]
	EM8	Shortage of supplies, delays in delivery	[1], [2], [4], [5], [7], [12], [15], [16], [23], [24], [37]
	EM9	Low quality building materials	[1], [11], [15], [16]
Control, Communication, and Management (CCM)	CCM1	Poor communication and coordination among stakeholders	[1], [2], [3], [4], [7], [9], [13], [15], [16], [20], [21], [23], [24], [31-34]
	CCM2	Lack of information flow between the parties	[1], [2], [4], [13], [15], [16]
	CCM3	Ineffective site management and supervision	[1], [2], [4-7], [11], [12], [16], [30]
	CCM4	Delay and lack of supervision in the quality control process	[2-5], [7-9], [11-13], [15-17], [23], [24], [36]
	CCM5	Resource shortage and management issues	[4-8], [12], [15-17], [19]
	CCM6	Project management issues	[2], [3], [5-7], [11-13], [15], [16], [31], [34], [43], [46], [47], [49], [55]
Bureaucratic and Economic (BE)	BE1	Bureaucratic effects	[2-4], [6], [7], [9], [12], [16], [28], [31], [55]
	BE2	State, Law and Order Status	[2], [3], [5], [9], [10], [12], [15], [16]
	BE3	Making extremely low bids	[1], [3], [4], [7], [15]
	BE4	Price fluctuations	[1], [2], [4], [6], [7], [15], [24], [35]
	BE5	Payment delays	[2], [4], [5], [6], [9], [12], [15], [16], [23], [24], [31], [37], [45], [48]
	BE6	Economic problems and poor financial market conditions caused by inflation and sanctions	[3], [4], [9-11], [13], [15], [23], [34], [50], [51], [55]
Scheduling (S)	S1	Delays in responses to information requests	[4], [5], [7], [20], [43]
	S2	Control and approval delays in design documents	[1-4], [7], [12], [13], [28], [37]
	S3	Delayed permits from the municipality	[1], [2], [5], [13]
	S4	Delay in performing final inspection and certification	[2], [7], [12], [20]
	S5	Delay in delivery of the construction site to the contractor	[2], [3], [5], [7], [9], [24]
	S6	Suspension of work	[5], [9], [12]
	S7	Ineffective project planning and work schedule	[1-7], [9], [11], [12], [15-17], [19], [21], [23], [33], [36], [41], [56]
	S8	Unrealistic deadlines and work schedules	[1-7], [9], [13], [16], [17], [21], [23], [35]

Table 1. Construction time overruns causes (continue).

Cause category	Codes of causes	Time overrun causes (TOCs)	Sources
Labor Conflict (LC)	LC1	Shortage of qualified white-collar (architects, engineers, project managers)	[4-6], [7], [12]
	LC2	Insufficient labor productivity	[1], [2], [4], [5], [7], [11], [12], [14-16], [21], [24], [42], [44], [54]
	LC3	Lack of skilled workers	[1-7], [11-13], [15], [27], [55]
	LC4	Low productivity of skilled workers	[1], [4], [7], [9], [11-13], [15], [21], [27], [39], [42]
	LC5	Personal conflicts between workers	[5], [9], [11], [13], [14], [16], [21], [23], [43]
	LC6	Frequent change of subcontractors	[2], [4], [9], [12], [13], [15]
	LC7	Delays in subcontracting work	[4], [7], [9], [12], [15]
	LC8	Problems between contractor and subcontractors	[2-5], [9], [13], [14], [16], [21], [23], [42]
Reworks (R)	R1	Design changes	[4], [5], [7], [9], [12], [13], [15-18], [20], [21], [24], [29], [35], [40], [45], [52], [58]
	R2	Material changes	[4], [5], [7], [9], [12], [13], [16], [20], [24], [40]
	R3	Drawings are not clear	[4], [5], [7], [12]
	R4	Technical specifications are not clear/not prepared at all	[2], [3], [7], [9], [12], [13]
	R5	Change in business volume	[2], [6], [12], [13], [16-18], [20], [40], [51]
	R6	Rebuilds due to errors	[2], [4], [5], [7], [12], [13], [15], [21], [25], [38], [53]
	R7	Design errors and shortcomings	[5-7], [12], [13], [15], [16], [20], [21], [23], [24], [25], [33], [39]
	R8	Errors and delays in the production of design documents	[2], [7], [9], [12], [13], [15], [16], [18], [23]
	R9	Inappropriate/old/wrong construction methods	[1], [2], [7]
	R10	Incompatibility between projects	[3], [9], [12], [13]
Construction Site and External Sources (ES)	ES1	Limited access to construction site	[2], [5], [7], [12], [15], [16], [28]
	ES2	Delay/start delay in site mobilization	[2], [5], [7], [9], [28]
	ES3	Accidents and injuries during construction	[2], [12], [24], [31], [36]
	ES4	Unexpected surface and subsurface conditions (soil, water table, etc.)	[1], [2], [5], [7], [13], [16], [24], [26], [39]
	ES5	Unpredictable weather conditions	[1], [2], [5-7], [12], [13], [15], [16], [24], [34], [39]
	ES6	Environmental restrictions	[5], [11], [15], [16], [26], [49]
	ES7	War, earthquake, pandemic etc. as force majeure.	[4], [9], [12], [24], [57]

Note(s): [1](Derakhshanfar et al., 2019); [2](Doloi et al., 2012); [3](Jahangoshai Rezaee et al., 2019); [4](Ansah & Sorooshian, 2018); [5](Parchami Jalal & Shoar, 2017); [6](Amarkhil et al., 2021); [7] (Khatib et al., 2018); [8] (Thunberg & Persson, 2014); [9](Asiedu & Alfen, 2016);[10](Marella & Antoniucci, 2019); [11](Alzahrani & Emsley, 2013); [12](Kavuma et al., 2019); [13](Larsen et al., 2016); [14](Vidaković et al., 2020); [15](Al-Janabi et al., 2020); [16](Rauzana & Dharma, 2022); [17](Forcael et al., 2020); [18](Ajmal et al., 2021);[19](Abioye et al., 2021); [20](Khalafallah & Shalaby, 2019); [21](Yap et al., 2021); [22](Gunduz et al., 2020); [23](Bagherpour et al., 2020); [24](Yılmaz, 2020); [25](Yap et al., 2017); [26](Issa et al., 2021); [27](Li, 2020); [28](Memon & Rahman, 2014); [29](Saad et al., 2021); [30](Zaman et al., 2022); [31](Amoatey et al., 2015); [32](Yap et al., 2018); [33](Assaad et al., 2020); [34](Habibi & Kermanshachi, 2018); [35](Olawale & Sun, 2013); [36](Xia et al., 2021); [37](Abdellatif & Alshibani, 2019);[38] (Hwang et al., 2019);[39](Plebankiewicz et al., 2021); [40](Naji et al., 2022); [41](Olawale & Sun, 2015); [42](Altuncan & Tanyer, 2018); [43](Sinesilassie et al., 2017); [44](Palikhe et al., 2019); [45](Yap et al., 2019); [46](Aladağ & Işık, 2019); [47](Shojaei & Haeri, 2019); [48](Hyari et al., 2017); [49](Sun et al., 2022); [50](Mahdavian & Shojaei, 2020); [51](Safapour & Kermanshachi, 2019); [52](Yap & Skitmore, 2018); [53](Panwar & Jha, 2021);[54](Musarat et al., 2021); [55](Akogbe et al., 2013); [56](Wang et al., 2015); [57](Ling et al., 2022); [58](Vahabi et al., 2022); [59](Ko & Han, 2015)

To identify the internal consistency among questions using a Likert scale in a questionnaire, reliability should be measured (Nunnally & Bernstein, 2007). Cronbach's alpha (α) was utilized to determine the statistical reliability and validity of the participants' replies. The α

coefficient ranged from "0" to "1"; the minimum acceptable reliability threshold was determined as 0.7 (Cronbach, 1951; Tavakol & Dennick, 2011).

To determine the critical time overrun causes (CTOCs) among identified TOCs, normalized mean values (NMVs) analysis was conducted for each of the 60 TOCs. The calculation of NMVs for each TOCs follows Equation 1.

$$Normalized\ mean\ value = \frac{(mean\ of\ TOC - lowest\ mean)}{(highest\ mean - lowest\ mean)} \quad (1)$$

Any TOCs with an NMV higher than 0.5 is considered to meet the CTOCs.

Findings

To determine the internal consistency of the questionnaire reliability analyses was conducted using Cronbach α coefficient. The α coefficient of the data set for the 60 TOCs were determined to be 0.950, which is above the minimum threshold of 0.7 (Tavakol & Dennick, 2011).

Regarding the critical time overrun causes the means, normalized mean values (NMV) and standard deviations (SD) were computed and presented at Table 2.

Table 2. Ranking and determination of CTOCs.

Cause category	Codes of causes	Mean	Sd	NV[a]	Ranking
Contractor and Employer (CE)	CE1	3.300	0.8739	0.426	-
	CE2	3.029	1.0211	0.271	-
	CE3	3.343	1.0340	0.451	-
	CE4	3.157	1.0582	0.344	-
	CE5	2.971	0.9627	0.238	-
	CE6	**3.594**	**0.9126**	**0.595***	**7**
Equipment and Material (EM)	EM1	2.786	0.9308	0.131	-
	EM2	3.000	0.8847	0.254	-
	EM3	3.000	0.8847	0.254	-
	EM4	3.057	0.9614	0.287	-
	EM5	2.671	0.9437	0.066	-
	EM6	2.943	1.0886	0.221	-
	EM7	**3.486**	**0.8638**	**0.533***	**15**
	EM8	**3.557**	**0.9111**	**0.574***	**10**
	EM9	2.729	1.1283	0.098	-
Communication. and Control. Management (CCM)	CCM1	3.257	0.9431	0.402	-
	CCM2	3.100	0.9502	0.312	-
	CCM3	3.000	1.0901	0.254	-
	CCM4	3.000	1.0495	0.254	-
	CCM5	3.029	0.9627	0.271	-
	CCM6	3.029	1.0286	0.271	-

Table 2. Ranking and determination of CTOCs (continue).

Cause category	Codes of causes	Mean	Sd	NVa	Ranking
Bureaucratic and Economic (BE)	BE1	3.357	1.1676	0.459	-
	BE2	3.286	1.0093	0.418	-
	BE3	**3.571**	**1.0977**	**0.582***	**9**
	BE4	**4.300**	**0.7680**	**1.000***	**1**
	BE5	**4.086**	**0.9440**	**0.877***	**3**
	BE6	**4.257**	**0.7554**	**0.975***	**2**
Scheduling (S)	S1	3.286	1.0515	0.418	-
	S2	**3.443**	**0.9268**	**0.508***	**18**
	S3	**3.857**	**0.9369**	**0.746***	**5**
	S4	**3.486**	**1.0035**	**0.533***	**16**
	S5	3.186	1.0535	0.361	-
	S6	2.768	1.0311	0.121	-
	S7	3.145	1.0329	0.337	-
	S8	3.420	1.2415	0.495	-
Labor Conflict (LC)	**LC1**	**3.500**	**0.9129**	**0.541***	**14**
	LC2	**3.500**	**0.8969**	**0.541***	**13**
	LC3	**3.886**	**0.8434**	**0.762***	**4**
	LC4	**3.586**	**0.9705**	**0.590***	**8**
	LC5	2.871	1.0484	0.180	-
	LC6	3.261	1.0383	0.404	-
	LC7	**3.855**	**0.9279**	**0.745***	**6**
	LC8	**3.551**	**1.0223**	**0.570***	**11**
Reworks (R)	**R1**	**3.529**	**0.9887**	**0.557***	**12**
	R2	3.290	1.0015	0.420	-
	R3	3.114	1.1234	0.320	-
	R4	3.232	1.1395	0.387	-
	R5	3.243	1.0417	0.393	-
	R6	3.371	1.0656	0.467	-
	R7	3.371	1.0656	0.467	-
	R8	3.314	0.9712	0.434	-
	R9	3.200	1.1112	0.369	-
	R10	**3.449**	**1.1053**	**0.512***	**17**
Construction Site and External Sources (ES)	ES1	2.586	0.9853	0.016	-
	ES2	2.800	0.9570	0.139	-
	ES3	2.557	0.8950	0.000	-
	ES4	2.729	0.9619	0.098	-
	ES5	3.114	0.8771	0.320	-
	ES6	2.986	0.8596	0.246	-
	ES7	2.743	1.0992	0.107	-

Sd = Standard deviation, NVa = normalized value = (mean - minimum mean)/ (maximum mean - minimum mean)

Normalization value ≥ 0.50 Critical time overrun cause:*

The results revealed 18 CTOCs out of 60 TOCs have normalized values greater than 0.50, which can be listed in descending order as follows: BE4, BE6, BE5, LC3, S3, LC7, CE6, LC4, BE3, EM8, LC8, R1, LC2, LC1, EM7, S4, R10, S2.

When the distribution of the determined 18 CTOCs analyzed according to groups, 1 of contractor and employer; 2 of Equipment and Material; 4 of Bureaucratic and Economic; 3 of Scheduling; 6 of Labor Conflict; 2 of Reworks found to be critical. It is significant that none cause related to communication, control, and management and construction site and External Source were found to be critical.
Top ten CTOCs were determined as follow:

1. Price fluctuations (BE4)
2. Economic problems and poor financial market conditions caused by inflation and sanctions (BE6)
3. Payment delays (BE5)
4. Lack of skilled workers (LC3)
5. Delayed permits from the municipality (S3)
6. Delays in subcontracting work (LC7)
7. Decision change of the employer during the design and implementation phase (CE6)
8. Low productivity of skilled workers (LC4)
9. Making extremely low bids (BE3)
10. Shortage of supplies, delays in delivery (EM8)

It is significant that top three CTOCs are related to bureaucratic and economic issues. In addition, three CTOCs are related to labor conflict. Therefore, economic and labor related problems play significant role for time overrun during construction.

Conclusion

In Turkey, the construction industry contributes significantly to the national economy. Time overrun is a problem that this industry encounters frequently. In order to prevent or minimize this issue, it is crucial to identify the critical causes of the time overrun given the significance of the industry. The results of this research have a considerable impact on the construction sector in this regard.

A systematic literature review methodology is used to investigate time overruns causes. A total of 181 full-text studies are examined, and 59 of these studies are included. From the initial systematic literature review, 60 causes were obtained for time overrun categorized under contractor and employer (CE), equipment and material (EM), communication, control, and management (CCM), bureaucratic and economic (BE), scheduling (S), labour conflict (LC), reworks (R), and construction site and external sources (ES), only 18 out of 60 TOCs were determined as critical tine overrun causes. While this does not imply that the other 42 causes do not have any importance in term of time overrun, their impacts may not be adequate to be deemed as “critical” for this study.

When the context of the top ten CTOCs were analysed, it is significant that most of them are related to bureaucratic and economic and labour conflict issues. Whereas communication, control, and management and construction site related issues are not critical for time overruns during construction.

This study provides some implications to government regarding to CTOCs as the results revealed that Price fluctuations (BE4), Economic problems and poor financial market conditions caused by inflation and sanctions (BE6), Payment delays (BE5), which are mainly attributed to government policies, are among the causes that can give rise to time overrun during construction. Governments should border the limit cost for the project.

This study contributes construction project managers with an understanding of the main sources of delay. They can provide corrective solutions for their projects by using the identified critical reasons. With the awareness of the most important delay factors identified, they can reduce the impact of these factors on their projects so that they can make the most improvement in the system. These elements need to be considered and effectively integrated into the construction processes for developing countries. Overall, the study significantly raises awareness and can be applied to work evaluating the performance of projects as well as delay control in project environments.

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Constructing the Added Value for AEC Industry: An Interdisciplinary Learning Style 'The Multidimensional Exploration Methodology'

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Abstract

The Multidimensional Exploration Methodology (MDEM) is a holistic learning approach based on spiral progress loops of design-thinking and experimentation. The main objective of the methodology is to augment creativity, productivity, and learning efficiency thanks to cognitive learning styles and self-challenges that trigger design-driven innovation. This method helps the learner to align with the recent developments in the industry and adapt to the contemporary world as active thinkers and future change-makers. Previously, under the title, 'The Adoption of Multidimensional Exploration Methodology to the Design-Driven Innovation and Production Practices in AEC Industry', the methods of adaptation from the academy through industry were discussed. In this paper, the basis of this learning method is explained briefly. Also, the method is discussed as a learning style, by its' interconnected relationship with the methodological references and their global impacts in the future.

Keywords: *challenge-based learning, design-driven innovation, digital design-thinking, fabrication and construction tools, interdisciplinary approach, prototyping and production practices.*

Introduction

The Multidimensional Exploration Methodology (MDEM) is a holistic learning approach based on spiral progress loops of design-thinking and experimentation (Birgonul & Carrasco, 2021). Our proposal for the learning method for architectural design studio education is based on various learning methods such as Cognitive Learning Theory (Greenwald, 1968; Bloom & Krathwohl, 1984), Kolb's' Experiential Learning Methodology, (Kolb, 1984; Kolb et al., 1999) and Design Science Research Methodology (Van Aken, 2005; Henver et al., 2004; Peffers et al., 2006). Our learning methodology is developed based on aforementioned learning techniques and adapted to the Challenge-Based Learning theory (CBL) (Apple Inc., 2010). The CBL is a collaborative learning experience in which teachers and students work together to learn about compelling issues, propose solutions to real problems, and take an action (Birgonul & Carrasco, 2022).

MDEM is a current approach for design education that blends those learning methods for creating a more actualized learning style for architectural design. MDEM aims to cover solution oriented projects for global concerns by encouraging the learning to work within interdisicplinary approaches.

Previously, under the title, 'The Adoption of Multidimensional Exploration Methodology to the Design-Driven Innovation and Production Practices in AEC Industry' *(*Birgonul & Carrasco, 2020), the methods of adaptation from the academy through industry were discussed. In this paper, from a bottom-up perspective, the basis of this learning theory is discussed and explained with the interconnected relationship between the methodological references and their' future global impact.

The main objective of this paper is the introduction of the learning style: Multidimensional Exploration Methodology (MDEM). Accordingly, this study questions 'why interdisciplinarity is the current trend in both learning and practice?', and discusses 'how the MDEM can lead a sustainable practice for the Architecture, Engineering and Construction (AEC) Industry?'.

Basis of the Proposed Learning Method

Interdisciplinary has become a standard practice that should be applied to all business segments including the AEC industry. However, the gap between the educational models and application in industry field is still unbalanced and incompatible. There is an increasing need for interdisciplinary professionals who are capable of managing various tasks for organization and execution. Academy is the first step that the practitioner meets with the specific discipline. The skills that lead the production and application practices are developed in the university. Therefore, MDEM aims to create a sustainable solution for the question that asks; how the learning methodologies can shape the impact of AEC and global issues, by challenges and interdisciplinarity.

During the very first phases of this method, the cognitive knowledge is aimed to align with the essentials of the current architectural design understanding. To do so, adding the new values to the design-thinking and blending it with the active experimentation during the design education; students' cognition is re-shaped by the necessities of this alignment, which involves a responsible manner of new generation essentials for shaping the future. Training the future's practitioners require this new methodology that applies to interdisciplinary problem solving by a collective way of learning. To conclude, MDEM provides a holistic design thinking (Birgonul, 2020) that has an innovative learning technique, depending on the real-world challenges.

'Architecture is a representation saturated problem domain' (Akin, 2001) and consequently, design is not linear (Oxman, 2006) so the learning methodology neither should be. Thinking is also an organic process, and it is inseparable from its means of representation and expression (Herbert, 1992) in an intellectual way. Architecture and design students use diverse knowledge, versatile representation mediums and digital tools for augmenting the creative design thinking with multi-disciplinary ways.

In this section, we briefly discuss the existing learning theory 'challenge-based learning', define the references that we took for our proposed learning method, and moreover explain how this approach is applied to the MDEM.

Challenge-Based Learning (CBL)

'Challenge-Based Learning (CBL) is a collaborative learning experience in which teachers and students work together to learn about compelling issues, propose solutions to real problems, and take an action. The approach asks students to reflect on their learning and the impact of their actions and publish their solutions to a worldwide audience' (Apple Inc., 2010) and (Nichols et al, 2016), (See Figure 1).

Similarly, Problem Based Learning (PBL) is a method evolved from innovative health sciences and triggered by the existing problem, in which students learn about a subject through the experience of solving an open-ended problem found in trigger material. The PBL process does not focus on problem solving with a defined solution, but it allows for the development of other desirable skills and attributes (Schmidt, 1983; Boud & Feletti, 1998; Wood, 2003; Savin-Baden & Howell Major, 2004; Savery, 2006). Yet there is only a limited literature available on the relevancy and effectiveness of CBL and PBL implementation in architectural education (Maitland, 1998; Bridges, 2006). Although CBL and PBL resemble each other, in PBL, students are aspired to explore a set problem which has been provided by the tutor (Roberts, 2007), on the contrary in CBL, the challenge is created by the learner.

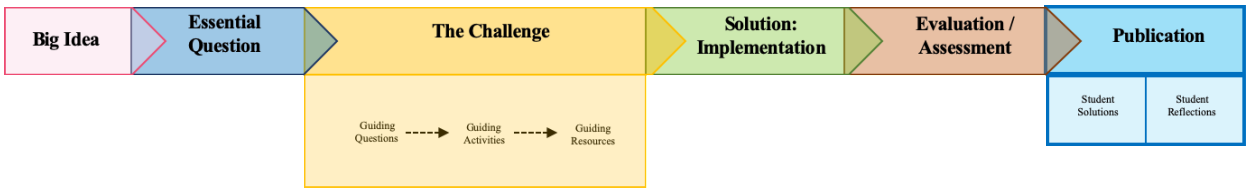


Figure 1: Challenge-Based Learning Framework, context from (Apple Inc., 2010), visualized by the authors.

Both CBL and PBL are methods that are based on an interdisciplinary way of thinking. The versatile approach that the learner creates is a key point on those methods, that triggers an authentic idea, which would suggest a good solution for an existing problem.

Multidimensional Exploration Methodology (MDEM)

MDEM takes reference from the challenge-based learning, and reflects this method to AEC industry with an interdisciplinary standpoint. Interdisciplinarity is essential of this learning method due to create a sustainable practice environment for the learner. This fact is directly connected to the cognitive learning approach that is included in the MDEM. This method aims to reshape the cognitive skills of the learner by aligning with the actual concerns that applies to the design problems. Additionally, developing strong cognitive bonds between the researcher and the topic of research generates a more consolidated knowledge, thanks to the experiential approach.

The main objective of this method is to create collective consciousness of design students as they will be the futures' change-makers. The methodology steps are constructed by taking the reference from CBL. The constituents of CBL are adapted to architectural design context. The methodology application steps are as following (see Figure 2): Big Idea: Introspection**,** Essential Question: Identification of the problem**,** The Challenge: Learning by designing**,** Solution / Implementation: Design Development**,** Evaluation / Assessment: Discussion**,** Publication: Communication; Repeating (Spiral Development).

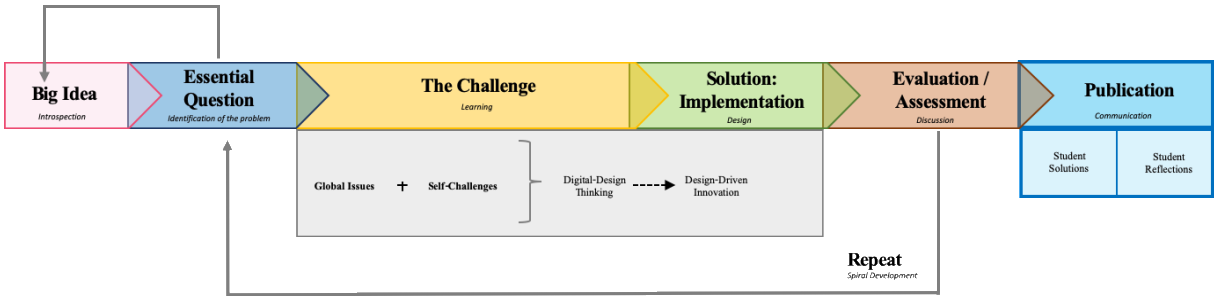


Figure 2: Multidimensional Exploration Methodology Flowchart.

The first step of the proposed methodology is Introspection where the big idea emerges. It is the initial step which is 'an ongoing process of tracking, experiencing, and reflecting on one's own thoughts, mental images, feelings, sensations, and behaviors' (Gould, 1995) and "introspection, as a humanistic, interpretative, and naturalistic approach to understanding subjective experiences has a unique value for experience-driven design" (Xue & Desmet, 2019). Starting the design thinking by introspection; creates the big idea of CBL by the student's cognition. The aim is to oblige the student to dream and define the problem-solving by a personal approach. While design thinking, it enables them to be creative without limits. Introspection; out of the case study experiences and its results that will be explained in further chapters, is most probably the most critical step through the projects' development because it is where the unique ideas are being conceived creating thus, a new standard. The significance of the identification of the problem and its' connection with creativity have been studied and discussed by various authors previously (Newell & Simon, 1972; Holyoak, 1990; Rosenman & Gero, 1993). On the second step, the essential questions are asked and the main problem of the project is defined by the student. The importance introspection leads the student to find the essential questions, which derives from the uniqueness of the personality of the designer (student).

The teaching process and learning action interact intensely with each other as a collective operation. This operation is creating hybrid moments where knowledge is exchanged in the classroom by digesting the necessities of the brief via experiencing the ample resources of the projects in its different representational aspects. The acquisition of the student is usually more significant in terms of knowledge acquired (Gould, 1995) and produces a new learning style in the first position, and secondly, a new way of dealing with problems and taking design decisions. As a consequence, thanks to challenge-based learning applied to MDEM, knowledge is not thought; it is generated by the collective actions of the learner and the mentor.

The questions and concerns lead to the third step where the challenges emerge. This step involves the main learning and development stages of the research project. This step is subjected to the personal learning styles and each student has their own way of doing and

learning. This is the fundamental formation of this method where the self-exploration and the creation happens. “Study behaviors stem from cognitive preferences which are broadly manifested as personality. Specific learning preferences are called learning styles, and they serve as stable indicators of how learners perceive and interact with learning environments” (Schmeck, 1985).

Learning styles are personal and unique. By blending cognitive learning theory with CBL, it is possible to observe the value of specific preferences for processing information. Learning through cognition, ensures each student to think and create uniquely, within the same context and the results would be surprisingly diverse. It is strongly believed that, the inclusion of personality in design education and design-thinking processes would augment the creativity, productivity and the uniqueness of the designed artifact. This fact could be the key for proposing this new methodology for extending the creativity limits, by liberating the design student by their cognitive actions.

During the solution/ implementation step covers the design development and digital-design thinking. On this step students’ progress by self-challenging to discover the possibilities of each concern. This step is followed by the evaluation step where the public presentations are made and discussions occur. Lastly, the students should communicate their outcomes and reflections by their own way of preference.

These steps and functions generate the spiral diagram of the methodology by being repeated until the required results are fulfilled. Each step is self-challenge based, meaning that the learning progress is the variable for each subject. Therefore, the multidimensional learning evolves, not only in one direction but also through various axes, by time, self-knowledge generation and knowledge flows. Early phases of design decisions and problem-solving generally start with analog methods, followed by digitalized representations. The methodology also creates an extra complication as classical design studios follow a top-down design approach, whilst in this method, most of the processes are bottom-up and design decisions are solely taken upon theories and profound interdisciplinary research and data-analysis. Additionally, this method highly encourages the learner to align with digital-design thinking. Regarding the design thinking and design phases, the digital tool using abilities are getting developed within the scope of this methodology.

To sum up the application phases of MDEM, it is crucial to apply a versatile and interdisciplinary manner both for learning stages, and for productive and genuine professional practice.

Discussion: Challenges and Interdisciplinarity

Interdisciplinarity is one of the most important values in innovative projects in both learning and practice. Currently, research and development projects are pursued by various disciplines due to add radical and disruptive outcomes.

Even though AEC industry is considered as a technical discipline, the core of it is based on its’ user. Human-centered approaches that facilitate good solutions for the user are achieved by a multidimensional standpoint that involves interdisciplinary way of thinking. As it was mentioned previously, in challenge-based learning and multidimensional exploration methods, the challenges that address global concerns also involves the ‘human-centered’

proposals for sustainable solutions. Therefore, it is crucial to approach the design problem with a multidimensional and interdisciplinary way.

On the other hand, by MDEM the understanding of many terms and context has got under reformation. One of the significant ones is the way of creation of knowledge. Eventually, the teacher is not a classical authority symbol with full decision power nor with an absolute truth. Yet, the teacher position became expanded to become a moderator for students' exploration journey. Teachers are now a project leader, where they may have the last word, but the learning methodology is built based on the self-challenges, cognitive styles and creativity of the students. It is important to note that, neither the students or the teachers have the answers on the questions proposed by the course syllabus, but the challenges direct the research through ‘big ideas.’ This blurriness of the outcome allows design evolution to be the predominant tool for refine, evolve projects and find a design solution to complex topics. Moreover, excluding the authority also enables more margin to include various disciplines and standpoints to a defined problem.

The architectural design studio education by MDEM does not search for absolute truths, but; it encourages the student to search for possible creative ways to approach a current problem. By this method, we value the process as much as the end result.

Upon constant discussion in class and self-evaluation of the learner, the project evolves more profoundly within the cognitive development processes. It is essential to discern which design solution should be developed further. These findings from the previous iteration are then documented and used as inputs for the next one, where more complexity will be added, creating thus, and a richer artifact. Above all, a challenge-based, hands-on learning process shapes the latest findings in each week, and consequently the knowledge gains of the semester.

MDEM can lead a sustainable practice for AEC Industry through its unique learning style. By collectively creating an actual cognitive position for the student, would induce fruitful products when the student starts working in real practice after graduation. Therefore, learning with challenges trains the student with a more conscious way. Also challenging the student by this method helps them to develop skills in multi-disciplinary ways, in contrary with the classical learning styles.

Teaching design with MDEM aims to transform the design students to the change-makers; thanks to the CBL and also to the availability of information and technologies**.** The application of this methodology inevitably changes both the perception of architecture and the ways of designing it. Architecture of the current era has become something much more complex than just a decade ago. It has social implications that expand further into the digital world, environmental considerations and added values and new ways of interaction between user and spaces. The resulting architecture is a hybrid that deals with a wider variety of inputs and offers a more abundant array of the solution to classical problems. Designers of the new age should have a responsible manner on global issues and receive education with an interdisciplinary approach; which could be achieved MDEM.

Conclusion

This study investigated the CBL application to architectural design and AEC education the proposed methodology. The process is defined as MDEM, which aims to train the students with a self-challenging approach, as well as augmenting creativity and creation of collective consciousness upon global issues by challenges. Results of our experience for the past years applying this method in our classes showed that the students using the MDEM on their research project, propose interdisciplinary solutions that aligns with the global concerns. Furthermore, the students create their own challenges during the semester to put the project proposal and project's design thinking further. Those challenges include, the questioning the project context itself, conducting interdisciplinary research, having the digital-design thinking, mastering necessary software, and developing the big idea with respect to global issues. Moreover, the highest correlation was between the proposed challenge and overall creativity of the project. At last, but not the least, in both case studios, the positive effect of discussion of their introspection with the classmates was highly oblivious as the students' challenge each other, while learning from each other too.

The spiral applications of the phases are repeated until the required results are achieved. Moreover, the spiral development expands through three dimensions, as the student develops skills and reforms cognitive activates, knowledge flows by between participants, and by emergent information and experience, knowledge flows are enhanced within time. Learning by exploration method and re-framing cognition by experience is a new approach to link all generated knowledge together. The method is very much related to thinking, testing, re-thinking, and consequently uniting previous knowledge and skills to new contexts while learning and producing. This method enables the student to reach edges of creativity since it focuses on personal interests, skills, and cognitive styles. The results of the case studies show that the main contribution of the method is successful. The method provides a sustainable learning technique for design studio education, aligning with the current architectural design understanding and with the requirements of the information age.

The most significant difference between the classic methods and the MDEM is due to the type and style of the education received and partly to the topic to study, which goes much more than the classic distribution in the plan. This emergent context of the contemporary architectural design understanding is much more complex than what any design student could know by a classic education method. Moreover, adding interdisciplinary approaches to simple problems crates extraordinary outcomes. The only way to acquire that knowledge and make the shift from classic to advanced design is to use new learning techniques, blending actual technologies, current problems, new working methods, innovative problem-solving skills, digital-design thinking approach, and new representation mediums all together in a melting pot.

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Determination of Type of Construction Activities During the Construction Execution Phase

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Abstract

Today, the more complex design of construction projects becomes even more important in terms of construction management, especially in the control and supervision of workers during the construction execution phase. Therefore, this study, it is aimed to create machine learning models to predict workers activities in construction work. For this purpose, data were collected with the sensors attached to the arms of workers working in tiling, formwork, rendering, and waiting activities. This raw data is trained and modeled by machine learning algorithms such as Extra Tree (ET), Support Vector Classifier (SVC), Decision Tree (DT), Random Forest (RF), K Nearest Neighbors (KNN), and Logistic Regression (LR), after preprocessing and statistical feature extraction. According to the analysis results, the best prediction was obtained with the SVC algorithm with an accuracy of 96.66%. In the ET, RF, and KNN algorithms, approximately 95% prediction accuracy was obtained. In consideration of the results obtained, it was seen that the type of construction activities determined were highly predicted. In this way, together with the developing technology and artificial intelligence, the activities of the workers can be detected automatically with a certain accuracy.

Keywords: *construction technology, construction worker activities, machine learning, estimation, artificial intelligence.*

Introduction

The construction site is one of the most complex work environments due to its dynamic nature, combination of different stakeholders and knowledge domains (Behzadan et al., 2008). Therefore, it is essential to use construction technologies to manage the construction more effectively and more productivity. Recently focused on advanced technologies and cyber-physical systems, significant technological developments with Industry 4.0 emerged in the 21st century (Boyes et al., 2018). The construction industry has also endeavored to adapt to these technological developments and the term Construction 4.0 emerged in 2016 (Berger, 2016). Technologies researched for use in the construction industry include Building Information Modeling (BIM), Cloud-based Project Management, Augmented Reality, Virtual Reality, Laser Scanning, Big data and Analytics, Blockchain, Artificial Intelligence, Internet of Things (IoT), and Sensing Technologies (Forcael et al., 2020). With the concept of Construction 4.0, it is thought that project performance and worker productivity will increase in the construction industry (Bock, 2015).

It is clear that technologies will increase worker productivity. However, this requires measuring worker productivity. In addition, to measure worker productivity, it is necessary to know which technologies to use and how to use them. In traditional construction projects, data on worker productivity is often collected manually. This makes the data error prone. In addition, data collection in this way requires significant time and cost (Roberts & Golparvar-Fard, 2019). Therefore, the development of an automated site data collection method for construction worker monitoring and automated recognized worker activity is important for worker productivity (Ryu et al., 2016). Recently, researchers investigated construction worker activity monitoring and recognizing with by means of sensing technology tools such as global positioning system (GPS), radio-frequency identification (RFID), ultra-wide-band (UWB), QR code, smartphones and Inertial Measurement Unit (IMU) sensors (Akhavian & Behzadan, 2016; Jiang et al., 2015; Valero et al., 2017; Zhou & Ding, 2017).

The use of body worn IMU sensors and smartphones to measure workers' motions and to recognize their activities has received more attention. In addition, IMU sensors are flexible and robust in harsh conditions and have a small size, good accuracy, and reasonable power consumption. Therefore, these sensors may be more appropriate to use instead of smartphones (Joshua & Varghese, 2011). In addition, the activities to be used in this study will generally focus on the manual work of the skilled workers and data will be collected with IMU sensors embedded in wristbands in order to obtain more accurate results. The aim of this study is to estimate what work the workers working at the construction site do with the help of this data collected by machine learning algorithms. In this way, the use of IoT, one of the digital technologies, on the workers at the construction site can be evaluated and the workers can work more efficiently. It is inevitable to increase the efficiency of the entire project by increasing the productivity of the workers.

Literature Review

Since approximately 50% of the total project cost in the construction industry is worker cost, the construction industry is considered a labor-intensive industry (Kazaz & Ulubeyli, 2004). Therefore, it is important to monitor workforce activities and effectively manage these activities in order to increase the performance and productivity of construction projects (Kim & Cho, 2020). In addition, the need for a real-time or non-real-time performance monitoring system is increasing day by day in order to increase the productivity of the workers at the construction sites (Luo et al., 2018; Sherafat et al., 2020). Recently, the use of wearable IMU-based sensors for recognition of workers' activities has gained popularity (Antwi-Afari et al., 2019).

Joshua and Varghese (2011), in their study, collected data in a laboratory environment with a cabled accelerometer sensor attached to both the right and left sides of a mason's waist. The data made ready for the model were trained with Naive Bayes (NB), Decision Tree (DT) and Multi-Layer Perception (MLP) algorithms. With these trained models, the activities of bringing mortar and spreading, bringing, and laying bricks and filling joints were tried to be estimated. As a result of the analysis, the estimation accuracy of the activities ranged from 76% to 79% (Joshua & Varghese, 2011).

Akhavian and Behzadan (2016) aimed to design an activity recognition system that can predict various types of worker activities at construction sites. In line with this purpose, accelerometer and gyroscope data collected from smartphones worn on the arms of the workers were collected. The collected data was processed and made ready for the model. The estimation model was

created Multi-Layer Perception (MLP), Decision Tree (DT), K-Nearest Neighbors (KNN), Logistic Regression (LR) and Support Vector Machine (SVM) algorithms. With this estimation model, activities were estimated in 3 different categories. In category 1, only two activities are considered, Sawing and waiting (wasting time). In the second category, hammering, turning a wrench, and waiting activities were classified. Finally, in the third category, loading of the wheelbarrow, pushing the loaded wheelbarrow, unloading the wheelbarrow, returning with the empty wheelbarrow, and waiting activities were estimated. According to the results obtained, the estimation accuracy obtained in the 1st category varies between 95-97%. In other categories, as the activities to be estimated increased, it was seen that it decreased compared to the 1st activity and changed between 78-88%. It was determined that the algorithm with the highest estimation accuracy was SVM in the 1st category, MLP in the 2nd and 3rd categories. It was stated that the potential of using the estimation of worker activities in the construction sector is high. However, it was stated that the experiments were not carried out at the real construction site and the workers were not real workers, which would affect the results. In addition, the limited battery power of smartphones, limited storage space, inability to work properly in sudden movements and the large size affecting the work of the worker can be said as another factor affecting the results (Akhavian & Behzadan, 2016).

When the studies carried out in recent years are examined, Zhang et al. (2018) collected accelerometer and gyroscope data from nine workers with smartphones. With the obtained data, he tried to predict standing, walking, squatting, clean up the template, fetch and place rebar, locate the rebar, band rebar and place concrete pad activities in the rebar work. The classification estimation accuracy obtained in the model analyzed using the DT algorithm was calculated to be 89.85% (Zhang et al., 2018). Ryu et al. (2019) tried to estimate the activities of spreading mortar, laying blocks, adjusting blocks, and removing mortar in masonry work with the help of data collected with an accelerometer sensor worn on the wrist of a masonry worker in a laboratory environment. For this, 10 workers were used. Afterwards, the model was analyzed using KNN, MLP, DT and SVM algorithms, and the SVM algorithm gave the best result with 88.10% prediction accuracy (Ryu et al., 2019).

When the literature studies are examined, construction worker activity recognition studies were generally carried out in the laboratory environment. In addition, in most studies, either only accelerometer data or accelerometer and gyroscope data are used together as sensor data. In this study, workers were selected from the workers at the real construction site and data were collected with sensors attached to their arms. In addition, it is aimed to make the workers activity recognition the more accurate by using the magnetometer sensor in addition to the accelerometer and gyroscope sensors.

Research Methodology

In this study, it is aimed to estimate the data collected from the formwork, rendering, and tiling workers in the construction site and the activities of these workers by using machine learning algorithms. For this purpose, a flowchart was created as shown in Figure 1. According to this flowchart, data were collected and made ready for the model. Afterwards, the model was analyzed with machine learning algorithms. Finally, the results were evaluated by using evaluation metrics to evaluate the results obtained.

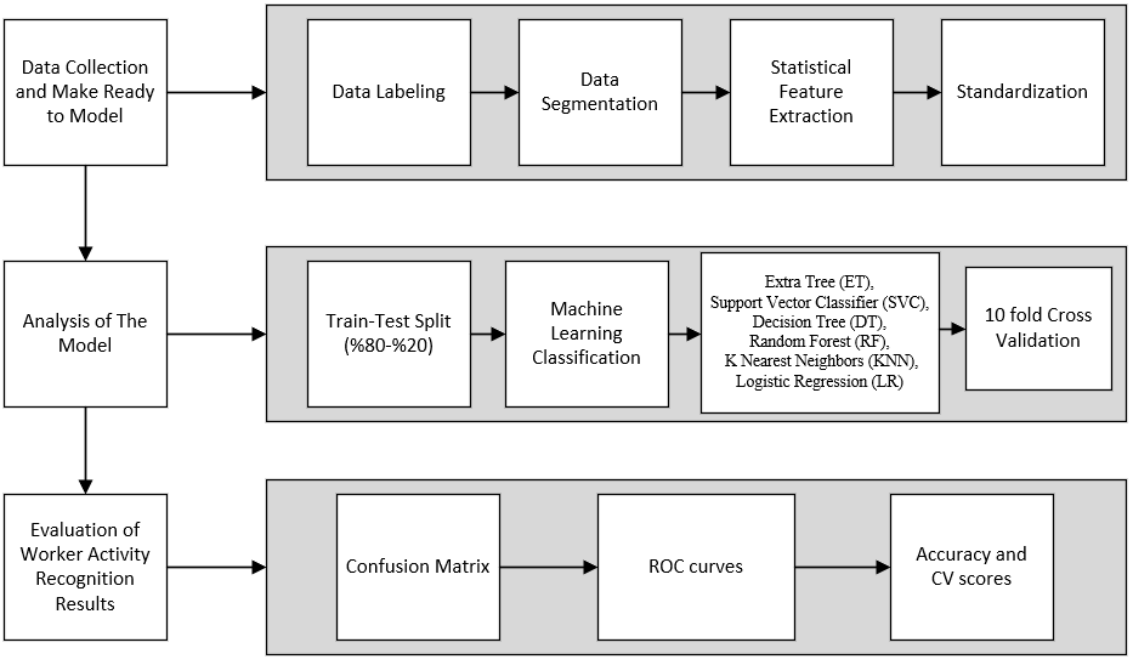


Figure 1: Flowchart for worker activity recognition.

In the first stage of the study, as shown in the Figure 2, the data of the accelerometer, gyroscope and magnetometer were collected with the sensors attached to the arms of the workers working in the formwork, rendering, and tiling work at the construction sites. In addition, the collection of these data continues at 50 Hz and for approximately 40 minutes.



a. Formwork activity b. Rendering activity c. Tiling activity

Figure 2: Data collection with sensor attached to the workers' arm.

Collected accelerometer, gyroscope and magnetometer data in x, y, z axis was labeled in 4 different activities as formwork, rendering, tiling and waiting according to the work done by the workers. The accelerometer, gyroscope and magnetometer data in the x, y, z axis of the tiling activity is shown in the Figure 3.

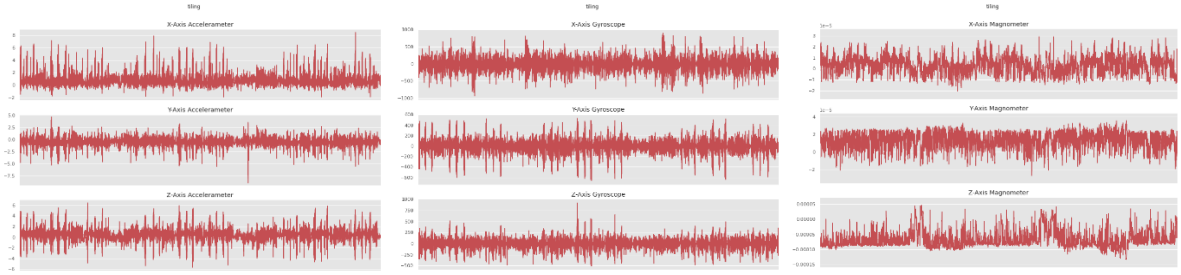


Figure 3: The accelerometer, gyroscope and magnetometer data in the x, y, z axis of the tiling activity.

Data segmentation process was applied in order to make the labelled data ready for the model. With this process, the data is separated into fixed width sliding windows consisting of 100 data, starting from the beginning. These windows are created by running on top of each other with 50% overlap. In these windows, statistical properties of each accelerometer, gyroscope and magnetometer data were extracted. The statistical properties made are given in the Table 1. After this process, the data were standardized so that the mean value was 0 and the standard deviation was 1 in order to increase the accuracy of the model.

Table 1. Features and description created with statistical feature extraction.

Statistical Features Names	*Description*
Sum values	Calculates the sum over the seperated windows values
Median	Calculates the median the seperated windows values
Mean	Calculates the mean the seperated windows values
Length	Calculates the length the seperated windows values
Standard deviation	Calculates the standard deviation the seperated windows values
Variance	Calculates the variance the seperated windows values
Root mean score	Calculates the quadratic mean the seperated windows values
Maximum	Calculates the maximum value the seperated windows values
Minimum	Calculates the minimum value the seperated windows values

In the second stage of the study, the data prepared for the model was divided into 80-20% train and test data for analysis. Because the model analyzed with the train data will be compared with the test data and the estimation accuracy will be calculated. In this study, train data analyzed using machine learning algorithms such as Extra Tree (ET), Support Factor Classifier (SVC), Decision Tree (DT), Random Forest (RF), K-Nearest Neighbors (KNN), and Logistic regression (LR) were used to estimate worker activities. After creating and analyzing these models, k-fold cross validation was used to verify whether these models were random and to eliminate bias of the data (Farooq et al., 2021). In this study, the proposed 10-fold cross-validation (CV) (Kohavi, 1995) was performed to obtain the optimum variance. With 10-fold cross validation, the data is divided into 10 layers and analyzed as 1 different layer validation data and the other 9 layers train data in each round. CV accuracy values were calculated by averaging the accuracy values found for each layer.

At the last stage of the study, the results of the analysis were evaluated. Confusion matrixes of all models were created to evaluate these results. In addition, TP (True Positives) and TN (True Negatives) values obtained with confusion matrices as in the Figure 4 show the correct estimated values of the model. FN (False Negatives) and FP (False Positives) values are expressions that show incorrectly estimated values of the model. While evaluating the results in this study, accuracy score values, which is one of the evaluation metrics, were calculated as shown in Equation 1. In addition to these evaluation metrics, the ROC (Receiver Operating Characteristic) curve, which is determined by the ratio of TP values to FP values, was also used.

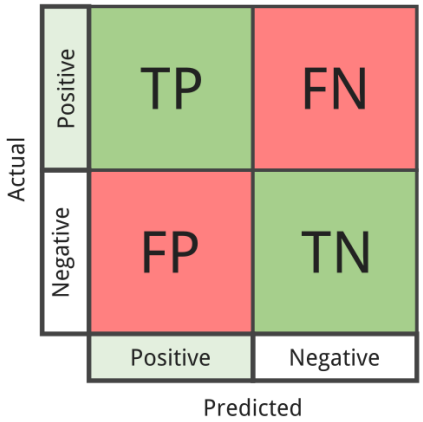
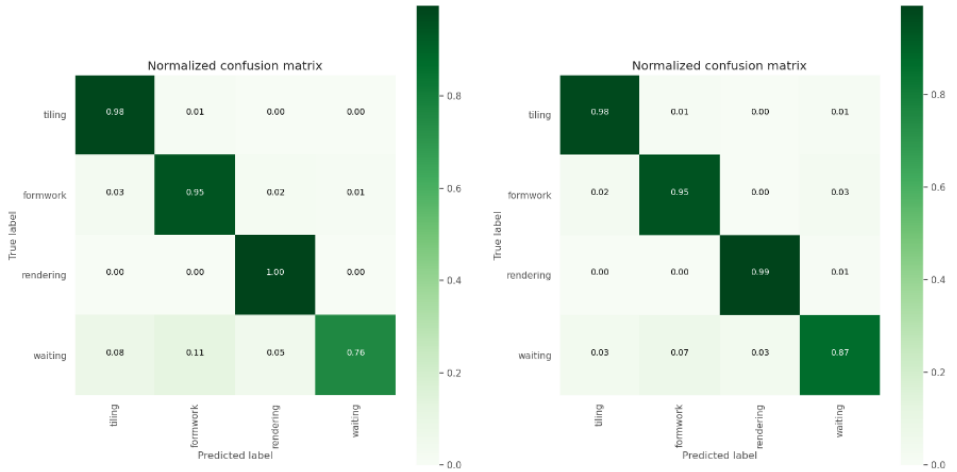


Figure 4: Confusion matrix example.

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

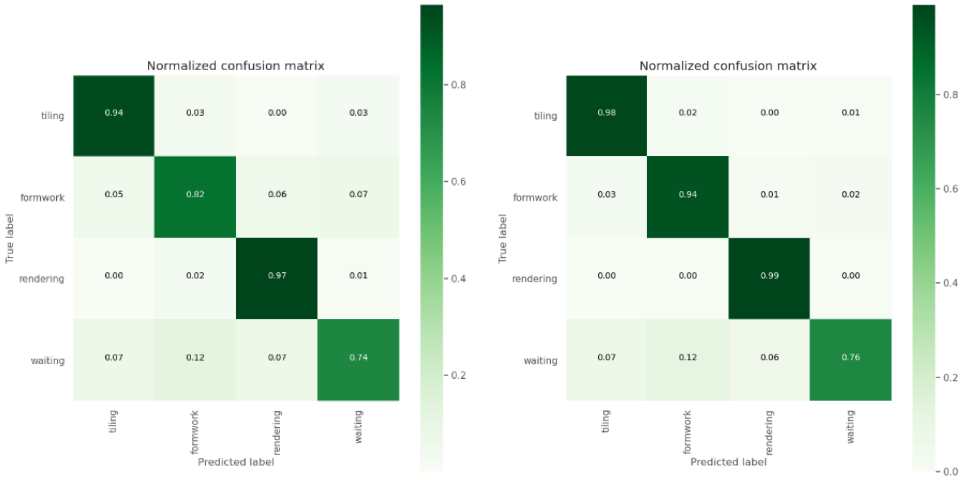
Results and Discussions

6 machine learning models such as ET, SVC, DT, RF, KNN, and LR, which were created to estimate the activities and waiting activities of the formwork, rendering and tiling workers working at the construction site, were created and analyzed. According to the analysis results, firstly confusion matrixes of the models were created. Confusion matrixes created as a result of the analysis of ET and SVC models are shown in Figure 5. Accordingly, although the predictions of tiling, formwork and rendering activities in the ET model have high accuracy rates, the estimation accuracy of waiting activity was calculated as 76%. On the other hand, in the SVC model, tiling activity was 98%, formwork activity 95%, rendering activity 99% and waiting activity 87% accurate. Confusion matrixes created as a result of the analysis of DT and RF models are shown in Figure 6. In the DT model, tiling and rendering activities were obtained with estimation accuracy of 94% and 97%, respectively. On the other hand, 82% of formwork activity and 74% of waiting activity were predicted correctly. In the RF model, similar to the ET model, the estimations of tiling, formwork and rendering activities have high accuracy rates. Waiting activity was estimated correctly at the rate of 76%. On the other hand, confusion matrixes created as a result of the analysis of KNN and LR models are as calculated in Figure 7. In these models, the activities with the highest prediction accuracy are rendering, tiling, formwork and waiting activities, respectively. The waiting activity in the LR model, on the other hand, has the lowest prediction accuracy among all models, with a prediction accuracy of 67%.



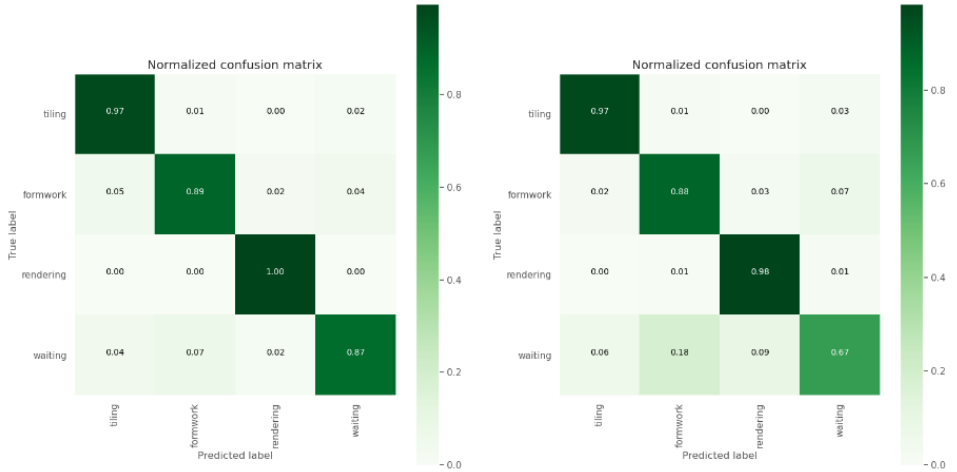
a. ET model b. SVC model

Figure 5: Confusion Matrix of the ET and SVC models.



a. DT model b. RF model

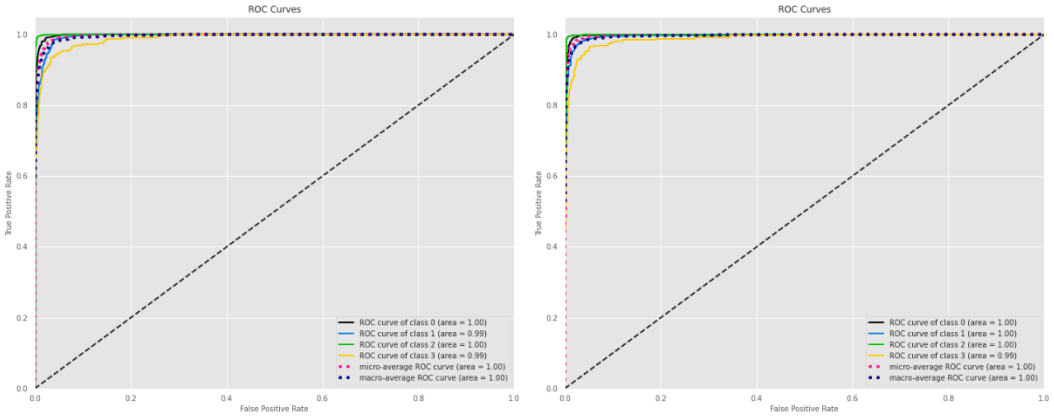
Figure 6: Confusion Matrix of the DT and RF models.



a. KNN model b. LR model

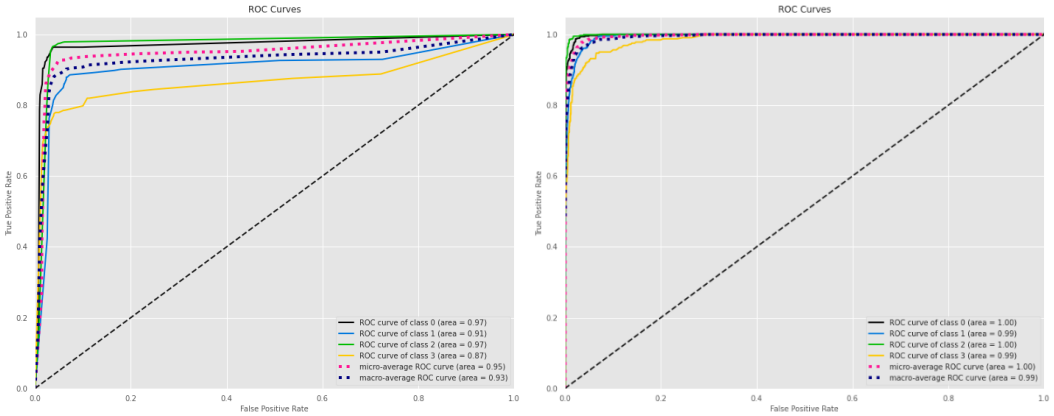
Figure 7: Confusion Matrix of the KNN and LR models.

In addition to confusion matrixes, another evaluation metric used in this study to see the estimation accuracy of machine learning models and also to see which activity these models estimate more accurately is ROC curves. As the area under the ROC curves increases, the prediction accuracy will increase. Figure 8 shows the ROC curves obtained as a result of the ET and SVC models. It is seen that the estimation accuracy of both models is quite high. Here, class 0 denotes tiling activity, class 1 denotes formwork activity, class 2 denotes rendering activity, and class 3 denotes waiting activity. Figure 9 shows the ROC curves created as a result of the DT and RF models. The RF model has high predictive accuracy for all activities, similar to the ET and SVC model. However, although the tiling and rendering activities achieved high estimation success in the DT model, the formwork activity and waiting activity achieved a estimation success of 91% and 87%. Figure 10 shows the ROC curve obtained from the KNN and LR models. In the LR model, it is seen that the waiting activity is estimated correctly at a rate of 95%. Other activities showed higher estimation success than this activity. In the KNN model, the estimation success of tiling, formwork, rendering and waiting activities is 98%, 94%, 99% and 93%, respectively.



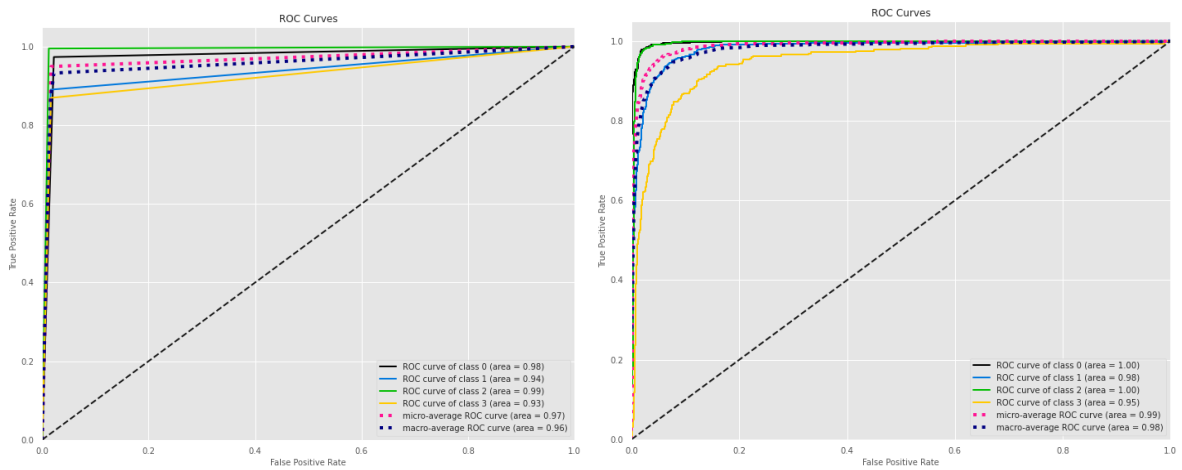
a. ET model b. SVC model

Figure 8: ROC curve of the ET and SVC models.



a. DT model b. RF model

Figure 9: ROC curve of the DT and RF models.



a. KNN model b. LR model

Figure 10: ROC curve of the KNN and LR models.

Confusion matrices and ROC curves are used to find the estimate success of any activity in any model. Considering the general estimate success, which model has the higher estimate success will be determined according to the accuracy scores of the models as in Table 2. The accuracy scores of the models were explained in two ways in this study. Each model was evaluated first with training accuracy scores, then with accuracy values generated using 10-fold CV, a more accurate and robust technique for modeling evaluation. It is seen that the accuracy score values obtained by using 10-fold CV in all models are higher than the training accuracy scores. When the models are compared, it is seen that the SVC model has the highest estimation accuracy with a value of 0.9666. After this model, the models with the highest estimation success are ET, RF and KNN models, respectively, with 95% estimation success. LR and DT models show a lower estimation success than other models.

Table 2. Accuracy score for machine learning models.

	ET	*SVC*	*DT*	*RF*	*KNN*	*LR*
Training	0.9523	0.9633	0.8982	0.9474	0.9493	0.9164
10-fold CV	0.9581	0.9666	0.9041	0.9533	0.9513	0.9195

The results obtained in this study, which was carried out within the framework of construction worker activity recognition, are given above. According to these results, it is seen that the formwork, rendering, tiling and waiting activities determined within the scope of the study are highly estimated by the analysis of the collected sensor data. Joshua and Varghese (2011) achieved approximately 79% estimation accuracy with the MLP model using only the accelerometer sensor. On the other hand, Zhang et al. (2018), when she analyzed the accelerometer and gyroscope data with the DT model, achieved 89.85% estimation accuracy. Ryu et al. (2019) obtained 88.10% estimation accuracy with the SVC model in the laboratory environment and using only accelerometer data.

In this study, the estimation success of all 6 machine learning models was found to be over 90%. The reason for the high estimation accuracy in all models is that the activities are thought to be more distinctive by collecting the accelerometer, gyroscope and magnetometer data together while collecting the data. In addition, when the models are compared, it has been found that the SVC model has higher estimation accuracy than other models. Considering the

estimation accuracy of the activities, the reason why waiting activity is underestimated compared to other activities is explained as the fact that workers can make different kinds of motions during the waiting phase.

Conclusion

Today, the rapid development of technology also affects the construction industry. However, since the construction industry is a labor-intensive industry, it is thought to be very difficult to adapt to technology. In addition, recently, studies have been carried out on the adaptation of the construction sector to technology. Accordingly, in this study, it is aimed to estimate the activities of the workers with machine learning models in line with the data obtained from the construction workers. As a result of this study, it is thought that it will provide automatic estimation of worker activities, automating the controls performed by the technical staff at the construction sites and facilitating the construction activity.

This study is especially important in terms of collecting data from the worker who does the work in the construction site environment. In addition, accelerometer, gyroscope and magnetometer data from the workers were collected together and analyzed. These data collected to estimate 4 different activities such as formwork, rendering, tiling and waiting, were analyzed with 6 different machine learning models such as Extra Tree (ET), Support Factor Classifier (SVC), Decision Tree (DT), Random Forest (RF), K-Nearest Neighbors (KNN), and Logistic regression (LR). According to the results of the analysis, the activities showed an estimation success of over 90% in all models. In addition, the SVC model has the highest estimation success with 96%. KNN, RF and ET models showed 95% estimation success. On the other hand, LR showed 91% and DT 90% estimation success. Considering at the estimation success of the activities, the highest estimated activity was rendering, and the lowest estimated activity was waiting activity.

It is considered that the results obtained from the analyzes are sufficient for the recognition of the activities of the workers. In addition, adding different activities to the models or using advanced alternative models may result in better estimate performance. The contribution of this study is thought to be the enhance of productivity measurement processes, as well as continuous monitoring of construction activities and automatic activity recognition and increasing labor productivity at construction sites. In addition, new models can be created by developing the artificial intelligence models used in this study. As a result of the sensors attached to the worker, the tracking of the worker and the tasks he performs can be automatically arranged and an efficient working strategy can be followed. In addition, the use of technology in construction management is expected to assist the three construction milestones of time, cost and quality.

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Identifying the Universal Rework Factors in Construction Projects

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Abstract

Rework is described as an activity that carried out more than once or activities that involve the removal of previously completed work which arises due to changes, errors, and omissions that occurs in the design and construction phases of the project. Rework is a common and global phenomenon that caused by many factors. While it remains problematic issue in construction industry, there is limited study to date has examined rework even though it significantly affects project performance negatively such as cost and time overruns. In order to minimize negative rework impacts and improve project performance, the causes of reworks at construction industry should be known. Therefore, this paper aims to identify, classify and rank the root causes of universal rework factors in construction projects. To reach this aim, a systematic literature review was conducted on the causes of rework and studies from 13 different countries were examined. Based on this investigation in the study area, a total of 41 different rework factors were identified and classified in six groups which are client, design team, project manager, labors, site related and general/external factors. The study concluded that the top five universal factors causing rework as: (1) ineffective management of project manager, (2) errors and omissions in design, (3) poor planning and coordination, (4) lack of labour skills, and (5) poor communication. The results of this study establish that effective rework management is necessary. The detection of rework factors assumed to lead identification the indicators, contribute to the construction management and reduce the occurrence of rework factors.

Keywords: *rework, rework factors, construction management, project management, systematic literature review.*

Introduction

Construction projects performance depends on particular success criteria such as completion on time, reaching the desired quality, fulfilling the requirements and not exceeding the estimated budget. Since construction projects consist of multiple stakeholders and various

phases of practices, the majority of them experience time overruns, cost overruns and quality defects. Although, one of the main causes of poor project performance is rework, there are few studies on its occurrence and consequences.

According to Construction Industry Institute (CII) (2001) rework is defined as "activities that have to be done more than once, or activities that remove previously work that installed as part of the project." Many construction professionals recognize rework as one of the most significant elements in project failure (Love and Edwards, 2004); since it is thought to be as a factor that responsible for delays, cost overruns and quality failures. Calculations of rework cost have been done in numerous studies, and the results range from 16.5% (Forcada et al., 2014) to 52.1% (Love, 2002) of the total cost overrun of the project. While projects can expect a certain amount of rework that can be estimated during the architectural practice, the real impact of late change orders and rework is often greater than expected (Kermanshachi et al., 2018).

It is difficult to identify a single cause for rework in construction projects, because there are complex and interdependent variables or conditions that interact with one another to produce rework events (Love et al., 2016). Since rework causes and potential consequences are largely unclear, it remains an unsolved problem. (Enshassi et al., 2017). However, by identifying and managing common root causes, it can be reduced and manageable (Al-Janabi et al., 2020). Therefore, this study aimed to investigate and rank the most significant rework factors in construction projects. To achieve these objectives an extensive systematic literature review was conducted to identify the main causes of rework.

Literature Review

The occurrence of rework in construction projects is a global problem. As a result, many countries are still being investigated the reasons of rework to be able to manage this issue. Researchers made classifications of rework factors under different groups. Love (2014) and OLove (2017) categorized rework factors as "People", "Organization" and "Project". Another study suggests five categories that cause rework as process, human resources, materials and equipment, technical and general/external (Asadi et al., 2021). Errors, changes and omissions at the design or construction stages are other examples of classification for causes of rework that have been used in the literature (Love & Li, 1999). In brief in the literature different methods have been proposed to classify causes of rework.

Ye et al. (2015) investigated the reasons for rework in construction projects in China through semi-structured interviews and a questionnaire survey with professionals. The results concluded that 11 main groups are responsible for rework; communication management, design management, field management, project process management, project scope management, active reworks, project plan changes, subcontractor management, contract management, owner capability, and the external environment (Ye et al., 2015).

Enshassi et al. (2017) categorized 57 rework factors under seven groups to be able to analyze and investigate their impact on project performance. According to this study, contractors' related rework and rework relating to human resource capability are the two groups that have the most influence on projects performance. In addition, the top five rework factors were identified as attempts to fraud, competitive pressure, ineffective management, schedule pressure and the absence of job security (Enshassi et al., 2017).

In addition, Forcada et al. (2017) analyzed 788 construction incidents that occurred in Spain and revealed that characteristics of construction have an impact on factors of rework costs such as complexity of a project, project type and type of contract. This study identified that errors and defects assumed by contractors, and extensions to project scope requested by clients were the most critical factors (Forcada et al., 2017).

Trach et al. (2019) carried out a study on factors for the emergence of rework in 42 Ukrainian construction projects and results revealed that design modification and lack of coordination were the factors with the highest effects. In addition, researchers stated the following key finding as all rework causes resulted one from the other (Trach et al., 2019).

Mahamid (2016) carried out a study related to rework in residential building projects in Palestine and identified most severe causes of rework as poor communication between construction participants, use of poor-quality materials and poor site management (Mahamid, 2016). He conducted another study in the Kingdom of Saudi Arabia on rework causes and revealed that errors and omissions, lack of labour skills, non-conformance with specifications, insufficient supervision, and changes of scope were the top causes (Mahamid, 2020).

As seen from brief review, of related research, several causes were identified particularly focusing on one country, all of which are important, however, it is unclear which of them are universal rework factors in construction projects. Therefore, in the first stage, it is impossible to take precautions to minimize the amount of construction reworks. From this perspective, knowing the universal rework factors is crucial.

Research Methodology

Rework data are usually challenging to collect, and the majority of studies have been carried out in developed countries (Trach et al., 2021). This research aims to gather these studies under a single roof and determine whether or not rework causes differ from one country to another. To achieve the main objective of identifying the universal rework factors, systematic literature review (SLR) was conducted.

Using SLR, extensive literature was examined. SLR is identified as a method-driven, transparent, and reproducible method (Booth et al., 2012) for analysing and understanding all research related to a certain issue, subject, or phenomenon (Wolfswinkel et al., 2013). Data collected from Web of Science (WoS) and Scopus databases that involves articles, conference papers, and book chapters. At the initial screening, 1071 documents were obtained with using search terms; “rework” AND “construction” on topic. 393 of them were remained after filtering, the rest 678 documents were out of research scope. After reviewing these documents, the following parameters were used to specify the research scope; search term “rework in construction” on title, subject areas “Engineering Civil” and “Construction Building Technology”. According to these inclusion criteria, total of 91 articles from 2002 to 2022 were chosen for the search, 4 of article could not be accessed. Then obtained 87 articles were examined and 41 items that cause rework in construction projects were determined and classified under six categories (client related factors, design team related factors, project manager related factors, labour related factors, site related factors and general - external related factors).

At the second phase, obtained data was classified based on the country that the studies conducted. Based on these analyses, the top 5 rankings of rework causes are determined and discussed.

Findings

Based on the findings of the systematic literature review, 41 rework factors were identified and divided into six groups; “client related factors”, “design team related factors”, “project manager related factors”, “labours related factors”, “site related factors” and “general - external related factors”. The major rework factors are summarized in Table 1.

Table 1. Selected rework factors with categories.

Factor categories	**Factor Code**	**Rework Factors**	**Sources**
Client related factors	C1	Client directed changes	[1], [2], [7], [10], [15], [16], [17], [20], [29]
	C2	Poor communication	[2], [5], [16], [18], [21], [25], [29], [32]
	C3	Lack of client involvement	[1], [2], [15], [16], [18], [21], [25], [29]
	C4	Changes of plan or scope	[2], [9], [17], [21]
	C5	Inadequate or weak feasibility study	[1], [2], [5], [18]
Design team related factors	D1	Incomplete design	[1], [2], [5], [9], [10], [15], [16], [17], [18], [21], [25], [29]
	D2	Design changes	[2], [6], [9], [15], [16], [17], [21], [22], [23], [25], [29]
	D3	Errors and omissions in design	[2], [5], [6], [7], [8], [9], [10], [17], [20], [21], [25], [28], [29]
	D4	Poor contract execution	[2], [6], [9], [25], [32]
	D5	Lack of understanding of user	[2]
	D6	Insufficient experience	[1], [2], [5], [15], [20], [21], [29]
	D7	Design management failure	[9], [10], [15], [16], [18], [20], [25], [29]
	D8	Fixed time for a task	[2], [7], [18], [20], [21], [25], [32]
	D9	Lack of using modern technology and software	[2], [18], [20], [29]
Project manager related factors	P1	Ineffective management	[1], [2], [5], [6], [8], [16], [19], [20], [21], [22], [23], [25], [31], [32], [33]
	P2	Lack of experience	[2], [5], [15], [18], [22], [23
	P3	Poor planning and coordination	[1-2], [5], [8], [10], [16], [18], [21-22], [23], [25], [29], [31-32]
	P4	Poor workload planning	[1], [15-16], [21], [31]
Labours related factors	L1	Lack of labour skills	[2], [5], [6], [8-9], [16], [18], [20-23], [25], [29], [31]
	L2	Time pressure	[1], [2], [8], [19], [21]
	L3	Poor workmanship	[1], [2], [6], [9-10], [17], [20], [25], [28], [29]
	L4	Non-compliance with specifications	[22-23], [29]
	L5	Shortage of skilled labours required to complete work tasks	[1], [2], [9], [15-16], [18], [21-22], [25], [29]
	L6	Lack of motivation	[5-6], [8], [22-23]

Site related factors	S1	Poor site condition	[1], [2], [6], [17], [21-23], [25], [31-32]
	S2	Complexity of design	[7-8], [21]
	S3	Inaccurate or lack of site investigation	[1-2], [8], [15-16], [20-21], [29]
	S4	Lack of safety considerations in the site	[1-2], [5], [21], [25], [32]
General - External related factors	G1	Changes in project scope	[8-9], [16], [21-23], [29], [32]
	G2	Wrong initial budget	[6], [32]
	G3	Poor information flow	[28], [31]
	G4	Poor communication	[2], [5], [6], [8], [9], [21-22], [28], [31-33]
	G5	Use of poor-quality materials	[1-2], [16-18], [20-22], [25], [28], [32-33]
	G6	Lack of technological equipment // Ineffective use of technology	[1-2], [5], [16], [20-22], [25], [31-32]
	G7	Economic situation of the country (inflation, currency exchange)	[2], [5], [9]
	G8	Change of laws	[2], [5], [32]
	G9	Natural Disasters (such as rain, wind, earthquake) // Force major	[2], [5], [6], [9], [17], [21-22], [32]
	G10	Shortage of construction materials in market	[32]
	G11	Time constraints // Schedule pressures	[5], [6], [8], [15-16], [19], [21], [23], [31]
	G12	Inadequacies in contract documentation	[1], [2], [16], [21], [28-29], [32]
	G13	Changes in construction method to improve constructability // Errors due to inappropriate construction method	[1-2], [9], [15-17], [21-23], [25], [31-32]

Note(s): [1] Ajayi (2017); [2] Al-Janabi et al. (2020); [5] Enshassi et al. (2017); [6] Forcada et al. (2017); [7] Forcada et al. (2017); [8] Forcada et al. (2014); [9] Hwang et al. (2019); [10] Josephson et al. (2002); [16] Love et al. (2010); [17] Love and Li (2000); [19] Love et al. (2018); [20] Love and Edwards (2004); [21] Mahamid (2016); [22] Mahamid (2020); [23] Mahamid (2019); [25] Palaneeswaran et al. (2008); [28] Trach et al. (2021); [29] Trach et al. (2019); [31] Chong et al. (2020); [32] Ye et al. (2015); [33] Zhang et al. (2018)

To reveal the country-based studies obtained articles reviewed, and 59 out of 91 articles were excluded due to not having specific country information in the studies. Then, 10 of remained 31 articles were excluded from the study due to limits of research scope and one of them was not accessible. Finally, 21 articles were analyzed, and findings presented in Table 2. From the existing studies that cover 13 countries worldwide; all factors could be listed and ranked according to number of mentions. Table 2 shows all selected studies based on countries and authors.

Table 2. Rework factors according to countries.

| Rework Factor Code | Countries | | |

L5	*	*	*					*					*			*		*		*	
L6				*	*										*	*					*
S1	*	*	*		*	*		*	*			*				*					*
S2			*											*	*						
S3	*	*	*								*		*		*			*			
S4	*	*	*	*		*		*													
G1			*		*	*							*		*	*		*		*	
G2						*															*
G3									*								*				
G4	*	*	*	*		*	*		*						*	*	*			*	*
G5	*	*	*			*	*	*			*	*	*			*	*					
G6	*	*	*	*		*		*	*		*		*			*						
G7	*			*																	*	
G8	*			*		*																
G9	*		*	*		*						*				*					*	*
G10						*																
G11			*	*	*				*	*			*		*							*
G12	*	*	*			*							*				*	*				
G13	*	*	*		*	*		*	*			*	*			*					*	

According to the findings of SLR of country-based articles, rank order of the 41 items was determined by the number of studies they were uploaded. The top five most cited factors were mentioned in more than 10 articles, whereas others were not.

Table 3. The top five universal rework factors and related groups.

Rank	Factor Code	Related Group	Rework Factor	Number of Related Country-based Articles
1	P1	Project manager related factors	Ineffective management of project manager	15
2	D3	Design team related factors	Errors and omissions in design	13
3	P3	Project manager related factors	Poor planning and coordination	13
4	L1	Labours related factors	Lack of labour skills	13
5	G4	General - External related factors	Poor communication	11

Even though the results vary, studies have shown that specific conditions of countries have little impact on rework factors; there is a certain level of similarity among them. The findings of the systematic literature review show that the top five most cited rework factors are ineffective management of project manager, errors and omissions in design, poor planning

and coordination, lack of labour skills, poor communication. These factors are discussed in more detail in the following paragraphs:

1) Ineffective management of project manager: Ineffective management leads to misunderstanding and poor communication between construction parties, which prevent labours to perform the job as designed or scheduled, as a result led to conflicts between them that may lead to rework. Poor management has significant influence on construction project productivity (Enshassi et al., 2017).

2) Errors and omissions in design: Poor communication flow between design team members and client may result in errors and omissions in design documents (Love and Edwards, 2004). In addition to that, unskilled designer, fixed time for a task, inefficient use of technology for architectural drawings may lead to errors and omissions. This is a critical issue; especially after construction started, later design failures directly influence performance, cost and productivity (Love et al., 2014). To achieve correct and complete design documents and minimize changes some quality management practices should be adopted like, producing drawings according to the specifications, coordinating team and checking the documents regularly (Love & Li, 2010).

3) Poor planning and coordination: Poor planning and coordination may result from failure in job distribution, poor skills of the project manager, insufficient work separation. All of these quality failures are responsible for large part of rework cost (Hammarlund & Josephson, 1991). In order to prevent that and to avoid conflicts; specifications should be clear, and distribution of work should be balanced and realistic.

4) Lack of labour skills: Skilled and well-trained labours perform mistake free works that prevent rework and enhance the productivity on the contrary to unskilled labours (Mahamid, 2020). There is no construction project that is free of labor-related faults (Al-Janabi et al., 2020). However, to be able to reduce the probability of occurrence, Mahamid suggested that a method should be improved for selecting subcontractors (Mahamid, 2020). Since Subcontractors prefer to work with unskilled labours in order to pay less which affect project performance negatively (Al-Janabi et al., 2020).

5) Poor Communication failure: According to a questionnaire survey done in Palestine; three of the five most influential factors were poor communication between construction parties which affects workflow negatively (Mahamid, 2016). Another study done in Malasia (Yap et al., 2020) that is in line with previous studies, ranked insufficient communication highest. BIM suggested as one way to strengthens communication and opens communication channels, because that it makes visible connections (Hwang et al., 2019).

Conclusion

Rework has significant influence on project performance such as cost overrun, schedule overrun, and quality failures. It is an ongoing issue in construction industry. There have been no reports of a project achieving zero rework; almost every construction experiences some degree of rework. The study's goal is to highlight significant rework factors through a systematic literature review.

This study identified rework factors through systematic literature review which are classified under six groups: client related (5 items), design team related (9 items), project manager related (4 items), labors related (6 items), site related (4 items) and general/external related (13 items). As a second contribution, all country-based studies were gathered that investigate reasons of rework in construction projects and aimed to draw attention to the most significant ones. The results of this investigation show that the top five most cited universal rework factors are ineffective management of project manager, errors and omissions in design, poor planning and coordination, lack of labour skills, and poor communication. Based on the findings, the major rework factors do not differ significantly among countries; there is some degree of similarity. The findings of this research will raise the awareness of construction stakeholders on the critical sources of rework in construction projects, which can contribute to decrease its occurrence.

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Barriers to E-Tendering Adoption and Implementation in The Construction Industry: 2010 – 2022 Review

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Abstract

Recent technological advancements are making the traditional paper-based tendering methods quickly becoming obsolete. E-tendering is widely regarded as a valuable tool for enhancing efficiency and empowering construction industry experts to better oversee the tendering process in order to reduce project delays and increase profits. Despite the benefits of e-tendering over the years, it is new to some construction industry stakeholders, and its acceptance and implementation have encountered many problems, according to global reports. This research aims to identify the critical barriers to e-tendering implementation in the construction industry. A systematic literature review technique was used to determine the barriers. A thorough literature analysis was undertaken using the relevant scientific databases. The findings were distributed based on six geographical regions. The eight (8) critical barriers that were consistent in all the 6 geographical regions include; inadequate data security, the high investment cost of implementation, resistance to change, lack of support, technical challenges, lack of uniform standard or policy and legal framework, inadequate ICT infrastructure, and inadequate technical/skilled personnel. This study contributes to the in-depth understanding of global e-tendering barriers in the construction industry based on geographical regions. The findings could help researchers, practitioners, and governments make strategic investment decisions and overcome e-tendering challenges.

Keywords: *barriers, challenges, construction industry, e-procurement, e-tendering.*

Introduction

Tendering has long been regarded as the most equitable method of awarding government contracts and the method most likely to result in a favorable outcome for a government's spending of public funds (Betts et al., 2006). The fundamental principles of the traditional tendering process have been applied to many business areas, including purchasing goods, seeking service providers, business consulting and selecting general contractors for construction work for several years (Du et al., 2005) and is prone to many limitations. According to Arslan et al. (2006), the traditional bidding process are time-consuming and labor-intensive. Abdullahi et al. (2020) added that, the manual paper-based tendering processes are

known to be inefficient, less transparent, and prone to corruption, particularly in public sector procurement. As a result, nowadays, researchers, marketing managers, and business leaders are searching for innovative ways to exploit e-business technologies for business purposes (Naeem, 2021). Ilhan and Rahim (2017) buttressed that, in recent years, many business organizations worldwide have streamlined and automated their manual procurement process using software solutions that are known as e-procurement systems.

Alsaç (2017) observed that the term "e-procurement" has probably been the trendiest word in the public procurement profession in recent years. As a result, e-tendering has been defined in several ways according to the literature. Notable among the definitions are; "*E-tendering is the use of electronic communication systems and tools to disseminate information about tender opportunities, as well as to submit, receive, store, and make decisions on bids/tenders or proposals for construction works, goods, and services. In simple terms, e-tendering is an online process that manages the tendering cycle from notice advertisement to awarding" (Ibem & Laryea, 2017).* "*E-tendering is a platform for the exchange of construction project information between geographically dispersed individuals via the internet" (Solanke & Fapohunda, 2015).*

The primary goal of implementing e-tendering technology is to reduce transaction costs, increase order placement effectiveness, develop good relationships with suppliers, reduce the level of paperwork and time to order inventory, and reduce the purchasing cycle and overhead costs associated with the purchasing process, (Naeem, 2021). Despite the widespread e-tendering adoption and its benefits, (Yevu et al., 2021) argued that, within the construction industry, the anticipated increase of e-procurement adoption for construction procurement processes has suffered many setbacks in its implementation.

Additionally, there are many barriers to the adoption of e-tendering. In the Organisation for Economic Co-operation and Development (OECD) countries, the following e-tendering barriers have been identified to jeopardize the adoption of e-tendering: quality and understanding of the information provided, size of contracts being too large, an administrative burden too high, difficulties relating to the proportionality of qualification levels and financial requirements, lack of visibility on available contracts of smaller value, lack of dialogue and feedback with public contracting authorities, late payments or lengthy terms of payment, access to relevant information, emphasis on price only rather than value for money, too short a time to draw up tenders, and lack of integrity in the procurement process (OECD, 2020).

In the previous years, a lot of publications have been conducted on e-tendering in a bid to raise awareness and facilitate the adoption of e-tendering. Notable among them include: Critical success factors for e-tendering implementation in construction collaborative environments (Lou & Alshawi, 2009), E-Tendering: Benefits, Challenges, and Recommendations for Practice (Kajewski & Weippert, 2004), E-tendering readiness in construction (Al-Yahya et al., 2018), A cross-discipline comparison of rankings for e-procurement drivers and barriers within UK construction organizations (Eadie et al., 2010). Similarly, a systematic review of the drivers for electronic procurement adoption for construction project procurement, and barriers to electronic procurement adoption in the construction industry has been explored by (Yevu & Yu, 2019; Yevu et al., 2021). Even though a study on the barriers to e-tendering has been conducted by Yevu et al. (2021), a full understanding of the trends and barriers has not been presented in the literature, especially according to geographical regions leaving a research gap.

In an effort to fill this gap, this study is aimed at conducting a systematic literature review to identify the critical barriers to e-tendering based on geographical regions because of

homogeneous physical and cultural attributes. In this study e-tendering or e-procurement is defined as a digital framework that automates the management process of tenders which allows for smoother and more controlled procurement that lets the procurer manage and evaluate bids with ease electronically.

Background of E-Tendering in the Construction Industry

Since the late 1960s, electronic commerce has existed in various forms, such as Electronic Data Interchange (EDI), Electronic Tendering (e- tending), Electronic Mails (e-mails), and e-procurement (Anumba & Ruikar, 2002). Grilo and Jardim-Goncalves (2011) added that early e-procurement was associated with the proliferation of inter-organizational systems, communities, electronic platforms, meeting places, virtual locations, and infrastructures, which were often referred to as electronic marketplaces. After the introduction of the World Wide Web (WWW) and internet browsers in the early 1990s, internet electronic commerce has grown exponentially (Anumba & Ruikar, 2002). As a result, in the early 2000s, studies on the implementation of e-procurement in the AEC industry surfaced Isikdag et al. (2011). Researchers such as Neef (2001) studied E-Procurement from a strategy to implementation perspective and McIntosh and Sloan (2001) discussed the importance of electronic procurement and global sourcing procedures in the UK construction industry in 2001. The authors recommended that the construction sector should abandon traditional sourcing practices in favour of using the global marketplace to improve efficiency, competitiveness, and profits.

Moreover, e-tendering is gaining worldwide recognition in recent years (Goswami et al., 2020; Ibem & Laryea, 2013; Ibem & Laryea, 2017), primarily as a stand-alone and one of the tools for assisting in changing the culture and improving the processes of the construction industry. Even though Isikdag (2019) argued that the adoption of e-procurement for conducting project procurements to improve traditional paper-based procurement has had limited uptake in the project procurement process. Despite the widespread organizational adoption of e-procurement systems, the construction industry continues to witness disappointing performance outcomes from their implementation (Oyediran & Akintola, 2011; Kajewski & Weippert, 2004). Al-Yahya et al. (2018) opined that e-tendering guidelines requirements for organizations' successful implementation lack clear guidelines which cause confusion, particularly among stakeholders who want to use e-tendering. As a result, the systems and processes have raised a number of concerns among construction industry stakeholders which are impediments to the use of e-tendering (Ibem & Laryea, 2017; Oyediran & Akintola, 2011; Arslan et al., 2006). Therefore, understanding the barriers is crucial in the implementation of e-tendering. The section below presents a broader picture of the barriers that hinder the implementation of e-tendering in the construction industry.

The Barriers of E-Tendering

Despite all of the advantages of electronic tendering, there are certain fundamental challenges that must be addressed in order to boost public confidence in the use of electronic tendering apps. According to Anumba and Ruikar (2002), electronic tendering barriers can be divided into two categories: barriers common to all industry sectors, including the construction sector, and barriers specific to construction electronic tendering applications. The common barriers to electronic tendering mainly fall into three categories, that is issues related to infrastructure, trust and reliability, and regulatory issues. On the other hand, construction-specific barriers to

electronic tendering include the high initial investment required to build the necessary infrastructure and train personnel, quantifying the return on investment (ROI), data security in online transactions, integration with legacy systems, and interoperability of distributed software applications over the internet.

In addition, Goswami et al. (2020) opined, e-tendering focuses on ensuring transparency throughout the tendering process, however, it has flaws such as a centralized database that is vulnerable to attacks. Betts et al. (2006) buttressed that, the uncertainty caused by a lack of understanding of the legal rules and principles that are applied to electronic tendering systems makes security compliance for an e-tendering system paramount. Ibem and Laryea (2015) outlined the three main barriers to e-tendering use in the South African construction industry as slow internet connectivity, resistance to change, and expensive internet services. Oyediran and Akintola (2011)'s study revealed that there is a general lack of basic facilities required for the process, as well as a low level of proficiency in its application and the critical barriers are irregular power supply, the financial implications of putting up e-tendering infrastructure, poor telecommunications infrastructure, and lack of legal support for electronic transactions.

Furthermore, Tran et al. (2021) identified the most significant impediments to e-tendering adoption as people-related, such as a lack of awareness, a shortage of competent workers, poor cross-disciplinary communication, a fragmented supply chain, and inadequate industry standards for information transfer. Wimalasena and Gunatilake, (2018) carried out research to unveil the readiness of construction contractors and consultants to use e-tendering in Sri Lanka. They concluded that the main barrier to e-tendering implementation was a lack of e-tendering-specific legal rules, lack of awareness of the employees and senior management, and lack of legal rules and regulations.

The results from the literature suggest that despite the adoption and the benefits of e-tendering, its application has faced numerous challenges. To assist in mitigating e-tendering barriers in the construction industry, the barriers to e-tendering must be first identified. The major barriers to e-tendering have been identified through a systematic literature review below.

Research Methodology

The purpose of this study was to explore the barriers to e-tendering application in the construction industry through a systematic literature review. According to Chan and Owusu (2022), in order to perform a comprehensive systematic literature review, an appropriate approach or strategies to aid the review process must be chosen. This study employed the systematic review methodology as used by previous researchers (Chan & Owusu, 2022; Yevu & Yu, 2019) to guide the selection of relevant papers from the database and journals. The systematic review was selected because it compares and integrates the findings of the relevant studies (Yevu & Yu, 2019). The study used a comprehensive and in-depth three-phase process to extract relevant journals initially targeted and subsequently conducted a desktop search followed by another specified search as described below.

Phase 1: Search Target Journals

As in the work of Lu et al. (2015), in phase 1 of this study, relevant papers were chosen from the top 12 construction management journals in Wing (1997)'s ranking because they are generally recognized in the construction management community. The rationale behind this

was to increase the scope of the search (Yevu & Yu, 2019). The journals targeted were Construction and Architectural Management, Proceedings of the Institution of Civil Engineers – Civil Engineering, International, Construction Management and Economics, Journal of Construction Management and Engineering (JCEM), Engineering, Journal of Management in Engineering, International Journal of Construction Information Technology, Transactions of American Association of Cost Engineers, Automation in Construction, Journal of Construction Procurement, Journal of Project Management, Building Research and Information and Cost Engineering. The virtual libraries of these selected journals were used to find relevant English papers using the keywords listed below: "Barriers" OR "Challenges" AND "E-procurement", OR "E-Tendering" AND "Construction Industry" within the relevant databases and search engines, respectively. The systematic procedure for the literature review is depicted in Figure 1.

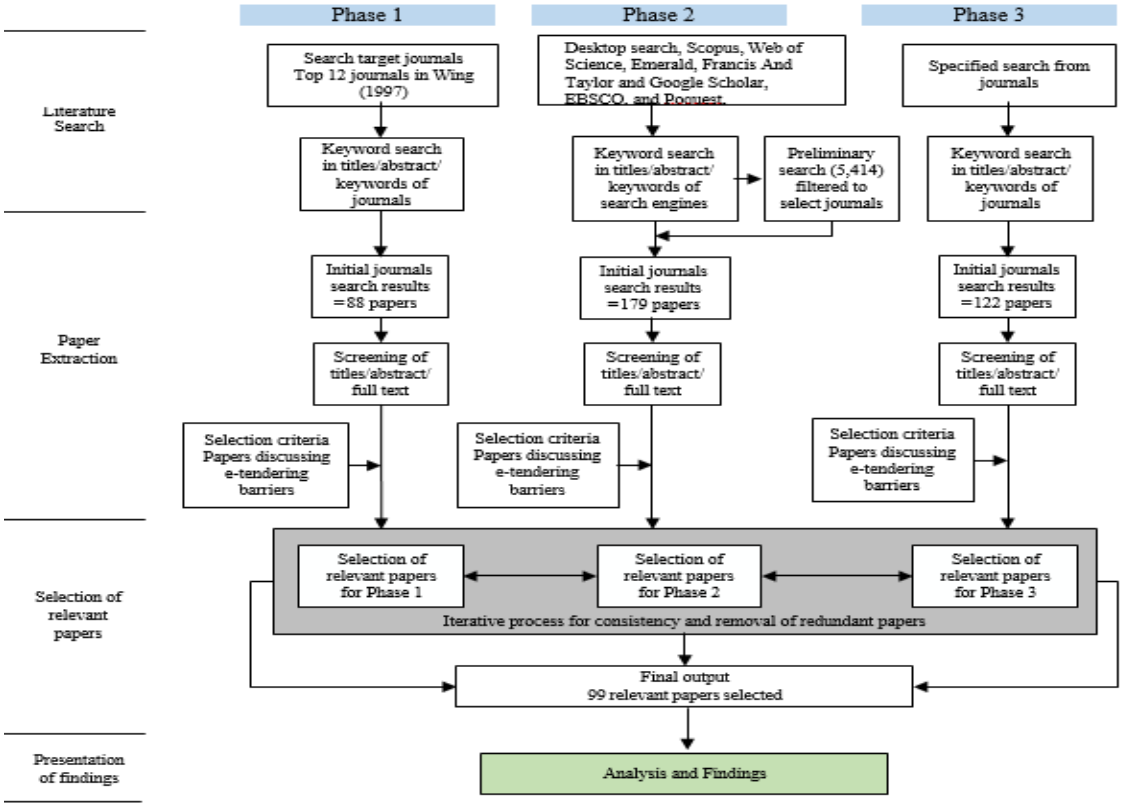


Figure 1: Systematic process for literature review adopted from (Yevu & Yu, 2019).

Phase 2: Desktop Search

To identify other construction journals relevant to the study, the largest database recognized in academia Web of Science, Scopus, EBSCO, Francis and Taylor, ProQuest, and Google Scholar using the same keywords. According to the search results, papers relevant to the study were selected for further analysis.

Phase 3: Specified Search from Journals

Finally, the obtained papers were analysed for duplication using Mendeley and excel. A total of 99 papers were considered relevant for the study after examining the papers. All the journals were searched in May 2022.

Results

The analysis and summary of findings from the selected papers are presented using descriptive analysis of papers and examination of the barriers identified. The first dimension adopts descriptive analysis to show the characteristics of selected papers for the yearly distribution of papers by journals and the geographical region of publication. This was done by recording the year of publication of the study and the number of authors in the geographical region.

Publication Trend

Figure 2 shows the annual publication trend of the reviewed papers. The papers identified showed a slow rise from 2010 and reached the peak in 2014 and 2015 recording 14 papers each, the highest number of publications. This could be the acceptance of e-tendering in the construction industry, especially the developing countries. On the other hand, Gunasekaran and Ngai (2008) attributed the rise to the emerging internet and the concept of applying e-procurement for project procurement. Subsequent years had declined publications until 2021 with five papers. In addition, 2022 recorded only one which was not surprising because the data was retrieved up to May 2022 which could have more than one number by the close of the year. Apart from the year 2022 recording just one, 2012 recorded the least number of publications with four number. The publication trend has been generally constant, with an average of 7.6 papers per year cumulatively.

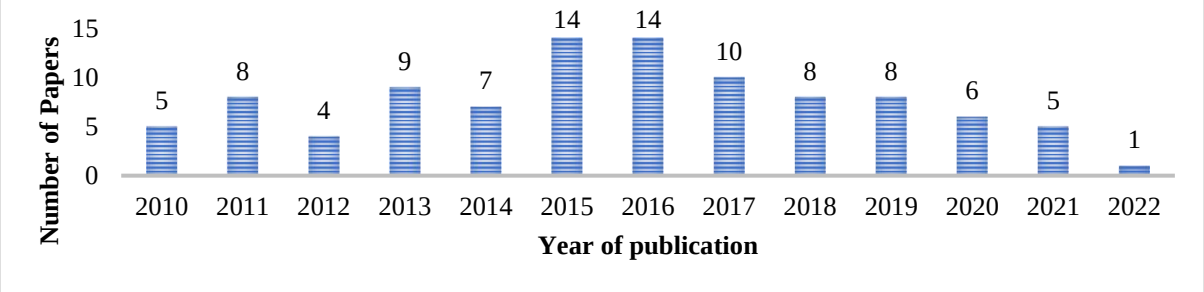


Figure 2: Number of papers published from 2010 to 2022.

Publication by Geographical Regions

Figure 3 shows the number of papers published according to geographical regions on the barriers to e-tendering adoption and application in the construction industry. From the figure, Africa is the leading geographical region with the highest number of publications (37). This can be attributed to African countries embracing new technologies to catch up with the developed countries in the quest to improve construction productivity. It was followed by Europe (24). After the year 2010, research about e-tendering in reduced according to the findings, and this may be that researchers in Europe turned their focus on other initiatives such as Building Information Modelling and other emerging software. Asia (20), Middle East and North Africa (10), Pacific (5), and North America (3) respectively. The number of papers by geographical region on the current study suggests the impact of the topic on industrial developments. In this case, the number of papers suggests the impact of the e-tendering on industrial developments.

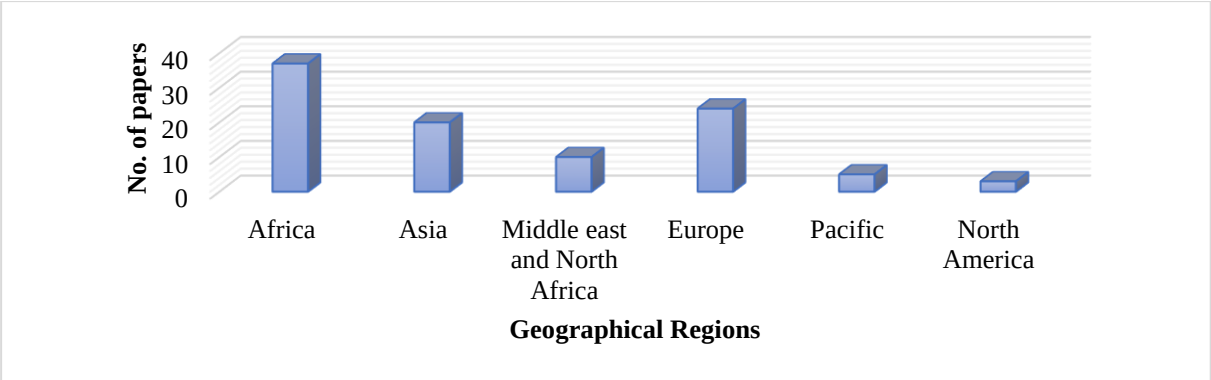


Figure 3: Number of papers by geographical regions.

Identification of Barriers to E-Tendering Implementation

After a thorough examination of the 99 relevant publications, 16 main barriers to e-tendering adoption and application were identified. Table 1 contains information about these barriers. The study identified 8 factors that appeared in all the regions in the literature as (1) inadequate data security (2) high investment cost of implementation (3) resistance to change (4) lack of support (5) technical challenges (6) lack of uniform standard or policy /Inadequate legal framework (7) inadequate ICT and internet infrastructure (8) inadequate technical/skilled personnel.

Table 1. The main barriers to e-tendering based on geographical regions.

E-tendering Barriers	Africa	Asia	Middle East & North Africa	Europe	Pacific	North America
Inadequate data security	X	X	X	X	X	X
High investment cost of implementation	X	X	X	X	X	X
Reluctance/ resistance to change	X	X	X	X	X	X
Lack of support	X	X	X	X	X	X
Technical challenges	X	X	X	X	X	X
Lack of uniform standard or policy /Inadequate legal framework	X	X	X	X	X	X
Inadequate ICT and internet infrastructure	X	X	X	X	X	X
Inadequate technical / skilled personnel	X	X	X	X	X	X
Lack of trust and awareness of benefits e-procurement systems/skepticism	X	X	X	X	X	-----
Software non-compatibility / interoperability challenges	X	X	X	X	----	----
Lack of widely accepted e-Procurement software solutions in construction	----	----	----	X	X	X
Lack of integration with business partners	-----	X	----	----	-----	X
Unreliable electric power supply	X	----	----	----	----	----
Ineffective communication/ very poor cross-disciplinary communication, Complex user interface	---	X	----	----	----	----
Lack of forum, pioneering firms, studies and pilot projects of e-tendering	-----	----	----	X	-----	-----
Other competing initiatives, Excessive number of e-platforms	----	----	----	X	----	----

Apart from North America, lack of trust and awareness of the benefits of e-procurement systems/scepticism is a key barrier that appears to be consistent in all geographical regions. This suggests the low level of e-tendering awareness and benefits in the construction industry. Software non-compatibility / interoperability challenges are also a major barrier in Africa, Asia, the Middle East & North Africa, and Europe. The lack of widely accepted e-tendering software solutions in construction was recorded as a key barrier in Europe, the Pacific, and North America. This can be attributed to technological advancement and as result too much unprofessional software available.

Lack of integration with business partners and ineffective communication/very poor cross-disciplinary communication complex user interface were recorded in Asia. This is a great challenge if business partners find it difficult in integrating e-tendering systems beyond company borders in supply chains if partners lack capacity. Furthermore, the unreliable electric power supply is also a major barrier that hinders the implementation of e-tendering in Africa. Most African countries are still struggling to meet the demand for electricity supply. This does not allow the full implementation of new technologies. Moreover, lack of forums, pioneering firms, studies and pilot projects of e-tendering, and other competing initiatives which are more advanced than e-tendering like Building Information Modelling and excessive number of e-platforms were recorded only in Europe.

Discussions

Based on the research findings in this study, certain critical barriers have been identified for further discussion in this section.

Lack of uniform standard or policy/Inadequate legal framework: Describes lack of legal rules and regulations to cover the e-tendering process, lack of laws or guidelines to resolve the disputes when processing e-tendering or in breach of legal transaction, lack of a reliable and uniform standard system, and lack of enforcement of electronic contracts. In addition, inadequate legal framework/ lack of a national IT policy relating to e-procurement issues, bureaucratic dysfunctionalities in practice, lack of pertinent case law, and e-signature issues. Anumba and Ruikar (2002) revealed that companies see unclear regulatory issues (such as tax issues, legal issues, ethical issues, etc.) as major deterrents to adopting e-tendering. A key determinant of e-tendering effectiveness is how well regulatory systems achieve their policy objectives. This implies that a standard policy is required for easy implementation of e-tendering, thereby minimizing disputes.

Inadequate data security: Under the umbrella of inadequate data security, the possibility of hacking, virus attacks, and data loss, confidential information getting into the wrong hands, lack of trust in electronic documents, document tampering / online crime, and authentication issues. This implies that a well-secured alternative must be chosen when applying e-tendering. Anumba and Ruikar (2002) opined that, according to electronic commerce researchers and analysts, the most crucial barrier stopping organizations from implementing electronic commerce measures is security. As a result, governments and organizations are launching a number of steps to counteract these widespread fears.

Technical malfunctioning of the portal and technical issues: In the case of e-tendering, it includes compatibility and support, system instability, frequent system errors, unknown errors of the system, technological updates, high maintenance cost, and the system crashing on the

very day the bid is due. Khalil and Waly (2015) revealed that Egyptians' lack of trust in any government-provided service has caused a great fear that the portal may malfunction (broken links, service unavailability, poor page load, etc.), particularly during the tender submission process. Furthermore, if the portal's technological fault makes it impossible for tenderers to submit their bids, many will be suspicious and will make charges of corruption against the company running the portal. Hence, the IT system must be user-friendly, and site managers must receive prompt support. Moreover, there is the need to train technical people to handle the technical issues.

Inadequate ICT and internet infrastructure of organization to support e-tendering: Inadequate ICT and internet infrastructure include unreliable internet, slow internet network connectivity, high cost of accessing the internet, etc. Mind Commence (2022) defines ICT infrastructure as the hardware and software required to construct and operate systems and networks for communications services, as well as to support applications, digital content, and e-commerce. Switching, transmission/transport, signaling, network access (such as radio base stations), and numerous platforms, databases, and ICT data are all components of ICT infrastructure. Most countries still lack this ICT infrastructure and as a result, hinder the full operationalization of e-tendering in the construction sector. This is confirmed by Wimalasena and Gunatilake (2018) in Sri Lanka, Hassan (2021) in Finland, and Sánchez-Rodríguez et al. (2019) in Canada. Therefore, governments and top managers must invest in ICT infrastructure to accelerate the implementation of e-tendering in the construction industry.

Reluctance/ resistance to change: From the findings, resistance to change could be an internal cultural issue. The culture of a company determines how employees should conduct their business within the company; lack of organizational readiness due to inadequate resources. According to Schnitzler and Österlund (2015), employees that are resistant to change do not want to learn a new system or working approach, especially if the system is still in the early stages of installation and some features may still need adjustment. Pop (2011) attributed resistance to change to a lack of information system skills and fear. Users are afraid and resisting to change because they don't have the required e-procurement skills. Khalil and Waly (2015), added high investment costs to adopt and maintain e-tendering with no substantial benefits realized. Bowmaster et al. (2016), suggested that cultural elements, organization, and strategy, and changing IT technical needs of an organization are some of the contributing factors to resistance to change. Khalil and Waly (2015), emphasized that it is generally assumed that if existing ways of doing things are good, there is no need to go the extra mile and do something contrary to the norms (e.g., transitioning to paperless procedures). Consequently, organizations need to be convinced of the benefits of the new working method and will not be forced to adopt it. It is therefore recommended that; top management should know and educate their organization about the benefits of e-tendering to pave way for smooth adoption of e-tendering technology.

Lack of support: For the successful implementation of e-tendering, maximum support is needed. According to the findings, lack of support can be attributed to; lack of top management support, lack of government support, limited resource, SMEs access difficulties, and lack of capacity issues to implement e-tendering. Ibem et al. (2017) ranked the fear that e-procurement will help curb corruption in the Nigerian construction industry. This implies that in an institution whereby the top management is corrupt, they will do their possible best to hinder the successful implementation of e-tendering. The efficacious implementation of e-tendering requires massive support hence the construction industry stakeholders and governments must

support the adoption and implementation of e-tendering to help improve the numerous limitations of the traditional tendering systems.

Inadequate technical / skilled personnel: Lack of e-tendering skilled personnel includes, for example, older generations who are less acquainted with IT-Systems and rely heavily on traditional working techniques. Amuda-Yusuf et al. (2019) stated that ICT skill/competency capability specifies the extent to which IT workers have the abilities and knowledge to undertake jobs outside of their initial area of instruction or domain. As a result, a high level of skill in the use of ICT technologies is required for industry stakeholders to use the e-tendering facility. Therefore, knowledge/skill of technological innovation is recommended in this study as another organizational component that can influence firms' adoption of e-tendering.

High investment cost of implementation: E-tendering implementation costs include IT systems cost, system licenses cost, cost of training staff affects many organizations, especially small and medium scales companies. Since most firms cannot afford for the paradigm shift from paper-based to a paperless system, it deters them from adopting e-tendering as has been reported in Hassan (2021)'s study for Finland.

Lack of trust and awareness of benefits e-procurement systems/skepticism: Since the traditional paper-based has been used for several years, the organizations are used it and are reluctant in finding new solutions and therefore not aware of the e-tendering. Others too do not trust the system and are skeptical about the benefits of e-tendering. This is confirmed by Mehdipoor et al. (2022) for Malaysia, Hassan (2021) for Finland, and Khalil and Waly (2015) for Egypt.

Software non-compatibility / interoperability challenges: In the construction industry, compatibility of tools and resources among projects is essential because numerous organizations work significantly on unique projects in temporary groupings. The interchange of data in e-tendering is critical inside the construction process. The project partners should use an e-tendering solution offered by the same or compatible manufacturers to ensure a flourishing exchange of data and prevent information loss. By developing a specification for an open data format, the industry can make a reasonably early start to facilitate data exchange (Hassan, 2021). In support of this, previous researchers such as (Wimalasena & Gunatilake, 2018; Oyediran & Akintola, 2011) have confirmed this.

Conclusions and Recommendations

This study investigates the critical barriers to e-tendering adoption and implementation in the construction industry through a systematic review from January 2010 to May 2022. The aim of the study was to identify the main barriers to e-tendering in the construction industry. This was achieved through a systematic review based on geographical regions. The following conclusions can be drawn from the findings. The barriers identified were grouped based on six geographical regions as Africa, Asia, Middle East & North Africa, Europe, Pacific, and North America. 16 critical barriers were identified. Out of the overall barriers identified, (1) inadequate data security (2) high investment cost of implementation (3) resistance to change (4) lack of support (5) technical challenges (6) lack of uniform standard or policy /Inadequate legal framework (7) inadequate ICT and internet infrastructure (8) inadequate technical/skilled personnel are the 8 critical factors that consistently appeared in all the geographical regions. The unreliable electric power supply was also one of the major barriers to e-tendering in Africa

and some parts of Asia. Lack of widely accepted e-tendering software solutions in construction dominates Europe, the Pacific, and North America while lack of integration with business partners and ineffective communication/very poor cross-disciplinary communication complex user interface was common in Asia. This research is a foundation for the development of solutions by construction stakeholders to identify and address the barriers in the construction towards the adoption and implementation of e-tendering, hence improving the uptake of e-tendering specifically for the construction public works globally.

This study contributes knowledge to existing theory and can be used for further reference. In addition, managers from organizations operating in the construction industry may apply the results for decision-making when they consider implementing e-tendering or when they aim to assess the barriers of e-tendering.

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Value Engineering in Construction Management Literature

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Abstract

Value engineering (VE) is an effective management approach in construction industry to maximize value and reduce cost of a project composed of multidisciplinary teams. It provides an understanding the needs of the budget, ensure objective perspective on project durations, costs, and other functions for the project investors. Additionally, value engineering enables a base for decision-making while decreasing the risks of design variations. However, the studies conducted in the construction management literature are limited. The aim of this research is to convey a comprehensive literature review of value engineering in the construction management body of knowledge. Scientific articles which were published between 2000-2022 years were reviewed and analysed according to research themes, related sub-themes, applied methodology types and country's attention.

Keywords were defined as "value management, value engineering, earned value management, construction management" for descriptive analysis. By using Web of Science, Scopus, and Google Scholar databases 291 articles were retrieved. These studies were categorized through thematic coding method and then frequencies were determined. The literature review indicated that the majority of the researched areas focused on the adoption of Value Engineering (VE)/Value Management (VM)/Earned Value Management (EVM) to construction industry (14,43%), following the use of knowledge management in VE/VM/EVM (10,31%), decision making strategies (9,97%), and finally the integration VE/VM/EVM into sustainability (9,28%). On the other hand, contract management, facility management, creating a guideline, innovation management and legal regulation themes were the least researched areas (each 0,34%) within the construction management literature. Additionally, the most common methodology types in VE/VM/EVM implementation are case studies (26,80%), model proposal (18,90%), only exploratory survey research (16,40%) and literature review (15,80%) respectively. Researches from Egypt, Malaysia, Hong Kong, USA, China and India were the countries where VE/VM/EVM in construction industry studied the most.

Keywords: *construction management, earned value management, value engineering, value management.*

Introduction

Researchers attributed "Value" different meanings, such as need, desire, interest, standard/criteria, beliefs, attitudes, and preference (Katzell, 1964; Rescher, 1969; Rokeah,

1973). Value Engineering (VE), on the other hand, is an organised effort based on systematic workshops managed by multidisciplinary teams through investigating the functions and costs of a system, supply, equipment, service, project or facility (Shen, 1993). VE aims to achieve optimal balance between client's goal values, time, cost, quality, performance and functions of a project all at once (Shen, 1993). From this point of view, VE approach can be also defined as a success factor of a project. It also enables a base for dynamic decision-making process and an organizational behaviour system within the context of decision rationality, psychological value and goal setting theory, (Lewin et al., 1944; Kluckhohn, 1959; Locke & Latham, 1990) while decreasing the risks of design variations. Beside all, VE accepted as an important cost management tool in construction management literature.

Value analysis (VA) technique was first mentioned in the 1940s by Lawrence Miles in the manufacturing industry during Second World War (Bowen et al., 2010). Afterwards, it was used to control the cost in the construction industry in 1963 within the construction projects (Cheah et al., 2005). The concept of VE was evolved by the time of progress, and it has primarily accepted in US and then in many countries such as UK, Australia, China, Malaysia etc, (Oke et al., 2018). Nowadays, Value Management (VM) referred to as VE in the construction management literature (Lin et al., 2007).

Male et al. (1998) defined VE/VM/EVM as a proactive, innovative, problem-solving method to increase the functional value of a construction project during decision making process. Moreover, this methodology aimed to accomplish the total budget of a construction project at the lowest cost and at the highest performance within context of life cycle cost. This tool effectively enables decision- making strategy and optimize project output in the context of cost and function. Olawumi et al. (2016) emphasized that an efficient VE/VM/EVM approach can be achieved at least 5– 15% total cost saving for a project.

The construction industry is one of the important drivers that significantly lead the economic growth (Musarat et al., 2021). Construction projects generally have high budgets and long-term building period. Although VE/VM/EVM is an effective technique for cost management, project planning, cost control, conflict management, and dispute resolution of a construction project, the implementation and adoption of VE/VM/EVM is still at the lowest level especially in developing countries. (Alsehri, 2020; Abd-Karim et al., 2017).

Though VE/VM/EVM can be applied to any type of a construction project and has capability to save cost and increase the function of a construction project, studies are limited in construction management literature. The main aim of this research is to understand the current status and future trends of VE/VM/EVM in literature through conveying a comprehensive literature review of VE/VM/EVM in the construction management body of knowledge. Literature review is accepted as an efficient technique to achieve comprehensive information on the present practice (Li et al., 2019). It provides to researchers in capturing the trends for future studies (Nabawy, 2020). This review also attempts to point out that VE/VM/EVM can be widely applied. It provides information for scholars to gather a map of past, current, and even future research on the topic and also promotes the development of VE/VM/EVM studies in the construction industry.

Research Methodology

A semi-systematic literature review approach is an efficient strategy for themes approaches. It offers an overview of current knowledge, allowing to identify relevant theories, methods, existing gaps and future trends within the literature (Snyder, 2005). Therefore, a comprehensive literature review of VE/VM/EVM was conveyed in the construction management body of knowledge related with research objectives.

Firstly, the related keywords were produced such as "value engineering", "value management", "earned vale management" and "construction management". Then, these keywords have been grouped to attain the studies for descriptive analysis. The keyword group was "Value engineering and construction management", "Value management and construction management ", "earned value management and construction management ". Next, Google Scholar, Scopus and Web of Science databases were selected as research tools to reach for articles from journals published between 2000 and 2022 years. These databases contain high number of publications, including scientific journals, books and conference proceedings. The articles achieved from literature have been eliminated regarding to title reading, abstract reading and full paper reading related with research question. All accessible articles have been listed with their access web links. After eliminating articles which were repetitive, off-topic and had different context level, 291 article were gathered for analysis. Workflow of the semi-systematic literature review was illustrated in Figure 1.

Basically, two quantitative evaluation techniques termed as thematic coding and frequency analysis were used for descriptive analysis. First of all, to explore the occurrence of these studies in the context of research themes, subthemes, country, applied methodology types they were categorized by using thematic coding method through reading title, abstract, keywords and full paper. Following, each context was analysed by means of frequency technique. The findings were visualized by VOSviewer (version 1.6.18) software programme which is a common science mapping tool used for creating maps based on network data and visualizing maps (Van Eck & Waltman, 2019).

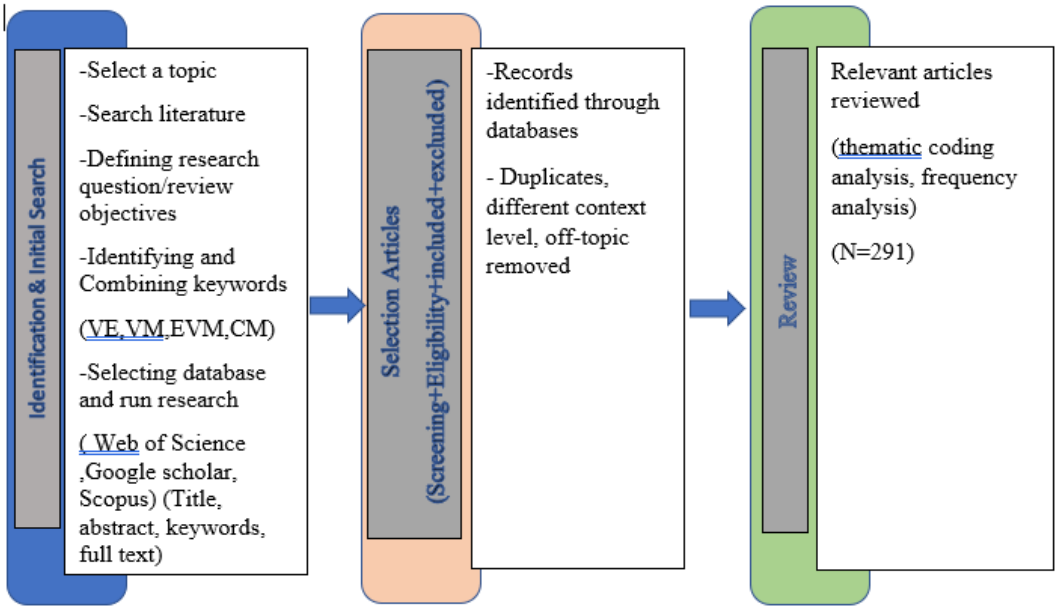


Figure 1: Workflow of semi-systematic literature review.

Table 1. Breakdown structure of research themes & subthemes in reviewed articles.

Main Category- Research Themes	**Quantity**	**Subthemes**	**Quantity**
Adoption Level	42	Critical Success Factors (CSF)	1
		Whole life cycle	1
		Implementing VE/VM to construction industry	40
Application of VE Tool	19	Building Materials	2
		Emerging Implementation Model	3
		Project type(residential, commercial, education etc.)	14
Conflict Management	2	Conflicts and the participants' satisfaction	1
		VM workshop	1
Contract Management	1	Variation orders	1
Discussion/General Approach	6	Discussion VM Theory	4
		Functional perspective	2
Cost & time management	5	Completion estimation model	2
		The performance measurement	3
Cost management	14	Completion estimation model	2
		Contractors Roles	1
		Cost control	3
		Cost Management	1
		Cost overrun	5
		Financial basis	1
		quantity surveyor's role in VM workshops	1
Education	2	Education Programme	2
Facilitiy Management	1	Construction stage	1
Guidelines	1	General Guideline	1
Supply Chain/Procurement Management	3	Procurement Management	2
		The level of adoption Supply chain management	1

Table 1. Breakdown structure of research themes & subthemes in reviewed articles (continue).

Main Category- Research Themes	**Quantity**	**Subthemes**	**Quantity**
Decision Making Strategy	29	Benchmarking partner Selection Technique	1
		Building Materials Selection Technique	11
		Contractor Selection Technique	2
		Fuzzy Decision-Making Model	2
		Problem Solving Technique	6
		Project Delivery System Selection Technique	5
		Project Management Process Selection	2
Literature Review	12	Application status of VE /VM	3
		Comparison of Different Methods of management Improvement	1
		General Review	3
		Historical development in Countries	2
		IT supported collaborative work (CW) in A/E/C projects	1
		Project Delivery Systems	1
		VE technologies	1
Knowledge Management	30	BIM (Building Information Modelling)	13
		Discontinuity of Information	1
		Using with IT	15
		Virtual collaboration	1
Design Management	17	Quality Management	2
		Using as a Management Tool	2
		Using VM as a Decision-Making Tool	1
		Using as a Design Problem Solving Technique	11
		Value perception	1

Table 1. Breakdown structure of research themes & subthemes in reviewed articles (continue).

Main Category- Research Themes	**Quantity**	**Subthemes**	**Quantity**
Lean Construction	6	BIM (Building Information Modelling)	2
		End-customer/end-user value	1
		Integration VE job plan into Lean Construction	1
		Social Value	1
		Sustainability	1
Performance Management	13	Consultancy project performance	1
		Organizational Performance	1
		Project performance measurement	2
		The performance measurement of VE/VM	9
Legal regulation	1	Government responsibilities	1
Innovation Management	1	Client's approach	1
Productivity	1	Using VM Technique	1
Quality Management	3	Integration VM to Quality Management	3
Real Estate Development	5	Historical buildings	1
		Real Estate Development Processes	3
		Real Estate Market valuation	1
Risk Management	9	Integrating VM/VE to Risk Management	6
		Literature Review (RM+VM)	1
		Safety Risks	1
		Sustainability	1
The Performance of VE/VM	14	Critical Success Factors (CSF)	14
Project Management Process	8	Project Management Monitoring	1
		Using in Briefing Process	7

Table 1. Breakdown structure of research themes & subthemes in reviewed article (continued).

Main Category- Research Themes	Quantity	Subthemes	Quantity
Sustainability	27	BIM (Building Information Modelling)	1
		Cost Management tool	3
		Critical success factor	1
		Integration VE into Sustainability	22
Time management	6	BIM (Building Information Modelling)	1
		Time completion estimation model	5
Value Perception	13	Value Perception of a project goal	3
		Value Perception of Client's	7
		Value Perception of Contractors	2
		Value perception of Stakeholders	1

Findings

According to research themes, the findings of frequency analysis are discussed in this section. While the majority of the research areas were focused on the adoption of VE/VM/EVM to construction industry (14,43%), the use of knowledge management in VE/VM/EVM (10,31%), decision making strategies (9,97%), and finally the integration of VE/VM/EVM into sustainability (9,28%) follows that respectively. The analysis indicate that the least studied themes are contract management, facility management, creating a guideline, innovation management and legal regulation (0,34%) within the construction management literature. The occurrence of research themes map was retrieved by using VOSviewer software illustrated in Figure 2.

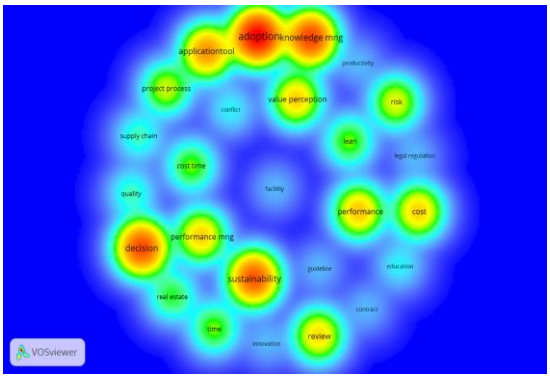


Figure 2: The occurrence map of research themes.

The findings of frequency analysis within the framework of applied methodology types in VE/VM/EVM in construction management literature are case studies (26,80%), model proposal (18,90%), only exploratory survey research (16,40%), and literature review (15,80%) respectively. The prevalence of methodology types is demonstrated in Figure 3.

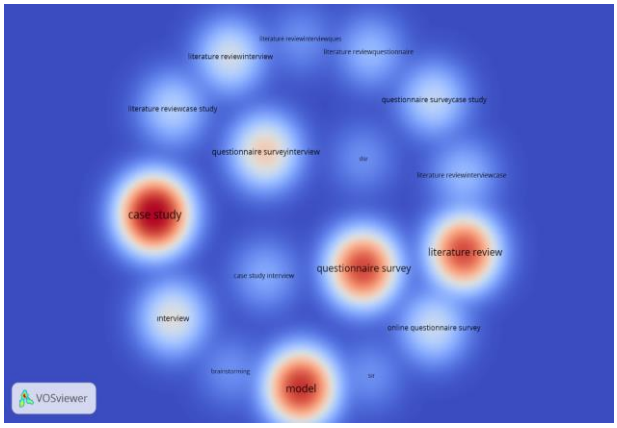


Figure 3: The prevalence of applied methodology types.

The findings of latest frequency analysis in the context of country's concentration on VE/VM/EVM methodology are visualised through a map shown in Figure 4. According to this map it is specified that Egypt, Malaysia, Hong Kong, USA, China, and India are the most concentrated countries on VE/VM /EVM approach in construction management literature.

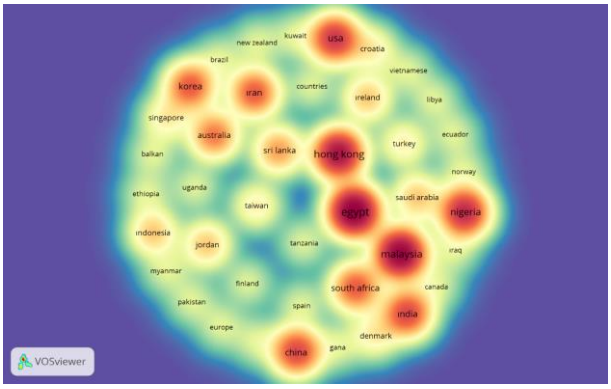


Figure 4: The deployment of country's concentration.

Conclusion

In this study a comprehensive literature review conveyed on VE/VM/EVM approach in construction management body of knowledge between the years 2000 and 2022. After gathering and eliminating the articles from journals 291 relevant studies are reviewed, and the content of themes are classified as per articles in recent research main themes, subthemes, country's concentration and applied methodology types in order to detect the current status and future trends for these methodologies. Following the in-depth review of themes, methodology types, country's attention and the categorization, the studies analysed via frequency method as a quantitative study. As a consequence, it is derived from the analysis that the majority of the researched areas focused on the adoption of VE/VM/EVM to construction industry (14,43%). Thus, the implementation and acceptance of these approaches is still open to research which is also identified by Alsehri (2020) and Abd-Karim et al. (2017). Additionally, the VE/VM/EVM studies for the construction sector in Turkey are very limited. The researcher was able to access only two articles with subthemes "design management" and" quality management" within the context of VE/VM literature. Therefore, this area is open for further research.

Concerning cost management problems in construction project, it is highly beneficial for construction projects to adopt VE/VM/EVM path to be able to take significant precautions against negative results on total cost before building constructed. In conclusion, if these methodologies would be used regularly in construction sector, the unnecessary cost would be eliminated, and final budget of construction would be reduced.

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A Systematic Literature Review on Lean Construction for Tendering

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Abstract

Research concentrated on lean construction demonstrates that the adoption of lean principles has a great impact on the construction industry. However, it is believed that the industry does not benefit from the implementation of lean principles during the tendering process. In this regard, it is important for the stakeholders to be aware of how to integrate lean construction principles into the tendering process, and what gains will be achieved. The lean construction awareness of the stakeholders in the tender processes, as well as the results of the implementation of the lean principles during the tender process, are the motivation of this study. Therefore, this study comprehensively reviews and analyzes lean concepts, principles, and implementations in the tendering process by applying a systematic review approach. The study will raise the level of awareness and show the potential of the integration of the principles of lean construction to present solutions for the encountered problems during the tendering process.

Keywords: *lean construction, lean principles, literature review, tendering.*

Introduction

Construction projects are completed by the organization of many different expert stakeholders and sectors that feed each other. This ensures that construction projects need qualified organizations. Regardless of its function, a well-organized construction project can be completed within the targeted time, within the specified budget, and with the desired quality (Nanda et al., 2016). Considering the opposite situation, it will not be possible to talk about the success of construction projects that were not completed in the planned time, could not reach the targeted quality, and exceeded the determined budget. Such a failed construction project negatively affects its stakeholders and other sectors in the organizational chain (Dargham et al., 2019).

To consider projects to be successful in the construction sector, they must be planned, implemented, and made ready for delivery in a systematic way. All this process planning will be possible by achieving the targets in the triangle of time, budget, and quality. However, it is observed that the sector is more wasteful in achieving these targets compared to other sectors. Of course, the approach of the stakeholders and their competencies in their fields of expertise make this situation worse (Zimina & Pasquire, 2010).

Lean thinking or lean principe approach aims to provide a product or service with better quality, in a shorter time, with less effort and cost. With this philosophy, ways to achieve higher quality in a short time and with less budget are sought, a continuous improvement and development approach is shown by not being satisfied with the quality obtained. It is seen in the ongoing projects and process planning that the construction sector adopts innovations and developments in a long time compared to other sectors, as well as for lean principles (Vilasini et al., 2011). Due to the wide and complex structure of the construction sector, it is normal for the stakeholders of the sector to show resistance to changing a conventional step with a new method and technique. For this reason, it may take many years to adapt to change and development. Despite this, it is an inevitable end that lean principles will gain a place in the construction sector as well as in many other sectors in recent years. It is thought that the necessity of using limited resources together with the technological developments and the lean principles will penetrate every stage of the projects in the construction sector. As a matter of fact, the steps taken, and the developments experienced by the stakeholders of the sector show that the adoption of lean principles has a great impact on the construction sector. Even if the adaptation process will take a long time, there is no doubt that the gains to be achieved by applying lean principles will whet the industry's appetite. Thus, it is up to the construction sector to close the gap with other sectors (Kim et al., 2016).

Despite the lateness in the construction sector in the research carried out in this field, it is seen that the lean principle practices adopted day by day do not take enough place in the tender processes and this area of the sector does not benefit (Heidemann & Gehbauer, 2010). Raising awareness for the sector to adopt lean principle practices in the tender process and gaining more works in research may be the first steps to be taken. It is thought that with the research concentrated in the field, the stakeholders' knowledge on how to integrate lean principle practices into the tender process and what gains they will gain will enable adaptation in a short time (Forgues & Koskela, 2009). The results of the implementation of lean principles in the tender process and their awareness of lean structure constitute the motivation of this study.

This study aims to comprehensively review and analyze lean concepts, lean principles, and lean practices in the tendering process by applying a systematic approach. With the aid of the study, the awareness level of the stakeholders will increase, and it will reveal the potential of lean principles to find a response in the tender processes and to offer solutions to the problems experienced. The study will be a guiding step for future research, and a reflex for stakeholders to gain competence in lean policy implementations in the tender process.

Research Method

In the study, a comprehensive and two-way scanning method of the literature has been adopted to examine and analyze the integration of the lean principle concept into the tender process in the construction sector and to present the results of the gap in the study area for future research. First, a systematic literature review was conducted to observe the relational association of the concepts of 'lean', 'construction', 'tender' in current studies. Thus, findings on the density and coexistence of the concepts in the literature were reached. Then, the research findings were evaluated with the meta-analysis method. The meta-analysis method helped to reveal much more concentrated and unfocused research areas by associating the obtained findings with each other in terms of the investigated concepts.

Systematic Literature Review

In the first stage of the study, a search was made on the Scopus database that covers. publications from academic publications such as the American Society of Civil Engineers (ASCE), Elsevier, Emerald and Taylor & Francis,.. and others. Keywords for the search were determined as “lean”, “construction”, “tender”, “procurement” and “bidding” and these keywords were scanned as title/abstract/keyword. As a result of the search, a total of 214 papers containing the specified keywords between the years 2005-2021 were reached. A total of 214 articles were reviewed, and 74 related papers that were suitable for the purpose of the study, were selected for more detailed examination. Flowchart outlining the protocol adopted in this systematic review is represented in Figure 1.

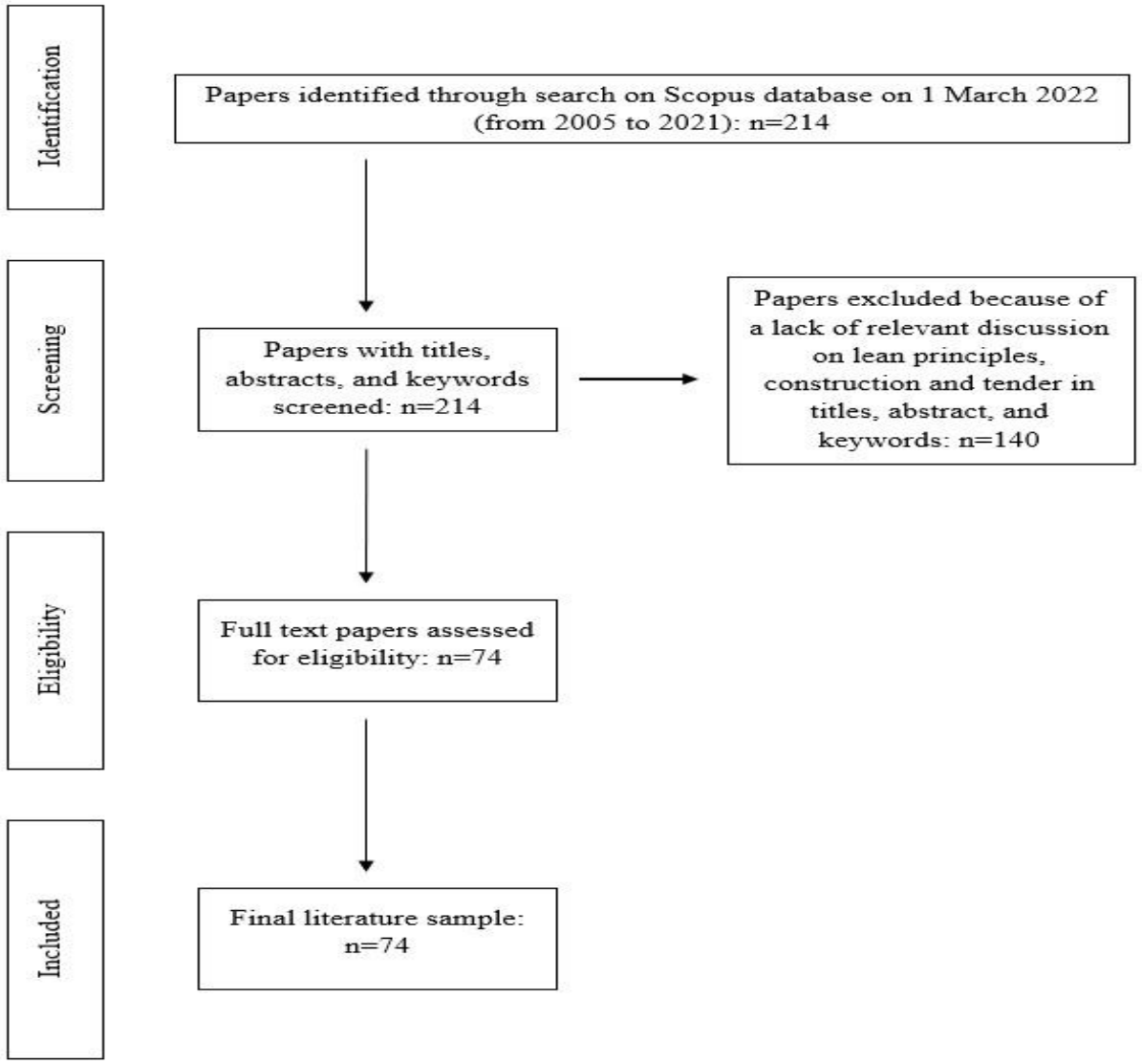


Figure 1: Flowchart for systematic review.

Meta-Analysis Method

In the second stage of the study, selected papers were classified e using the meta-analysis method, and in the framework of 7 main categories such as publication year of the papers, scientific database, journal or conference name, keywords, research focus, information source,

and future directions. 15 subcategories connected to 7 main categories, analyzed as shown in Table 1. For each of the 74 papers, different and more analysis results can be seen according to the evaluations in the main and sub-categories.

Table 1. Research framework.

Category	Subcategory
Year	Publication date of the article
Scientific database	Scopus (ASCE, Elsevier, Emerald, Taylor & Francis,… etc.)
Journal/Conference	Name of journals/conferences
Keyword	'Lean"
	'Construction"
	'Tender"
	'Procurement"
	'Bidding"
Research focus	Lean construction
	Lean principles
	Lean tender
	Lean procurement
Source of information	Review
	Case study
Future directions	Future research identified in the articles

Data Analysis and Results

The literature review covering certain years for the adoption of lean principles in the construction industry and their integration into tender processes was analyzed according to the meta-analysis classification method given in Figure 2. In Figure 2, it is examined that the first steps were taken, but not enough yet, depending on the increasing trend of the idea of integrating lean principles into processes in the construction industry between 2005 and 2021, as well as the awareness of using them for tender processes. As a matter of fact, the majority of the studies have been published at the Annual Conferences of the International Group for Lean Construction, and currently, the conference is organized with the aim of applying lean principles to all areas of the construction industry. For this reason, it will not be possible to talk about the fact that the research field has still reached sufficient saturation today.

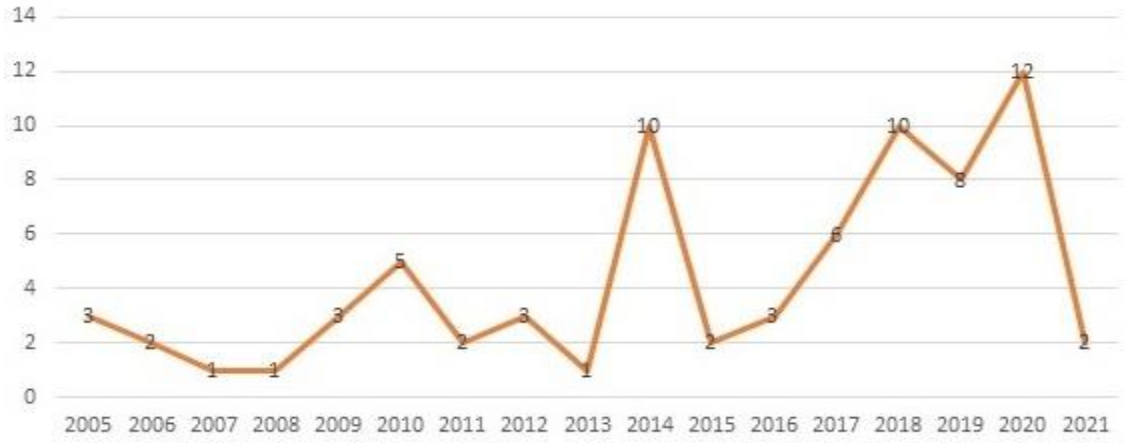


Figure 2: Distribution of the selected papers within the time span.

In Figure 3, the distribution of use of the keywords in the publications over the years is examined. The use of keywords together or separately shows us that the concepts of construction, lean, tender and procurement together take more place in research, researchers have examined the subject, but the latest situation is not sufficient for the construction sector in the current situation. Again, in Figure 3, it is predicted that the concept of 'lean construction' is accepted in the literature as lean principles begin to gain ground in the construction sector, so that the researches will move in depth and penetrate the tender processes of the sector, opening a research area for future research. Considering that more than half of the publications belonging to the research study covering a total of 17 years between 2005 and 2021 were published in the last 5 years, it is thought that lean principles for tender processes in the construction sector will be intensively examined in the coming days.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total number of papers within time span
LC				1		1				2		1	1	4	2	6		18
LC+P						1	1	1		1		3	1	1	2			11
C+P					2					2		1	1	1	1	1		9
L+C														2		2	1	5
L								1		1	1	1				1		5
C					1							1	1		2			5
L+P	1	1							1				2					5
C+B/T													1	1		1		3
L+C+P						1	1									1		3
LC+B/T	2															1		3
P		1													1			2
L+B/T+C								1					1					2
L+B/T													1					1
L+P+B/T					1													1
C+P+B/T											1							1

LC: Lean Construction, P: Procurement, C: Construction, L:Lean, B:Bidding,T:Tender.

Figure 3: Analysis of selected papers according to the research focus for keywords.

As a result of the analyzes made in the papers in the research, the most frequently used keywords are examined in Figure 4. Accordingly, ‘Lean Construction’ is the most observed keyword (24.30%). This shows that, as stated before, the concept of lean construction is accepted in the sector and awareness of lean principles will increase day by day. The number of papers with the keywords ‘Lean Construction’ and ‘Procurement’ together is the second highest total number of studies (14.80%). In the third place comes the studies in which the ‘Construction’ and ‘Procurement’ keywords are used together (12.10%). These are followed by studies covering the use of Lean and Construction, Lean, Construction, Lean and Procurement (6.70%), Construction and Tender, Lean-Construction-Procurement, Lean Construction and Tender (4%), Procurement, Lean-Construction-Tender (2.70%), Lean and Tender, Lean-Procurement-Tender and Construction-Procurement-Tender (1.35%) keywords together.

Keywords	Number of papers	Frequency (%)
LC	18	24,32
LC + P	11	14,86
C + P	9	12,16
L + C	5	6,76
L	5	6,76
C	5	6,76
L + P	5	6,76
C + B/T	3	4,05
L + C + P	3	4,05
LC + B/T	3	4,05
P	2	2,70
L + B/T + C	2	2,70
L + B/T	1	1,35
L + P + B/T	1	1,35
C + P + B/T	1	1,35
LC: Lean Construction, P: Procurement, C: Construction, L:Lean, B:Bidding,T:Tender.		

Figure 4: Analysis of selected papers according to the keywords.

The analysis of the publication distribution of the papers in different journals and proceedings by years is presented in Table 2. As a result of the examination of the table, it is seen that the publications were published in 21 different journals, 22 different serial conferences, and 2 different congresses. In this context, it is concluded that lean principles have been determined, researched, and scrutinized for tender processes in the construction sector as an agenda in a wide range of academic media. This proves the statement of this study that the field should be approached with more appetite and focused.

Table 2. Analysis of papers by publishing platform and years.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total number of papers within time span
Journal of Management In Engineering					1													1
Journal of Engineering, Construction and Architectural Management														1			1	2
International Journal of Building Pathology and Adaptation															1			1
International Journal of Lean Six Sigma													1					1
International Journal of Civil Engineering and Technology													1	1				2
Key Engineering Materials												1						1
Journal of Purchasing & Supply Management	1																	1
An International Journal of Supply Chain Management						1												1
International Journal of Managing Projects in Business					1							1						2
Journal of Construction Engineering and Management	1				1													2
Journal of Financial Management of Property and Construction							1											1
International Journal of Management															1			1
Journal of Lean Construction						1												1
Journal of Construction Innovation																1		1
Journal of Buildings																1		1
Journal of Management, Procurement and Law										1								1
The International Journal of Construction Management							1											1
Journal of Civil Engineering and Management										1								1
Journal of Advances in Civil Engineering																1		1
Journal of HERD Health Environments Research & Design												1						1
Journal of Sustainability																1		1
Annual Conference of the International Group for Lean Construction (IGLC)	1	2	1	1		3		1		4	1	4	4	6	6	3		37
Other Conferences/Congress								2	1		1			2		5	1	12
	3	2	1	1	3	5	2	3	1	6	2	7	6	10	8	12	2	74

As can be seen in Table 3, the area where lean principles remain weak in the examined studies is the tender process. Despite the increase in the subject title in recent years, the tender process could not get what it wanted from these developments. These studies focused on areas such as selection of qualified contractors, decision-making techniques for the right offer, and supplier processes. The benefits to be gained by the construction industry by integrating lean principles into the tender process still remain an exciting area for researchers today.

Table 3. Analysis of articles by focused research topic.

Year	Pre-Design	Design	Tendering	Construction	Post Construction
2005		1	1	1	
2006		2			
2007				1	
2008				1	
2009		1		2	
2010		1		2	1
2011		1		1	
2012			1	2	
2013		1			
2014	1	1		3	1
2015		1		1	
2016	2	1		4	
2017	2	1	4	1	
2018	2			6	1
2019	2	1	1	3	1
2020	2	4	1	5	1
2021	1				
	12	16	8	33	5

Conclusion

These findings further support the idea that researchers should focus more on this area to integrate lean principles into construction tendering processes. For this reason, some papers show that lean principles have not yet achieved the desired integration in tender processes and that the lean concept will have much greater potential for gains in the construction industry. In addition, these results coincide with the idea that the contributions of lean principles to procurement, production, material selection, bidding, contractor selection and similar topics can contribute to tender processes in the construction industry, as mentioned in previous studies. The study aimed to address and analyze the previously uncontacted research field gap in past research.

The lean principle approach is applicable to all production based industries. As a priority, it is necessary to realize the lean principles and take steps with this awareness. Since the implementation of lean principles requires a full disciplinary process, there is no phase that can be ignored or any step that can be considered later. However, it always supports steps that can be improved and developed. Considering the wide range of work areas covered by the construction industry, it seems difficult to adapt the lean principle applications with full capacity at the same time. However, the lean principle approach offers a constructive picture to the stakeholders of the construction industry, with improvement and continuous development at every step.

More qualified execution of the tender process, which affects the construction projects from the design to the implementation and post-delivery process, and then to the system maintenance and repair processes in the facility management process of the building, will be

possible with the application of lean principles. In addition, although the integration of the construction industry with lean principle practices has improved in recent years, it has been observed in the researches that the tender processes are weak in this integration. It is concluded that in order to find the desired level of the lean policy response in the tender processes in different titles where the researches are examined with the meta-analysis method, the research intensity should increase in this field, the awareness of the sector stakeholders should be drawn, and the tender experts should be trained on the lean principle implementation principles.

The aim of the study is to reveal that lean principles are not adequately met in the construction tender processes. With the research, it has been examined that the lean principles are still in their early stages for the construction industry in general, and that there are studies on proposal preparation, project duration calculation and similar titles in the tender processes, but that sufficient research saturation has not been reached.

As the results show, it is predicted that lean principles will experience the infancy and development process of the building information modeling process in the construction sector, and their integration into the tender processes will again take place with the legal legislation and stakeholders' awareness of the lean principle.

As a result, the study was conducted to observe the reflections of lean principles on the tender process in the construction industry. The literature examines that not enough research has focused on lean principles for the tendering process. Future research should take a holistic approach to the procurement process and focus on the integration of lean principle practices. It is expected that this systematic review will be a guide for future research and gaps in the literature and contribute to the tender process for the construction industry. The fact that the concept of lean has been adopted and gained ground in the construction industry in recent years shows that the number of papers in the specified years is not sufficient and the field is open to further research.

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A Modified Oppositional Teaching-Learning-Based Optimization Model for Solving Construction Time-Cost-Quality Trade-Off Problems

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Abstract

This paper intends to develop a modified oppositional teaching-learning-based optimization (MOTLBO) model for solving construction Time-Cost-Quality Trade-Off problems (TCQT). The model is based on a negative correlation scheme of opposition-based learning concept for population initialization and generation jumping of the current population. Furthermore, to handle objectives effectively, the MOTLBO is incorporated with non-dominated sorting (NDS) approach and crowding distance computation mechanism. Well-known 7- and 13 activity construction benchmark problems are solved to illustrate the applicability of the model proposed in the current study. The obtained results are compared with genetic algorithm (GA), ant colony optimization (ACO), and differential evolution algorithms. The simulation results exhibit that the utilized MOTLBO is able to ensure a superior set of Pareto-front solutions maintaining good convergence speed as well as diversity.

Keywords: *opposition-based learning, time-cost-quality trade-off problem, generation jumpin, construction projects.*

Introduction

In a construction project, efficiency can be maintained with good project management, and based on project requirements, the application of knowledge, skills, and techniques to use time and cost resources appropriately is the key point to be considered. To achieve it, optimizing the project duration, and total cost has to be performed effectively. Moreover,

Time–cost trade-off analysis is a part and parcel of any construction work and both the researchers as well as contractors are enthusiastic about paying attention to this glamorous subject, due to the academic/real field nature of the issue. Another crucial development is to increase the number of objectives i.e. quality of each alternative as an objective in the optimization algorithm.

Reviewing the literature, solving the TCTPs were not straightforward for ages. In spite of existing the vast majority of techniques developed in optimization research and other fields to handle this problem. The complex nature of it calls for alternative approaches such as weighted sum method and non-dominating sorting approach. Particularly, weighted sum method is one of the firstly used methods on solving the time-cost trade-off problems. It is the approach which involves the straightforward formulation and easy to be fulfilled. It is able to obtain optimum or near optimum solutions despite having a basic formulation.

Deb (2001) has indicated for the first time that the weighted sum method (WSM) combines a series of objectives into a single objective by pre-multiplying each objective with a pre-known weight. Despite the simplicity of the concept, the issue is specifying which weight value to be utilized. It is determined by the importance of each objective in the context of the problem, as well as a scaling factor.

Ascertaining the most suitable combinations of weight factors for the wieght approach to enhance the multi-objective solution process seems to be extremely complicated. However, Adaptive Weight Approach (AWA) (Gen & Cheng, 2000) and Modifie Adaptive Weight Approach (MAWA) (Eirgash & Dede, 2018; Toğan & Eirgash, 2019a; Afshar et al., 2006; Feng et al., 1997) still have been utilized in the literature. Time and cost parameters are highly correlated with the quality which is a critical parameter and is not basically quantitative one and are hardly these objectives developed in the literature (Narayanan & Suribabu, 2014). However, when applied to more sophisticated medium and large-scale problems, the MAWA performs poorly and is incapable of discovering global optima. The second way to deal with the conflict between time and cost objectives is through the non-dominated sorting (NDS) concept. Using NDS improves the solution(s) obtained at the end of a MOP process with distinct metaheuristic algorithms such as Teaching Learning Based Optimization (TLBO) (Eirgash et al., 2019; Toğan & Eirgash, 2019b). Since the academic/real field nature of the issue, there is a convincing requirement for the improvement and enhancement of optimization problem-solving techniques, a modified oppositional teaching-learning-based optimization (MOTLBO) model is developed to minimize the deficiencies associated with the traditional MAWA.

Abovementioned studies were restricted to single or bi-objective optimization because probability of discovering the non-dominated solutions decrease exponentially as the number of conflicting objectives increase (Gen & Cheng, 2000). Given the importance of construction quality, many researchers have tried to extend the time-cost trade-off to time-cost-quality trade-off (TCQT).

This study follows the given arrangement: Firstly, it demonstrates the time–cost trade-off formulation. Secondly, it presents the opposition-based learning concept along with the modified oppositional TLBO to solve the TCQTs. The application of MOTLBO in benchmark TCT optimization problems are then investigated to exhibit its effectiveness, and eventually, it provides the results and conclusions of the utilized algorithm. Flowchart of the proposed algorithm is given in Figure 1.

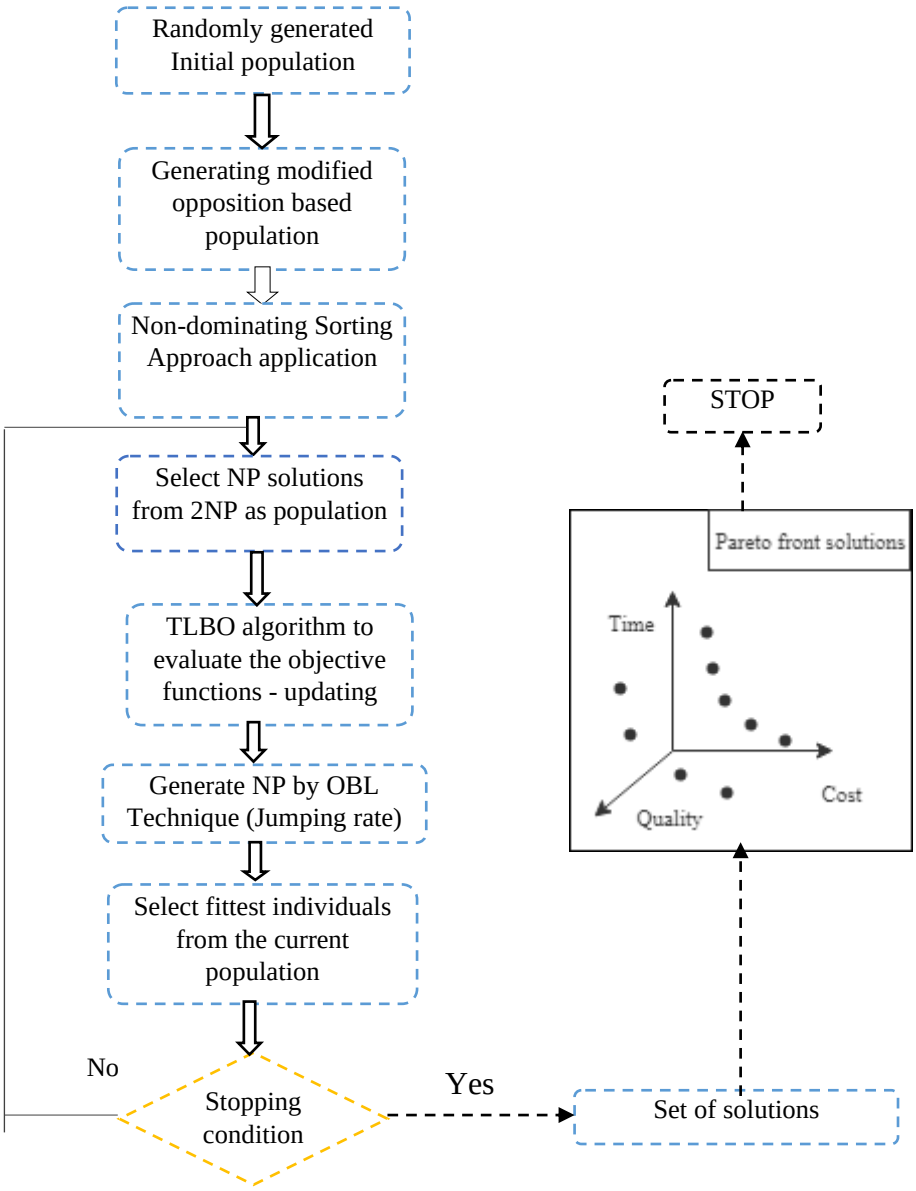


Figure 1: Flowchart of the MOTLBO algorithm for the solution of TCQT.

Problem Formulation

Obtaining the time-cost objectives of a project by selecting suitable options for each activity is done through the TCTP concept. Calculation of the time objective function of a project is operated using Equations (1) to (2).

Activity time (AT), activity cost (AC), and activity quality (AQ) are taken as input for employed TCQT model. This study intends to simultaneously optimize project time (PT), project cost (PC), and project quality index (PQI), all of which are functions of AT, AC, and AQ. Explanations of the three objectives are given as follows:

Objective 1: Minimization of project time (PT)

PT is a crucial construction project parameter that has a significant impact on the successful completion of a project. The precedence diagramming method (PDM) is used to determine PT. PDM is based on activity on node (AON) project networks with critical path (CP). The total number of activities on the critical path of a construction project is equal to PT.

$$\text{PT} = \sum_{A \in CP} AT_A \tag{1}$$

Here PT is the completion of the project duration and ATA is the critical path activity completion time (A).

Objective 2: Minimization of Project Cost (PC)

PC is one of the key factors affecting the success of construction projects. PC is simply the algebraic sum of each activity cost (AC). Whereas AC is the sum of direct cost and indirect cost of activity. Direct cost (D.C) include mainly the cost of labour, material and equipment while indirect cost (I.C) include overhead expenses and outage losses.

$$\text{PC} = \sum\nolimits_A D.C + \text{I.C per day} \times \text{PT in days} \tag{2}$$

Where PC is project completion cost, $\sum_A D.C$ is sum of direct cost of each activity. Indirect cost of construction project is simply estimated by multiplying the PT and indirect cost of project per day.

Objective 3: Maximize Project Quality Index (PQI) or Minimize 1/PQI

Since the project quality (PQI) is of paramount importance objective of construction project, to measure the PQ quantitatively is very challenging task. In this paper, PQ is measured in terms of project quality index (PQI), which is estimated by taking the weighted sum of each activity quality (AQ). On the other hand, AQ depends upon three quality indicators i.e. labour, material and equipment. Therefore, AQ can be measured by taking the weighted sum of quality indicators of activity.

$$\text{AQ}=\text{wt}_A.\sum_{k=1}^{k} \text{wt}_{\text{A,k}} . Q_{\text{A,k}}^{m} \tag{3}$$

$$\text{PQI} = \sum\nolimits_{\text{A}=1}^{\text{n}} \text{wt}_{\text{A}} . \sum\nolimits_{\text{k}=1}^{\text{k}} \text{wt}_{\text{A,k}} . \text{Q}_{\text{A,k}}^{\text{m}} \tag{4}$$

Where $Q_{A,k}^{m}$ is performance of quality indicator (k) in activity (A) using alternative (m); $wt_{A,k}$ is weight of quality indicator (k) compared to other indicators in activity (A); and wt_A is weight of activity (A) compared to other activities in the project.

The OBL for Optimization

The basic principle behind opposition-based learning is to employ opposites for better and faster learning in the optimization process. The algorithm's rapid convergence to the ideal solution is related to the point that not far away from it (Rahnamayan et al., 2007). In lack of any prior knowledge, it seems to be challenging to make the best initial estimate. In other words, this approach enables it to carry-out the search for the optimum solution in both directions concurrently (Tizhoosh, 2005).

Opposite number: Let's put x∈ [a; b] a real number and its opposite number $\tilde{x}$ is given $\tilde{x}$ =a+b-x. Likewise, following is the opposition number in N-dimensional space: let's assume X= (x_1; x_2 ;…. x_N) a point in N-dimensional space in which x_1;x_2 ;.....x_N ∈R and xi∈[a_i,b_i] ∀i=1;2;....., N, and its opposite point $\tilde{x} = (\tilde{x}_1, \tilde{x}_2 .... \tilde{x}_N)$ is represented by its elements as $\tilde{x}_i$ = $a_i + b_i - x_i$.

Initialization of OBL Population of Size Npop

For OBL population initialization following simple steps are followed:
Step 1: Initial population (pop) is generated randomly within the upper and lower limits.

$$X_{i,j}{}^{G=0} = Lb_j + x_{i,j} \times (Ub_j - Lb_j) \tag{5}$$

Step 2: Generate opposite population (Opop) as described below.

$$X^o{}_{i,j} = Lb_j + x^o{}_{i,j} \times (Ub_j - Lb_j)(j = 1,\ldots,D; i = 1,\ldots,N_{pop}) \tag{6}$$

$$Opop_{i,j} = a_i + b_j - pop_{i,j} \quad i = 1, 2....Npop \ , \ j = 1, 2.....D \tag{7}$$

Step 3: Select Npop (pop.size) fittest individuals from population (pop) and opposite population (Opop).

Generation Jumping of Opposition Based Learning

In this phase, calculation of generation jumping of the opposition population is performed dynamically on contrary to the initial population process of OBL. Instead of applying variables' pre-defined interval boundaries, based on the min^m and max^m values of the current population for that variable, the opposite of each variable is calculated as equatin (8).

$$X_{i,j}{}^{o,current} = Min_j^p + Max_j^p - x_{i,j}^{current} \ (j = 1,....,D; i = 1,....,N_{pop}) \tag{8}$$

Modified Oppositional Teaching Learning Based Optimization Algorithm

This paper considers the modified oppositional teaching learning-based optimization (MOTLBO) algorithm, which combines the opposition-based learning (OBL) concept with the original teaching learning based optimization (TLBO) approach to solve optimization problems. MOTLBO expedites the convergence rate of the standard TLBO algorithm by employing opposition-based population initialization and generation jumping. The sole TLBO comprises significant weaknesses, such as being caught in local optimal solution, and doesn't

preserve a good convergence rate in relation to the complexity of the problems (Eirgash, 2018). Thereby, the proposed algorithm eliminates these drawbacks using a negative correlation notion of OBL. The size of the initial population required to enhance convergence to the optimal solution can thus be reduced while maintaining diversity. The steps of the modified learning strategy are outlined below:

Step 1: Initial population (pop) of the entire individuals is generated randomly within the upper and lower constraints.
Step 2: Generate modified opposite population (Opop) as described below.

```
for i=1:Pn
for j=1:Dv.size
    opp_no=rand(1);
      if  opp_no<=0.5
        opp_no=-1;
      else
         opp_no=1;
       end
   opp_pop(i,j)=population(i,j)+opp_no;
  end
opp_pop=alt_ust_sinir_kontrolu(opp_pop);
```

Step 3: Value of the objective function of all the individuals of the modified opposite population set are evaluated.
Step 4: Select np (population size) fittest individuals from population (P) and modified opposite population.
Step 5: Apply teaching factor to modify the grade point of each subject of each of the individual student.
Step 6: Through mutual contacts with other students, the grade point of all students in each subject is updated.
Step 7: The feasibility of newly created solutions is verified, and infeasible solutions are substituted with a random subset generated new solutions.
Step 8: The modified opposing population is formed from the feasible population set employing a jumping rate and is explained as follows:

```
for i=1:Pn
for j=1:Dv.size
    lb=1;
    ub=length(eval(['Dv.Ta', num2str(j)]));
   opp_jump_no=rand(1);
      if  opp_jump_no<=0.3
        opp_jump_no=ub+lb-current_population(i,j);
      else
         opp_jump_no= current_population (i,j);
      end
  Opp_jump_population(i,j)=opp_jump_no;
 end
end
```

Step 9: Select np fittest individuals from current population and the modified oppositional population.

Numerical Examples

The proposed algorithm is coded in MATLAB (R2021a) environment compiled on a personal computer having Intel (R) Core (TM) i3 CPU 2.40 GHz and 3GB RAM.

Empirical Example of 7-Activity Project

The example was originally introduced by Feng et al. (1997) and then solved by Zheng et al. (2005) for construction time-cost trade-off analysis and shown in Figure 2. Table 2 includes the related data on different resource utilizations and their corresponding time, cost and quality. Originally the example did not contain the information about quality level of resource utilization options.

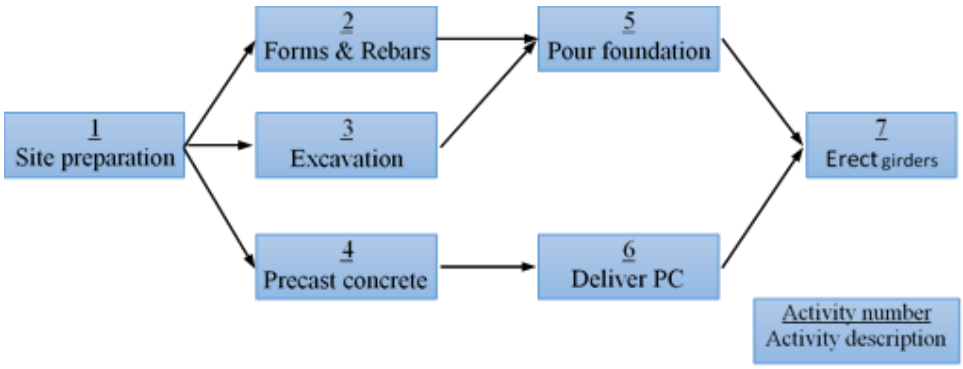


Figure 2: Network configuration of 7-activity test example.

Table 2. Options for 7- activity project for daily indirect cost of $500/day.

Activity Description	Activity number	Precedent activity	Option / Mode	Duration (days)	Direct cost ($)	Activity weight (%)	Quality %
Site Preparation	1	-	1 2 3	14 20 24	23000 18000 12000	8	98 89 84
Forms and rebar	2	1	1 2 3 4 5	15 18 20 23 25	3000 2400 1800 1500 1000	6	99 95 85 70 59
Excavation	3	1	1 2 3	15 22 33	4500 4000 3200	14	98 81 63
Precast concrete girder	4	1	1 2 3	12 16 20	45000 35000 30000	19	94 76 64
Pour	5	2,3	1	22	20000	17	99

foundation and piers			2 3 4	24 28 30	17500 15000 10000		89 72 61
Deliver PC girders	6	4	1 2 3	14 18 24	40000 32000 18000	19	100 79 68
Erect girders	7	5,6	1 2 3	9 15 18	30000 24000 22000	17	93 71 67

Table 3. Result comparison between benchmarked algorithms.

Approaches	Models	Time (day)	Cost ($)	Quality (%)	Resource options
Lakshminaryana et al. (2010)	MOOM	60	165500	97	1/1/1/1/1/1/1
Afshar et al. (2006)	*50, 30 MOACO APPROACH	60	155500	92	1/1/1/2/1/1/1
Narayanan and Suribabu (2014)	*30, 30 DE APPROACH	60	165500	97	1/1/1/1/1/1/1
Random Key Variant for Time-Cost-Quality (2005)	*30, 35 RKV-TCQ	60	165500	97	1/1/1/1/1/1/1
This paper	*20, 10 NS-MOTLBO	60	155500	92	1/1/1/2/1/1/1

**50, 30 – the first number is the number of iterations and the second is the population size.*

Table 4. Best non-dominated solutions obtained by MOTLBO.

Solutions	Partial set	Project performance			Alternative options						
		Time (days)	Cost ($)	Quality (%)							
1	Sorted by time	60	155500	92	1	1	1	2	1	1	1
2		61	142500	86	1	1	1	3	1	2	1
3		62	163000	95	1	1	1	1	2	1	1
4		63	131000	84	1	1	1	2	2	3	1
5		65	162400	95	1	2	1	1	2	1	1
6	Sorted by cost	132	95800	63	2	5	1	3	1	3	3
7		92	98300	70	3	5	1	3	1	3	3
8		126	104600	73	1	3	3	1	2	2	3
9		78	107500	76	3	1	1	3	4	3	1
10		71	117900	77	1	2	1	3	4	3	1
11	Sorted by quality	62	163000	95	1	1	1	1	2	1	1
12		60	185500	92	1	1	1	2	2	1	1
13		87	150200	93	3	5	1	3	2	3	3
14		80	115500	90	3	4	1	1	2	1	1

15		82	113500	91	3	3	1	3	4	3	3
16	Compromised	89	144500	92	3	5	3	3	4	3	3
17		68	118500	77	1	1	1	3	4	3	1
18		66	128500	82	1	1	1	2	3	3	1
19		67	127300	83	1	3	1	3	1	3	1
20		74	112500	73	1	1	1	3	4	3	2

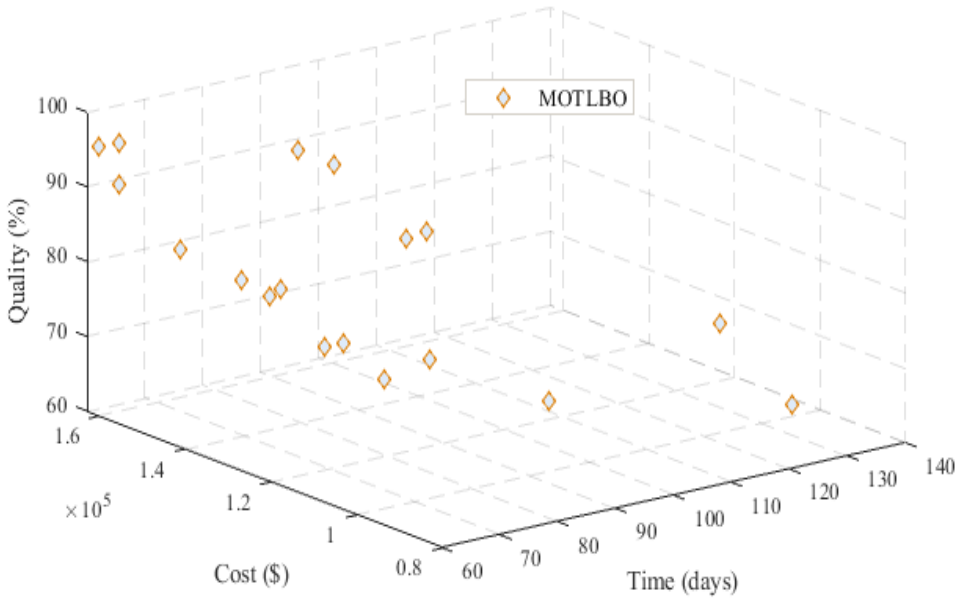


Figure 3: Pareto optimal solutions of time-cost-quality trade-off problem.

Pareto front solutions of the different algorithms considering the different number of function evaluation is given in table 3. It is clear that the MOTLBO has the potential to provide a large number of Pareto optimal solutions with a significantly smaller NFC, implying a faster convergence rate. The graphical representation of the results (Pareto front solutions) obtained by employing MOTLBO is illustrated in Figure 3 while table 4 presents details for the non-dominated solutions.

Empirical Example of 13-Activity Project

In the presented paper, the working of the proposed TCQT model is demonstrated through solving one case study project introduced by Sharma and Trivedi (2020). The case study project with 13 activities of possible alternatives is shown in table 5. Likewise, the three-dimensional plot for obtained PT, PC and PQI values is shown in Figure 4.

Table 5. Details of the case study project.

								Q_I k=1		Q_I k=2		Q_I k=3	
Sr. No.	Activity Name	Succ.	AOs	Time (days)	Cost ($)	Res. (units)	Act. weight wt_i	IW ($wt_{i,k}$)	Q_P ($Q_{i,k}$)	IW ($wt_{i,k}$)	Q_P ($Q_{i,k}$)	IW ($wt_{i,k}$)	Q_P ($Q_{i,k}$)
1	Ground-works	2	1	8	10039	8	0.16	0.45	97	0.30	99	0.25	93
			2	8	9850	11			70		73		71
2	Excavation	3	1	6	1082	12	0.16	0.20	94	0.35	91	0.45	89
			2	6	891	12			83		88		84
3	Footing	4	1	12	15546	38	0.19	0.30	95	0.45	94	0.25	95
				10	17039	56			85		87		89
4	Formwork	5	1	5	562	11	0.13	0.35	89	0.35	92	0.30	94
			2	4	590	10			83		83		87
5	Retaining wall	6	1	26	15834	46	0.07	0.30	85	0.35	92	0.35	95
			2	16	17275	52			78		95		89
6	Basement	7	1	32	74125	27	0.06	0.40	99	0.30	78	0.30	94
			2	29	76346	32			90		85		88
			3	23	84312	23			85		90		86
7	Slab	8	1	22	32646	32	0.06	0.50	94	0.40	93	0.10	87
			2	11	29759	35			80		85		96
8	Exterior wall	9	1	18	65959	38	0.04	0.40	90	0.50	78	0.10	73
			2	29	105297	44			85		90		94
			3	11	157433	49			90		95		95
9	Interior wall	13	1	37	58570	12	0.03	0.40	97	0.50	98	0.10	97
			2	21	59999	22			89		96		67
			3	32	57668	21			81		85		63
			4	17	63321	31			95		84		90
10	Flooring	–	1	34	38411	15	0.02	0.45	85	0.45	90	0.10	78
			2	17	65326	12			88		92		90
			3	12	50214	12			78		84		93
11	Exterior finish	–	1	9	12216	18	0.02	0.40	70	0.50	85	0.10	90
			2	12	3846	20			95		88		85
12	Interior finish	–	1	41	90219	17	0.02	0.40	70	0.50	85	0.10	90
			2	31	233034	13			95		88		85
13	Roof	10 11 12	1	23	127642	13	0.02	0.30	98	0.40	95	0.30	99
			2	24	81323	9			87		86		83

Table 6 indicates all 25 Pareto optimal solutions with selected activity modes. The Pareto-front obtained using MOTLBO and Kamal and Trivedi (2020)'s modal is compared in table 6. It can be seen from table 6 that MOTLBO obtains identical Pareto solutions, adopting the smaller objective function values.

Table 6. The options selected with the corresponding objectives.

S.No.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	PT	PC ($)	1/PQI
1	2	2	2	1	2	3	2	3	4	1	2	2	1	164	783378	1.205
2	1	1	2	1	2	3	2	3	4	1	2	2	2	165	737439	1.141
3	1	1	1	2	2	3	2	3	4	1	2	2	2	166	735974	1.114
4	1	2	1	1	2	3	2	3	4	1	2	2	2	167	735755	1.113
5	1	1	2	1	2	3	2	1	4	2	2	2	2	169	672881	1.146
6	1	2	2	2	2	3	2	3	4	1	2	1	2	171	594462	1.169
7	1	1	1	2	2	3	2	3	4	2	2	1	1	172	666393	1.112
8	1	2	1	2	2	3	2	3	4	1	2	1	2	173	592968	1.128
9	2	2	1	1	2	3	2	3	4	1	2	1	2	174	592750	1.169
10	1	1	1	1	2	3	1	3	4	2	2	2	2	175	765747	1.094
11	1	1	2	1	2	3	2	3	2	1	2	1	2	176	591303	1.144
12	1	1	2	1	2	2	2	3	4	1	2	1	2	178	586658	1.143
13	1	1	1	2	2	3	2	1	4	2	2	1	1	179	574919	1.118
14	2	1	1	2	2	3	2	1	4	1	2	1	2	180	501496	1.176
15	1	1	1	1	2	3	2	1	4	2	2	1	2	181	528572	1.110
16	1	1	1	1	1	3	2	3	4	3	2	1	2	184	603494	1.103
17	2	1	1	2	2	2	2	1	4	1	2	1	2	186	493529	1.176
18	2	1	1	2	1	3	2	1	4	1	2	1	2	190	500056	1.173
19	1	1	1	1	2	3	1	1	4	2	2	1	2	192	531459	1.103
20	1	1	1	1	2	3	1	2	4	2	2	2	2	193	713611	1.097
21	1	1	1	1	2	3	2	1	3	1	2	1	2	196	496004	1.113
22	1	1	1	1	2	2	1	1	4	2	2	1	2	198	523492.	1.102
23	1	1	1	1	2	2	1	2	4	2	2	2	2	199	705644	1.096
24	1	1	1	1	1	1	2	1	4	3	2	1	2	200	501832	1.106
25	1	1	1	1	1	1	1	1	4	3	2	1	2	211	504718	1.099
Sharma and Trivedi (2020)				Pop. Num				100								
				Num. of iteration				150								
				NFE = f-count				15000								
This paper (MOTLBO)				Pop. Num				100								
				Num. of iteration				50								
				NFE = f-count				10000								

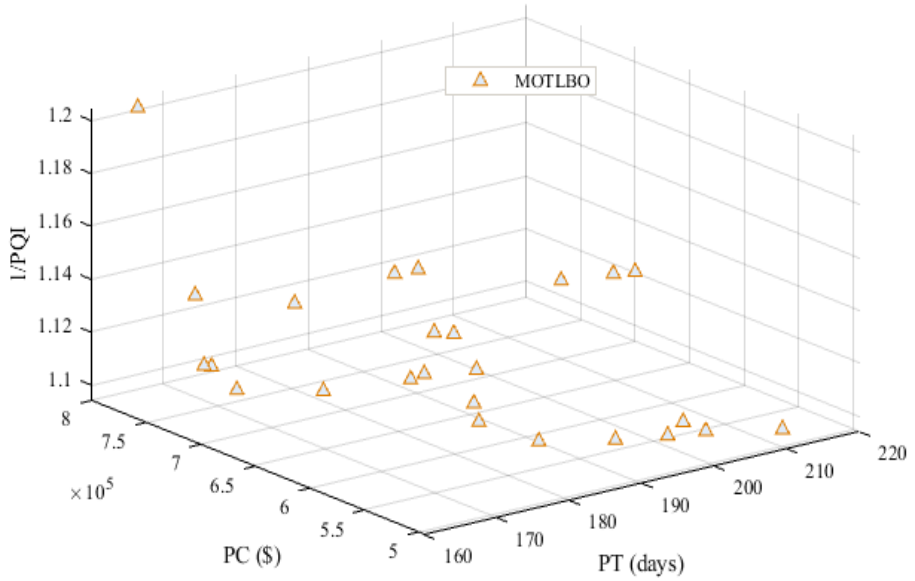


Figure 4: Pareto optimal solutions of time-cost-quality trade-off problem.

Conclusion

This paper besides examining the effects of the opposition-based learning (OBL) concept to demonstrate the variation of the optimal solutions, presented a multiobjective approach that aims to optimize time cost, and quality simultaneously by utilizing modified oppositional teaching learning-based.To maintain the diversity in the search process, the negative correlation concept of OBL is coupled with the original TLBO. Instead of opposite numbers, here, negative correlated numbers are used for population initialization and also for generation jumping. The proposed modal is successfully tested and implemented in benchmark problems. If the numerical simulation results are observed, the results demonstrate the benefits of MOTLBO compared with the multiobjective ant colony optimization (MOACO), differential evulotion (DE), and RKV-TCQ methods in obtaining satisfactory Pareto-front solutions. This research contributes to improving construction project scheduling and decision-making.

From the results, it is clear that the applied MOTLBO algorithm is proficient of finding optimum solutions for the small 7 activities and 13 activity problems. For the small 7 activities the proposed algorithm is able to achieve Pareto front solutions with an average deviation of %0 from the optimal costs and a smaller number of function evaluation. Similarly, 13 activity problem could provide Pareto front solutions with an average deviation of %0.7 from the optimal solution. Further research can be extended to the optimization model which considers the safety factors along with the new variants of the OBL technique i.e comprehensive learning strategy.

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The Importance of Value Engineering in Construction Industry

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Abstract

Sustainable development is one of the most important strategies in responding to social, economic and environmental problems. The construction sector is an important sector with social and economic support for national sustainable development due to its great impact on the gross domestic product of both developed and developing countries. In order to provide cost efficiency, improve project performance, improve quality, use new technologies, reduce the use of raw materials, Value Engineering (VE) has been adopted by public and private companies in the construction sector in many countries. In this study, a literature review will be conducted and it will be evaluated by classifying the areas of use of value engineering and the contributions they provide to the construction sector on a country-by-country basis according to the frequency of repetition in the sources in the literature using the content analysis method. Thus, the areas of use of value engineering in the construction sector and the benefits they provide, as well as their weights, will be determined on a country-by-country basis. An assessment will be made by comparing the areas and frequencies of use in Turkey and other countries, taking into account the characteristics of the countries.

Keywords: *construction industry, sustainable development, value engineering.*

Introduction

Increasing competition in the business world, aggravation of economic conditions, reduction of natural resources has caused various searches in the construction sector. For many years, value engineering has been applied to provide innovative ideas and solutions to increase the project value in construction projects around the world. (Masengesho, 2021) Value engineering has been used in public and private sector. It has contributions to reduce costs, improve performance, use the material, labor and time effectively, increase the production capacity, reduce the construction time, and increase the functional utility of design, environmental protection, and the use of new technology.

In the literature review conducted on Web of Science, 67 publications have been accessed in various fields on value engineering applications. 53 publications have been made in China on value engineering applications. There is one publication in the field of Industrial Engineering in Turkey (Web of Science, 2022).

42 of the 67 publications are covered by the construction sector. Figure 1 shows the number of publications related to value engineering applications in construction sector for different

countries. China has 31publications on value engineering applications in construction sector. The USA has 3 publications. Also, The Czech Republic, Iran, Pakistan, Sri Lanka and Saudi Arabia has publications on value engineering applications in construction sector. In the literature review conducted on Web of Science, Turkey has not a publication on value engineering applications in construction sector. Although there are graduate theses related to this subject, there has been no publication within the scope of Web of Science.

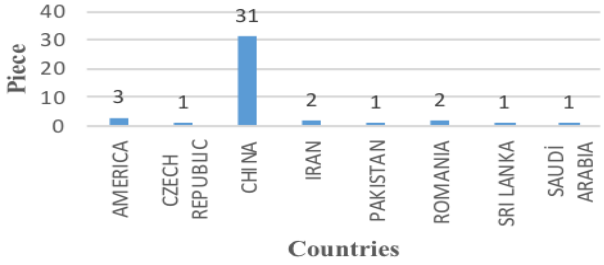


Figure 1: Number of publications on value engineering applications in construction sector for different countries (Source: Web of Science).

As of 1997, Value Engineering has been used extensively in public contracts in the United States with government encouragement and government enactment. The ratio of the profit obtained by Value Engineering to the budget of the entire business is not to be underestimated. Figure 2 shows the ratio of the profit from the application of Value Engineering on highways as of 1997 to the budget of the entire business. The contribution of Value Engineering to reduce costs has been used in highway applications for many years (Save summary report).

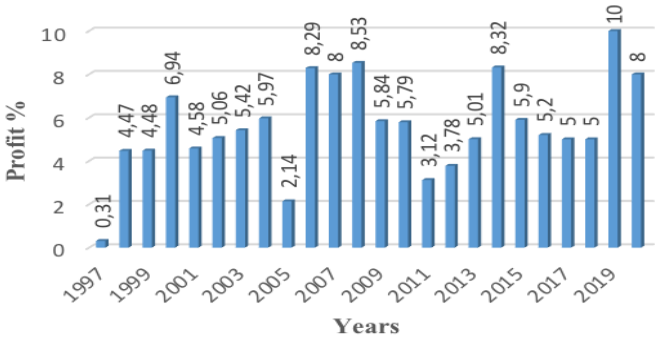


Figure 2: The ratio of the profit obtained from the State-Supported Value Engineering Works of Highways in the United States of America over the years to the budget of the entire business (Source: Save summary report).

It is known that there are various contributions of value engineering applications in developed countries such as Malaysia, Japan, the United Kingdom, and the United States (Wei, 2021). It is aimed to call attention to the contributions of value engineering and to generalize the use of value engineering in Turkey.

Method

After the publications about value engineering applications in construction sector have been scanned on Web of Science, the contributions of value engineering in construction sector will be specified and the contributions will be assessed for different countries. The flowchart of the method is shown in Figure 3.

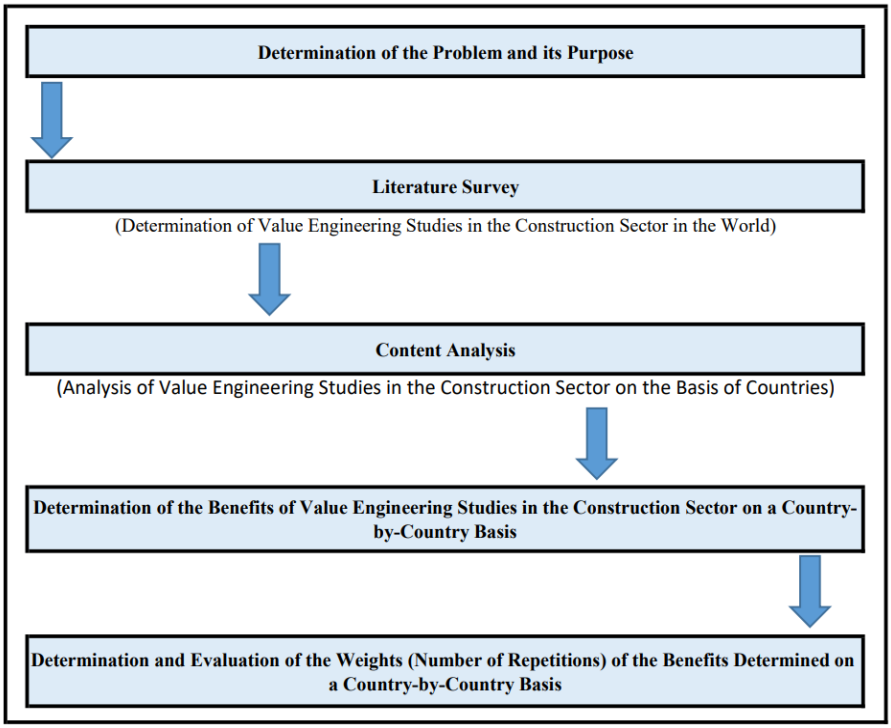


Figure 3: Flow chart of the method.

Content analysis is a method of analyzing written, oral or visual communication messages. (Cole, 1988) It allows the researcher to test theoretical issues to enhance understanding of the data. Through content analysis, it is possible to distil words into fewer content related categories. It is assumed that when classified into the same categories, words, phrases and the like share the same meaning (Cavanagh, 1997) It is the systematic examination of text and field notes by identifying and grouping themes and coding, classifying and developing categories (Jonge et al., 2007) In qualitative content analysis, the results are presented in the form of categories and/or themes. (Graneheim et al., 2017).

Content analysis is an appropriate method that can be used to scan the texts in the literature to classify the contributions of value engineering with specific words. When scanning the relevant literature within the scope of the content analysis method, the frequency of the contributions of value engineering in construction sector will also be revealed.

Determining the Contributions of Value Engineering Applications

The areas and the contributions of value engineering applications the construction sector will be determined by the content analysis method. The frequency of the contributions will be determined on the basis of countries. The steps of the content analysis are described below.

Determination of the Sample

The sample has been selected as the publications about value engineering applications in construction sector. In order to reach the data, the publications on Web of Science have been scanned. There are 42 publications about the value engineering applications in construction sector. 40 of them are articles and 2 of them are books.

Determination of Categories

In content analysis, the determination of the sample is followed by the determination of the categories step. In the analysis carried out; the contributions of value engineering applications in construction sector have been determined from 42 publications. When determining the categories, similar contributions has been collected under a same category. Contribution categories has been determined as “reducing cost”, “improving performance and coverage”, “reducing working time”, “increasing the functional utility of design”, “increasing total value/quality”, “contribution to environmental protection”, “supporting the new technology use". The contribution categories of value engineering in construction sector for different countries are seen in Table 1.

Table 1. The contribution categories of value engineering in construction sector for countries.

	Country	Publication	Contribution Categories						
			reducing cost	improving performance/coverage	reducing working time	increasing the functional utility of design	increasing total value/quality	contribution to environmental protection	supporting the new technology use
1	USA	Dorvil & Benjamin (2022)	X	X					
2	USA	Norton et al. (2013)	X						
3	USA	Sankey (1998)		X					
4	Czech Republic	Heralova (2016)	X	X	X				

5	China	Wang (2005)							X
6	China	Zhang (2005)				X	X		
7	China	Jayakumar (2009)	X	X			X		X
8	China	Dong (2009)	X	X					
9	China	Pei (2009)		X		X		X	X
10	China	Chen (2009)	X		X		X	X	
11	China	Liu (2009)	X	X					
12	China	Liu (2009)				X			X
13	China	Zhong (2009)	X	X					
14	China	Tang (2009)	X	X					
15	China	Wang (2009)	X	X					
16	China	Li (2009)	X					X	
17	China	Dong (2009)	X	X					
18	China	Lin (2009)		X		X		X	
19	China	Chen (2010)		X			X		
20	China	Zhang (2010)	X				X		
21	China	Liu (2010)	X	X				X	
22	China	Wang (2010)	X		X	X			
23	China	Feng (2011)	X			X	X		

24	China	Li et al. (2011)	X						
25	China	Yan et al. (2011)	X					X	
26	China	Yan (2012)	X	X					
27	China	Liu & Wei (2012)	X	X		X			
28	China	Duan (2012)	X	X			X		X
29	China	Liu et al. (2012)	X				X		
30	China	Cheng & Ma (2013)	X	X					
31	China	Cheng et al. (2013)	X	X					
32	China	Maisenbacher et al. (2013)	X	X					
33	China	He & Tao (2015)	X	X					
34	China	Xu et al. (2016)			X			X	
35	China	Wang et al. (2018)					X		
36	Iran	Rohaninejad & Noorzad (2009)	X			X			X
37	Iran	Rad & Yamini (2016)	X			X			
38	Pakistan	Shaikh et al. (2015)	X			X	X		
39	Romania	Chichernea & Veteleanu (2013)	X			X	X		
40	Romania	Veteleanu & Chichernea (2013)	X						X
41	Sri Lanka	Ekanayake & Sandanayake (2017)	X	X				X	
42	Saudi Arabia	Assaf et al. (1996)		X					

	Total		32	23	4	11	11	8	7

Data Analysis

Identified categories have been assessed on the basis of the 42 publications. Abstracts of the 42 publications have been reviewed and the categories identified have been analyzed based on the words in the abstracts. The countries of publications have been assessed, too. As can be seen from Table 1, multiple contributions of value engineering applications have been discussed in many countries.

Determination of the Counting System

Frequency of the data has been considered as counting system. Data in Table 1 have been assessed and the number of occurrences of categories has been established which then has been demonstrated in a graph in Figure 4. As a result of the analysis, we have found out the number of times categories have been featured in the publications and the most frequently featured categories.

Evaluation of the Findings

The contributions of value engineering applications in construction sector have been analyzed from the literature. The contribution categories of value engineering applications have been assessed in Table 1. Frequency of the contribution categories in terms of countries has been specified and the assessment is seen in Figure 4.

In 42 publications in the literature, “reducing cost” has been repeated 32 times, “improving performance and coverage” has been repeated 23 times. "Reducing cost" is the most important contribution of value engineering applications in every country except Saudi Arabia. The country where the most value engineering studies are carried out in construction sector is China. China has 31 publications on Web of Science. In the 31 publications in China, “reducing costs” has been repeated 23 times, “improving performance and coverage” has been repeated 18 times, “reducing working time” has been repeated 3 times, “increasing the functional utility of design” has been repeated 7 times, “increasing total value/quality” has been repeated 9 times, “contribution to environmental protection” has been repeated 7 times, “supporting the new technology use" has been repeated 5 times. “Reducing cost” has been the most important contribution of value engineering applications in China.

As shown in Table 1 and Figure 4, publications in the United States have focused on the contributions of “reducing costs” and “improving performance and coverage”; while publications in Czech Republic have focused on the contributions of “reducing costs”, “improving performance and coverage” and “reducing working time”. Publications in China have focused on “reducing costs”, “improving performance and coverage”, “reducing working time”, “improving the functional utility of design”, “increasing total value/quality”, “contribution to environmental protection” and “supporting the new technology use". Publications in Iran have focused on the contributions of “reducing cost” and “improving the functional utility of design”, while in Pakistan have focused “reducing cost”, “improving the

functional utility of design", "increasing total value/quality". The contribution of "increasing total value/quality" has only been mentioned in publications of China and Pakistan. "Contribution to environmental protection" category has been discussed in publications of China and Sri Lanka.

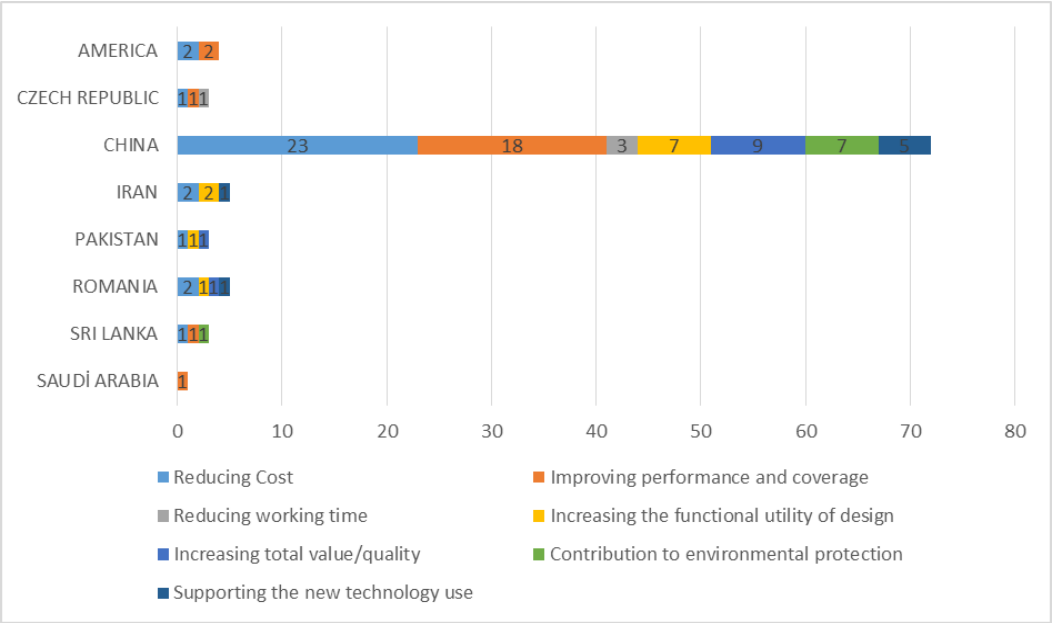


Figure 4: Frequency of contribution categories of value engineering applications in terms of countries.

The publication about value engineering applications of Turkey on Web of Science has been about mass production. The study conducted in the field of Industrial Engineering was published in 2022. In this study, the contributions of value engineering such as "reducing cost" and "improving the functional utility of design" have been emphasized. Although there are no publications on value engineering applications in construction sector of Turkey on Web of Science, there are 8 graduate theses about this subject. These studies were conducted between 1994 and 2021 (YOK Thesis Center).

As shown in Figure 5, 6 of the 8 theses focus on the contribution of "reducing cost", while 5 of them focus "increasing total value/quality". The contribution category of "improving performance and coverage" has not been mentioned in graduate theses of Turkey.

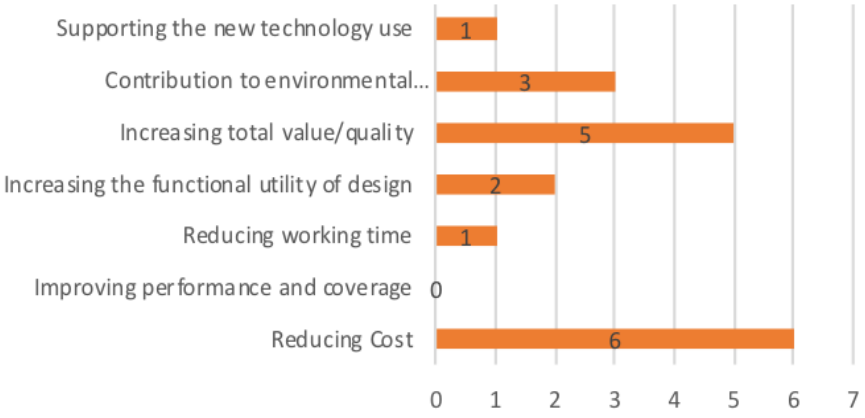


Figure 5: Contributions of value engineering applications in construction sector of Turkey (Source: YÖK Thesis Center).

It has been observed that the most contribution of value engineering applications in construction sector is "reducing cost" in the publications of Turkey like the other countries. Although the contribution of "improving performance and coverage" has been mentioned in the publications of USA, Czech Republic, China, Sri Lanka and Saudi Arabia; this contribution has not been emphasized in graduate theses of Turkey. The contribution of "improving performance and coverage" has been the only mentioned category in publications in Saudi Arabia. "Increasing total value /quality" contribution has been discussed in the publications of China, Pakistan and Romania like Turkey.

Conclusion and Recommendations

As a result of the content analysis, 42 of the 67 publications related to value engineering applications in the literature belong to the construction sector. China has 31 publications on value engineering in construction sector. In publications of China, the most important contribution of value engineering is "reducing costs", while the second place is focused on "improving performance and coverage". The most repeated contribution in all publications is "reducing cost". It shows the impact of the economy on the construction sector on a global basis. Publications in all countries except Saudi Arabia have focused on the contribution of "reducing cost". The problems in the economy have caused the studies to focus on this issue.

After the assessment of the contributions of value engineering applications in the construction sector, it is seen that the aim of the value engineering application differs depending on the level of development and economic situation of countries. There is no publication on Web of Science examining the contributions of value engineering in construction sector of Turkey. Developed and developing countries has provided different contributions from value engineering applications in construction sector. Turkey can provide contributions from value engineering applications in public and private organizations.

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An Integrated Multi-Criteria-Decision-Making Approach for Spare Parts Supplier Selection

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Abstract

Construction equipment plays an important role in construction projects. It is commonly acknowledged that decisions regarding the type of equipment to use on a construction project have a significant impact on the success of a construction project. Even though researchers have generated quite a volume of academic studies on selection of the type of equipment to use on a construction project, a limited number of studies focus on the selection of a spare parts supplier. The selection of a spare parts supplier is as important as the selection of the type of equipment to use because the production may stop when the construction equipment breaks down. At this point, the equipment starts only costing money to its owner rather than providing a benefit. Therefore, this study proposes an integrated multi-criteria-decision-making (MCDM) model that will assist decision makers to select the most appropriate spare parts supplier. The proposed model consists of two stages: (1) the criteria weights are calculated using Decision Making Trial and Evaluation Laboratory (DEMATEL), (2) the ranks of the suppliers are determined via Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). It is expected that the proposed model will provide a beneficial framework for the selection of spare parts suppliers.

Keywords: *construction equipment, spare parts supplier, decision making.*

Introduction

In the construction industry, contractors perform several types of construction activities which may require different types of construction equipment. The use of construction equipment is essential in completing construction projects whether it is a residential construction project or an infrastructure construction project. In other words, construction equipment is widely used in construction projects (Uzun, 2012). For example, in Turkey, according to values taken from, a total of 88,000 new construction equipment has been sold in Turkey in 67 years (T.C. Ministry of Industry and Technology, 2009). According to the report published by IMDER (Turkey Construction Equipment Distributors & Manufacturers Association) in 2018, the quantity of construction equipment sales increased from 4.400 to 12.030 from 2009 to 2017. Hence, it is no wonder then that the equipment usage is as important as other factors that may have an impact on the success of a construction project (Day & Benjamin, 1991). Therefore, researchers have conducted numerous studies and proposed many different models to select most appropriate construction equipment in construction projects. However, in the literature, the

studies that focus on selecting spare parts supplier are limited. The selection of a spare parts supplier is as important as the selection of the type of equipment to use because the production may stop when the construction equipment breaks down. For that reason, the purpose of this study is determined to develop an integrated multi-criteria-decision-making (MCDM) model that will assist decision makers to select the most appropriate spare parts supplier. For this purpose, first, a literature review was performed. In addition, interviews were conducted with participants (purchasers, site managers, construction equipment renters) of supplier decision processes to determine the criteria which are directly or indirectly related to spare parts supplier selection. Then, an integrated multi-criteria-decision-making (MCDM) model is proposed to assist decision makers to select the most appropriate spare parts supplier in construction projects. The proposed model uses Decision Making Trial and Evaluation Laboratory (DEMATEL) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. While DEMATEL method is used to determine the criteria weights, the spare parts suppliers are ranked due to their appearances and criteria weights with the help of TOPSIS method. A case study was carried out to illustrate how the proposed model can be applied in a real-life case.

The Proposed Model

The proposed model is developed thorough several steps. First, the spare parts supplier selection problem is defined. Identification of the decision-making group responsible for the spare parts supplier selection process is the second step. The main and sub-criteria of the spare parts supplier selection problem are determined by this decision-making group. In addition, the hierarchy and direct-influence matrices of the spare parts supplier selection problem are formed by the decision-making group. This step is followed by the step of calculating the weights of the main and sub-criteria by DEMATEL method.

After that, the computation steps of TOPSIS method are followed to develop the model. First, the decision matrix which shows the evaluations of the decision-making group on spare parts supplier alternatives is constructed. In the following step, the weighted normalized decision matrix is constituted via using the weights of main and sub-criteria that are calculated by DEMATEL method. Then, positive and negative ideal solutions for criteria and the distances of the supplier alternatives to these solutions are computed. In the final step, these distances to positive and negative ideal solutions are used to rank the spare parts supplier alternatives in descending order.

The DEMATEL method was introduced by the Geneva Research Centre of the Battelle Memorial Institute with the purpose of analyzing multifaceted connections between matrixes (Gabus & Fontela, 1972). It is commonly claimed that DEMATEL method is strongly beneficial to identify the connections between reasons and outcomes (Si et al., 2018). A review of the recent literature reveals that the DEMATEL method is used in development of several decision-making models. Moreover, the studies conducted to improve the DEMATEL method have expanded the variety of fields in which it can be used (Si et al., 2018). According to Celik and Akyuz (2015), the DEMATEL method consists of the following stages:

Stage 1: Constructing the direct-relation matrix (A) using a scale of 0 to 4 (see Table 1).
Stage 2: Determining the normalized direct-relation matrix (X).
Stage 3: Obtaining the total influence matrix (T) with derivations.
Stage 4: Computing the threshold value (a).

Stage 5: Constructing the casual diagram.

Table 1. The linguistic scale.

Linguistic Terms	Influence Score
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

The TOPSIS method was firstly presented by Hwang and Yoon (1981). Researchers consider this method as one of the most important MADM methods. It is mainly based on finding the best option via identifying the shortest geometric distance from the positive ideal solution (PIS) and the longest geometric distance from the negative ideal solution (NIS) (Assari et al., 2012). According to Çam et al. (2015), the calculation stages of the TOPSIS method consists of the following stages:

Stage 1: Formation of the decision matrix with n alternatives and m criteria
Stage 2: Formation of the normalized decision matrix.
Stage 3: Formation of the weighted normalization matrix.
Stage 4: Determination of Positive Ideal Solution (A^+) and Negative Ideal Solution (A^-).
Stage 5: Calculation of the distances between alternatives.
Stage 6: Determination of relative margins from ideal solution.
Stage 7: Ranking the alternatives.

In this study, the DEMATEL method is used for calculating the weights of given criteria and the TOPSIS method is used for determining the best spare parts supplier alternative.

Case Study: Spare Parts Supplier Selection Using the Proposed Model

The illustration of the proposed model can be best demonstrated by a case study. This case study focuses on a procurement problem of a company that performs geotechnical construction. This company is specialized in mini-piling, bored piling, anchoring and jet grouting. The use of construction equipment is very common in activities related to geotechnical construction. The geotechnical construction companies may maximize their profit and productivity, if they maintain their construction equipment carefully. Spare parts play a critical role in these maintenance stages. Therefore, the case of a spare parts supplier selection problem of a geotechnical company is used in this study.

In this study, the main criteria and sub-criteria are identified via a comprehensive literature review and conducting interviews with professional who are involved in decision making process of spare parts supplier selection. There are five main criteria used in this study, namely, (1) Financial, (2) Supplier, (3) Delivery, (4) Service, and (5) Quality. The first main criterion (i.e., Financial) has three sub-criteria, namely, (1) product price, (2) payment terms, and (3) quantity discount. There are four sub-criteria of the second main criterion (i.e., Supplier), namely, (1) number of employees, (2) reputation, (3) production capacity, and (4) financial capability. Another main criterion “Delivery” also has four sub-criteria, namely, (1) lead time, (2) percentage of on-time delivery, (3) percentage of order fulfillment, and (4) geographical

location. The fourth main criterion (i.e., Service) has four sub-criteria, namely, (1) communication ability, (2) response speed, (3) buyer-supplier relationship, and (4) after-sales services. If one takes a closer look at the fifth main criterion (i.e., Quality), one will notice that it has three sub-criteria, namely, (1) percent of rejections, (2) duration of use, and (3) insurance/warranty. In this case study, the geotechnical construction company has six different spare parts supplier alternatives which are named as Supplier 1, Supplier 2, Supplier 3, Supplier 4, Supplier 5 and Supplier 6. The decision hierarchy of the spare parts supplier selection problem is presented below (Figure 1).

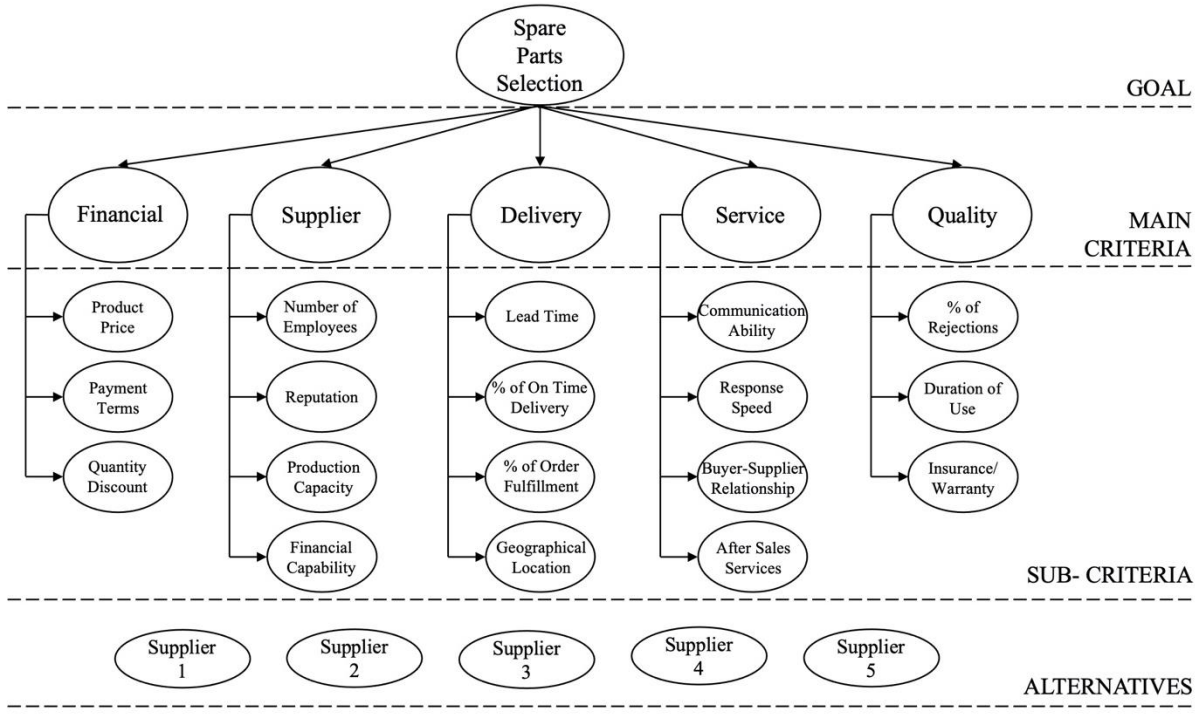


Figure 1: Hierarchy of the spare parts supplier selection problem.

Following the development of the decision hierarchy of the spare parts supplier selection problem, the weights of the main criteria and sub-criteria must be calculated via utilizing DEMATEL method. To calculate these weights, the proposed model needs pairwise comparison matrices of the main criteria and sub-criteria. These pairwise comparison matrices are formed by three decision-makers. Since there is a need of making a group decision, three pairwise comparison matrices are aggregated using the arithmetic means of each preference. Thus, the weights of the criteria of spare parts supplier selection problem are computed via the DEMTAEL method (Table 2).

Table 2. Aggregated pairwise matrix of criteria for the spare parts supplier selection problem.

Criterion	Product Price	Payment Terms	Quantity Discount	No. Of Employees	Reputation	Production Capacity	Financial Capability	Lead Time	% of on time Delivery	% of Order Fulfillment	Geographical Location	Communication Ability	Response Speed	Relationship	After-Sales Service	Percent of Rejections	Duration of Use	Insurance/Warranty	**Weights**
Product Price	0.000	0.068	0.068	0.017	0.044	0.034	0.061	0.017	0.017	0.017	0.056	0.027	0.017	0.061	0.039	0.017	0.044	0.031	**0.110**
Payment Terms	0.068	0.000	0.061	0.017	0.056	0.034	0.061	0.031	0.021	0.017	0.056	0.039	0.017	0.068	0.044	0.017	0.021	0.021	**0.068**
Quantity Discount	0.068	0.068	0.000	0.021	0.056	0.027	0.068	0.021	0.017	0.017	0.039	0.034	0.017	0.061	0.031	0.017	0.021	0.021	**0.058**
No. Of Employees	0.027	0.017	0.017	0.000	0.044	0.056	0.044	0.068	0.061	0.068	0.017	0.017	0.061	0.017	0.056	0.021	0.021	0.017	**0.035**
Reputation	0.061	0.056	0.044	0.027	0.000	0.027	0.056	0.027	0.017	0.044	0.017	0.061	0.051	0.061	0.051	0.021	0.017	0.017	**0.091**
Production Capacity	0.031	0.031	0.027	0.027	0.068	0.000	0.044	0.068	0.068	0.061	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	**0.048**
Financial Capability	0.068	0.056	0.061	0.039	0.061	0.056	0.000	0.054	0.056	0.051	0.017	0.017	0.021	0.021	0.017	0.017	0.017	0.021	**0.057**
Lead Time	0.049	0.027	0.017	0.034	0.061	0.027	0.017	0.000	0.049	0.034	0.049	0.021	0.021	0.017	0.017	0.017	0.017	0.034	**0.059**
% of on time Delivery	0.049	0.039	0.021	0.021	0.068	0.051	0.017	0.051	0.000	0.068	0.034	0.021	0.017	0.061	0.017	0.017	0.017	0.017	**0.055**
% of Order Fulfillment	0.021	0.027	0.017	0.017	0.061	0.051	0.017	0.051	0.051	0.000	0.017	0.021	0.017	0.056	0.017	0.017	0.017	0.017	**0.052**
Geographical Location	0.024	0.021	0.017	0.017	0.031	0.031	0.017	0.061	0.068	0.039	0.000	0.017	0.068	0.051	0.049	0.017	0.017	0.017	**0.043**
Communication Ability	0.039	0.056	0.056	0.027	0.068	0.017	0.021	0.044	0.031	0.027	0.017	0.000	0.056	0.068	0.051	0.017	0.017	0.034	**0.049**
Response Speed	0.039	0.021	0.027	0.027	0.068	0.017	0.017	0.043	0.031	0.017	0.017	0.056	0.000	0.068	0.017	0.017	0.017	0.017	**0.048**
Relationship	0.068	0.068	0.061	0.017	0.068	0.021	0.056	0.039	0.039	0.017	0.017	0.061	0.056	0.000	0.039	0.017	0.017	0.017	**0.077**
After-Sales Service	0.044	0.049	0.017	0.021	0.061	0.017	0.017	0.017	0.017	0.017	0.021	0.034	0.017	0.068	0.000	0.017	0.027	0.049	**0.049**
% of Rejections	0.034	0.034	0.017	0.017	0.068	0.017	0.017	0.021	0.017	0.027	0.017	0.034	0.021	0.039	0.017	0.000	0.017	0.021	**0.028**
Duration of Use	0.061	0.021	0.021	0.017	0.056	0.017	0.017	0.017	0.021	0.021	0.017	0.021	0.017	0.039	0.017	0.017	0.000	0.027	**0.033**
Insurance/Warranty	0.061	0.039	0.027	0.017	0.061	0.017	0.017	0.017	0.017	0.017	0.017	0.000	0.017	0.044	0.017	0.017	0.021	0.000	**0.038**

The findings of the study reveals that the “Product Price” criterion has the greatest weight (i.e., 0,110) among the criteria. Since the product price is commonly a game changer in a procurement process, it is no surprise that it has the greatest weight. On the other hand, the second and third greatest weight belong to “Reputation” and “Relationship” criteria, respectively. These results can be interpreted as an expression of that decision makers attach more importance to trust and social factors when the product price is determined. The fourth and fifth highest ranked criteria were “Payment terms” and “Quantity discount”, respectively. However, some professionals state that these criteria may have more importance in unstable economies. The “Percentage of rejections” criterion has the lowest weight among the spare parts supplier selection criteria.

In the second phase of the proposed model, TOPSIS method is employed to determine the ranking of the spare parts supplier alternatives. Decision makers evaluated six spare parts suppliers by considering 18 different sub-criteria. Several significant measurements were used for these evaluations. Product price is a cost criterion which is measured in terms of dollars. Payment terms, reputation and communication ability were measured on a scale of 1-9 where a greater number is desirable. For quantity discount, percentage of on-time delivery, percentage of order fullfillment and percentage of rejections were determined in percentages. Number of employees and buyer-supplier relationship were measured in numbers. On the other hand, response speed, lead time and duration of use were measured in days. For lead time and response speed criteria, a lower number is preferable where a greater number is preferable for duration of use criterion. Production capacity is the amount of goods which the supplier can manufacture monthly and financial capability is the yearly endorsement of the supplier companies which defined with dollars. Geographical location criterion was measured in kilometers by considering the distance between the company and supplier. After-sales services and insurance/warranty were measured in terms of presence/absence (i.e., 0 for absence and 1 for presence). The initial decision matrix of evaluation criteria for spare parts supplier alternatives is given in Table 3.

Table 3. Initial decision matrix of evaluation criteria for six spare parts supplier alternatives.

Criteria	Measurement Unit	Supp. 1	Supp. 2	Supp. 3	Supp. 4	Supp. 5	Supp. 6	Sum
Product price	**k $**	6.25	6.68	7.35	6.4	6.65	6.55	16.303
Payment terms	**1-9 scale**	5.31	5.65	4.64	5.94	5.94	7	14.189
Quan. Discount	**%**	6	5	4	2	7	4	12.083
# of Employees		4	4	6	5	3	4	10.863
Reputation	**1-9 scale**	7.65	6.32	6.32	7.65	7.65	7.32	17.578
Prod. Cap.		400	350	300	250	450	450	916.51
Fin. Cap.	**k $**	300	200	250	150	125	280	555.9
Lead time	**day**	2	2	1.5	1	2	1,5	4.183
% of on-time delivery	**%**	95	92	90	95	91	90	225.821
% of order fullfillment	**%**	85	80	90	90	90	95	216.679
Geog. location	**km**	5	3.5	8	6	13	9,5	19.912
Comm. Ability	**1-9 scale**	6.32	6.65	7.32	6.32	6.65	7.27	16.572
Response speed	**day**	1.15	1.65	1.65	1	0.63	1	3.026

Buyer-supplier rel.		4.76	3.48	5.09	2.62	8	3.04	11.865
After-sales services	**0-1**	0	1	1	0	0	1	1.732
% of rejections	**%**	5.5	3.5	5	4.5	5	5	11.737
Duration of use	**day**	250	200	300	300	200	400	694.62
Insurance/Warranty	**0-1**	1	1	0	1	0	1	2

After forming initial decision matrix of evaluation criteria for spare parts supplier alternatives, the items of it were normalized. Following this step, the weighted normalized decision matrix was developed. Then, the Positive Ideal Solution (A^+) and Negative Ideal Solution (A^-) were determined. Afterwards, the distances of spare parts supplier alternatives from these ideal solutions were calculated. After completing the mathematical calculations of TOPSIS method, the proposed model ranks the spare parts supplier alternatives (Table 4).

Table 4. The result matrix of TOPSIS method.

Alternatives	Si+	Si-	Ci	**Ranking**
SUPPLIER 1	0.042	0.042	0.504	3
SUPPLIER 2	0.042	0.045	0.512	2
SUPPLIER 3	0.041	0.040	0.495	5
SUPPLIER 4	0.055	0.033	0.375	6
SUPPLIER 5	0.048	0.048	0.497	4
SUPPLIER 6	0.040	0.046	0.538	1

According to the findings obtained in this study, SUPPLIER 6 is the best alternative as it has the maximum value for the relative closeness. On the other hand, when one reviews the values of relative closeness for the other alternatives, one will observe that SUPPLIER 2 and SUPPLIER 1 are the second and third most appropriate alternative, respectively.

Conclusion

In the construction industry, it is commonly acknowledged that decisions regarding the type of equipment have an impact on the success of a construction project. If one reviews the literature, one will notice that there are several studies on selection of the type of equipment to use on a construction project. However, there is a limited number of studies that focus on the selection of a spare parts supplier. The selection of a spare parts supplier is as important as the selection of the type of equipment to use because the production may stop when the construction equipment breaks down. This kind of importance makes the selection of spare parts suppliers a compelling task for decision makers. The study presented in this paper is initiated as a response to the lack of an integrated multi-criteria-decision-making (MCDM) model that will assist decision makers to select the most appropriate spare parts supplier. The illustration of the proposed model is demonstrated by a case study. DEMATEL method is employed to calculate the weights of the main and sub-criteria in the first stage of the proposed model. After that, TOPSIS method is used to determine the ranking of 6 spare parts supplier alternatives. The

findings of the study reveal that the Supplier 6 is the most appropriate alternative. The results also show that the proposed model is beneficial and appliable in selection of spare parts supplier in the construction industry. Future can consider using different MADM techniques in order to make comparisons.

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Active Information Search as a Research Method in Construction Management Studies

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Abstract

Information search is a research area under the cognitive sciences to study decision making and judgement processes: It focuses to understand information acquisition and cognitive insights of decisions and judgements by using several process training approaches such as information boards, eye fixation, active information search, thinking aloud protocols, etc. Information search has been the focus of interest in the several research areas in the literature such as marketing, business management, psychology, legal and healthcare issues. Yet the impact of information search has not yet revealed in the construction management studies. This research aims to introduce the use "Active Information Search" as a research method to the construction management literature. The proposed research method could lead to the use of information search in the construction management literature to derive inferences about decision making processes by analyzing changing variables such as content, context and time, cognitive and heuristics backgrounds as well as uncertainty and subjectivity effects. A research design based on "Active Information Search" is to be presented to illustrate its application protocols and also the utility of the method.

Keywords: *active information search, construction management, decision making, research methods.*

Introduction

Cognitive science focuses on information acquisition and cognitive representation studies by using different process training methods that explore the cognitive processes and the tools and techniques of decision-making processes (Kühberger et al., 2011). Basically, these methods focus on the fields of information acquisition, integration, evaluation and the psychological and neurological insights of cognitive processes through a two-step analysis approach that includes indicating cognitive attributes and collecting data for hypothesis testing. Various methods under each field of study have been developed to analyze decision making processes such as information boards, eye fixation, Active Information Search (AIS) is located the under information acquisition; thinking aloud protocols, structured response dictation under information integration and evaluation; and final reaction time, Galvanic skin conductance,

Pupil dilation and eye-tracking, and neural techniques of the location under cognitive process analysis (Kühberger et al., 2011).

In this study, Active Information Search (AIS) method is analyzed in detail and its potential contribution to the construction industry will be presented. The main reason to focus on AIS method is that it allows to analyze decision makers' attitudes and interests under risky decision-making processes that includes subjectivity and probabilities (Huber et al., 2011). Some research areas that attach importance to stakeholders' decisions in construction industry practice such as design and group decision making processes, user/consumer pattern analyses, marketing, work environment improvements and entrepreneur management, etc. in order to take the advantage of AIS method and other information search methods by detail analyzing risky, uncertainty, subjectivity, heuristic, explanatory insights of decisions (Schulz-Hardt et al., 2000; Dhami & Harries, 2010; Urbany et al., 1989; Ozanne et al., 1992; Loibl & Hira, 2009; Cooper et al., 1995). Within the framework of this paper, methodological background of the AIS method will be summarized, and a research design is illustrated to indicate its application protocols and also the utility of the method in the construction industry.

Active Information Search as a Decision Analysis Method

Active Information Search (AIS) method has been developed to analyze risky decisions with respect to the subjective values and the probabilities of decision makers (Huber et al., 1997; Huber & Seiser, 2001; Huber et al., 2009; Huber et al., 2011). With the AIS method, information search, justification pressures and risk defusing operators (RDOs) in risky and natural decision-making processes can be evaluated. Justification with respect to explaining and believing reason of choosing is shaped by justification pressures that are mainly externally sourced. With the AIS method, the justification pressures ending up with risk defusing operators (RDOs) are developed by decision-makers to defuse or decrease risk in decisions (Huber & Seiser, 2001; Huber et al., 2009; Huber & Huber, 2008).

The analysis of decision of AIS method begins with presenting decision tasks/scenarios to subjects (participants or experiments). Subjects ask questions about the proposed tasks to understand the details of task. Analyzers consider this process as a pilot study to reconsider decision tasks and constituting coding schemas that are used in question phase and verbal protocols. Coding schemas can be prepared by considering the approach of subjects on indicated protocols such as the protocol based on probability, evaluation, new alternatives, worst-case planning, control, long-term plans, decisions, irrelevant and not categorical categories (Huber et al., 1997; Huber & Seiser, 2001; Huber et al., 2009; Huber et al., 2011). After this process, analyzer ask for the decisions of subjects in written or verbal formats to begin to analyze cognitive representation of their decisions (Huber et al., 2009). Qualitative data derived from the process of question and answer are transformed into quantitative data by using coding schemas. After that statistical analyses are applied to understand decision making patterns (Huber et al., 1997; Huber et al., 2009). The table below summarizes phases of the AIS method (Table 1) (Huber et al., 2011).

Table 1. Phases of active information search method (Source: Huber et al., 2011).

Phases and Components of Active Information Search Method	
The phase of Information Acquisition and Coding	
Reading	-giving quasi-realistic scenarios -explicitly mention the possibility of the negative outcome -no probability provided
Questions	-participant asking questions to obtain more information -the question coded by the experimenter (code is recorded)
Answers	-for each question, the experimenter presenting an answer in printed or computer (for standardization purposes and avoiding non-verbal influences)
Decision	-after having sufficient information, a decision is given by the participant
The phase of Construction of AIS Scenarios and Categorization of Questions	
Selection of Topic	-should be interesting -the participant should not know much knowledge about the topic for preventing external search -testing topic by informally interviewing a few participants of the same population -can be used for both expert and non-expert decision making analysis
The first version of Basic Description and Preparation of Answers	-including the role of the participant and a short description of the decision situation -description of alternatives -brainstorming for indicating possible questions to answer -generating appropriate answers -during the application, only the code of answer is recorded (*in the basic type of AIS)
Optimization of Task Description and Answers	-modifications for indicating the dominance of alternative, the implausibility of fact and rich description of the task -thinking aloud procedure (can be costly and time-consuming, post-experimental interviews, testing task description by generating a list of questions can be helpful methods to use
Categorization of Questions	-required for the information acquisition process -coding scheme to capture the category of question and test model comprehensibility
Problems in Coding Scheme	-considering additional issues during the construction of questions and answers as well as coding during the process
-construction of answer	-considerations; type of questions and its order, proposing RDO that are actions to choose an alternative to minimize risk and its applicability, negative event identification, the scale used for answers, existence and probabilities of RDOs, answering new alternative options
-procedural issues	-problems; asking more questions for the same alternative, asking for facts that are already described, repeated questions for positive and negative consequences -has to be standardized -asking for more precise and reformulated questions -comparing the importance
-reliability of the coding scheme	-required for questions and answers and validity of research -inter-rater reliability (Cohen's Kappa) of the coding system should be tested in pre and final processes
Statistical Analyses	Raw data analyzed in different ways; -quantity of information in total and specific coding category -the sequential aspect of information search; Parametric analysis for several questions analyzed Mann-U and Wilcoxon tests for biased means due to repeated and 0 questions Logit analysis for concurrent analysis of several factors varied between subjects by fitting them in a hierarchy of logic model for identification of effective factors Sign and Cochran Q tests for factors varied within sub-headings

In the task/scenario preparation, two different perspectives can be considered both in (1) design and (2) application phases. In task design, (1a) descriptive and (1b) empirical approaches are considered. In descriptive approach, decisions can be design two ways that are choice and judgement. While choice focuses on preferable outcomes, judgment considers subjective values in the decisions. In empirical perspective, two ways of process design that are outcome and process oriented are considered. While the outcome-oriented process design emphasizes on radical and specific decisions, process oriented analyzes pre and post decisional phases (Huber & Seiser, 2001). The application of AIS method can be also differentiated with respect to (2a) process and (2b) behavior dominated. The process dominated is designed to make a decision based on monetary aspects whereas the behavior dominated analyzes risk with respect to utility and subjective probabilities.

The presentation of information may also vary (Huber et al., 1997). Accordingly, information can be presented completely and administered by the task giver. In the administered option, two main types of AIS procedures that are basic and list type are summarized in the below table with respect to advantages and disadvantages (Table 2) (Huber et al., 2011).

Table 2. Types of presenting AIS method (Huber et al., 2011).

Types of AIS procedure	
Basic Type	**List Type**
Advantages: -**does not push information** to the participant	**Advantages:** -questions are designed and presented to participants that can **ask more questions** -questions do not have to be coded during experimental sessions; **practical advantages** -behavior coded that **eases implementation** of alternative attribute matrix in computer -**alerting participant about risk diffusing operators** -can be used in **Internet experiments**; chatrooms, e-mail; sending questions, responding and answering and web-based processes
Disadvantages: -questions **administered during the experiment** -questions are **coded during the experiment** -**no structure** for information search -participant may **not be aware of RDOs** -applied **only face-to-face**	**Disadvantages:** -**computerized AIS application**, WebDib (ability to judge text is low that may result in unexpected results) -**cost of information** in monetary and computational aspects in terms of the number of questions and their choice by the participant, indicating several questions and type of information

In the literature different scenarios/tasks are applied to conduct AIS method. Some of them are listed as;

- Post office task: Evaluating the pros and cons of renting/not renting the hall by the post office manager in the village that is resulted deciding whether to be appointed to the permanent position at the end of the decision made by post office manager (Huber et al., 1997),
- Machine task: Buying decision of a small factory owner between two machines that have different advantages and disadvantages to fulfil orders (Huber et al., 1997),

- Choice of head for corrective home: Decision of a member of the board of directors to be head of corrective home for criminal adolescents from a group of different personal characteristics having different importance (Huber & Seiser, 2001),
- Virus task: Evaluating the situation of two alternative treatments that can be applied for your spouse who has a lethal virus during the trip and deciding on the type of treatment (Huber et al., 2009),
- Gamble task: Conservation program manager's decision to place the endangered lemur species in one of eight alternatives (Huber et al., 2011).
- Maki task: Selection of a gambling alternative according to the possible wins and losses of the two gambling alternatives consisting of their selection from different tasks (Huber et al., 2011).
- Turtle task: To choose between a coast or an island that offers different living conditions in order to determine the natural habitats of the endangered turtle species (Huber et al., 2011).

As it is seen in the applied task/scenarios, stories include several risks or options to make decisions that are also affected on risky results. This circumstance can be seen almost any phase of design and construction practices. To give some examples.

- Any decision making on scope and schedule about the projects may have impact on the cost of project,
- Any decision making on the prequalification process may influence communication and stakeholder relationships,
- Any design decision may have impact on the social, the physical, the cultural characteristics of the existing physical environment,
- Any managerial decision may have influence on psychology and motivation of workers,
- Any decision making on resources and/or materials may have effect on health and safety issues and/or user/client contentment, etc.

Applying AIS method in construction practice may help to decision-makers to foresee possible risks and opportunities before they are making their final decisions. In this way, possible risks, uncertainties, problems occurring by subjectivity or heuristics can be minimized. In construction industry, organizational resilience can be improved by developing decision-makers' ability to adapt in different risky circumstances. In addition, as a natural risky situation, possible consequences of natural disasters that effect construction project in variable aspects can be studied with AIS method to develop preventive measures. Accordingly, this study aims to propose a research design that guide decision makers in the construction industry to imply AIS method more effectively.

Research Design

AIS method is begun with a decision task. Developing tasks are crucial for achieving effective conclusions to achieve a general idea about decision-makers' intentions. This research design deeply investigates decision tasks used in AIS method with the elements of Storytelling method. Storytelling is research method used for analyzing complex social interactions that allows to analyze cultural, social, natural, personal, managerial actions in a more comprehensive way to define strategic purposes of decision makers (Boje, 2006; Their, 2018; Machiavelli, 1950; Forman, 2013). The elements of story are important for revealing the

different influences of stories and achieving effective storytelling analysis. There are seven headings for defining the elements of stories that are *plot, character, theme, dialogue, melody, décor and spectacle* (Aristotle, 1954). Table 3 summarizes characteristics for each element of storytelling.

Table 3. Elements of storytelling.

Elements of Storytelling	
Plot	Indicating the **actions of characters** Actions mainly on overcoming struggles and challenges The aim is to improve positively their actions
Character	Indicating actors and their **personalities** Personalities based on emotions, needs, backgrounds The aim is to develop empathy on motivations
Theme	Indicating the **goal of the story** Focus of story
Dialogue	Indicating **what and how people talking** and not wanting to talk Emphasizing feelings
Melody/Chorus	Indicating the **ability of the storyteller** to use his/her emotions to better understand the theme
Décor	Indicating **the environment** How the environment affects teller actions and behaviours
Spectacle	The part **listening story**, remembering it and proposing discussion and ideas

This research design aims to develop a layout/canvas/template to improve the potential effects of stories that increase the power of narrative techniques. Accordingly, decision tasks applied with AIS method in the literature are systematically analyzed with the elements of storytelling. In this way, the potential of each element to influence decision-maker can be figured out and decisions tasks can be applied in different contexts (Table 4).

Table 4. AIS tasks and storytelling elements.

Reference	**Task name**	**Elements of Storytelling**						
		Plot	Character	Theme	Decor	Melody /Chorus	Dialogue	Spectacle
Huber, Wider and Huber 1997	Post office	✓	✓	✓	✓	X	X	X
Huber, Wider and Huber 1997	Machine task	✓	✓	✓	✓	X	X	X
Huber and Seiser 2001	Choice of head of a corrective home	✓	✓	✓	✓	X	X	X
Huber, Bär and Huber 2009	Virus task	✓	✓	✓	✓	✓	X	X
Huber, Huber and Bär 2011	Gamble task	✓	✓	✓	✓	✓	X	X
Huber, Huber and Bär 2011	Maki task	✓	✓	✓	✓	X	X	X
Huber, Huber, and Schulte-Mecklenbeck 2011	Turtle task	✓	✓	✓	✓	X	X	X

As it can be seen in the table above, some elements of the stories in the AIS tasks are used, while some were never used. To examine in more detail, tasks always are begun with defining the characters and environmental conditions of the story, and then emphasizing the subject of the story. After defining these, it explains the actions of decision makers and the environment in more detail and presents all the details to the decision maker. In some tasks, thoughts of storyteller are generally not presented. Apart from this, the ideas of listener and the dialogues

among characters are not included in the tasks. Table 5 presents some of the examples from the elements of stories used in the AIS method.

Table 5. Examples of storytelling elements used in AIS tasks.

Plot	**Post office task:** deciding whether the provisional manager becomes the permanent manager or not training its middle management **Machine task:** buying an additional high-capacity machine for production to meet the demand **Head of corrective home task:** selecting criteria on the base of their average importance measured in preexperiment **Virus task:** deciding on the treatment, imagining travelling on an island **Gamble task:** assigning moderate possible gains, asking questions **Maki task:** protecting an endangered maki species **Tuttle task:** turtle living in the southern pacific is acutely threatened by extinction.
Character	**Post office task:** New provisional manager, superiors, village administration, applicants **Machine task:** Owner of factory **Head of corrective home task:** Members of executive board, head of corrective home, criminal adolescents **Virus task:** Partners, participants of pilot experiments **Gamble task:** participants **Maki task:** Manager of preservation program **Tuttle task:** Head of program, marine biologists
Theme	**Post office task:** to decide whether to rent the hall or not **Machine task:** to assume the role of the owner of a small factory that produces weatherproof credit cards for ski lifts and to buy an additional high-capacity machine for production to meet the demand. **Head of corrective home task:** to choose the head of a corrective home for criminal adolescents. **Virus task:** to decide on the treatment instead of the partner. **Gamble task:** four gambles choice tasks with two versus eight gambles as alternatives. **Maki task:** decide which one of x possible areas **Tuttle task:** to protect turtles
Décor	**Post office task:** Village h, post office, local meeting hall **Machine task:** Machine A and B **Head of corrective home task:** Corrective home for adolescents **Virus task:** Island, Treatment A and B **Gamble task:** Alternatives **Maki task:** Areas **Tuttle task:** Beach and island
Melody/Chorus	**Virus task: "**It should be noted that participants in the pilot experiments considered the disorder of the immune system as more dangerous and undesirable than the symptoms of paralysis." **Gamble task: "**We used the AIS variant that was employed in Experiment 1, with questions for positive and for negative consequences presented on cards (randomized order)."
Dialogue	Not exist
Spectacle	Not exist

After deeply examining the elements of story in the tasks, some elements are required to be existed to explain tasks in detail such as, character, plot, and theme. While character defines roles of decisions makers, plot indicates the main aim in the task and theme highlights the subjects of task. Décor is also important for decisions-makers to achieve details about existing circumstances. Melody/chorus can be used for giving details about the task that are not always required to known by the decision-maker. Dialogue and spectacle elements are not observed in the existing tasks, but dialogue may be included if decision task is related about the

relationship among decision-makers and spectacle may be included if decision task is including also community opinion.

Figure 1 presents both the elements of story used in the AIS method and also the examples for the related elements that can be used to design tasks in the constructions industry (Figure 1). Accordingly, construction activities, stakeholders and subject of story, environmental factors related with the task, personal opinions of storyteller, dialogue among stakeholders and other stakeholders that are as the observer of story can be carefully designed for adapting AIS tasks to analyze decision making process in the construction industry. In this way, tasks designed for construction industry can be effectively designed to achieve appropriate decisions used for analyses.

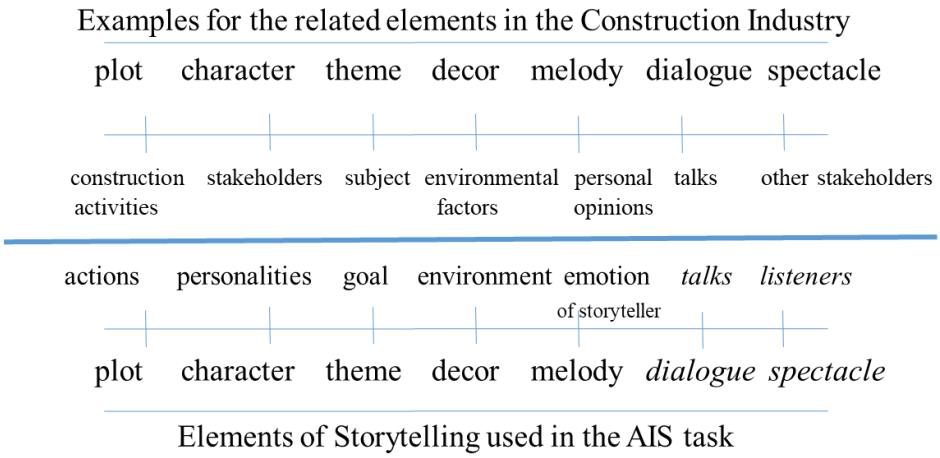


Figure 1: An outline for adapting task to construction industry.

This research design aims to provide an outline for the user of AIS method in the phase of task design. In construction industry, almost all elements of story can have important circumstances in the tasks to give information to decision-makers. In the stories written to carefully design the elements of the story, a lot of information can be obtained about the content, context and time, cognitive and heuristics backgrounds, the way the decision maker thinks and what the decisions will be. This information will be a guide for the evaluation of decision-making processes in the sub-fields of construction management both socially, physically and cognitively.

Conclusion

In this study, the possible benefits of Active Information Search (AIS) method, which is used as an information search method, in construction management studies are presented. In addition, the task part, which is the first stage of the AIS method, has been examined in detail, and a research design has been presented by examining its interaction with the elements of storytelling method in depth. In the light of the information obtained, the effects of storytelling elements used in AIS tasks on decision-making processes of the construction management were discussed and their possible benefits were emphasized.

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Management of Building Restoration Projects: Key Areas of Concern and Challenges

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Abstract

Building restoration is a complex process with a high level of uncertainty. It differs from many construction projects in terms of the need for research-based practices to define scope, planning, scheduling, design, supervision, decision-making, material use, construction methods, and also the legal environment. Restoration professionals can significantly benefit from the well-established discipline of project management to achieve their targets; however, available evidence shows that the use of the project management body of knowledge in restoration projects is far from the desired level. Although there are some bylaws and guides that are followed, peculiarities of the restoration projects with a project management lens are yet to be explored. This paper argues that a contemporary perspective which utilizes project management tools and techniques can contribute to the conservation of architectural heritage in line with the universal conservation principles. Following a literature review, the paper clarifies the knowledge gap regarding the management of restoration projects and identifies the key areas of concern and challenges for future research.

Keywords: *architectural heritage, conservation, project management, restoration projects.*

Introduction

Project management is a well-established professional discipline which has tools and processes that can be successfully implemented when understood; however, the situation is somewhat complicated when it comes to the management of restoration projects, because each restoration project has its own peculiarities and processes that are difficult to standardize, and most importantly, has considerable uncertainties due to the potential to contain very different techniques, materials and periods below the visible building layers (Perovic, 2015; LeBlanc, 2006; Prudon, 1986). Not all of these are easily foreseeable in the project initiation phase, and instant solutions are often required to respond to emerging situations. Moreover, restoration projects have various additional challenges regarding legislation and procedures, scope definition, tender and procurement, decision making, time and budget management, lack of information about the structure, and managing a large number of stakeholders with varying expectations. Accordingly, there is a need to question

the available project management methodologies, tools and techniques for the case of restoration projects to achieve better results in (Perovic, 2015). Although there are some sporadic studies at the intersection of “project management” and “building restoration” subjects which focus on the problems of building restoration projects, importance of project management methodologies, integration of Building Information Modeling (BIM) to these projects, or site management practices; to best of authors’ knowledge, no comprehensive study has yet investigated the management of building restoration projects in detail or proposed management model for these specific type of projects. A quick search of the academic publication databases also reveals that there is a significant knowledge gap regarding management of building restoration projects (Figure 1).

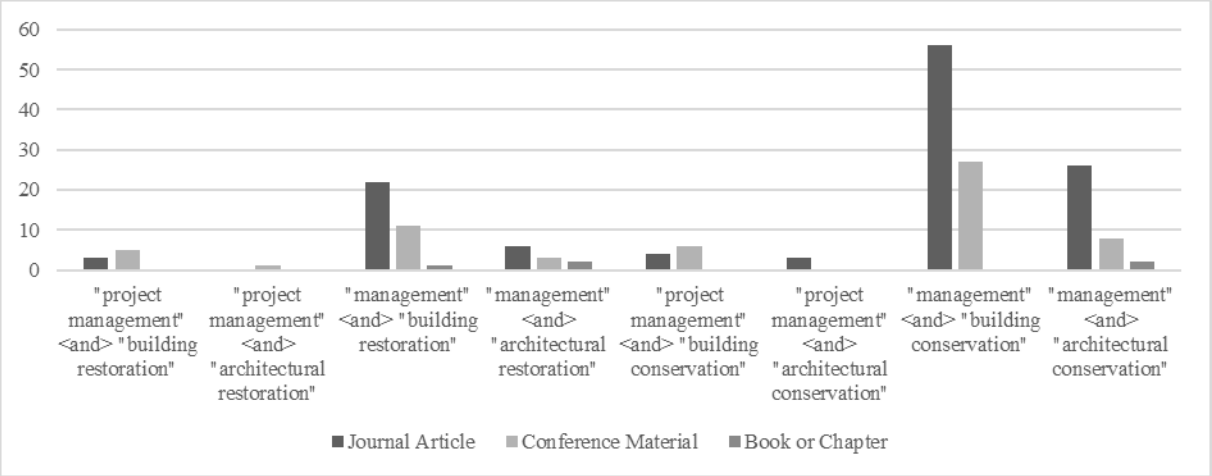


Figure 1: Search results from academic publication databases.
Sources: Scopus and Web of Science (as of June 2022)

As part of a broader research project which aims to develop a comprehensive project management model that considers the peculiarities of the building restoration projects, this paper clarifies the knowledge gap in the literature regarding the management of restoration projects and identifies the key areas of concern and challenges for future research. Following sections briefly review the literature on conservation and restoration and compare the typical new construction projects and restoration projects, before focusing on the relationship between restoration projects and project management body of knowledge.

Conservation and Restoration

There are various but parallel definitions of conservation made by different organizations (ICOMOS, 1964; UNESCO, 1972; Republic of Turkey Ministry of Culture, 1983; Australia ICOMOS Burra Charter, 2013) and researchers (Hasol, 1976; Duguay, 1992a; Earl, 2003; Burden, 2004; Ahunbay, 2007; Orbaşlı, 2008; Zakar & Eyüpgiller, 2018). Conservation can be defined in the shortest and most comprehensive way as all efforts designed to understand cultural heritage, know its history and meaning, ensure its material safeguard and as required, its presentation, restoration and enhancement (ICOMOS The Nara Document on Authenticity, 1994). It is often used with the prefix "architectural" when conservation relates to the built environment (Duguay, 1992a). The basic principles of conservation can be summarized as protecting as it is, minimum intervention, similar repair, reversible repair, distinguishable repair, self-respect and record keeping. Conservation includes physical intervention, when

necessary, where minimum is ideal, and relating strategies vary according to the degree of physical intervention (Table 1).

Table 1. Architectural conservation strategies (Duguay, 1992b).

<table>
<tr><td colspan="7">Most conservative ⟷ Most radical
Based on the amount of change to the existing state of the resource and the amount of conjecture required to make that change</td></tr>
<tr><td colspan="3">EXISTING BUILDING</td><td>RUIN</td><td colspan="2">NEW BUILDING</td></tr>
<tr><td>Unaltered</td><td colspan="2">Altered</td><td>Reassembly</td><td colspan="2">Copy</td></tr>
<tr><td>To retain as is</td><td>To return to a specific period in time</td><td colspan="2">To meet contemporary standards</td><td>To reassemble original components either in situ or on a new site</td><td>To reproduce a copy based on an existing building</td><td>To recreate a copy based on archaeological and historical evidence</td></tr>
<tr><td>1.
Preservation</td><td>2.
Restoration</td><td colspan="2">3.
Renovation
Sympathetic ⟷ Non-Sympathetic
Based on the amount of change to the integrity and appearance of the resource</td><td>4.
Reconstitution</td><td>5.
Replication</td><td>6.
Reconstruction</td></tr>
<tr><td></td><td></td><td>Retain both appearance and function

3.1
Rehabilitation</td><td>New function appearance may or may not change

3.2
Adaptive reuse</td><td>New appearance function may or may not change

3.3
Remodelling</td><td></td><td></td></tr>
</table>

In general, conservation can be summarized as all the processes that must be carried out in order for the building to survive without deteriorating and losing its importance, and it is essential that the conservation action is continuous. While restoration means a direct study of a piece, and even the replacement of that piece, any intervention is always under strict technical-scientific and historical-critical control (Carbonara, 2012). The main principle is to protect the originality of the building and building materials with evidence-based interventions. Since this paper approaches mainly the process based on physical interventions for architectural heritage structures, the main framework and terminology are set up as management of ‘restoration’ projects, instead of ‘conservation’ projects.

Challenges of Building Restoration Projects Compared to Typical New Construction Projects

Although there are a limited number of studies (most notables are Perovic, 2015; Duguay, 1992b; Prudon, 1986) that directly compare building restoration projects to typical new construction projects, a considerable number of studies deal with the peculiar characteristics and challenges of restoration projects in terms of practices and management. The most important aspects that stand out in the literature are as follows.

Planning and Research

Restoration projects require intensive historical and architectural research and analysis of existing conditions like survey, measurement, analytical survey, field and laboratory tests and material and structural analysis to gain an understanding of the building before the design begins, compared to a typical new construction project (Duguay, 1992b; Prudon, 1986). The planning phase is longer and more intense; moreover, the need for consultation is higher relative to new construction projects (Perovic, 2015). This phase includes the most fundamental and complex tasks for restoration projects. (Causevic et al., 2012). Searching for original drawings and records is probably one of the most important differences between a restoration practice and a new construction practice. (Prudon, 1986).

Scope Definition

Scope definition is the most difficult task for the restoration projects that are subject to uncertainty, as it is not always easy to determine the current state of the building in such projects, unlike typical new construction projects where the scope can be relatively more easily determined. (Perovic, 2015; Roy & Kalidindi, 2017). Although it is theoretically possible to reduce uncertainty by examining the building by taking samples from all materials, conducting field and laboratory tests, conducting a thorough field survey and making detailed application research; such efforts require time and budget. As a result, there is often a trade-off in this regard, and restoration projects often require decisions based on uncertainty in scope.

Stakeholders

Restoration projects have a greater number and types of stakeholders that are not typically found in new construction projects. (Perovic, 2015). According to ICOMOS Turkey Architectural Heritage Conservation Charter (2013), professionals from different disciplines specialized in the field of conservation, central and local governments, conservation boards, practitioners, property owners, universities, non-governmental organizations, the public, users, professional chambers and media organs are the main actors in the of architectural heritage. Restoration projects attract much more public, media and political attention than typical new construction projects (Roy & Kalidindi, 2017). Therefore, keeping the public's pulse right, establishing the right communication and interaction with the media and political stakeholders, and keeping open exchange of ideas with these stakeholders, when necessary, especially in buildings with monumental value, is critical for restoration projects. Ultimately, restoration projects are more likely to be successful when the decisions taken are adopted by all stakeholders (Perovic, 2015). Therefore, a consensus model should be developed with the contribution and participation of all stakeholders to manage their expectations correctly. In addition, the Conservation Boards, an external stakeholder that is not involved in new construction projects, play a decisive role in restoration projects. Conservation Boards are involved in the process at early stages such as design and even planning to determine and approve the acceptable level of intervention.

Risks

Due to the age, physical condition, qualities, and unfamiliarity with the construction techniques and materials of these structures, it is very difficult to evaluate from the beginning what will be encountered during the construction phase. Even when the research and analysis

are done in detail at the planning stage, there is always the possibility of encountering hidden layers and latent situations during the construction phase that cannot be foreseen at the beginning. In this respect, construction risks are quite high compared to new construction projects (Perovic, 2015).

Legislation

The laws, regulations and procedures to which restoration projects are more diverse and stricter than new construction projects. While customer requests are the focal point in new construction projects, the principles and procedures to be followed in restoration projects form the main basis (Perovic, 2015). This difference in legislation requires relatively longer and bureaucratic approval processes relative to new construction projects (Zolkafli et al., 2012). For a smooth and uninterrupted flow, the project process must be planned by considering these legal processes.

Freedom on Design

Unlike new construction projects, there is an understanding of taking care to preserve the existing architectural texture and to make changes in a minimum way in the restoration projects. There are severe restrictions on design freedom in restoration projects compared to typical new construction projects (Perovic, 2015).

Documentation

Although restoration projects are more demanding in terms of details, buildings that are subject of restoration are usually not fully documented, which makes it difficult to understand the relevant conditions (Prudon, 1986; Zolkafli et al., 2012; Roy & Kalidindi, 2017). The information about the building is usually in the archives and the archival information is either incomplete or does not reflect the latest situation; there is not always enough time and budget for the research, or the researcher's competence in restoration is weak; therefore, restoration projects often face the problem of managing unknown factors (Perovic, 2015). Every new finding that emerges has the possibility to pause the project and cause design and detail changes (Prudon, 1986). In addition to the need for historical documentation, restoration projects are also very demanding in terms of appropriate and adequate documentation of the intervention made. If qualified documentation cannot be produced during the planning and design phases, the frequency of returns that may slow down or even stop the work during the implementation phase is relatively higher than typical new construction projects.

Expertise and Original Materials

Some materials and production methods used in restoration projects, each involving unique situations, will be extinct, rare or unknown, and it will be difficult to work with stakeholders who are experienced in the relevant application and can meet the appropriate production quality as usually expert practitioners pool is quite narrow for restoration projects (Roy & Kalidindi, 2017; Harun, 2011; Prudon, 1986). The need for qualified people applies not only to the implementation but also to the stakeholders and team members who will participate in the project. The lack of skilled people is one of the most common problems of restoration projects (Hirsenberger et al., 2018; UNESCO, 1972). In addition, budgeting will be difficult in restoration projects compared to new construction projects, since there will be no data or similar building information to compare rare materials and techniques (Zolkafli et al., 2012).

Hidden Layers

Restoration projects have hidden layers, a feature that is almost never found in typical new construction projects (Perovic, 2015; Roy & Kalidindi, 2017; Lee et al., 2006). In other words, restoration projects have the potential to host very different techniques, materials and periods below the visible layers (Prudon, 1986). When a new hidden layer emerges, it is necessary to re-design, price, agree on methodology and intervention, and have it re-approved by the authorities. Therefore, considerable savings in time and cost can be achieved if these hidden layers can be identified before the application begins, although there is always a trade-off regarding this situation.

Scheduling

Due to the nature of the restoration work, one of the most obvious differences between a typical restoration project and a typical new building project is seen in the construction schedule. In general, restoration work is done piecemeal; that is, the work is not carried out completely, but only in the necessary parts of the building; meaning, location is determined, started, work completed, cleaned and moved to the next location. As a result, the restoration process will be more labor-intensive and time-consuming than the new construction (Prudon, 1986).

Project Success

Although there is no unique set of success criteria that clearly differentiates restoration projects from new construction projects in the literature, according to Shenhar and Dvir (2007), two criteria are appropriate for measuring the success of restoration projects: *project efficiency*, in terms of meeting planned targets according to time, budget, quality and scope, and the *impact on the client*, which can be measured by meeting major stakeholders' expectations, prolonging the useful life and recognition. In addition to these, preserving the aesthetic quality, identity, historical/social importance and universal heritage value of the buildings are often considered as success criteria (Mason, 2005; Provins et al., 2008; Roders & Oers, 2011).

Project Lifecycle

According to ICOMOS Turkey Architectural Heritage Conservation Charter (2013), conservation of an architectural heritage consists of documentation, research, analysis, interpretation, identification and determination of the conservation approach, definition of intervention, implementation and monitoring respectively. Considering that each cultural property has its peculiar characteristics, problems and potentials; studies aimed at examining, documenting and evaluating this heritage and defining conservation interventions should be specific to that structure and must comply with universal principles. Although there are some minor differences in practice of different countries, the restoration life cycle generally follows a similar pattern across countries (RIBA Plan of Work, 2020; ICOMOS Turkey Architectural Heritage Conservation Charter, 2013; Carbonara, 2012; Harun, 2011; Duguay, 1992b). While the basic structure remains the same when comparing a typical new construction project life cycle to that of a typical restoration project, particular attention should be paid to the preliminary assessment and research phases of restoration projects, as these phases differ significantly from the inception and feasibility phases of a new construction. In the restoration, much more research and analysis of existing conditions such as bibliographic and

archival research, a comprehensive survey, historical study based on direct analysis of the monument, material and structural analyses to determine the deterioration of the building in order to determine the appropriate intervention method and etc. must be done before the design begins. (Carbonara, 2012; Harun, 2011). During the implementation (design and construction) phases, these two project life-cycles are almost the same except for some minor differences from the project management lens, but the role of the architect is usually greater during the restoration (Duguay, 1992b). More attention should be paid to the initial phases of the conservation projects, which are highly interdisciplinary in nature and an area in which a wide variety of professionals from different fields participate (Cassar et al., 2001).

Building Restoration Projects and Project Management

Architectural conservation and restoration projects are particularly problematic in complying with time and cost constraints (Perovic, 2015). Major support for this proposition is the observation made by Reyers and Mansfield (2001) that conservation projects are more prone to go over-budget (62%) than new construction projects, and any conservation project over £10,000 is most likely will need a time extension based on RIBA reports. In addition, these projects contain more technical and economic risks compared to new construction projects (Dann & Cantell, 2007) and have a high number of varied challenging components which do not exist in typical new construction projects (Perovic, 2015). Looking at the bylaws and guides followed on restoration projects in the world (*such as charters of ICOMOS and UNESCO; the Venice Charter; Carta del Restauro; The Burra Charter; Conservation Principles, Policies and Guidance of English Heritage; BS7913:2013: Guide to the Conservation of Historic Buildings; RIBA Plan of Work; U.S. Department of The Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring and Reconstructing Historic Buildings; Federal Heritage Buildings Review Office's Standards and Guidelines for the Conservation of Historic Places in Canada; Central Public Works Department of India's Handbook of Conservation of Heritage Buildings; Law No. 2863 on the Protection of Cultural and Natural Assets of Turkey; Resolution 660 of the Supreme Council of Monuments of Turkey, etc.*); while they define the basic principles and procedures of restoration projects, none of them relies on a comprehensive project management knowledge and not recommend any project management method specific to restoration projects. Despite the development of various principles, policies and guidelines, there are still many problems affecting the management of restoration projects underpinning the need to research and adapt project management tools and techniques specifically to conservation and restoration projects for better performance (Perovic, 2015; Harun, 2011).

There are many project management frameworks and tools that have been transferred to the construction industry to carry out projects for various types of structures. Some of them are: PRINCE 2 (is widely used in projects of various scales that are publicly funded by the UK government and has also been adopted by Australia), CIOB's Code of Practice for Project Management for Construction and Development (is a guide to construction project management principles and practices, regardless of project size, nature or complexity), RIBA's Outline Plan of Work (provides a model framework for project management in the UK construction industry) and PMI's Project Management Body of Knowledge (is an internationally and widely recognized guide to project management, with an appendix specific to construction projects). None of them are yet extensively adopted by industry to apply in restoration projects. Considering its widespread and valid use, comprehensive and systematic

definition, having advanced tools and techniques, and the potential to be applied in projects with high uncertainty such as restoration projects, it was deemed appropriate to examine the management of restoration projects through the PMI's project management knowledge areas lens in this study when identifying key areas of concern.

Key Areas of Concern When Managing Building Restoration Projects

Architectural heritage buildings are mostly unique in the techniques and materials used and reflect the time in which they were built. One common challenging aspect of these projects is that they face uncertainties resulting in many and major changes that cause these projects to exceed time and budget during the implementation phase (Perovic, 2015). One of the main reasons for this is that project tasks cannot be pre-determined accurately in terms of specification, scope, time and cost (Reyers & Mansfield, 2001), although inadequate or incorrect scope definition is one of the leading causes of project failure and can lead to numerous causal relationships that can arise problems during the project (Dumont et al., 1997). In addition, while managing a project within the scope is difficult in most construction projects, this situation is even more difficult for restoration projects that involve higher levels of uncertainty over their life cycle (Zwikael & Smyrk, 2011). When the restoration life cycle is examined; a poor project brief will lead to problematic scope definition and possibly problematic design; a problematic design will lead to un-coordination with other disciplines, and this will create insufficient or wrong information about the structure. Insufficient or wrong information will lead to unnecessary amount of site queries, as a result, the desired project objectives will not be achieved, which means that lack of foresight in the scope definition in the early stages will complicate the next steps (RIBA Plan of Work, 2020). That is, ***scope management*** is the first key area of concern identified in terms of the management of restoration projects.

The importance of stakeholders for the planning, development and execution of successful projects has been acknowledged by many researchers (Frooman, 2010; Bourne & Walker, 2005; Newcombe, 2003; Freeman & McVea, 2001). As mentioned earlier, restoration projects have a greater number of stakeholders than typical new building projects and a variety of stakeholders that are not usually present in typical new building projects, such as the public, media, political parties and conservation boards. Managing the conflicting expectations of all these stakeholders is a critical challenge to address, and there is no contractual relationship with most stakeholders in general. When stakeholders are the main source of uncertainty in projects (Ward & Chapman, 2008), it is very difficult to predict, manage and respond to a wide variety of opinions and demands. Especially when the large number of stakeholders are involved in the process with conflicting expectations, goals and needs of these stakeholders add to the uncertainty and complexity of the restoration project life cycle, which result in deviations from the project goals (Alallafa & Torreb, 2010). Therefore, a proper stakeholder management strategy will help to clarify who the key stakeholders are, determine how they will be managed, manage the flow of information, and determine how to manage constraints or risks (RIBA Plan of Work, 2020). That is, another key area of concern in terms of the management of restoration projects has been identified as ***stakeholder management***.

Many of the relevant stakeholders lack sufficient knowledge and skills on conservation and restoration issues, especially in terms of materials, methods and processes (Perovic, 2015; Prudon, 1986; UNESCO, 1972). Proper communication and documentation are highly important for any type of project especially for projects involving stakeholders with

conflicting skills and perspectives. This need becomes even more important in large and complex activities where key decisions need to be made collectively; when different actors are engaged in different aspects of the project independently; critical errors that are often not noticed until it's too late and repetitive discussions are made to resolve the same problems repeatedly (Alallafa & Torreb, 2010). When documentation and communication systems are not detailed enough, information requests become an almost daily procedure and take up a significant amount of the project's time (Perovic, 2015). Consequently, these problems lead to time and budget overruns. In addition, agile project environments that are subject to various uncertainties and changes, such as restoration projects, require the frequent and quick communication of evolving and emerging details. This can be achieved by facilitating team members' access to information, frequent team checkpoints and bringing team members together as much as possible, and by publishing project documents transparently, conducting regular stakeholder reviews and encouraging stakeholder communication (Project Management Institute, 2017). Proper documentation of principles and activities is also a fundamental requirement for restoration projects (Hajialikhani, 2010). Accordingly, ***communications management*** based on innovative information and communication tools and methods is amongst the key areas of concern for restoration projects.

Another challenge arising from the inadequate knowledge and skills of stakeholders especially in terms of materials, methods and processes is the quality assurance in restoration projects. Some materials and production methods used in restoration projects, each of which contains unique problems, will be lost or not known enough, and it will sometimes not be possible to work with stakeholders who are experienced in the relevant application and can meet the appropriate production quality (Perovic, 2015). Likewise, this lack of necessary skills and knowledge is addressed in the Australian Environment Committee's 2016 report as the continued decline in the availability of specialist practitioners, the lack of training opportunities and the growing lack of skills are putting enormous pressures on the conservation of architectural heritage. For these reasons, ***quality management*** is identified as one of the key areas of concern for restoration projects, as it is one of the important challenges to meet the project targets defined by international organizations such as ICOMOS and local legislations.

As mentioned before, it is very difficult and challenging to evaluate what will be encountered during the construction phase due to the age, physical condition, qualities and familiarity of the construction techniques and materials of the buildings subject to restoration. Although research and surveying could be carried out extensively in the planning phase, there is always a possibility of latent situations to arise due to the building's condition. In this respect, construction risks are quite higher in restoration projects compared to new construction projects (Perovic, 2015). That’s why, another key area of concern in terms of the management of restoration projects has been identified as ***risk management.***

Although the above-mentioned areas of concern have utmost importance in terms of the management of restoration projects, other challenges related to project management knowledge areas should not be ignored including ***integration management*** in coordinating actions and changes to be carried out as a result of new findings; ***cost management*** to keep the project within budget targets; ***time management*** to minimize deviation from time targets; ***resource management*** in making it possible to work with the right people with sufficient knowledge and skills in restoration which plays a critical role in restoration projects that require advanced expertise not only in contractors but also in subcontractors; ***supply management*** in ensuring the trouble-free supply of disappeared, rare or unknown materials

and their equipment and workforce that will be required for restoration; ***health, safety and environmental management*** considering the fact that the buildings subject to restoration are generally old and sometimes contain physical risks and their effects on the environment are taken into account; and ***financial management*** since the majority of restoration projects are subject to large budgets and large cash flows (Perovic, 2015; Hajialikhani, 2010; Prudon, 1986).

Conclusion

Peculiarities of the building restoration projects such as the need for research-based practices to define scope, planning, scheduling, design, supervision, decision-making, material use, construction methods, latent conditions, stakeholders, information flow, the legal environment, etc. significantly complicate the project management efforts and raises the need to treat them with an unconventional approach. Although some guidelines, standards and by-laws that define the fundamental principles and procedures of building restoration projects are available, additional research is needed to exploit the opportunities of project management discipline through its well-established processes, tools and techniques. A contemporary perspective which uses project management tools and techniques can contribute to the conservation of architectural heritage in line with the universal conservation principles. Collaboration with professionals who have practical experience in the field is essential to address the peculiar requirements of the restoration field. The project management body of knowledge should be specifically examined for the case of building restoration projects and the possibility of adapting specialized methods should be explored to propose a management model that considers the peculiarities of such projects.

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Lean Construction and Simulation: A Case Study of Dry Batch Delivery and Concrete Placement Operations

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Abstract

Construction projects involve complex processes by nature with many uncertainties. Despite these uncertainties, many construction processes are repetitive. Identifying and modelling repetitive processes leads to efficient use of all kinds of repetitive materials, manpower, and machinery in construction. Lean thinking focuses on examining processes with the objectives of improving resource flow to minimize waste and increase efficiency. Repetitive construction processes can be efficiently modelled, analysed, and planned from a practical point of view using simulation, a tool that supports lean thinking. It is important to encourage the use of Simulation in the construction industry, which is one of the most traditional and change-resistant industries. The development of the CYCLONE modelling elements by Halpin, a pioneer in the use of simulation in construction processes, increased the interest in simulation and many simulation tools were developed. Simulation systems provide a quantitative way to observe, plan, analyse and control construction processes and operations, thereby significantly reducing complexity in construction processes, increasing efficiency, and balancing resources. Therefore, in this research, a comprehensive literature review on lean construction and simulation was conducted and repetitive work operation on a surveyed construction site was simulated using the EZStrobe modelling system which is based on STROBOSCOPE software.

Keywords: *EZStrobe, lean construction, simulation, STROBOSCOPE.*

Introduction

The lean approach aims to minimize waste, simplify the process, and increase value and efficiency (Mao & Zhang, 2008). The basis of this approach is to be clear, simple, and plain. With the implementation of the lean approach, activities that do not add value are identified and these are reduced, resources are used efficiently, more output is obtained with less effort, and the customer receives the best quality service at the most affordable price. This reduces production cycle time and cost, improves processes, and increases quality, value, and efficiency. The application of the lean approach in the manufacturing sector has resulted in success. This success has encouraged other sectors, including the construction sector, to adopt this approach (Koskela, 2000; Koskela et al., 2002; Abbasian-Hosseini et al., 2014; Bajjou et al., 2017).

Lean construction aims for excellence by maximizing value and efficiency and minimizing waste (Bajjou & Chafi, 2020). The application of lean principles in construction processes is effective in increasing performance. However, there is no practical guide for the application of these principles in the construction industry. The success achieved in lean applications in the manufacturing sector may not be achieved in the construction sector because of the uniqueness of the construction processes. Before these principles are applied in construction processes, they should be tested and their performance measured (Mao & Zhang, 2008). A simulation is an appropriate tool that makes this possible (Halpin & Kueckmann, 2002). Construction processes consist of repetitive processes (Alkoc & Erbatur, 1997). These processes can be efficiently modelled, analysed, and evaluated through simulation before they are applied in the real world (Abbasian-Hosseini et al., 2014). Thus, resources such as material, manpower, and construction equipment are used efficiently, potential problems are determined in advance and precautions are taken before they encounter them in the field, trial and error costs are eliminated, and productivity increases. Many researchers state that the use of simulation is an excellent complement to the application of the lean approach to construction processes (Goienetxea Uriarte et al., 2020). Halpin and Kueckmann (2002) state that simulation is a part of lean construction. Improving the flow and reducing waste are principles of lean thinking, and simulation uses these principles to increase productivity and gain performance (Pollesch et al., 2017).

Complex processes are difficult to analyse using standard mathematical methods, but the simulation tool can be used in all construction processes ranging from very simple to complex (Martinez, 1996). Halpin developed the Cyclic Operations Network (CYCLONE) simulation tool in the 1970s to encourage the use of simulation in construction processes (Halpin & Kueckmann, 2002). CYCLONE is an easy-to-learn, effective and simple system that is widely used in simple construction processes (Martinez & Ioannou, 1999). Inspired by CYCLONE simulation, advanced simulation software used in complex construction processes such as STROBOSCOPE or many construction simulation tools used in simple processes such as EZStrobe have been developed (Wang & Halpin, 2004; Bajjou & Chafi, 2020).

This study aims to simulate a repetitive construction operation at a construction site and evaluate the outputs by focusing on the relationship between lean construction and simulation. The construction operation chosen for this purpose is "dry batch delivery and concrete placement operations". To simulate this process, the EZStrobe simulation tool which is based on STROBOSCOPE software, and is capable of modelling moderately complex processes, is used instead of advanced simulation tools.

Lean

The term “lean” was coined to reflect the nature of the Toyota manufacturing system to reduce waste and increase productivity (Womack et al., 2007; Aziz & Hafez, 2013). Lean concepts have emerged with inspiration from the early work of Deming, Juran, Crosby, Feigenbaum, Ishikawa, and other researchers focusing on quality in the manufacturing industry. The Total Quality Management (TQM) approach ensures that waste of resources is prevented by increasing quality, better products and services are obtained by improving the process, costs are reduced, a more competitive position is achieved, and employees are happier and more productive (Deming, 2014). Although the Lean concept is inspired by TQM objectives such as avoiding waste that does not add value, continuous improvement, communication, and coordination among stakeholders (Aziz & Hafez, 2013), Lean manufacturing originates from

the Toyota production system (TPS), which focuses on production based on customer satisfaction (Bajjou & Chafi, 2020). Thus, lean manufacturing became a universal term beyond the manufacturing industry, suppressing the principles of Taylorism, Fordism, and Post-Fordism that dominated the manufacturing industry, respectively (Aziz & Hafez, 2013; Bajjou & Chafi, 2020). Lean manufacturing, which replaces the traditional manufacturing process, encompasses many ideas based on TPS, such as continuous improvement, elimination of waste, team coordination, efficient use of resources, and improvement of quality and safety (Agha et al., 2010). Lean manufacturing uses half of the generally required resources such as materials, labour, and equipment (Gao & Low, 2014; Bajjou & Chafi, 2020).

The lean approach is not a set of rules or tools, it covers the entire process and is a shared system of thought and behavior throughout the value stream (Diekmann et al., 2004; Bajjou & Chafi, 2020). The starting point of lean thinking is that Womack and Jones published "Lean Thinking" in their book "The Machine That Changed the World" to answer the question asked about how lean manufacturing methods are applied (Halpin & Kueckmann, 2002). Lean is a management philosophy behind lean production that aims at maximizing the value offered to the customer, minimizing waste, and excellence (Ohno, 1988; Womack & Jones, 1997). Womack and Jones (1997) present five principles for embracing lean thinking; value, value stream, continuous flow, pull, and excellence. The starting point of lean thinking is value and value must be defined correctly. Even if the producer creates the value, the customer determines the value, so the satisfaction of internal and external customers is important (Ohno, 1988). With the value stream, activities that do not add value are identified and waste is prevented. By providing a continuous flow of value-creating actions, activities that cause unnecessary waste are eliminated. The pull principle allows the customer to pull the product they need instead of pushing the undesired product to the customer. Excellence symbolizes the ideal situation that can never be reached in practice, and zero error is aimed at continuous improvement (Ohno, 1988; Womack & Jones, 1997). The most important principle of lean thinking is to identify and eliminate all kinds of waste in the process. There are three Japanese concepts to express waste in the terminology of TPS: muda, mura, muri (Ohno, 1988). Muda is waste that does not create value but wastes resources. Mura is waste that expresses irregularities such as unbalanced loading of resources. Muri is waste caused by unreasonable overloads (Womack & Jones, 1997). Waste is activities that do not create value but consume resources or the results of these activities. There are eight types of waste; unnecessary transportation, excess stock, unnecessary movement, unnecessary waiting, overproduction, over processing, errors and fixes, and unused capabilities (Ohno, 1988; Liker, 2004; Bajjou et al., 2017).

Lean Construction

The success of the lean manufacturing system in manufacturing has led to the spread of the lean approach to new areas such as customized manufacturing, services, management, and product development. This approach has also been applied in the construction industry since 1992 in order to reduce waste and increase efficiency (Koskela, 2000; Aziz & Hafez, 2013; Bajjou et al., 2017). Lean construction ensures minimizing waste, improving processes, increasing efficiency, listening to the voice of the customer, providing a full understanding of the customer, and coordination among stakeholders. Lean construction is a way of designing systems that will minimize any waste to maximize value (Koskela et al., 2002; Aziz & Hafez, 2013).

Lean construction has changed the traditional transformation perspective and embraced the concept of flow and value creation (Aziz & Hafez, 2013). Construction has traditionally been managed from a transformation perspective (Koskela, 2000). Halpin and Kueckmann (2002) liken the transform to a "black box" with inputs on one side and desired output on the other. In this black box are the construction processes. In the transformation perspective, the value of the output and the cost of the overall process depends only on the value and cost of the inputs (Halpin & Kueckmann, 2002; Abdel-Razek et el., 2007). The concepts of value creation and flow are largely ignored as attention is directed to inputs (Bajjou & Chafi, 2020). This trend leads to a mismatch of processes, loss of value, inefficiency, and massive waste (Koskela, 1992; Koskela, 2000; Halpin & Kueckmann, 2002; Abdel-Razek et el., 2007). The smooth running of the process impacts the productivity of high quality and value. The lean perspective focuses on processes to completely rebuild or create new processes (Halpin & Kueckmann, 2002). Lean construction emphasizes the consideration of flow and value, not just transformational steps, in the design of construction processes (Aziz & Hafez, 2013; Bajjou & Chafi, 2020). Therefore, it is important to adopt the concept of lean construction in the construction industry to reduce waste, cycle time, and variability and increase efficiency and value (Aziz & Hafez, 2013).

Simulation and Lean Construction

Simulation is defined as the construction of a mathematical and logical model of a real-world system or process in a virtual world (Goienetxea Uriarte et al., 2020). Simulation is an efficient method that improves planning in construction projects (Sacks et al., 2007). Many researchers have benefited from simulation in construction processes. For example, Balbontin-Bravo (1998), used simulation in the manufacture of precast elements to increase efficiency, reduce costs, and obtain various working alternatives and achieved great cost savings in many operations through simulation. Simulation for studying construction operations was first proposed and developed by Halpin (Wang & Halpin, 2004). Halpin developed the Cyclic Operations Network (CYCLONE), one of the first simulation tools to simplify the simulation modelling process for modelling construction operations, and then, a computer program called MICRO-CYCLONE based on CYCLONE modelling elements (Wang & Halpin, 2004). This simulation tool has been used in many studies, as an example is, Alkoc and Erbatur (1997), used MicroCYCLONE simulation software for the design and optimization of the pouring process and concrete delivery to increase the productivity of the concreting operations. Thus, inspired by the benefits of simulation, many construction simulation programs have been developed based on CYCLONE modelling elements such as STROBOSCOPE, SIMPHONY, and ARENA (Wang & Halpin, 2004; Bajjou & Chafi, 2020).

Halpin and Kueckmann (2002) state that lean thinking and simulation are linked. Lean thinking provides a format that improves processes, simulation provides a methodology that evaluates processes (Halpin & Kueckmann, 2002). In a controllable environment, processes can be efficiently modelled, analysed, and improved using simulation, without the waste of trial and error in the real world (Halpin & Kueckmann, 2002; Wang & Halpin, 2004; Abbasian-Hosseini et al., 2014). Simulation of construction operations enables analysis of all construction processes, from very simple to complex, in an experimental environment that does not require many data entries (Martinez, 1996; Halpin & Martinez, 1999; Abbasian-Hosseini et al., 2014). Simulation created with the information of the process provides an inexpensive, fast and effective method to evaluate more than one alternative action and choose the best course of action and produces outputs such as cycle time, daily throughput, productivity, resource and crew utilization (Halpin & Kueckmann, 2002; Sacks et al., 2007; Bajjou & Chafi, 2020). Thus,

time and cost savings are achieved, productivity is increased, non-value-adding activities are identified, and lean construction waste can be measured and avoided (Balbontin-Bravo, 1998; Halpin & Kueckmann, 2002; Wang & Halpin, 2004). With these benefits of simulation, lean construction concepts can be tested and validated before being implemented in the field (Halpin & Kueckmann, 2002; Abbasian-Hosseini et al., 2014).

Previous researches show simulation as a useful tool for modelling and analysing the applicability of lean construction principles in construction processes (Tommelein, 1998; Halpin & Kueckmann, 2002; Sacks et al., 2007; Mao & Zhang, 2008; Wang et al., 2009; Abbasian-Hosseini et al., 2014; Bajjou & Chafi, 2020). Tommelein (1998), evaluates the pipe-spool installation process using STROBOSCOPE simulation software to compare push-driven and pull-driven processes, and states that the simulation improves the performance of the pull technique in material delivery. Halpin and Kueckmann (2002) used simulation as a tool to evaluate the benefit of using lean construction techniques for the wall erection and concrete forming construction processes and noted that the relationship between lean construction and simulation provides operational gains such as increased productivity, reduced the idle times of the crews, and reduced overall cycle time. Sacks et al. (2007), evaluated the benefits of the lean approach by using the simulation technique for the execution of fine works in high-rise apartment buildings with personalized apartment designs and stated that using STROBOSCOPE simulation increased efficiency, improved cash flow, and reduced apartment delivery cycle time. Mao and Zhang (2008) developed a construction process reengineering framework that integrates lean principles and computer simulation techniques, and with a case study of the tunnel project, they indicated that this framework can be applied in construction processes for improved productivity, efficiency, and cost-effectiveness. Wang et al. (2009), used simulation to apply lean production principles and flow production to shop fabrication and demonstrate that the simulation-based lean approach improves the performance of a spool fabrication system. Abbasian-Hosseini et al. (2014), discovered the potential impact of lean construction using simulation in the bricklaying process. This discovery revealed a 27% increase in operational efficiency, a more than 40% increase in productivity, and a 41% decrease in cycle time. Bajjou and Chafi (2020), evaluated the impact of lean construction principles on the performance of reinforcement operations using a discrete-event simulation approach and stated that this approach was effective in increasing its performance by presenting a 41% improvement in process productivity, 14% enhancement in process efficiency and 17% reduction in cycle time in performance measurements.

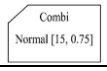
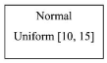
STROBOSCOPE and EZStrobe

STROBOSCOPE is a programming language designed for the simulation of construction processes (Martinez & Ioannou, 1999). General-purpose simulation systems cannot easily model the multi-source requirements and dynamic complexity of construction processes. The STROBOSCOPE simulation software makes these models possible (Martinez, 1996). Martinez and Ioannou (1999) describe the STROBOSCOPE as "a programmable and extensible simulation system designed to model complex construction operations in detail and develop special-purpose simulation tools". STROBOSCOPE is an acronym for "STate and ResOurce Based Simulation of COnstruction ProcEsses" (Martinez, 1996). Stroboscope is an efficient and effective simulation system (Martinez & Ioannou, 1994). The STROBOSCOPE dynamically accesses the properties of sources and with this access, is sensitive to properties of sources such as size, weight, and cost. Besides, this software can dynamically choose the routing of resources and the order of operations (Martinez, 1996). STROBOSCOPE is designed for advanced

modelling tasks. Therefore, the simpler and easier to learn EZStrobe was developed to model easy to moderately complex problems (Martinez, 2001).

EZStrobe is based on extended and annotated Activity Cycle Diagrams (ACD) (Martinez, 2001). This simulation tool is powerful, easy to learn and use, and does not require direct knowledge or use of STROBOSCOPE. EZStrobe is a discrete-event simulation system with capabilities such as drag-and-drop model building, visual network-based logic, and ACD network animation. EZStrobe shows the movement of resources and interaction with activities with ACD network animation and uses simple modelling elements such as the Queue, Combi, Normal, Fork, and Link to illustrate this animation. (Ioannou, 2020). Table 1 shows the basic EZStrobe modelling elements (Martinez, 2001).

Table 1. The basic EZStrobe modelling elements.

Elements	Function	Parameter	Description
Queue	holds idle resource until used	Queue name number of resources	
Combi	constrained activity, starts when required resources are available	Combi name probability distribution density function	
Normal	not constrained activity starts when a previous activity is completed	Normal name probability distribution density function	
Fork	probabilistic element to randomly select the path to follow		
Link	Connects different activities and queues	condition necessary for the successors activity start, number of resources to be consumed	

Methodology

Aim. This research aims to simulate a repetitive construction operation at a construction site and evaluate the outputs, using simulation as a tool for applying lean construction principles to construction processes.

Scope. In this research, the dry batch delivery and concrete placement construction operation of a completed construction project was examined.

Method. The method of this study is to evaluate the simulation outputs by comparing them with real-world data. Data is collected from field workers and to simulate this process, the EZStrobe simulation tool based on STROBOSCOPE software is used.

Project description. The project is the construction of a facility where the modernization training of military aircraft in the fleet of a country of great strategic importance in the Middle East will be given. Within the scope of the project, the facilities including the mosque, cafeteria, training classes, water tank, apron, and hangars, with a closed area of approximately 40,000 m2, including sports and technical training areas, were completed and put into use between 2015 and 2017 with a cost of approximately 150 million USD.

Description of dry batch delivery and concrete placement operation. In the works completed within the scope of the facility, 2,200 tons of reinforcement, 38,500 m^3 of structural concrete, 30,000 m2 of apron taxiway works, approximately 3,000 m of clean water line, 9,000 m of facade panel works are within the scope of some works completed within the scope of the project.

For the concrete works within the scope of the project, it is aimed to complete the works within the scope by establishing a concrete batching plant at a distance of approximately 7 km from the project site. In this context, although the situation that the construction site has sufficient space for the concrete plant installation was not included at the beginning of the project, it will also be examined from this perspective in the simulation study.

Model development. The activities and cycles in the model simulated in Figure 1 are as follows;

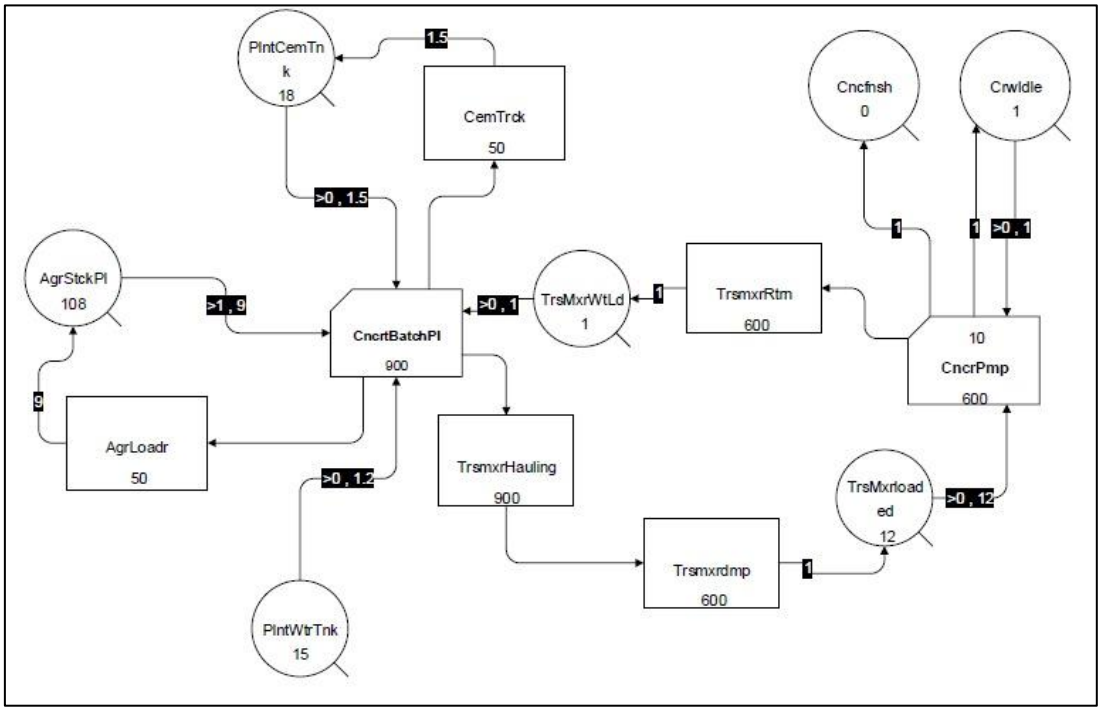


Figure 1: Activity cycle diagram for dry batch and delivery placement.

The batch plant area will be set up on land 7 km away from the project site. The batch plant is set up as shown in Figure 2. Concrete mix materials that form aggregates are transported to the factory site and delivered are stocked in factory site stockpiles. During the concrete mix producing materials, are loaded to the plant with a wheel loader. The batch plant has a cement tank and water tank system that is integrated with the batch plant. Cement and water are stocked in the tank as per their use. The water tank is used for the project's other parts. The cement trailer is organized as per demand and stocked remained amount on the cement tank. A weighbridge is installed in the batch plant area for controlling and checking delivered materials and the aggregate stockyard is controlled using survey equipment.

The trans-mixer is loaded at the plant and goes to the concrete site until the concrete pump arrives. The trans-mixer discharges the concrete mix into the concrete pump until it is completely empty, and then returns for reloading. The discharged concrete is evenly distributed on the floor by the concrete pump, and then the spreading process begins. The trans-mixer is

loaded at the plant and goes to the concrete site until the concrete pump arrives. The trans-mixer discharges the concrete mix into the concrete pump until it is completely empty, and then returns for reloading. The discharged concrete is evenly distributed on the floor by the concrete pump, and then the spreading process begins. After the concrete placement, the finishing process begins. The Queue element controls the termination of the model. For this particular model, the total concrete quantity installed during a 1.5-h work period was 72 m^3.

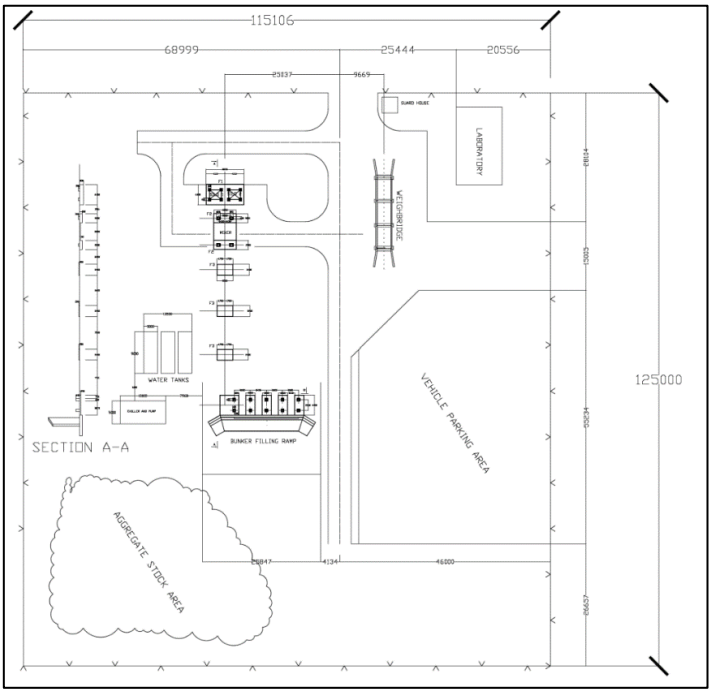


Figure 2: The plan of this dry batch and delivery placement.

Results

As shown in Table 2, two different simulations were performed. The first simulation was carried about with the option concrete batch plant has been constructed 7 km away from the construction site. Another simulation was carried out with the option concrete batch plant has been constructed in the construction area, which is the same as the project area and that will be the same until project completion. The simulation results are shown in Figures 4 and 5. After that, simulation results were compared with each other.

Table 2. Parameters of two different simulations.

Parameters	First Simulation	Second Simulation
Mixers Number	4	3
Load Mixer	15 min / 12 m^3	15 min / 12 m^3
Loaded Trans-mixer Time	15 min	5 min
Empty Trans-mixer Time	10 min	3 min
Trans-mixer Discharge to Pump	10 min	10 min

```
** Model input parameters **

Overhead Cost ($/hr): 300
Crew Cost ($/hr)    : 700
Number of Truck     : 4

Statistics report at simulation time 10200


Queue          Res              Cur       Tot  AvWait    AvCont    SDCont MinCont   MaxCont
=============================================================================================
AgrStckPl      ezs           108.00    162.00 6483.33    102.97      4.47   99.00    108.00
Cncfnsh        ezs             6.00      6.00 4800.00      2.82      1.62    0.00      6.00
CrwIdle        ezs             1.00      7.00  942.86      0.65      0.48    0.00      1.00
PlntCemTnk     ezs            18.00     27.00 6483.33     17.16      0.74   16.50     18.00
PlntWtrTnk     ezs             7.80     15.00 7320.00     10.76      1.98    7.80     15.00
TrsMxrWtLd     ezs             0.00      6.00    0.00      0.00      0.00    0.00      1.00
TrsMxrloaded   ezs             0.00     17.00    0.00      0.00      0.00    0.00     12.00


Activity        Cur     Tot     1stSt     LstSt   AvDur  SDDur   MinD    MaxD   AvInt  SDInt    MinI    MaxI
=============================================================================================================
AgrLoadr          0       6    900.00   9300.00   50.00   0.00  50.00   50.00 1680.00 657.27 1200.00 2400.00
CemTrck           0       6    900.00   9300.00   50.00   0.00  50.00   50.00 1680.00 657.27 1200.00 2400.00
CncrPmp           0       6      0.00   9600.00  600.00   0.00 600.00  600.00 1920.00 657.27 1200.00 2400.00
CncrtBatchPl      0       6      0.00   8400.00  900.00   0.00 900.00  900.00 1680.00 657.27 1200.00 2400.00
TrsmxrHauling     0       6    900.00   9300.00  900.00   0.00 900.00  900.00 1680.00 657.27 1200.00 2400.00
TrsmxrRtrn        1       6    600.00  10200.00  600.00   0.00 600.00  600.00 1920.00 657.27 1200.00 2400.00
Trsmxrdmp         1       6   1800.00  10200.00  600.00   0.00 600.00  600.00 1680.00 657.27 1200.00 2400.00
```

Figure 3: First simulation results.

```
** Model input parameters **

Overhead Cost ($/hr): 300
Crew Cost ($/hr)    : 500
Number of Truck     : 3

Statistics report at simulation time 10140


Queue          Res              Cur       Tot  AvWait    AvCont    SDCont MinCont   MaxCont
=============================================================================================
AgrStckPl      ezs           108.00    180.00 5704.00    101.25      5.11   90.00    108.00
Cncfnsh        ezs             8.00      8.00 4770.00      3.76      2.25    0.00      8.00
CrwIdle        ezs             1.00      9.00  593.33      0.53      0.50    0.00      1.00
PlntCemTnk     ezs            18.00     30.00 5704.00     16.88      0.85   15.00     18.00
PlntWtrTnk     ezs             5.40     15.00 6376.80      9.43      2.71    5.40     15.00
TrsMxrWtLd     ezs             0.00      8.00    0.00      0.00      0.00    0.00      1.00
TrsMxrloaded   ezs             0.00     19.00    0.00      0.00      0.00    0.00     12.00


Activity        Cur     Tot     1stSt     LstSt   AvDur  SDDur   MinD    MaxD   AvInt  SDInt    MinI    MaxI
=============================================================================================================
AgrLoadr          0       8    900.00   9420.00   50.00   0.00  50.00   50.00 1217.14 545.21  780.00 1800.00
CemTrck           0       8    900.00   9420.00   50.00   0.00  50.00   50.00 1217.14 545.21  780.00 1800.00
CncrPmp           0       8      0.00   9540.00  600.00   0.00 600.00  600.00 1362.86 545.21  780.00 1800.00
CncrtBatchPl      0       8      0.00   8520.00  900.00   0.00 900.00  900.00 1217.14 545.21  780.00 1800.00
TrsmxrHauling     0       8    900.00   9420.00  300.00   0.00 300.00  300.00 1217.14 545.21  780.00 1800.00
TrsmxrRtrn        1       8    600.00  10140.00  180.00   0.00 180.00  180.00 1362.86 545.21  780.00 1800.00
Trsmxrdmp         1       8   1200.00   9720.00  600.00   0.00 600.00  600.00 1217.14 545.21  780.00 1800.00


TmWgtCollector    TtlTime    CurVal      Mean        SD       Min       Max
=============================================================================
QueNameStats     10140.00      0.00      0.00      0.00      0.00      1.00
```

Figure 4: Second simulation results.

Discussion

In this research, simulation was used as a tool to present the application of lean construction principles in construction work processes. For this purpose, a work operation of a completed construction project was simulated in two different ways. Two different simulations were carried out by using different parameters for changing the place of the batch plant, the distance between the construction site and the concrete batch plant area, and reducing the transmixer number. The first simulation has been run with the option, that is concrete batch plant is operating 7 km away from the construction site. In this way, the simulation time was calculated as 170 minutes. The second simulation has been run with different parameters which have been shown above related parameters' table. In this way, simulation time was calculated as 169

minutes with less equipment as compared with the first simulation. Thus, positive improvements were achieved in project activities by shortening the distance of the concrete plant from the construction site. With the installation of the concrete plant on the construction site, the full mixer transfer time was reduced from 15 minutes to 5 minutes, and the empty mixer turnaround time was reduced from 10 minutes to 3 minutes. In this direction, the number of mixers has been reduced and the same work has been completed in less time with fewer resources. When evaluated with these results, the concrete transfer work done with 4 mixers in simulation 1 was completed in less time with 3 mixers within the same time limits, and the efficiency was increased by increasing the usage period of the resources from 6 to 8. In this case, the number of mixers has been reduced, and the same work has been completed with % 25 fewer resources. Besides, hourly cost savings have been achieved, due to the distance change and use of less resources. As a result, it has been determined that construction operations can be implemented with less resources, low cost, and high efficiency with simulation models.

Conclusion

This research aims to present that simulation can be used as a tool to apply lean construction principles. To achieve this goal, a repetitive operation in a completed construction project is simulated in two different ways using the EZStrobe simulation tool which is based on STROBOSCOPE software, and the outputs are evaluated. As a result of these evaluations, the study presents the following; real-time projects can be simulated with different parameters at the beginning project to evaluate the productivity of resources; in projects that have started and/or are in progress and/or will begin, by using the simulation system, resources can be used correctly and efficiently to minimize waste, or the most appropriate decisions can be made about their use; construction operations can be implemented with less resources, low cost and cycle time, and high productivity with simulation models; the objectives (minimize waste, simplify the process, increase value and efficiency) of the lean construction approach can be achieved; previous studies state that simulation is a tool for the adoption of lean principles in the construction industry are supported. Future research can encourage the adoption of lean construction principles in the construction industry through simulation, using simulation tools in different construction operations.

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Schedule Delay & Cost Overrun Analysis in Large Scale Construction Projects Using MS Project Software - A Case Study

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Abstract

Project duration and project cost are the main factors of the project in construction management. Most of the conflicts between contracting parties are based on incorrect time management and delays. For contractors, although the cost is at the forefront, especially in public projects, the duration of the project is also very important. Contractors who fail to complete the project on time may face penalties for delay. It is necessary to analyze schedule delays and cost overruns, and research the most significant causes of delay and cost overruns in construction projects to avoid or minimize their adverse impacts on the project and project participants.

Since the Turkish construction industry is a labor-intensive industry, it has been greatly affected by Covid-19 during the pandemic period. This has led to serious time and cost overruns, especially in large construction projects.

In this study, firstly, the causes of delays and cost overruns in large-scale construction projects in Türkiye were determined based on previous academic research, surveys and interviews with experts. Then, delay analysis and cost overrun analysis were performed on the data collected from an ongoing public construction project using MS Project software. Subsequently, the results were interpreted.

Keywords: *case-study, construction projects in Türkiye, cost overrun, pandemic, delay analysis, MS Project.*

Introduction

The construction industry plays a vital role in developing countries' economies. Construction projects provide many investment opportunities across various related sectors. Therefore, the

construction sector is an important economic indicator for developing countries like Türkiye. Although the Turkish construction industry has the potential to reach an international level, the construction management subjects have not been fully adopted by our companies yet.

For a construction project to be considered successful, it must be completed within the planned time/budget, in accordance with the relevant drawings and specifications, and to the satisfaction of the project stakeholders. Unfortunately, in developing countries like Türkiye, most construction projects face time and cost overruns due to a large number of uncertainties in the construction industry (Vyas & Birajdar, 2016).

Delays in construction can cause a number of changes in a project such as late completion, lost productivity, acceleration, increased costs, and contract termination. The party experiencing damages from delay needs to be able to recognize the delays and the parties responsible for them in order to recover time and cost. However, in general, delay situations are complex in nature. A delay in an activity may not result in the same amount of project delay. A delay caused by a party may or may not affect the project completion date and may or may not cause damage to another party. A delay can be caused by more than one party; however, it can also be caused by none of the parties (such as unusually severe weather conditions). A delay may occur concurrently with other delays and all of them may impact the project completion date. A delay may sometimes contribute to the formation of other delays. In construction contracts, schedule delay analysis is commonly conducted to demonstrate cause and effect relationships of time-related disputes. Schedule delay analysis makes use of the as-planned schedule, the as-built schedule, and schedule updates (Mohammed & Jafer, 2011).

Cost overrun can be defined as when the project objectives have not been achieved within the estimated budget (Avotos, 1983). Cost overrun is a very frequent phenomenon and is almost associated with nearly all projects in the construction industry. This trend is more severe in developing countries where these overruns sometimes exceed 100% of the anticipated cost of the project. Cost overruns are a major problem in both developed and developing countries (Angelo & Reina, 2002). Therefore, the problem of cost overruns is critical and needs to be studied to alleviate this issue in the future. In developing countries, the trend is more severe where the cost overruns sometimes exceed 100% of the estimated cost of the project. The reason for those overruns is poor management of the resources such as man, materials, and money.

There are several factors that are responsible for construction schedule delays and cost overruns. This paper attempts to identify the major factors of schedule delay and cost overrun in the construction sector of Türkiye and can serve as the way forward for future work in coping with these overruns. The literature, work experiences and expert opinions were used to determine the factors causing schedule delays and cost overruns.

In this study, first, some information is given about schedule delay and cost overrun subjects. Then a literature review has been presented on these topics. Within the scope of this study, the schedule delay and cost overrun analysis was applied to a real construction project data, and the results were interpreted with a case study. A G+5 reinforced construction building is selected for analysis as a case study. Later, Microsoft Project has been used for planning, scheduling and for delay analysis As Planned As Built technique has been used. The schedule delay and cost overrun analysis were done over some clusters of activities related to the construction project. Finally, the analysis results are interpreted.

Schedule Delay

Schedule delay is defined as the extension of time beyond the planned completion date specified in the contract or beyond the date that parties agreed upon for delivery of the project (Subramani et al., 2014). Delays are incidents that impact a project's progress and postpone project activities, delay causing incidents may include weather delays, unavailability of resources, design delays, etc. In general, project delays occur as a result of project activities that have both external and internal cause-and-effect relationships (Vidalis et al., 2002). Ameh and Osegbo (2011) describe schedule delay as the time during which some part of the construction project is completed beyond the project completion date or not performed as planned due to an unanticipated circumstance. Choudhry (2014) defined the schedule delay as the difference between the actual completion time and the estimated completion time.

Causes of Schedule Delay

Construction projects, which have a complex structure and require large investments, are faced with unexpected delays for many reasons. In order to be able to describe the schedule delays in the project as a whole, first of all, it is necessary to identify the delay elements that occur during the process. For this, both local and international studies on the subject have been examined and two important studies that examined delay causes in Turkish construction projects are given below.

Arditi et al. (1985) investigated the causes of delay in publicly funded construction projects in Türkiye between 1970 and 1980. They explained the reasons for the delay with 23 items. The reasons for delay according to the findings; are shortage of materials (e.g. iron and cement), difficulties in getting payments from stakeholders (e.g. not making payments on time, not making advances, expensive bail bonds, the insufficient budget of public enterprises), contractor difficulties (e.g. shortage of liquid funds, difficulty in collecting debts, obtaining loans' difficulty), organizational characteristics of contractor companies and public institutions (e.g. defined task and responsibility problems, lack of authority of the field manager, insufficient and slow decision-making mechanism, an abundance of bureaucratic obstacles, multitude of transformations of technical personnel).

Kazaz et al. (2012) have a detailed study on the causes of delays in construction projects in Türkiye. According to this study, 34 factors that cause time overruns in construction projects were gathered under 7 factor groups.

These classified factor groups are as follows.

- Environmental factors
- Financial factors
- Labor-based factors
- Managerial factors
- Owner-based factors
- Project-based factors
- Resource-based factors

Considering the views of participants, the most predominant ten causes of time overruns out of 34 factors were determined as can be seen in Table 1. The first five factors were described as "very important", alerting the industry considerably against to the time extension threat. Three

of them belong to financial factors, and this shows that the main notion behind the endemic timing problem in the sector depends largely on the economic conditions of owners and contractors. Overall, the most significant factor was found to be “design and material changes”, followed by “delay of payments”, “cash flow problems”, “contractor’s financial problems”, and “poor labor productivity”, respectively (Kazaz et al., 2012).

Table 1. The top ten causes of schedule delay (Kazaz et al., 2012).

Factor Groups	Factors	Rank	Importance Level
Managerial factors	Design and material changes	1	Very important
Financial factors	Delay of payments	2	Very important
Financial factors	Cash flow problems	3	Very important
Financial factors	Contractor’s financial problems	4	Very important
Labor-based factors	Poor labor productivity	5	Very important
Managerial factors	Estimation problems	6	Important
Project-based factors	Lack of feasibility studies	7	Important
Labor-based factors	Construction defects	8	Important
Labor-based factors	Unbalanced number of workers	9	Important
Financial factors	Fluctuation in material prices	10	Important

Cost Overrun

The notion of “cost overruns” is defined in a variety of ways in the literature. For example, Hinze et al. (1992) suggested that cost overrun is the difference between the original contract value and cost at practical completion. Derakhshanalavijeh (2017) described project cost overrun as the positive difference between the actual cost upon project completion and the agreed estimation of the project budget. Flyvbjerg et al. (2002) and Odeck (2004) interpreted cost overrun as the difference between forecasted and actual construction costs.

According to Zhu et al (2021), cost overrun is defined as the excess of actual cost over budget. Cost overrun is also sometimes called “cost escalation,” “cost increase,” or “budget overrun.” (Al-Najjar, 2008). Choudhry (2004) defined cost overrun as the difference between the original cost estimate of the project and the actual construction cost on completion of works of a commercial sector constriction project.

Cost overrun is defined as an instance in which the provision of contracted goods or services are claimed to require more financial resources than was originally agreed between a project sponsor and a contractor (Nega, 2008). Wideman (1992) defined cost overrun as the amount by which actual costs exceed the baseline or approved costs.

Cost Overrun= (Final Contract Amount – Original Contract Amount)/(Original Contract Amount)

Causes of Cost Overruns

The literature shows that there are various reasons for cost overruns in construction projects. Ameh, et al. (2011) identified 42 reasons for cost overrun and found that the main major factor causing cost overrun in Nigeria are inexperienced contractors, price of material, variation of

material prices, changes in design, economic stability, and high-interest rates charged by banks on loans. Al-Kharashi and Skitmore (2009) mentioned ten (10) out forty-two (42) identified factors resulting in cost overrun in Gaza construction projects, these factors are the increase of materials prices due to border closures, slowness in construction supply of raw materials and equipment by contractor, changes in the prices of building materials, unsettlement of local currency in relation to dollar value, monopoly of the project materials by some suppliers, design changes, and insufficient quantity take off.

Methodology

Delay Analysis Methods

There are four methods often mentioned in the literature that are professionally acceptable (Mohammed & Jafer, 2011).

They include:
• As-planned versus as-built schedule analysis method,
• Impact as-planned schedule analysis method,
• Collapsed as-built schedule analysis method, and
• Window analysis method, and they are known by different terminologies among practitioners.

The as-planned vs. as-built method is the observation of the difference between an as-planned schedule and an as-built schedule. The method identifies the as-built critical activities, compares these activities with the activities on the as-planned schedule, assesses the impact of delays on the project, identifies the sequences which actually define the duration of the project, and determines the causation and responsibility of delays that impact project completion. (Mohammed & Jafer, 2011).

The impact as-planned method uses only an as-planned or baseline schedule for delay analysis. It is based on the theory that the earliest date by which a project is completed can be determined by adding the delays into the as-planned schedule. New activities that represent delays, disruptions, and suspensions are added to the as-planned schedule and are used to demonstrate the reason why the project was completed later than planned. Contractors, who submit claims that involve a time extension, add only owner-caused delays to the as-planned schedule in the appropriate sequence to document the total project delay caused by the owner. (Mohammed & Jafer, 2011).

The collapsed as-built method is also referred to as the ‘‘but-for’’ schedule method. This analysis is popular in claim presentations because it is easily understood. Society of Construction Law (SCL) defines it as a method where the effects of delays are ‘‘subtracted’’ from an as-built schedule to determine what would have occurred but for those events (Society of Construction Law, 2002). This approach is a method of choice when a contractor lacks an acceptable schedule during the project, or when no as-planned schedule was required in the contract.

The window analysis method breaks the construction period into discrete time increments called “window” and examines the effects of the delays attributable to each of the project

participants as the delays occur. It adopts the as-planned schedule as its baseline, but the as-planned schedule is periodically updated at the end of each planned time period. The windows analysis method is distinguished from the impact as planned and collapsed as-built analyses in the fact that it incorporates both party delays into the analysis. In addition to this advantage, window analysis also provides a disciplined basis for the contractual parties to keep a project schedule up-to-date and properly adjusted. The majority of the viewpoints reviewed in the literature agree that windows analysis yields the most reliable results. In spite of its advantages, this method still has limitations which are summarized as follows:

• Window size can have a significant impact on the results of the analysis.
• Windows analysis has no mechanism for considering owner directed versus contractor acceleration.
• Windows analysis procedures do not include a systematic approach for calculating the responsibility for delays when multiple baseline updates have been used at different construction stages.
• Windows analysis does not consider the impact of resource over-allocation resulting from delays caused by various parties. (Mohammed & Jafer, 2011).

Case Study

In this study, a six-storeyed (G+5) university administrative building construction project which is in progress in Istanbul was selected as a case study. One of the authors is working as a technical office chief on the related project and the data were collected by him. The project's original duration is 785 days and the budgeted cost is ₺ 103,159,000,00. Construction, electrical and mechanical disciplines are included in the project planning.
The relevant project schedule program was prepared in MS Project software and the schedule is updated every month. In this study, the most important project schedule delay and cost overruns are given and the results are interpreted.

Scheduling in Ms. Project:

First of all, all project activities were determined. The activities were grouped under different groups. The Work Breakdown Structure (WBS) was established. Critical Path Method is the project scheduling method used in MS Project to link all the activities. The total baseline duration of the project was found to be 785 days.

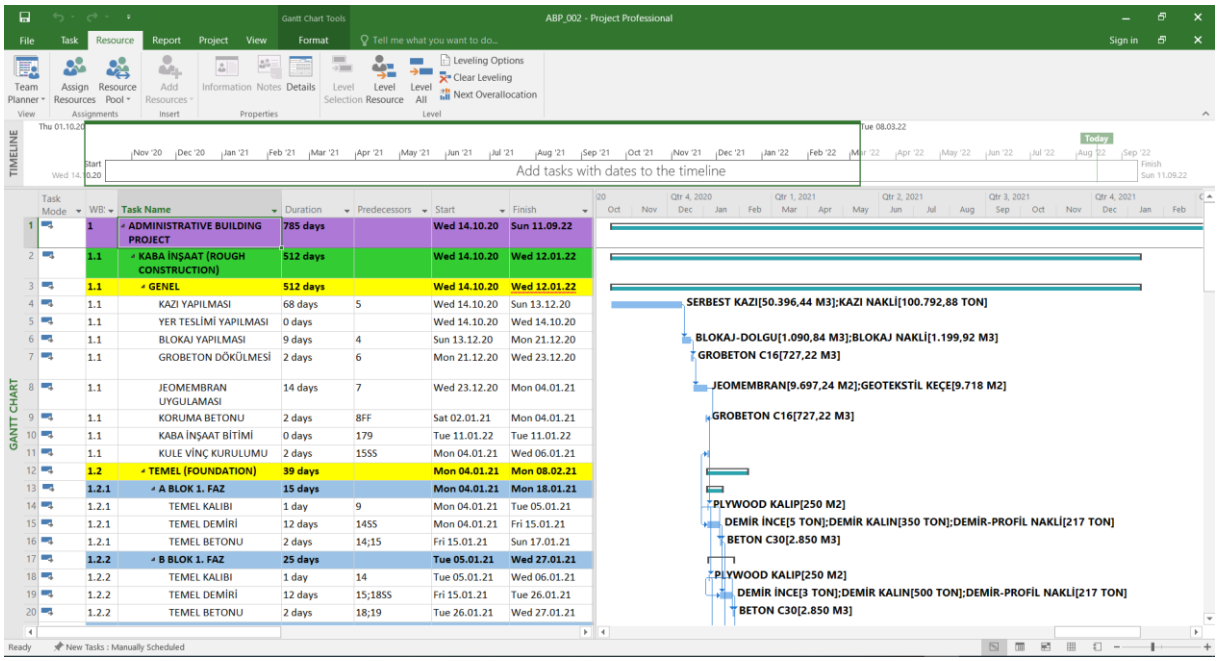


Figure 1: The project schedule and Gantt graphic.

Then, the quantity of each activity was calculated, and the man-hour calculation was made for each activity. Resources entries were made in the Ms project and the project baseline was saved.

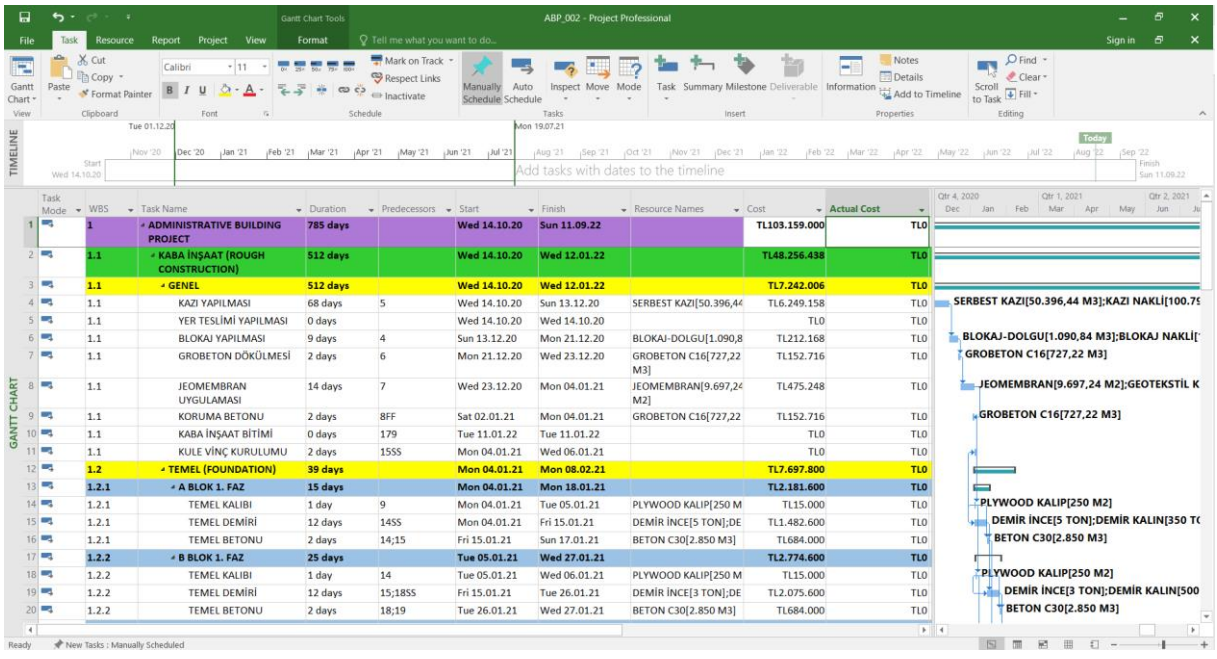


Figure 2: Activities with baseline.

Results

Examining The Duration and Cost Calculation of the Project

In this study, the most important schedule update results are given below;

WBS	Task Name	Duration	Finish Slack	Cost	Cost Variance
1.1	ROUGH CONSTRUCTION	512 days	-160 days	TL48.256.438	-TL12.626.363
1.1	GENERAL	512 days	-160 days	TL7.242.006	-TL1.665.661
1.2	FOUNDATION	39 days	0 days	TL7.697.800	-TL1.770.494
1.3	2nd Basement Floor	58 days	0 days	TL7.328.360	-TL1.312.890
1.4	1st Basement Floor	62 days	-20 days	TL7.049.532	-TL1.248.759
1.5	Ground Floor	62 days	-30 days	TL4.877.440	-TL1.707.104
1.6	1st Floor	62 days	-110 days	TL4.800.200	-TL1.680.070
1.7	2nd Floor	62 days	-110 days	TL4.814.500	-TL1.685.075
1.8	3rd Floor	62 days	-110 days	TL4.446.600	-TL1.556.310

Figure 3: Project schedule delays and cost overruns.

The project was delayed for 2 months due to project revision, 10 days due to bad weather conditions, 1 month due to leaving work of a subcontractor and the start of the new sub-contractor, 2 months due to the lack of allowance of the administration, thus160 days in total.

Conclusions

The contractor must properly manage his own financial resources in order to complete the work on time and on budget. It should distribute the progress payments from the owner in a planned manner for the payments to be made to the subcontractors and suppliers. In other words, it should provide control of cash flow. Site management and inspection are vital issues in order to ensure that the project is completed within the desired time and at the desired quality. This can be done with a sufficient number and qualified administrative and technical personnel selected by the contractor. In addition, the employer/administration must be faithful to the allowances specified in the contract and pay the progress payment to the contractor on time. In the current construction market, material prices increase more than the price difference given by the government to the contractor, this puts the contractors in a difficult situation and even causes them to go bankrupt.

Delays caused by stakeholders, namely individuals, can actually be minimized by corrective actions. But in some cases like unforeseen natural disasters, pandemics, civil war, conflicts, etc. delays are inevitable. For example, a work schedule can be prepared according to the number of rainy days by looking at the last 10-year average of the weather conditions, but no one can guarantee that the number of rainy days will be below or above the average in that year. Unforeseen external factors cause delays. In such cases, there may not be a way to follow other than taking action to accelerate the work.

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Lean Tools in the Construction Industry: A Bibliometric Analysis

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Abstract

Construction, as a leading sector in Turkey's economical perspective, an industry challenging with time and cost overruns related to construction wastes. As a consequence, total quality of the project is not provided as expected at the initial phases of the project life cycle. In recent years, some lean tools have been used to deal with this problem. Due to the variety of tools used in lean approaches, it becomes a critical issue which tool could be used. This study aims to classify the tools used in lean approaches in the construction industry, based on their participation in academic studies with a bibliometric study review. The study is limited with the articles written in time of 2013-2022 in Scopus database. According to the frequency of tools based on articles, availability of tools in implementation process in construction projects is examined.

Keywords: *construction, construction industry, lean, lean management, lean tools analysis.*

Introduction

Lean construction theory is the application of lean production principles in the construction industry, by eliminating all kind of waste, reducing variability in projects, and increasing quality for customer satisfaction. On transferability of lean principles into the construction industry, all the consultants and the contractors admitted that it would be possible to transfer the principles of lean to the construction industry. Transferability of lean principles into the construction industry can help to change current practices such as the generation of excessive waste and sub-standard products (Can &Tas, 2018). Lean approaches have been gained an importance internationally, with their benefits such as preventing time and cost losses and increasing total quality in construction projects. Different lean construction tools which originated from lean manufacturing approaches are used in different construction projects. Therefore, it is a critical issue to decide which lean tool to use in a specific project. At the same time, academic research focusing on lean tools in the construction industry shows a great tendency and analyzing the existing studies is complicated.

Defining the lean tools used and searched in the construction industry is important to improve application areas of these tools in an effective way in that industry. So, this study aims to highlight the most subjected lean construction tool in academic studies with a bibliometric analysis. Due to high numbers of studies focusing on the subject, Vos Viewer, a software tool for constructing and viewing bibliometric map is used to analyze the existing research. By this way, a searching pathway will be conducted for future studies in the subject of lean construction tools.

Methodology and Data Collection

In this study, Scopus search engine, which has a large source, was used to classify the last ten year's research (2013-2022) on lean tools and construction. Then, Vos Viewer software tool was used to analyse links between lean tools and to determine the most used lean tool in academic studies. The bibliometric study is limited with articles and conference papers written in the English language in engineering area. This study was composed by four main steps as below:

1. Step:

- Keyword search in the Scopus database using the keyword "Lean tools"
- Due to the high number of studies, 1123 documents, containing the subjects other than construction (like lean production, lean management strategies etc.); limiting the search with keywords of "Lean tools" and "Construction"
- Selection of articles and conference papers in English language, in engineering area between 2013- 2022.
- Exporting the data of 144 documents, with CSV format to analyse in the Vos Viewer software tool.

2. Step:

- Developing a map of links and analysis of clusters in the Vos Viewer software tool, containing the data of selected 144 documents.
- Analysing the findings on occurrence of all keywords.
- Listing of lean construction tools which have the most strength links with selected articles and conference papers.
- In accordance with the bibliometric analysis findings, selection of 4 most focused lean construction tool, to make more detailed analysis.

3. Step:

- Keyword search of most researched lean construction tools, which have been obtained with second step, in the Scopus database in addition to "Lean tools" and "Construction"
- Limiting the studies with articles written in English language in engineering area between 2013- 2022 by one by for each lean construction tool.

4. Step:

- Listing the articles about the most focused lean construction tool with descriptive information of authors, country, publication date, research methodology etc.
- General review of articles in the context of lean construction tools.

Analysis of Findings

Lean construction strategies, which take their origins from lean production management, show some common goals and tools like lean production system. Therefore, at the beginning of this research, lean tools keyword is searched in the Scopus database. The search is limited with articles and conference papers, written in English language in engineering area between 2013-2022. 1123 documents are analysed in Vos Viewer software tool and Figure 1 is derived.

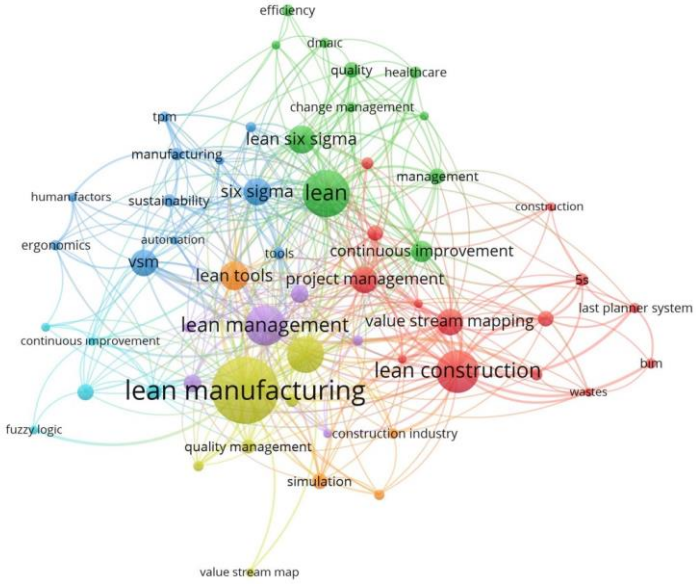


Figure 1: Lean tools occurrence keyword occurrence map in Vos Viewer software tool.

It shows that, 'lean manufacturing' issue has a greater impact on lean tools than lean construction. But the scope of this research is to analyse the lean construction tools; the search is redone with keywords of 'lean tools' and 'construction' within the same limitations. Figure 2 is derived. The lean construction tools in the keywords shown with links in the figure is chosen according to 40 lean construction tools in the thesis of Can (2020). The most impactful lean tools are listed as following.

- Last planner system
- Visual management
- Value stream mapping
- Building Information Modelling (BIM)

In the following step, the most occurred 4 lean construction tools in academic studies are researched in Scopus database again. Each tool is researched one by one with the keywords of

'lean tools' and 'construction'. For this step, only the articles are chosen written in English language in engineering area between 2013- 2022. The numbers of studies about each tool as follows:

- Last planner system- 26 articles
- Visual management- 7 articles
- Value stream mapping- 18 articles
- Building Information Modelling (BIM)- 20 articles

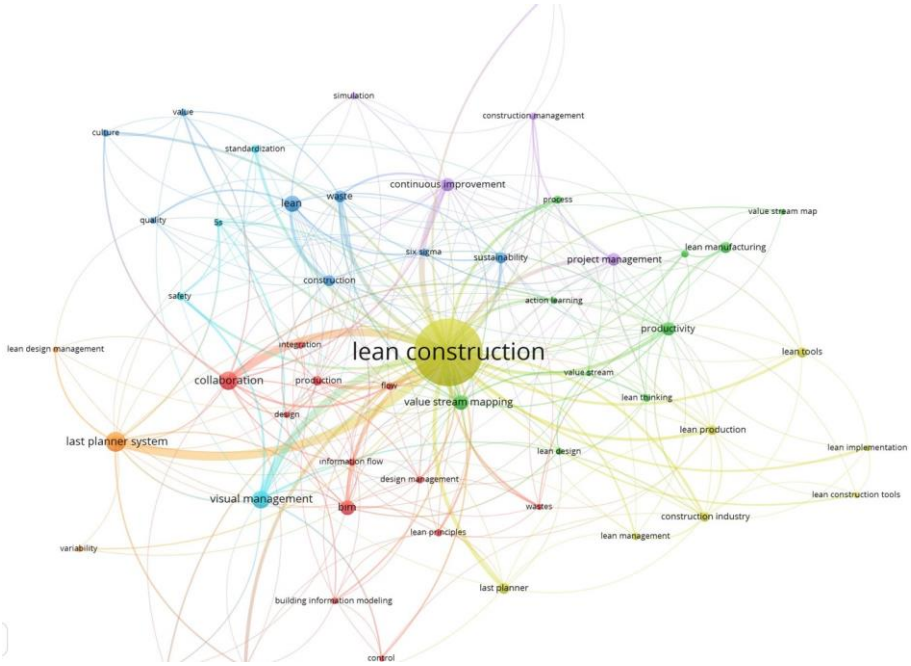


Figure 2: Lean tools and construction keyword occurrence map in Vos Viewer software tool.

According to the numbers of articles about lean construction tools, it is seen that 'Last Planner System' shows a majority than the other tools in the context of academic studies. So as a next step, 26 articles written about Last planner system is listed and analysed descriptively (Table 1). In the conclusion the data derived from the articles are evaluated and discussed.

Table 1. Articles with the keywords of "last planner system" & "lean tools" & "construction".

No	Journal Info	Document Title	Authors	Year	Keywords
1	International Journal of Lean Six Sigma 13(3), 557-593	Prospect of lean practices towards construction supply chain management trends	Le, P.L., Nguyen, N.T.D.	2022	Supply chain management, lean tools, construction supply chain management trends, lean construction principles
2	Advances in Civil Engineering 2022,7846593	The Usefulness of Adopting the Last Planner System in the Construction Process of Addis Ababa Road Projects	Limenih, Z.M., Demisse, B.A., Haile, A.T.	2022	--

Table 1. Articles with the keywords of “last planner system” & “lean tools” & “construction” (Continuation of table).

No	Journal Info	Document Title	Authors	Year	Keywords
3	International Journal of Civil Engineering 18(6), 701-715	Development of Innovative Integrated Last Planner System (ILPS)	Aslam, M., Gao, Z., Smith, G.	2020	Integrated last planner system (ILPS), lean tools and techniques, shortcomings, look-ahead planning, constraint analysis, visualization
4	Applied Sciences (Switzerland) 10(6),1913	BIM-LEAN as a methodology to save execution costs in building construction-An experience under the spanish framework	Andújar-Montoya, M.D., Galiano-Garrigós, A., Echarri-Iribarren, V., Rizo-Maestre, C.	2020	BIM, construction clashes, last planner system, building information modelling, lean construction
5	Automation in Construction 104, 246-254	BIM-based Last Planner System tool for improving construction project management	Heigermoser, D., García de Soto, B., Abbott, E.L.S., Chua, D.K.H.	2019	Automation Building Information Modeling (BIM) Construction productivity Construction waste Continuous improvement Last Planner System (LPS) Lean Construction
6	International Journal of Recent Technology and Engineering 8(2), 2534-2541	Importance of lean concepts and its need in construction projects	Shetty, P., Prakash Rao, B.	2019	Non Value added Activities, Lean Construction, Muda Walks, Value Stream Mapping, Fishbone Diagram
7	International Journal of Recent Technology and Engineering 8(1), 173-178	The planning in lean construction methodology at Colombian civil sector	AraqueGonzález, G.A., García Arango, D.A., Aguirre Mesa, E.D., (...), Echeverry Gutiérrez, C.A., Sidek, S.	2019	Lean Construction, Last planner system, weekly planner, civil engineering

Table 1. Articles with the keywords of “last planner system” & “lean tools” & “construction” (Continuation of table).

No	Journal Info	Document Title	Authors	Year	Keywords
8	Lean Construction Journal 2019, 76-90	Singularity functions for early warning guidance in the last planner system®	Shehab, L.G., Ezzeddine, A.M., Hamzeh, F.R., Lucko, G.	2019	Singularity functions; Last Planner System; Lean Construction; Percent Plan
9	Buildings 9(5),109	Applying level of detail in a BIM-based project: An overall process for lean design management	Uusitalo, P., Seppänen, O., Lappalainen, E., Peltokorpi, A., Olivieri, H.	2019	level of detail; lean design management; BIM; last planner system
10	Journal of Management in Engineering 35(1),04018050	Effect of Autonomous Agents on Last Planner System Performance in Texas	Rincón, J.L., Fernández-Solís, J.L., Lavy, S., Du, J.	2019	Autonomous agent; Construction; Game theory; Labor productivity; Last planner system; Lean; Self-interested; Subcontractor
11	Open Construction and Building Technology Journal 12(1), 389-403	Success factors and barriers of last planner system implementation in the gaza strip construction industry	Tayeh, B.A., Al Hallaq, K., Al Faqawi, A.H., Alaloul, W.S., Kim, S.Y.	2018	Barriers; Construction industry; Gaza strip; Last planner; Likert scale data; Success factors
12	International Journal of Civil Engineering& Technology 8(10), 461-471	Evaluation of latest trends and developments in lean construction in India: A model study	Chamberlin, K.S., Asadi, S.S., Chaitanya, D.S.	2017	Eliminating Waste using Lean Technique; LPS; Lean Construction
13	Sustainable Cities and Society 32, 348-356	Effect of lean tools to control external environment risks of construction projects	Ansah, R.H., Sorooshian, S.	2017	Analytic Hierarchy Process (AHP); Construction projects; Environmental-based delays; Framework; Lean tools; Prioritization

Table 1. Articles with the keywords of “last planner system” & “lean tools” & “construction” (Continuation of table).

No	Journal Info	Document Title	Authors	Year	Keywords
14	Construction Management and Economics 35(1-2), 45-63	Construction flow index: a metric of production flow quality in construction	Sacks, R., Seppänen, O., Priven, V., Savosnick, J.	2017	Building industry, lean construction, production process, workflow
15	International Journal of Engineering Research in Africa 33, 179-193	The potential effectiveness of lean construction tools in promoting safety on construction sites	Bajjou, M.S., Chafi, A., En-Nadi, A.	2017	5S; Error-proofing; Last Planner System; Lean Construction; Safety; Visual Management
16	International Journal of Civil Engineering and Technology 8(8), 623-636	Area of linkage between lean construction and sustainability in indian construction industry	Dixit, S., Mandal, S.N., Sawhney, A., Singh, S.	2017	Indian Construction Industry; Lean Construction; Sustainability and Waste Reduction
17	Construction Innovation 17(3), 324-339	Implementation of the LPS using an excel spreadsheet: A case study from the New Zealand construction industry	Zaeri, F., Rotimi, J.O.B., Hosseini, M.R., Cox, J.	2017	Automation; Challenges; Construction management; LPS; Percent plan complete; Spreadsheet
18	International Journal of Civil Engineering and Technology 8(4), 1918-1927	A case study of implementing last planner system in Tiruchirappalli District of Tamil Nadu - India	Vignesh, C.	2017	Contract management; LPS; Lean Construction - LC; Planning and control; Project management
19	Production Planning and Control 28(9), 707-726	Variability propagation in the production planning and control mechanism of construction projects	Zegarra, O., Alarcón, L.F.	2017	bullwhip effect; complex adaptive systems; language action perspective; last planner; Lean management

Table 1. Articles with the keywords of “last planner system” & “lean tools” & “construction” (Continuation of table).

No	Journal Info	Document Title	Authors	Year	Keywords
20	International Journal of Engineering Research in Africa 29, 118-132	A comparative study between lean construction and the traditional production system	Bajjou, M.S., Chafi, A., En-Nadi, A.	2017	5S; Comparative study; Just-in-time; LPS; Lean construction; Value stream mapping; Visual management
21	Journal of The Institution of Engineers (India): Series A 97(1), 19-26	Efficient Project Delivery Using Lean Principles - An Indian Case Study	Kovvuri, P.R.R., Sawhney, A., Ahuja, R., Sreekumar, A.	2016	Construction planning; LPS; Lean construction; Lean project delivery systems; Percent Plan Complete
22	KSCE Journal of Civil Engineering 20(1), 1-11	A survey on production planning system in construction projects based on Last Planner System	Khanh, H.D., Kim, S.Y.	2016	last planner; lean construction; planning and control; production; Vietnam; workflow
23	Journal of Professional Issues in Engineering Education and Practice 141(4), 04015002	LEBSCO: Lean-Based Simulation Game for Construction Management Classrooms	González, V.A., Orozco, F., Senior, B., (...), Forcael, E., Alarcón, L.F.	2015	Last planner; Lean production; Learning; LEBSCO lean construction; Simulation management games
24	Journal of Management in Engineering 31(5),05014021	Impact of measuring operational-level planning reliability on management-level project performance	Kim, S.-C., Kim, Y.-W., Park, K.S., Yoo, C.-Y.	2015	Construction; Cost performance index; Earned value; Empirical analysis; Lean; Percent-plan-completion; Schedule performance index
25	Alexandria Engineering Journal 52(4), 697-704	Implementation of lean construction techniques for minimizing the risks effect on project construction time	Issa, U.H.	2013	Last planner; Lean construction; Risk management; Time quantification

Table 1. Articles with the keywords of “last planner system” & “lean tools” & “construction” (Continuation of table).

No	Journal Info	Document Title	Authors	Year	Keywords
26	Alexandria Engineering Journal 52(4), 679-695	Applying lean thinking in construction and performance improvement	Aziz, R.F., Hafez, S.M.	2013	Construction industry; Improvement theories; Lean construction; Lean production; Lean thinking; Performance

Evaluation of Findings

The Last Planner System is a lean construction tool based on production control by dividing the project process into stages and preparing separate programs for each stage (Aydın, 2019). It helps to increase reliability of work plans, improve workflow, and improve the coordination and collaboration between construction industry actors by controlling the productivity in construction process. In accordance with the analysis of bibliometric study about lean construction tools, ‘Last Planner System (LPS)’ is the most emphasized research topic in academic studies. In 26 articles about LPS; it is focused on integration of LPS tool to ongoing construction projects, to avoid time and cost losses. In researched articles, the challenges of using LPS as well as its benefits have been explored. According to the articles, LPS tool is handled with the other lean construction tools rather than alone. According to keywords of 26 articles; the mostly dealt lean tools with LPS are Building Information Modelling (BIM), Visual Management, Value Stream Mapping, 5S, Earned Value Management etc. In most of articles, the availability, and benefits of using these lean construction tools integrated with LPS are tested with case studies, observations and measurements of cost and timeline data in real projects. So, the efficiency of the LPS tool is examined. In research, new lean construction models are built to increase the productivity of projects and decrease construction wastes related to construction risks in projects. So, in articles, LPS tool is emphasized as a lean management tool. Some articles emphasize on the supply chain management with the use of lean construction tools as LPS. Autonomy and visualization of project data are other related factors with lean construction tools in studies. Additionally, the comparison of project efficiency in the context of time, budget, and quality limits in addition, in the studies, comparisons in the context of time, budget and quality factors are made on how LPS is applied or not in the projects.

Conclusion

Construction industry is growing at a rapid pace. Along with this growth, the industry is facing numerous challenges that are making delivery of projects inefficient. At that point, lean principles that increase project efficiency and productivity come to prominence. So, in this study, it is aimed to analyze the studies of last 10 years about lean construction tools with a bibliometric study. Although many lean tools have emerged in the lean construction industry, the Last Planner System (LPS) is one of the most important. According to analysis of

bibliometric study, 26 articles about LPS within the research scope are evaluated and discussed in the context of; keywords, research topics and aims of the studies. According to articles, the implementation of LPS with other lean construction tools in construction projects is one of the most emphasized subjects. Benefits of LPS implementation by increasing reliability of work plans, smoothing workflow, and strengthening the communication and collaboration between project actors, challenges faced during the implementation of LPS tool and comparison of LPS tool with traditional management models are other most researched subjects. By analyzing the LPS related research, this study aimed to draw a research pathway about implementation of lean tools like LPS in the construction industry for further studies.

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Estimation of Winning Bidding Price for Construction Sector

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Abstract

The most critical issue faced by companies during the tender preparation process, especially in public construction tenders, is to give an exact bidding price. The calculation of bidding price for public tenders is a comprehensive and detailed process for Tender Management teams in construction companies. The performances of these tender teams are categorized as two key performance indicator (KPI) "Competitive" and "Not Too Low" depending on the bidding value given in the tender process. "Competitive" as a KPI score shows whether the offered price is within the standard deviations of all the offers given in tender process; whereas "Not Too Low" as a KPI calculates whether the offered price falls over the lowest limit decided by the local authority. It is important to meet those two KPI's targets to be included in bargaining process, instead of a firm that is eliminated due to too low or too high bidding prices. Therefore, it is beneficial to have decision support system that guides them in estimation process of the bidding price for tender teams.

Being able to give an exact bidding price to the tenders depends on the variety and accuracy of the datasets available regarding the contract during the tender preparation phase. Because of these prerequisites, the publicly available tenders of European public procurements were selected, and the detailed data sets and explanations needed for analysis were driven from European public procurement. Critical data sets in deciding the right bidding price were determined by multiple regression analyzes. Regression analysis results, to estimate winning bidding price for construction sector, were validated by European publicly shared sample tenders.

Keywords: *estimate winning bidding price, too low KPI, competitive KPI score, classification of construction contracts, regression analysis, decision support systems for construction business.*

Introduction

Tender preparation phase for construction companies, is a detailed and comprehensive process to work on. Since most of the public tenders heavily rely on infrastructure jobs, tender

teams need to make analysis through field visits and technical drawings. However, during the preparation phase of tenders, they do not have enough consultancy to guide them through finding the winning bidding price for an offer. Mostly, previous similar tenders are analyzed and people with similar project experience are used as a support. This research aim is to create a decision support system for tender teams, by using the public procurements results by regression analysis using machine learning algorithms developed in python.

To develop the proposed decision support system, detailed information about the tenders and its results should be accessible. Especially since it is important to have a relationship between the bidding prices offered and the actual contract values, the European Public Procurements were selected. Especially in developing countries, it is common to encounter tenders where there is a high difference between the estimate and actuals prices of projects and high variance between offers given by participant firms.

After the target region is decided and CSV notice results downloaded, all parameters received from the data set and codebook is studied. All data were cleaned by removing unnecessary or unusable information regarding the estimation process. After the dataset is analyzed and data cleaning is applied, the second task is to make feature selection. If there is irrelevant and redundant information such as noisy or unreliable data, then the training phase of models would be much more inefficient (Karagiannopoulos M., Anyfantis D., Kotsiantis S.B., Pintelas P.E., 2004). For this reason, a detailed feature selection control is applied in this study with three alternatives; "SelectKBest", "Recursive Feature Elimination" and "SelectFromModel" method alternatives are used.

Those selected parameters coming from the feature selection phase is trained and tested with "GradientBoostingRegressor" and "RandomForestRegressor" algorithms, which are two most common tree-based algorithms used for regression analysis.

The results from the two models are analyzed by comparing the estimated bidding prices in respect to winning bidding price values. The model results will be compared by checking their "Root Mean Squared Error (RMSE)" and "Mean Absolute Error (MAE)" result, as these two measures of error methods are useful in contrasting paired observations. The following figure presents the research framework of this study.

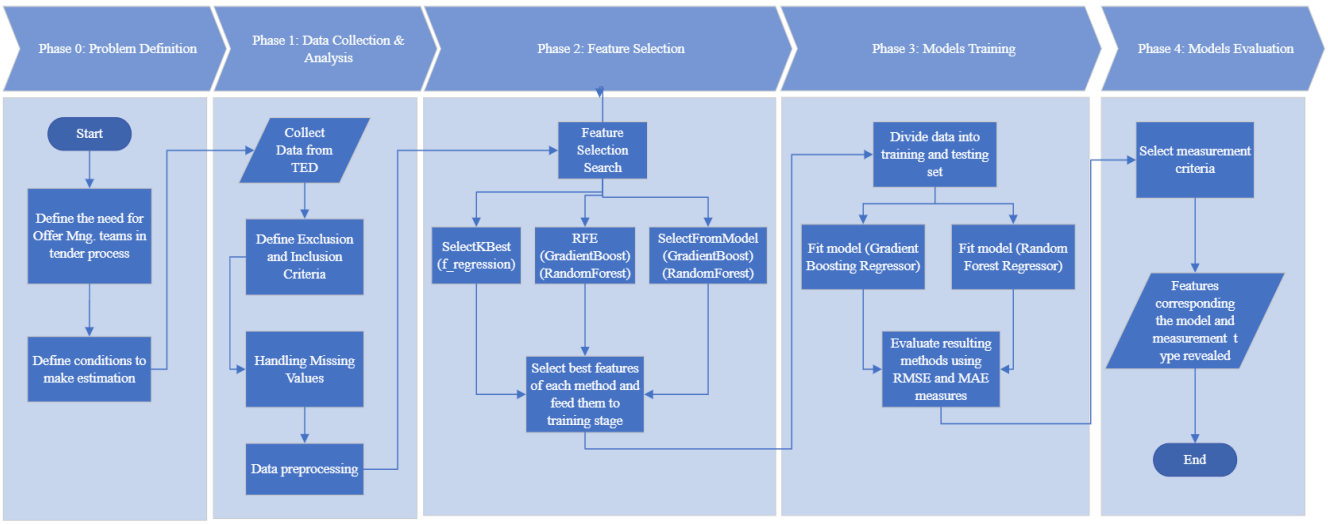


Figure 1: Research framework.

Literature Review

There are numerous studies on factors that affect cost and bidding prices in construction projects, however only a few of them is about estimating the bidding price through the analysis of tenders.

In Petrusava et al. (2016)'s study, authors have developed a model for predicting bidding price for construction projects in Skopje, Republic of Macedonia. In this research, they have used Support Vector Machine instead of linear regression models and reached a very high accuracy of prediction. Although, the research aims forecasting of parameters in construction sector overall, it is only focused on 26 signed agreements in Skopje; therefore, this study stays local and hard to implement to tenders outside Macedonia.

In another research (Stiti & Yape, 2019), authors have written a thesis on public procurements in Sweden, aiming to stream and digitize public procurement sector in general. The first contribution of project is looking at the factors affecting the bid/no bid and pricing decision of bidders, rather than giving an estimation on winning bidding price.

Data Collection & Analysis

The Tenders Electronic Daily (TED) comma separated value (CSV) open data, covering public procurement for the European Economic Area, Switzerland, and the Republic of North Macedonia, and the codebook that includes details of parameters were downloaded from the website "https://data.europa.eu/euodp/en/data/dataset/ted-csv" . Total of 75 parameters were analyzed, the following parameters were found relevant and usable for machine learning for model prediction (Petrusava et al., 2016)

Table 1. European public procurement feature analysis.

YEAR	It is the year of publication of the offer results. Since in TED (Tenders Electronic Daily dedicated to European public procurement) site, only result from 2007 to 2019 are shared; these years are used for training the dataset.
CANCELLED	The notices which were published before but cancelled afterwards are marked as *CANCELLED* value by 1.
B_MULTIPLE_CAE	This value shows if there is more than one contracting authority or not. This value is converted into a Boolean data type.
B_ON_BEHALF	It is a Boolean feature that shows if there is a central purchasing body or several buyers buying together. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
B_INVOLVES_JOINT_PROCUREMENT	It is a Boolean feature that shows if the contract involves any joint procurement. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
B_AWARDED_BY_CENTRAL_BODY	It is a Boolean feature that shows if contract is awarded by a central purchasing body. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
B_FRA_AGREEMENT	It is a Boolean feature that shows if the notice involves the establishment of a framework agreement. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.

B_FRA_CONTRACT	It is a Boolean feature that shows this notice is probably about specific contracts within a framework agreement.
B_DYN_PURCH_SYST	It is a Boolean feature that shows if the notice involves contract is based on a dynamic purchasing system.
B_GPA	It is a Boolean feature that shows if the contract is covered by the Government Procurement Agreement.
B_EU_FUNDS	It is a Boolean feature that shows if the contract is related to a project and / or programme financed by European Union funds
B_ACCELERATED	It is a Boolean feature that shows if the option to accelerate the procedure has been used.
B_ELECTRONIC_AUCTION	It is a Boolean feature that shows if an electronic auction has been used.
B_AWARDED_TO_A_GROUP	It is a Boolean feature that shows if the contract has been awarded to a group of economic operators. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
ISO_COUNTRY_CODE	It shows the country code of the first listed authority. There are about 33 country codes listed in a total of 13-year span.
CAE_TYPE	It shows the type of contracting authority. The possible values are listed as below: 1 “Ministry or any other national or federal authority, including their regional of local subdivisions” 3 “Regional or local authority” 4 “Water, energy, transport and telecommunications sectors” 5 "European Union institution/agency" 5A "other international organization" 6 "Body governed by public law" 8 "Other" N "National or federal Agency / Office" R "Regional or local Agency / Office" Z “Not specified" This parameter is defined as a categorical feature.
EU_INST_CODE	Type of EU Institution. For this value to be active, CAE_TYPE value must be 5. Below are possible values: AG "agencies" BC "European Central Bank" BI "European Investment Bank" BR "European Bank for Reconstruction and Development" CA "European Court of Auditors" CJ "Court of Justice of the European Union" CL "Council of the European Union" CR "European Committee of the Regions" EA "European External Action Service" EC "European Commission" ES "European Economic and Social Committee" FI "European Investment Fund" OB "European Patent Office" OP "Publications office of the European Union" PA "European Parliament"
TYPE_OF_CON	This a categorical feature that shows the type of contract. This is an

TRACT	important feature that differentiate contract types. Below are possible values: W "Works" U "Supplies" S "Services"
FRA_ESTIMATED	This is a categorical feature that shows whether there are indications that this notice is about a framework agreement that depends on *B_FRA_AGGREMENT* parameter. If this parameter values are "Y", then below are possible values: (These parameter combinations are available also) K "The keyword `framework', in the appropriate language, was found in the title or description of the notice." A "Multiple awards were given per one lot, which is legally admissible only in case of framework agreements, dynamic purchasing systems, innovation partnerships, and qualification systems." C "Consistency across notices: the contract notices which preceded this notice was marked as a framework agreement."
CPV	Common procurement vocabulary (CPV) establishes a single classification system for public procurement aimed at standardizing the references used by contracting authorities and entities to describe procurement contracts. ➢ The first two digits of CPV is identified as divisions (XX000000-Y). ➢ The first three digits identify the groups (XXX00000-Y), ➢ The first four digits identify the classes (XXXX0000-Y), ➢ The first five digits identify the categories (XXXXX000-Y).
TOP_TYPE	Type of procedure feature (Categorical feature): ➢ AWP: award without prior publication of a contract notice ➢ COD: competitive dialogue ➢ NOC/NOP: negotiated without a call for competition ➢ NIC/NIP: negotiated with a call for competition ➢ OPE: open ➢ RES: restricted ➢ INP: innovative partnership
OUT_OF_DIRECTIVES	It is a Boolean feature that shows if the procurement falls outside the scope of application of the directive. This feature is available if TOP_TYPE value is either NOC/NOP or AWP.
NUMBER_OFFERS	Number of tenders received for the contract notice. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
NUMBER_TENDERS_SME	Number of tenders received from SMEs. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
NUMBER_TENDERS_OTHER_EU	Number of tenders received from tenderers from other EU Member States. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.
NUMBER_TENDERS_NON_EU	Number of tenders received from tenderers from non-EU countries. Since this parameter is a result of contract notice, this parameter should be filled as an estimate value.

AWARD_EST_VALUE_EURO	Estimated Contract value in EUR, without VAT. This is the most critical parameter in estimating new contracts.
AWARD_VALUE_EURO	It is the winning bidding price in contract in EUR, without VAT. This is the parameters that our estimation model tries to predict.

Above parameters are worked on from the data received between 2007 and 2019. There are in total 7.347.867 entries in total; for these all records below data cleaning actions are taken:

➢ *AWARD_VALUE_EURO* and *AWARD_EST_VALUE_EURO* are two most important features to consider in estimation. *AWARD_VALUE_EURO* is the contract price that is the value to be estimated in our model. *AWARD_EST_VALUE_EURO* is the estimated contract value, which has the highest correlation with the contract price and critical in making prediction. For those reasons, entries with missing contract and estimated contract value are omitted from estimation process.

➢ Cancelled contracts are also withdrawn from estimation process as there are also a lot of intersection with *AWARD_VALUE_EURO* and *AWARD_EST_VALUE_EURO* empty fields. Cancelled notices (Value of 1) are withdrawn from the training data.

➢ Since the paper is about predicting the bidding price in construction sector, a filter is applied on *TYPE_OF_CONTRACT* feature. Only contracts with "W" (Works category) are considered in the prediction process, which means contracts of Supplies and Services are withdrawn from the data. From the total of 2,464,816 entities, the status of the contract type is examined, the distribution is presented below (This is the distribution after 1st and 2nd controls are applied)

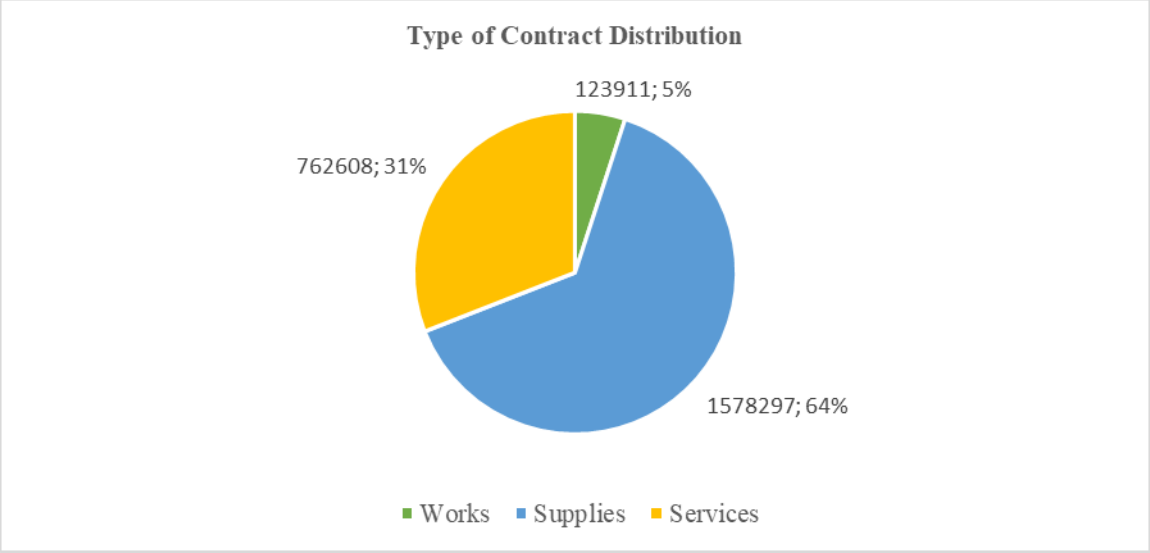


Figure 2: Type of contract distribution for contracts between 2007-2019.

Works category has in total 123911 entities; this is also normal as "Works" contracts are less in quantity, but high in budget.

➢ A new feature named "*CPV_DIVISON*" is created from the existing *CPV* feature. Because *CPV* value by itself is not helpful in the estimation process with unnecessary

separation of sample with detailed information. From the existing options, it has been decided to use the “Division” identifier as it is helpful in distinguishing the type of projects.

When all data is investigated, there are possible of 68 divisions available. The other options are excluded, because those options are more detailed definitions and there are not many samples to make estimation for each option.

➢ The entities with null values on Boolean features are assigned to values “N” (No), to be used in the estimation model.

➢ Missing *FRA_ESTIMATED* entities are updated as “K” which means the keyword `framework', in the appropriate language, was found in the title or description of the notice.

➢ Missing *TOP_TYPE* entities are update “OPE”, since this is an open procedure procurement which is the most common style public tenders.

➢ Missing GPA_COVERAGE entities are updates as “2” which is equivalent to entity not covered by GPA.

➢ Missing *NUMBER_OFFERS, NUMBER_TENDERS_NON_EU, NUMBER_TENDERS_OTHER_EU, NUMBER_TENDERS_SME* entities are updated with their corresponding arithmetic means. Basically, missing *NUMBER_OFFERS* values are updated with the arithmetic mean of all projects NUMBER_OFFER parameter.

Mean values are calculated as below:

- *NUMBER_OFFERS* = 6.49
- *NUMBER_TENDERS_NON_EU = 0.024*
- *NUMBER_TENDERS_OTHER_EU = 0.14*
- *NUMBER_TENDERS_SME = 3.36*

➢ A new parameter named as “price_ratio” is defined, which is calculated from the division of Estimated Contract Value to Award Contract Value (*AWARD_EST_VALUE_EURO/ AWARD_VALUE_EURO*). This new parameter is defined to check the relationship between the estimations and realizations of contract values and to detect outlier contracts with unrelated (high/low) contract values. Below is the figure that shows the data density of Price Ratio value:

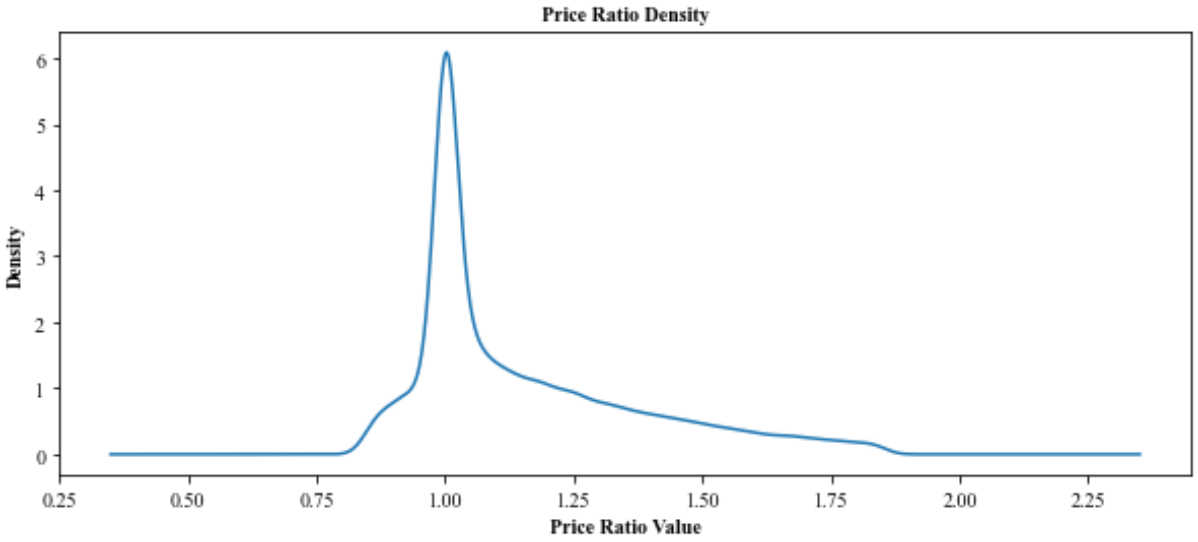


Figure 3: Data density of price ratio value.

As it can be checked from the figure, most of the contracts have a price ratio value close to 1 and the data is skewed. For this reason, Tukey's method (Boxplot) rule is applied on Outlier detection and treatment. Tukey introduced the rule to screen outliers which practices on quartiles instead of means or standard deviations (Saleem et al., 2021). Since most of the contract award notice price ratio values are concentrated around value 1 and extreme price ratio values are rare cases; the extreme observations that stays out of inner fences (Interval with 1.5 Interquartile range) are omitted from the estimation process.

For IQR rule, below operations are applied.

1) The data for price_ratio is sorted in ascending order.

2) The first quartile of price_ratio is calculated (Q1-%25)

3) The third quartile of price_ratio is calculated (Q3-%75)

4) IQR value is calculated which is equal to $Q3 - Q1$.

5) The lower range is calculated as $Q1 - (1.5 * IQR)$

6) The upper range is calculated as $Q3 + (1.5 * IQR)$

From the 123911 entries found, *Upper Limit* value is calculated as 1.85 and *Lower Limit* value is calculated as 0.83. After upper and lower limit are found; contracts with outlier price_ratio values are eliminated from the data, which cause 12801 entries to be removed from the model data.

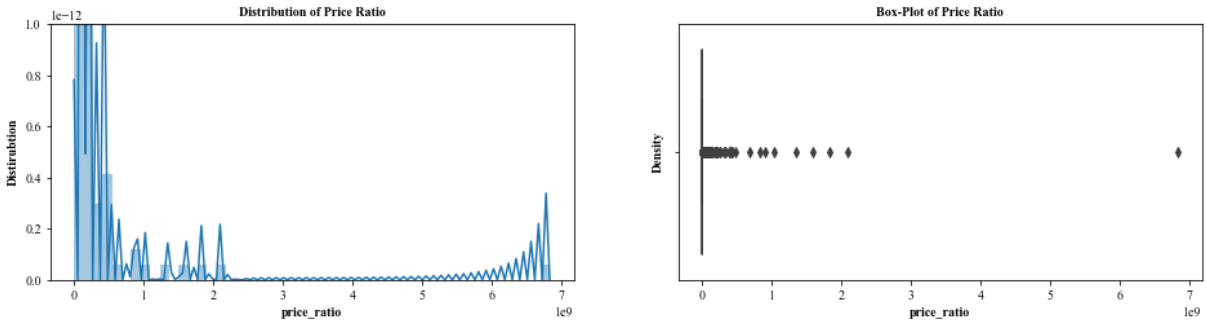


Figure 4: Density plots of price ratio value.

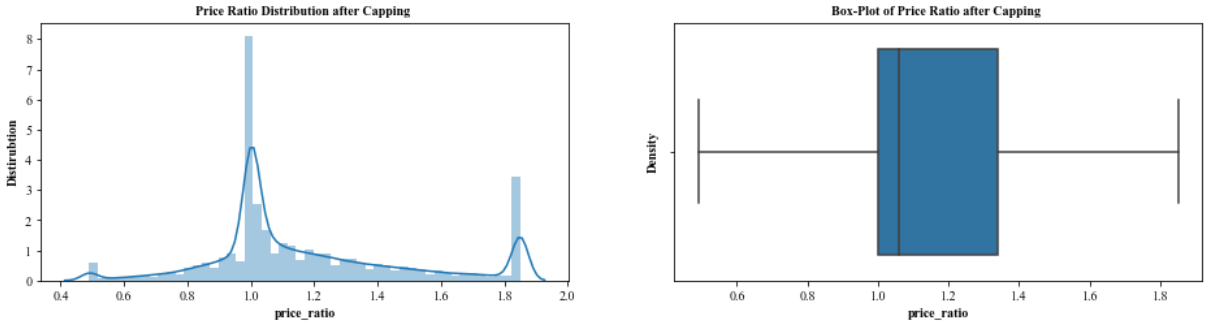


Figure 5: Density plots of price ratio value after capping data.

Correlation Feature Selection

At this stage, a work is done on which features to be selected and check the correlation of each with contract winning price value. These parameters selected from multiple correlation feature selection methods, then were used in model training stage. As stated in Blum and Langley (1997), as Machine Learning aims to address larger and more complex tasks, the importance of working with relevant information has become increasingly important. Since as the features and the number of constructions works increases, it is also important for the estimation of construction bidding prices. From the total of 75 features available; after data cleaning operation was completed, the number of features to be worked on estimation process is gathered to 23 features. Null values and categorical values were handled and prepared for estimation process.

To filter which features to exclude in the training phase of model, correlation of features in respect to winning bidding price (*AWARD_VALUE_EURO*) are checked. In correlation analysis check, "AWARD_EST_VALUE_EURO" (Estimated bidding price value by local authority) is excluded because this is the highest correlated value to winning bidding price and it is added to estimation model immediately. To extract other most relevant features, below methods are used:

- All Features
- SelectKBest method with f_regression
- Recursive Feature Elimination (RFE)
- SelectFromModel

SelectKBest with score_func option “f_regression” is commonly used for regression analysis, which combines p-values and F-test scores to evaluate the performance of parameters, making the method statistically robust (Otchere et al., 2022). Below is the bar chart showing the importance scores of those inputs. According to results received from SelectKBest; features with a correlation higher than 0.5 (CAE_TYPE with a value 0.78 is the lowest relevant) are received from the analysis result. Below 5 features are added in the estimation process.

- *B_FRA_AGGREMENT, B_FRA_CONTRACT, B_EU_FUNDS, B_GPA, CAE_TYPE*

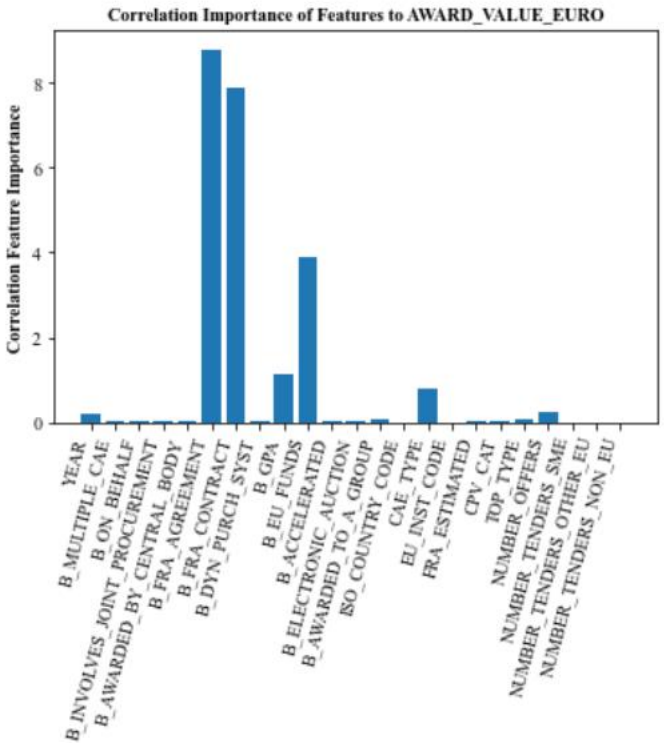


Figure 6: Correlation importance of features in respect to winning bidding price.

Recursive Feature Elimination (RFE) trains the model with full parameters at the beginning and ranks the importance of features. The same process is applied to smaller subsets and finally the features that belong to best model is revealed (Feng et al., 2017). The main parameter in RFE is the “estimator” and both “GradientBoostingRegressor” and “RandomForestRegressor” algorithms are used. Another important parameter is “n_features_to_select” which requires the number of features to be selected from the method. In our study, half of the parameters are tried which is equal to 11 parameters. Below is the list of 11 parameters:

- Gradient Boost Regressor: *B_FRA_AGGREMENT, B_FRA_CONTRACT, B_GPA, CAE_TYPE, YEAR, ISO_COUNTRY_CODE, FRA_ESTIMATED, CPV_CAT, TOP_TYPE, NUMBER_OFFERS, NUMBER_TENDERS_SME*
- *Random Forest Regressor: NUMBER_OFFERS, NUMBER_TENDERS_SME, YEAR, B_FRA_CONTRACT, B_FRA_AGREEMENT, TOP_TYPE, FRA_ESTIMATED, ISO_COUNTRY_CODE, B_GPA, CAE_TYPE, CPV_CAT*

SELECTFROMMODEL method starts with training the model with all parameters as well. In a backward way, least significant features are removed from the model until there is no

improvement observed on model performance (Badrouchi et al., 2021). Just like in RFE, this method requires "estimator" parameter as well. From this method, there are 2 critical attribute values received. One of them is the "threshold" value which shows the value used for feature selection and other is the list of features that are selected. From this method, below features are added to estimation process.

- Gradient Boost Regressor: *B_FRA_CONTRACT, CAE_TYPE, B_EU_FUNDS, B_FRA_AGREEMENT, NUMBER_OFFERS, YEAR*
- Random Forest Regressor: *B_FRA_CONTRACT, CAE_TYPE, YEAR, ISO_COUNTRY_CODE, NUMBER_OFFERS*

Training the Algorithms

After feature selection phase, the next step is to train and test the algorithms with corresponding features. At the end of this stage, it will be decided which regression algorithm presents the best estimation for public tenders in European Public Procurements. This study focusses on two tree-based regression algorithms that have ensemble learning techniques coming from linear regression model, to make more accurate predictions.

Gradient Boosting Regressor is an iterative collection of sequentially arranged tree models in which the model predictions are improved from the error of former models (Otchere et al., 2022). At each node, a regression tree is fit on the negative gradient of the loss function calculated.

Random forest is an algorithm that is built on two mechanisms "Bagging" and "Feature Sampling". Each tree in Random Forest is pre-built from sample data sets and at each node, variables are sampled as candidates at each split. The best split point is then for this random set variable. This process continues until all trees in random forest are fully grown (Callens et al., 2020).

Table 2. Algorithm results.

	Gradient Boost Regressor		Random Forest Regressor	
	RMSE	MAE	RMSE	MAE
All Features	22.068.217	1.511.664	32.012.699	1.009.447
SelectKBest	20.424.446	1.490.968	32.926.380	1.201.329
Recursive	20.762.825	1.488.853	30.072.299	990.801
SelectFromModel	19.496.648	1.470.041	21.121.527	876.450

As a result of our analysis, for RMSE, Gradient Boost gave better results compared to Random Forest, both in the set where all the features are applied, and in the sets where the SelectKBest, Recursive, SelectFromModel methods are applied. Random Forest, on the other hand, did better for MAE on all sets. The best value for RMSE was the SelectFromModel method with Gradient Boost as estimator and model, while the best value for MAE was obtained with SelectFromModel method again but with Random Forest estimator this time. Our best score is 19,496,648 for RMSE and 876,450 for MAE.

Models Evaluation

In this final model comparison stage, the results received from the two algorithms were compared in respect to "Root mean square error (RMSE)" and "Mean absolute error (MAE)" calculations. MAE calculation is done by averaging the absolute values of total errors, whereas RMSE is the standard deviation of prediction errors. In RMSE, since the calculation is done by squaring the errors first, it penalizes the variance as it gives errors with larger absolute values more weight than errors with smaller absolute values. On the other hand, same weight is given to all errors at MAE evaluation. (Chai & Draxler, 2014). From these two statistical evaluation methods, there are different opinions to count on.

According to Cort and Kenji, RMSE do not describe average error alone as it is not possible discern to what extent RMSE reflects average error and the variability within the distribution of squared errors (Willmott & Matsuura, 2005).

On the contrary, a study made by Chai and Draxler argue against this notion. According to this study, RMSE is more appropriate to use than MAE when there is normal distribution. If some of the outliers are examined and leave out the estimation process, the effect of penalization to large errors would be minimized (Chai & Draxler, 2014).

In this study, since outlier contracts are eliminated and it is not desirable to have high variance over estimated and actual bidding price, RMSE is selected as the critical evaluation method on control. For this reason, it is decided to proceed with the "Gradient Boost Regressor" algorithm and features selected from the "SelectFromModel" class with "GradientBoostingRegressor" estimator used.

Conclusion

Tender preparation phase for construction companies is an exhaustive stage which requires detailed work and analysis; for this reason, it is beneficial for them to have any decision support system in assisting their decision on final bidding price. The previous researches on this topic are mainly focused on local regions, whereas in this study, it is aimed to come up with a solution that includes multiple regions.

The results of this work will be used for Dogus Construction and the model created with "GradientBoostingRegressor" estimator, will be implemented to Offer Management system. The below declared features will be required for projects occurring in the region of European Union and the estimated bidding price value is going to be shared with Offer Team as a decision support system.

The features that are selected for the selected method can be summarized as:

- Estimated price value of contract (*AWARD_EST_VALUE_EURO*)
- Number of tenders received for the contract notice (*NUMBER_OFFERS*). This value should be filled as an estimate value by the estimating firm.
- Year of the contract notice (*YEAR*)
- If notice is probably about specific contracts within a framework agreement (*B_FRA_CONTRACT*)

- If the notice involves the establishment of a framework agreement (*B_FRA_AGREEMENT*)
- If the contract is related to a project and / or programme financed by European Union funds (*B_EU_FUNDS*)
- Type of contracting authority (*CAE_TYPE*)

Although the model is created based on the gathered from European Union public procurements, the same work can be applied to regions with similar characteristics (United States, Canada…etc.) and results (selection of parameters and model) received from those can be compared with the ones in this research.

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Total Construction Duration Calculation of TOKI Housing Projects: A Case Study

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Abstract

In modern project management principles, accurate estimations for construction duration are significant to successfully complete projects on time. However, in accordance with literature review and Supreme Court decisions, it was determined that considerable number of housing projects were delayed in Turkey. TOKI (Housing Development Administration of Republic of Turkey), as an authorized public entity, has been major client to build housing projects in Turkey. Therefore, it was decided to study the construction delays for TOKI housing projects in this case study. The objective of this study was to reveal the difference between calculated construction durations by TOKI's own calculation method and durations indicated in official construction contracts between TOKI as client and awarded contractors. This research was adopted as a case study methodology involving semi-structured interviews with TOKI personnel. The datasheet showing detailed project information about 2800 completed TOKI projects was obtained. Interviews also showed that TOKI has been using three factors, namely number of houses, type of project drawings utilized in tendering process, and non-working days to calculate total construction duration. Findings of the study showed that calculated construction durations by TOKI were way higher than of those indicated within official construction contracts. Study revealed that TOKI was significantly shortened the calculated durations while transferring to contract durations officially which ultimately resulted in considerable number of housing projects delayed.

Keywords: *case study, construction duration, planning in construction, project management, TOKI.*

Introduction

Planning and programming in tender phase were regulated by relevant laws and authorized organizations (FIDIC, 2017). However, it was observed that it is not the case for public construction sector in Turkey (Yitmen & Dikbas, 2002; Birgonul et al., 2007; Koktas et al., 2009; Akkaynak, 2013; Erbas & Ciraci, 2013; Usta, 2014) due legal regulations reckon without planning but prioritize only the lowest tender price (Public Procurement Law no. 4734 dated 04.01.2002, article 40) and this situation needs to be improved (Turesoy, 1989; Demirci, 2001; Karapinar, 2005; Tokalakoglu, 2010; Sevim, 2011; Kaplan, 2012). There are also studies in which project duration is considered as one of the least important factors (Walraven & de Vries, 2009; Shokri-Ghasabeh & Chileshe, 2016). It is emphasized that lower costs should not be the only basis for choosing contractors, but also time and performance factors should be considered

(Obodo et al., 2021). According to these findings, it is understood that construction duration was not studied much in researches although many factors are considered in different studies. Moreover, better tender system and effective planning specified in the Development Plans have not been fully implemented (DPT, 2001; DPT, 2007; Turkish Republic Presidency of Strategy and Budget, 2019).

The most significant factor affecting the project duration was cost and many factors affecting the project duration were not considered (Odabasi, 2009). Similar with the interviews with TOKI personnel, Baltaci (2012) observed that market experience and job efficacy of the contractor and environmental impacts are also considered and no findings regarding time planning were found. Sonmez (2019) emphasized that the total construction duration in time-cost relationship for TOKI housing cannot be done with a single mathematical equation and there were time planning failures due to own characteristics of each construction project. For these reasons, it has been shown that a dynamic system is needed in accordance with the complex structure of TOKI projects. Turhan (2006) confirms delays in TOKI construction projects.

On the other hand Supreme Court case law indicates that there are legal disputes due to timely delays related to housing projects tendered by TOKI in Turkey (Supreme Court Office, 2010, 2011, 2013, 2014, 2015). Literature also indicates the same findings (Al-Khalil & Al-Ghafly, 1999; Aibinu & Jagboro, 2002; Odabasi, 2009), suggesting that TOKI shall use modern planning and programming techniques rather than utilizing data from previously completed projects.

The purpose of this paper to introduce the findings of the case studies searching the reasons and results of construction delays in housing projects in Turkey. The research is the initial part of a PhD thesis that aims to determine ideal construction duration for housing projects by considering factors affecting total construction duration by proposing a novel model where the findings of this research constitute such requirement. At the beginning of the research it is aimed to analyze the state-of-the-art and reveal the gap between construction duration calculated with Construction Documents or with only Schematic Design by TOKI and official contract durations.

Background

The project management is principally based on planning and programming (PMI, 2021). Construction projects are considered successful if they are completed on time within budget in specified quality (Majid, 2006). During the tender phase, effective planning and programming leads success in construction phase (Luu et al., 2009; Ismail, 2013; Tunc & Ozsarac, 2015). The most important factor affecting time, cost and quality in construction projects is insufficient planning and programming (Elinwa & Joshua, 2001; Ibironke & Elamah, 2011).

TOKI (Directorate of Public Housing and Partnership Administration) is a kind of pioneer in the public construction sector in terms of the purpose of establishment and it is authorized to build housing projects as client. TOKI primarily operates within the scope of the Public Housing Law No. 2886, No.2985, No. 4966 and No. 5162 (Turkish Republic Official Gazette, 1983, 1984, 2004; Baltacı, 2012). The project budgets are determined annually and the project is suspended in case there are not enough funds at the beginning of the year. This causes the project delivery date to be exceeded (Solak, 2013).

In planning and programming for tender phase, Department of Tender Affairs of TOKI prepares cost estimations of construction projects and job descriptions in the contracts. Odabasi (2009) observed that contractor selection method was single stage. In other words, a tender process is used that allows the bid was awarded directly to the eligible bidder for the jobs described in the tender requests. In this process, the work is given to the contractor with the lowest bid. The contractor is examined and analyzed by technical committee of TOKI, and the construction firms that previously worked with the chosen contractor are also asked about the contractor. If the TOKI committee is convinced that the contractor is suitable for the job, they decide to give project to the contractor. If the committee is not convinced about it, the same procedure is applied to other contractors (Odabasi, 2009). From this perspective, it is suggested that the contracts are based on cost and precedent projects of the contractor to persuade the TOKI committee. In practice, there is no evidence related to an official calculation method for total construction time.

Literature findings indicated that case studies are necessary for analysis of status and problems of calculating construction duration along with a proposed model utilizing factors affecting the construction duration (Lee et al., 2009; Jin et al., 2016; Yeom et al., 2018). Moreover, two case studies were performed to propose construction duration models while one case study was used to validate a proposed model. Since project duration was defined by the Client or suggested by contractor (Jin et al., 2016; Bayram, 2017), the construction duration computational model utilized by the Client during tender phase should be a specialized standard for Turkish housing projects. Therefore, it was concluded that case study approach is more appropriate for conducting this kind of research.

Methodology

This study was adopted as a case study methodology. According to Yin (2003), the case study can be exploratory to create new knowledge, constructive to solve some problems, or confirmatory to test a hypothesis with empirical evidence. The purpose of this case study was to analyze the state-of-the-art of TOKI housing projects. Baseline Construction Durations (BCD) were calculated for 1530 housing projects within "TOKI Projects Status Table" by using below equation which is extracted from the calculation method used by TOKI to estimate total construction duration for housing projects;

Baseline Construction Duration (BCD) (days) = (Number of working days in Factor #2a: "Duration with Construction Documents (DCD)" *corresponding to Factor #1:* "Number of Flats"*) + (50 working days in case use of Factor #2b:* "Duration with Schematic Design (DSD)"*) + (Factor #3: "Number of non-working days")* (1)

After that these durations were compared with the official contract durations. Duration with Construction Documents (DCD) and Duration with Schematic Design (DSD) were calculated separately and Contract Duration (CD) data were used to reveal the gap between Baseline Construction Durations and Contract Durations.

In the case studies either primary data (the researcher collects the data) or secondary data (the researcher uses someone else's data) can be used. Two case studies were implemented according to the tender processes of TOKI;

Case 1 – Calculation Duration with Construction Documents (DCD)
Case 2 – Calculation Duration with only Schematic Design (DSD)

Each case study was carried out with the intent to present a valid comparison of DCD/DSD versus Contract Duration (CD). Both cases are based on 1530 housing projects. Analysis, in line with the objective of this case study shows not only comparison of DCD/DSD versus Contract Duration, but also compares with Delay Time (DT) for housing projects. The phases of case study are as below;

Phase 1: Identification of Construction Duration by Literature Review.

Phase 2: Identification of Construction Duration Factors which TOKI used via Literature Review, Semi-Structured Individual Interviews with TOKI officials, case study observations, Supreme Court case law and TOKI documents (TOKI Projects Status Table).

Phase 3: Identification of Contract Durations and Delay Times from TOKI Projects Status Table.

Phase 4: Calculation of Baseline Construction Duration with Construction Documents and with only Schematic Design by Numerical Analysis.

Phase 5: Implementation and Validation of the Case Study by comparing Phase 4 values vs. Phase 3 values.

The scope of this case study was limited to TOKI housing projects, planning and programming activities in the tender phase, bidding processes defined and indicated within Public Procurement Law No. 4734, Public Housing Law No. 2985, No. 4966 and No. 5162, TOKI Standard Contract for Construction, Regulation on the Use of TOKI Resources (2002) and the Regulation on Construction Tenders Implementation (2009). Descriptive data is limited with TOKI projects' datasheet extracted from TOKI Project Status Table.

TOKI documents were scrutinized to determine the number of delayed projects and delay times for all projects. Delay in construction projects is defined as exceeding of time beyond the completion date specified in contract or the date agreed by the parties for the delivery of a project (Shahsavand et al., 2017). Analysis of the "TOKI projects' datasheet" showed that most delays occurred in housing projects.

Project information includes but not limited to the following: "project description", "project location", "contract date", "contract duration", "start and finish dates" on TOKI Projects' datasheet. Data analysis were conducted by percentage and frequency statistics. Total number of projects were 3500 and 700 ongoing projects were eliminated and 2800 projects were remained where 1530 of them was housing projects. The minority data which has insufficient information was also eliminated.

Approximate construction duration in this research refers to the total construction duration from the beginning to the end of the construction during the construction phase, which is estimated in the project planning phase. In order to understand the existing situation in better way, semi-structured interviews were conducted with TOKI officials in Ankara on 22-23 December 2015 and in Istanbul on 24-25 December 2015. Verbal information obtained from the TOKI authorities was noted. No audio recordings were allowed by TOKI in the data collection.

Documents such as periodical and non-periodical TOKI publications were obtained. During the interviews, objectives and scope of this case study were explained. Current implementations for planning and programming in tender phase, time allocated by TOKI personnel for completed projects and factors used to calculate total construction duration were asked. Findings from interviews and observations were suggested that total construction duration was not calculated in line with modern project management principles. Instead, duration estimations were based on data of previously completed projects. Also, it is observed that TOKI officials directly decide construction duration without using any tool or software.

Furthermore, Supreme Court cases were examined to reveal whether disputes were arisen due to delays of construction duration. Many conflicts were generally arisen from delays in project delivery dates specified on the contracts. Claims showed that houses were not delivered to the beneficiaries on the contract date.

Results

Findings of this study primarily involved the analysis of all types of projects constructed by TOKI within "TOKI Projects Status Table" and later focused on housing projects. Descriptive statistics for 2800 TOKI projects in. There were 22 different types of projects and most of them were 1530 housing projects. It was followed by hospital projects (347 units) and school projects (327 units). Most of the TOKI projects were executed in Central Anatolia Region with 590 units and the least were in the Mediterranean Region with 238 units.

As primary focus, analysis of the housing projects constructed by TOKI was revealed that 720 out of 1530 housing projects were delayed. The ratio of delayed TOKI housing projects to total number of TOKI construction projects (720/2800=0.2571) was 25.71%. The number of delayed housing projects out of 1530 TOKI housing projects was calculated as 720 and the delay rate (720/1530=0.4706) was 47.06%.

Table 1. Number of delayed TOKI construction projects and (%) percentages according to geographical regions.

Geographical Regions	Number of Delayed Projects	Total Number of Projects	Percentage 1* (%)	Percentage 2** (%)
Mediterranean	130	238	54.62%	8.50%
Eastern Anatolia	253	536	47.20%	19.14%
Aegean	121	260	46.54%	9.29%
Southeastern Anatolia	152	301	50.50%	10.75%
Central Anatolia	305	590	51.69%	21.07%
Black Sea	177	385	45.97%	13.75%
Marmara	229	490	46.73%	17.50%
Total	1367	2800	48.82%	

In Table1, Geographical regional distribution of projects, Percentage 1 and Percentage 2 ratios were used. 1367 out of 2800 construction projects in Turkey were delayed and 48.82% of the projects carried out by TOKI are not completed on time.

Percentage 1*: Number of delayed project in the region/ Total number of projects in the region.

Percentage 2**: Total number of project in the region / Total number of projects in Turkey.

Geographical regional distribution of Percentage 1 showed that the most delays occurred in the Mediterranean region (54.62%) and this was followed by Central Anatolia (51.69%), Southeast (50.50%) and Eastern Anatolian Region (47.20%), respectively. The Black Sea and Aegean regions had the highest number of projects completed on time. Geographical regional distribution of Percentage 2 showed that most of TOKI projects were executed in Central Anatolia Region (21.07%) and least in Mediterranean Region (8.50%).

Table 2. Number of TOKI construction projects with time extension according to geographical regions and (%) percentages.

Geographical Regions	Number of projects with time extension				Total (Nos)	Percentages (%)
	1	2	3	4		
Mediterranean	107	16	4	3	130	9.51%
Eastern Anatolia	209	33	8	3	253	18.51%
Aegean	102	13	3	3	121	8.85%
Southeastern Anatolia	119	23	8	2	152	11.12%
Central Anatolia	279	18	6	2	305	22.31%
Black Sea	162	10	2	3	177	12.95%
Marmara	197	22	6	4	229	16.75%
Totals	1175	135	37	20	1367	100.00%

In Table 2, Number of projects without time extension was (2800-1367) equal to 1433, with time extension only once was 1175, with second time extension was 135, with third time extension was 37 and with fourth time extension was 20. 130 of the 1367 delayed projects was in Mediterranean Region, 253 in Eastern Anatolia, 121 in the Aegean, 152 in Southeast Anatolia, 305 in Central Anatolia, 177 in the Black Sea and 229 in the Marmara Region.

The city with the most project delays in the Central Anatolia Region was Ankara with 142 projects, Istanbul with 110 projects in Marmara Region, Trabzon with 29 projects in the Black Sea Region, Van with 46 projects in the Eastern Anatolian Region, Izmir with 26 projects in the Aegean Region and Diyarbakir with 27 projects in the Southeastern Anatolia Region.

Central Anatolia Region ranks first with 181 housing projects without any time extension. However, it was determined that the same region had the highest number of housing projects with one time extension compared to other regions. Marmara Region had the highest number of housing projects with 12 projects having second time extension. The Eastern Anatolia Region is the only region without having third of fourth time extensions. It was also observed that the total number of housing projects with one time extension to second time extension dropped

from 654 to 47 drastically. From the perspective of cities, Ankara ranks first with 87 delays, followed by Istanbul with 59 and both Bursa and Adana with 18 delayed housing projects.

Table 3. Number and average delay times of delayed housing projects by geographical region.

Geographical Regions	Average construction duration of housing projects (days)	Number of housing projects (Nos)	Number of delayed housing projects (Nos)	Percentage of delayed housing projects (%)
Mediterranean	450	106	60	56.60%
Eastern Anatolia	446	271	96	35.42%
Aegean	445	142	64	45.07%
Southeastern Anatolia	484	139	69	49.64%
Central Anatolia	508	370	189	51.08%
Black Sea	474	220	104	47.27%
Marmara	541	282	138	48.94%
Totals	486	1530	720	

In Table 3, Average construction duration for a housing project was 486 days. Marmara Region was above Turkey's average construction duration with 541 days and the Central Anatolia Region with 508 days. The Southeastern Anatolia Region also had an average construction duration of 484 days, closer to the Turkey's average. Other regions showed durations below the average.

60 out of 720 delayed housing projects were in Mediterranean region, 64 in the Aegean Region, 69 in the Southeastern Anatolia Region, 96 in the Eastern Anatolia Region, 104 in the Black Sea Region, 138 in the Marmara Region and 189 in the Central Anatolia Region. The ratio of delayed housing projects to total delayed housing projects was 56.60% in the Mediterranean Region, 35.42% in the Eastern Anatolia Region, 45.07% in the Aegean Region, 49.64% in the Southeastern Anatolia Region, 51.08% in the Central Anatolia Region, 47.27% in the Black Sea Region and 48.94% in the Marmara Region. It is a significant result that almost half of housing projects in all regions have delays with approximately 50%.

Case 1: Calculation Duration with Construction Documents (DCD)

In the last phase of this case study, Baseline Construction Duration with Construction Documents and Schematic Design were compared with contract durations and delay times for housing projects.

Table 4. Comparisons of DCD, CD and DT.

	Durations	Values (%)
Comparisons of DCD with CD	DCD-CD<0 (Negative)	37.29
	DCD-CD>0 (Positive)	62.71

Comparison of (DCD-CD) with DT	(DCD-CD)-DT<0 (Negative)	28.66
	(DCD-CD)-DT>0 (Positive)	71.34

In Table 4, the differences were found positive for 62.71% of the housing projects by subtraction of CD from DCD. The results equal to zero were negligible due having no significant meaning in view of the study. The positive value indicates that the DCD values are higher than CD values for majority of housing projects. In this case, it was determined that DCD obtained from total construction duration calculated by TOKI was usually longer than CD duration and it showed that TOKI was greatly shortened the total construction duration in official contracts. In other words, total construction durations have been proven to be shorter than they should be for almost 63 projects out of 100 housing projects.

Firstly, CD values were subtracted from DCD values in Table 4. This difference showed how much TOKI authorities were shortened the construction duration and used in the construction contracts. Second, the contract date was subtracted from the project completion (finish) dates to find delay time (DT). Third, (DCD-CD) values were subtracted from the DT value, resulting in 71.34% positive values. Positive value for 71.34% of housing projects indicated that shortening of total construction durations by TOKI officials was higher than the delays. In other words, the magnitude of the duration shortened was generally much higher than delay times in housing projects. Even if delay margins were added to the contract duration for a housing project, DCD value could not be reached at this case. This showed how major the shortenings were made by TOKI during the tender phase. This major difference means that the contract duration determined by TOKI have low reliability. It is clear that delays in total construction duration will lead more prosecutions against contractors rather than TOKI.

Case 2: Calculation Duration with Schematic Design (DSD)

In order to calculate DSD, DCD was firstly determined according to the number of flats in Equation 1. Afterwards, 50 days were added to DCD value and DSD was calculated and then the non-working days were also added and consequently final DSD values were reached according to the location of the project.

Table 5. Comparisons of DSD, CD and DT.

	Durations	Values (%)
Comparisons of DSD with CD	DSD-CD<0 (Negative)	23.20
	DSD-CD>0 (Positive)	76.80
Comparison of (DCD-CD) with DT	(DSD-CD)-DT<0 (Negative)	24.61
	(DSD-CD)-DT>0 (Positive)	75.39

In Table 5, the differences were found positive for 76.80% of housing projects by subtraction of CD from DSD. The results equal to zero were negligible due having no significant meaning in view of the study The positive value indicated that the DSD values were higher than CD values for majority of housing projects. In this case, it was determined that DSD obtained from total construction duration calculated by TOKI was usually longer than CD duration and it showed that TOKI was greatly shortened the total construction duration in official contracts. In other words, total construction durations have been proven to be shorter than they should be for almost 77 projects out of 100 housing projects.

Firstly, CD values were subtracted from DSD values in Table 5. This difference showed how much the TOKI authorities shortened the construction duration and used in construction contracts. Second, the contract date was subtracted from the project completion (finish) dates to find delay time (DT). Third, (DSD-CD) values were subtracted from the DT value, resulting in 75.39% positive values. Positive value indicated that shortening of total construction durations by TOKI officials was higher than the delays for 75.39% of housing projects. In other words, the magnitude of the duration shortened was generally much higher than the delay times in housing projects, similar to those DSD's. Even if delay margins were added to the contract duration for a housing project, DSD value could not be reached at this case. This showed how major the shortenings were made by TOKI during the tender phase. This major difference also means that the contract duration determined by TOKI have low reliability. It is obvious that delays in total construction duration will lead more prosecutions against contractors rather than TOKI.

Conclusion

This study revealed that 720 housing projects were delayed with a rate of 47.06% among 1530 housing projects. The ratio of delayed housing projects in all TOKI projects was 25.71%. Results from case study analysis for TOKI housing projects showed that DCD values were evidently higher than CD values. Thus, it was determined that CD values were greatly shortened by TOKI for the calculation of total construction duration. Similarly, as a result of comparison of (DCD-CD) with DT, positive values were obtained in excess amount of TOKI projects and it was observed that the magnitude of shortened duration was generally higher than the delays in housing projects. These findings suggested that the shortening of contract duration was considerably high. Greater contract duration shortenings also caused contractors to deliver projects more delayed to the stakeholders.

In conclusion, it is shown that three factors used by TOKI to calculate the total construction duration were not sufficient. TOKI officials determine the official contract duration by significantly shortening the Baseline Construction Duration through discernment other than these three factors. The study found that this shortening gap were excess where there were many housing projects delayed, and delays led to time and cost losses for all project stakeholders. Therefore, it became clear to propose a model which shall calculate ideal construction duration and consider additional factors affecting total construction duration.

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A Proposed Model for Estimation of Ideal Construction Duration in Housing Projects

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Abstract

There are various factors affecting construction duration such as number of flats, drawing type, priority of project and complexity, financial risks, location, and climatic factors. Estimation models for construction duration with various factors have been used by previous researches to estimate construction durations. Despite these models, only a few studies applied in tender phase and less in housing projects. Moreover, research related to construction duration in Turkey showed that there were considerable delays occurred in housing projects. For this reason, it was decided to investigate the factors affecting construction duration only for housing projects to propose a novel model to achieve "Ideal Construction Duration". Data was obtained from Housing Development Administration of Republic of Turkey (TOKI) which has been major client to build housing projects in Turkey. Statistical data analysis was performed by multiple regression analysis, CHAID and CART. Findings shown that several factors were significantly affected the Ideal Construction Duration for each statistical method. The cut-offs and standard errors were calculated to test the validity statistical methods. Testing of model was conducted with regression equation. After testing of model, it was observed that the delays in housing projects were significantly decreased.

Keywords: *CHAID and CART analysis, construction duration estimation, factors affecting construction duration, planning in construction, project management, regression analysis.*

Introduction

Construction project is regarded as successful if it is completed on time with other criterion such as cost, quality and stakeholder satisfaction (Chan & Kumaraswamy, 2002; Majid, 2006). Estimation of "Ideal Construction Duration" is necessary due to common delays, efficiency of organizations and benchmarking performance of a project in construction industry (Chan & Kumaraswamy, 2002; Mensah et al., 2017). Effective planning and programming prevents delays and provides enhanced construction project performance which results in time- and cost-savings (Gibson et al., 2006; Luu et al., 2009; Ismail, 2013; Lines et al., 2014; Tunç & Özsaraç, 2015). Poor planning and programming has negative impacts on Client, contractor and owner (Ndekugri et al., 2008). However, literature on planning and programming for construction duration during tender phase is limited.

Although time planning and programming in tender phase were regulated by relevant laws and authorized organizations (FIDIC, 2017), it was observed that it is not the case for public construction industry in Turkey (Yitmen & Dikbas, 2002; Birgonul et al., 2007; Koktas et al., 2009; Akkaynak, 2013; Erbas & Ciraci, 2013; Usta, 2014) due legal regulations reckon without planning but prioritize only the lowest tender price (Türesoy, 1989; Karapinar, 2005; Tokalakoglu, 2010; Sevim, 2011; Kaplan, 2012). It is emphasized that lower costs should not be the only basis for choosing contractors, but also time and performance factors should be taken into account (Obodo et al., 2021). Moreover, better tender system and effective planning specified in the Development Plans have not been implemented (DPT, 2001; DPT, 2007; Turkish Republic Presidency of Strategy and Budget, 2019). Although stakeholders of construction industry are aware of the importance of construction duration, it was determined that many contracts had not met requirements (Lin et al., 2011). According to these findings, it is evident that construction project completion on time is a prevailing issue and projects in Turkey are lacking of time planning and programming.

In Turkey, the most significant factor affecting housing project duration is cost and many other factors are not taken into account (Odabasi, 2009; Baltaci, 2012; Sonmez, 2019). In practice, most estimation methods for construction duration depends on the "subjective skill and cognition of the estimators and planners, rather than on objective assessment" (Lin et al., 2001). On the other hand, Supreme Court case law indicates that there are legal disputes due to timely delays related to housing projects in Turkey (Supreme Court 13. Law Office, 2010, 2011, 2013, 2014, 2015). Literature also indicates the same findings (Al-Khalil & Al-Ghafly, 1999; Aibinu & Jagboro, 2002; Odabasi, 2009), suggesting that clients shall use modern planning and programming techniques rather than utilizing data from previously completed housing projects. For these reasons, a reliable estimation tool is needed in accordance with the complex nature of housing projects.

As mentioned above, there is a potential gap for a research on modelling construction duration in tender phase for housing projects. In order to fill this research gap, it is necessary to develop, validate, and test a model calculating Ideal Construction Duration by utilizing necessary factors affecting construction duration from both literature and TOKI along with evaluation criterion to prevent delays in TOKI housing projects. Model should be also compatible with the existing bidding system and user-friendly, thus preventing cost and time losses. Therefore, this article proposes a model that can help Ideal Construction Duration for housing projects in tender phase. The model is based on data collected from TOKI regarding construction durations. Findings of this study are expected to allow all project stakeholders to estimate Ideal Construction Duration for housing projects during tender phase. This study is ultimately intended to contribute decision making processes for the project managers.

Background

The construction duration has been considered as one of the main criteria for performance of housing projects in the construction industry (Bromilow, 1969; Chan & Chan, 2004; Aibinu & Odeyinka, 2006; Ting et al., 2021). However, the delay of housing projects is still a common problem (Lin et al., 2011; Bromilow, 1969; Al-Khalil & Al-Ghafly, 1999; Blyth et al., 2004; Iyer & Jha, 2006).

Construction duration of projects are often overlooked by assumptions or comparisons and are not considered early stages of construction projects (Elinwa & Joshua, 2001; Walraven & de

Vries, 2009; Ibironke & Elamah, 2011; Shokri-Ghasabeh & Chileshe, 2016; Oyedele, 2013; Oyedele et al., 2015; Obodo et al., 2021). At the tender phase of construction project, stakeholders seek a reliable estimation of project duration (Qiao et al., 2019; Thing, 2006; Jin et al., 2016; Wang et al., 2012).

There were a wide variety of factors affecting construction durations (Oo et al., 2022). Although project costs are largely dependent on project duration, it was determined that complexity and size of the projects, rate of return and cash flow, type of contract, priority of projects, previous experiences and geographical area are given more importance across globe (Ahmad & Minkarah, 1988; Shash, 1993; Fayek et al., 1998; Fayek et al., 1999; Hillebrandt, 2000; Bageis & Fortune, 2009; Jarkas et al., 2013; Alsaedi et al., 2019). Researches for estimating construction duration were mainly focused on financial and economic factors (Turesoy, 1989; Wa'el Alaghbari, 2005; Shane et al., 2009; Musarat et al., 2021), climatic, geographical and topographic factors (Ellag et al., 2005; Shane et al., 2009; Cheng, 2014; IAEA, 2018), complexity and size of projects (Singh, 1984; Kerzner, 1991; Chevallier & Russell, 2001), priority of project (Yang et al., 2014), supply and logistic conditions of the project region (Asnaashari et al., 2009; Ramli et al., 2018; Tunji-Olayeni et al., 2018; Nayak, 2019), social and cultural factors (Imbert, 1990; Assaf & Al-Hejji, 2006; Salleh, 2009; Al-Sabah et al., 2014). Despite several factors are considered in different studies, literature findings showed that construction duration is mostly ignored.

Several construction duration estimation models have been developed from these factors. To predict duration, many researchers demonstrated the applicability of regression analysis in duration estimation in early phases of a project (Khosrowshahi & Kaka, 1996; Lin et al., 2011). Simulations model were also used to estimate construction duration. Sanni-Anibire et al. (2021) developed a machine learning model including Multi-Linear Regression Analysis (MLRA), k-Nearest Neighbors (KNN), Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Ensemble Methods for tall building projects (Fan et al., 2021). Yogesh and Rao (2021) developed a system to estimate road construction durations by using Delphi analysis. Yaseen et al. (2020) used hybrid artificial intelligence model. Lines et al. (2014) demonstrated that time planning model during tender phase results in cost and time reduction, as 44.0% and 44.9%, respectively. Another study by Lines et al. (2015) determined that the planning model at the tender stage reduced the cost and duration by 54% and 70%, respectively.

Decision tree algorithms, namely classification and regression tree (CART) and chi-squared automatic interaction detection (CHAID) are also used for duration estimation (Godinho & Costa, 2004). However, few researchers have used CART and CHAID in construction industry. Lin and Fan (2019) used CHAID and CART to identify defects in public construction projects to reduce adverse effects on completion duration. Pospieszny (2015) used CHAID for estimation of effort and duration of software projects. A hybrid software cost estimation approach was also developed by using CHAID and CART (Papatheocharous & Andreau, 2012).

Scope of This Paper

The scope of this paper was limited to TOKI housing projects, planning and programming activities in the tender phase, bidding processes defined and indicated within Public Procurement Law No. 4734, Public Housing Law No. 2985 (1984), No. 4966 and No. 5162 (2004), TOKI Standard Contract for Construction, Regulation on the Use of TOKI Resources (2002) and the Regulation on Construction Tenders Implementation (2009) in Turkish Republic

Official Gazette. During data collection from TOKI interviews, TOKI Projects Status Table was obtained. In addition, approximate construction duration in this research refers to the total construction duration from the beginning to the end of the construction during the construction phase, which is estimated in the project planning phase. The scope of quantitative methods involve regression, CHAID and CART by using SPSS 26.0 (Statistical Package for the Social Sciences) software.

Methodology

This research was adopted quantitative methodology. Research method and procedure was included four phases: Preparation phase, development phase, validation phase, testing phase of model. The research method steps were explained in Figure 1.

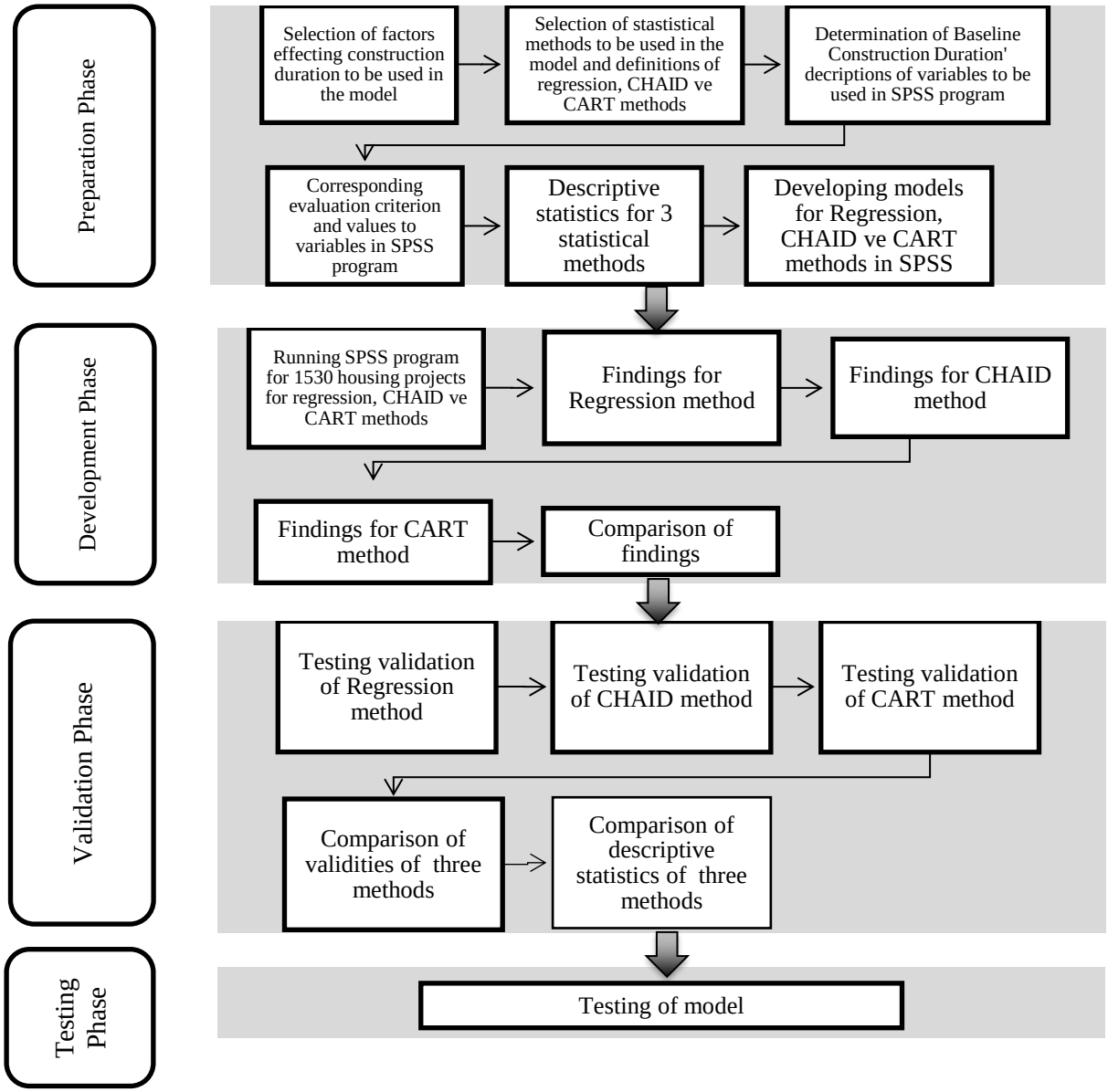


Figure 1: Flow chart for research method and procedures.

Preparation of the Model

Descriptive statistics for 2800 TOKI projects were determined by using the data in the "TOKI Projects Status Table" where descriptive data is limited with TOKI projects' datasheet extracted from TOKI Project Status Table.

There were 22 different types of projects and most of them were 1530 housing projects. Average construction duration of housing projects were 486 days. The housing projects corresponded to 25.71% of 2800 TOKI projects. 1367 out of 2800 construction projects in Turkey were delayed and approximately 49% of the projects carried out by TOKI are not completed on time. 720 out of 1530 housing projects were delayed. The ratio of delayed TOKI housing projects to total number of TOKI construction projects (720/2800=0.2571) was 25.71%. The number of delayed housing projects out of 1530 TOKI housing projects was calculated as 720 and the delay rate (720/1530=0.4706) was 47.06%. It was determined that number of delayed projects among TOKI projects was the highest for housing projects by 25.71%. Therefore, it was decided to establish the model with only housing projects.

In order to select the factors affecting construction duration, 56 factors were obtained from literature review and 11 factors selected to be used in the model were given in Table 1.

Table 1. Description of factors.

Factor No.	Description of Factors	Variable Type
F1+F2+F3 (standardized)	Baseline Construction Duration	Independent Variables
F4	Priority of Project	
F5	Complexity of Project	
F6	Special Request for Project	
F7	Difficulty of Project	
F8	Financial Risk of Project	
F9	Logistic Conditions of Project Region	
F10	Climatic Conditions of Project Region	
F11	Seismicity of Project Region	
Y	Ideal Duration (Days)	Dependent Variable

The determination of magnitude of effect on construction duration for each variable, evaluation criterion and values were used. For the first eight factors, evaluation criteria values were coded as "0, 1, 2" where 0 represents "no effect" on duration, 1 represents "reduce" the duration and 2 represents "increase" the duration. For F9 and F10, evaluation criteria values were coded as categorical from 1 to 7 where as the value increases, the effect on duration also increases. For F11, evaluation criteria values were coded as categorical from 1 to 5 where as the value increases, the effect on duration also decreases.

The purpose of this paper was to analyze the state-of-the-art of TOKI housing projects. Baseline Construction Durations (BCD) were calculated for 1530 housing projects within "TOKI Projects Status Table" by using below equation which is extracted from the calculation method used by TOKI to estimate total construction duration for housing projects.

Baseline Construction Duration (BCD)(days) = (Number of working days in Factor #2a: "Duration with Construction Documents (DCD)" *corresponding to Factor #1:* "Number of Flats"*) + (50 working days in case use of Factor #2b:* "Duration with Schematic Design (DSD)"*) +(Factor #3: "Number of non-working days")* (1)

Multiple linear regression analysis with backward elimination method and non-parametric CHAID and CART analysis were used to determine the factors affecting the Ideal Construction Duration. Chi-squared Automatic Interaction Detection (CHAID) is used for the identification and analysis of classified dependent variables. Classification and regression tree (CART) is a non-parametric statistical method to estimate categorical or continuous dependent variables is also used. Data analyses were performed by using SPSS 26.0. p-value less than 0.05 indicates that findings should be significant at least 95% level.

Results

Descriptive statistics in the study were shown in Table 2. The average Ideal Construction Duration was 679 days for regression analysis, 704 days for CHAID and 706 days for CART analysis respectively.

Table 2. Results of descriptive analysis for regression, CHAID ve CART analysis.

Method Used in Model	Ideal Construction Duration				
	N	Average	Std. Dev.	Min.	Max.
Regression Analysis	1530	679.16	133.20	387	1355
CHAID	1530	704.38	113.13	635	1051
CART	1530	705.98	109.50	640	926

The comparison of descriptive statistics implied that average Ideal Construction Duration was slightly higher in CHAID and CART methods with lower standard deviations. Minimum and maximum values of Ideal Construction Duration were considerably different.

Table 3. Results of regression analysis.

Variables	R^2	β	t	p	VIF
Constant	0,356	663630	21009	.000***	
Standardized Baseline Construction Duration (F1+F2+F3)		146447	27833	.000***	1.160
Priority of Project (F4)		-48437	-3733	.000***	1.341
Complexity of Project (F5)		-47053	-4057	.000***	1.402
Special Request for Project (F6)		-.029	-1249	.212	1.279
Difficulty of Project (F7)		43870	3800	.000***	1.047
Financial Risk of Project (F8)		-18510	-2326	.020*	1.011
Logistic Conditions of Project Region (F9)		-3953	-1716	.086	1.088
Climatic Conditions of Project Region (F10)		-13676	-4768	.000***	1.045
Seismicity of Project Region (F11)		-.024	-1205	.228	1.115

*p≤0.05, **p≤0.01, ***p≤0.001

In Table 3, Ideal Construction Duration was significantly affected by Baseline Construction Duration (F1+F2+F3), Priority of Project (F4), Complexity of Project (F5), Difficulty of Project (F7), Financial Risk of Project (F8) and Climatic Conditions of Project Region (F10). A one-day increase in the Ideal Construction Duration would increase the Baseline Construction Duration by 146 days, Complexity of Project by 47 days, Priority of Projects by 48 days, Difficulty of Project by 43 days, Financial Risk of Project by 18.5 days and Climatic Conditions of Project Region by 14 days. Baseline Construction Duration (F1+F2+F3) had a major impact on Ideal Construction Duration.

The root node at the top of the CHAID tree diagram was divided into six groups at the first tree depth in terms of Baseline Construction Duration. The root node at the top of the CART tree diagram was divided into two groups at the first tree depth in terms of Baseline Construction Duration and both results given in Table 4.

Table 4. Significant variables for all three methods.

Variables	Regression Method	CHAID Method	CART Method
Standardized Baseline Construction Duration (F1+F2+F3)	Significant	Significant	Significant
Priority of Project (F4)	Significant	Significant	Significant
Complexity of Project (F5)	Significant	-	-
Difficulty of Project (F7)	Significant	-	-
Financial Risk of Project (F8)	Significant	-	-
Logistic Conditions of Project Region (F9)	-	Significant	Significant
Climatic Conditions of Project Region (F10)	Significant	Significant	-
Seismicity of Project Region (F11)	-	Significant	-
Special Request for Project (F6)	-	-	-

Among the 11 factors affecting Baseline Construction Duration, eight, seven, and five factors were found significant in regression, CHAID and CART analysis, respectively. The first three factors were counted as one variable, as the Baseline Construction Duration was standardized. In this case, it was determined that six variables were significant for the regression method, five variables for the CHAID method, and three variables for the CART method.

The model equation, consisting significant variables in the regression method was obtained as follows:

*Ideal Construction Duration(Y) = 663.630 + 146,447*Std. Baseline Construction Duration - 48,437* Priority of Project (F4)-47.053*Complexity of Project (F5) +43.870* Difficulty of Project (F7)-18.510*Financial Risk of the Project (F8)-13.676*Climatic Conditions of the Project Region (F10)* (2)

Contrary to the regression method, Logistics Conditions of the Project Region (F9) showed significance in the CART and CHAID methods. Contrary to the regression and CART methods, the Seismicity of the Project Area (F11) was determined as a significant factor in the CHAID method. Special Request for Project (F6) was not significant in all three methods. While Logistics Conditions of the Project Region (F9) in the CHAID method showed significance, the Priority of Project (F4) in the CART method was found significant on the Ideal Construction Duration. CHAID and CART analysis provided the most suitable solution for the model by

using decision trees for all independent variables. The regression method did not categorize the effects of independent variables but evaluated them as numerical outcomes in the form of a model equation. The main and common purpose of all three methods was to estimate the Ideal Construction Duration in the most suitable way.

Validation Phase

The validity of CHAID and CART methods was obtained through 10-fold cross-validation, 70/30 training and test sets, and standard error values for estimations. Enter and Stepwise methods were used for the validation of regression method.

Validation of the regression method. Collinearity exists if the tolerance is less than 0.1 or if VIF > 10 (Yeom et al., 2018). In this model, collinearity did not exist because VIF of the construction duration was smaller than 10.

Table 5. Validity of regression method.

	Group 1 (Enter method)			Group 2 (Stepwise method)		
	B	t	p	B	t	p
Constant	696696	18876	.000***	646473	21562	.000***
Standardised Baseline Construction Duration (F1+F2+F3)	146765	27548	.000***	148020	28551	.000***
Priority of Project (F4)	-55102	-3981	.000***	-50401	-3897	.000***
Complexity of Project (F5)	-48665	-4179	.000***	-47116	-4060	.000***
Special Request for Project (F6)	-18039	-1329	.184	-.033	-1431	.153
Difficulty of Project (F7)	43636	3781	.000***	47520	4185	.000***
Financial Risk of Project (F8)	-17,797	-2,231	,026*	-18340	-2304	.021*
Logistic Conditions of Project Region (F9)	-4285	-1800	.072	-.037	-1716	.086
Climatic Conditions of Project Region (F10)	-13893	-4835	.000***	-14443	-5081	.000***
Seismicity of Project Region (F11)	-5978	-1205	.228	-.014	-.680	.496

*p≤0.05, **p≤0.01, ***p≤0.001

Results of regression analysis in Table 5 showed that regression method was valid due that results of enter method and stepwise method are close to each other.

Validation of the CHAID method. In Table 6, Standard error for CHAID method was similar with the one calculated by 10-fold cross validation which secures the validation.

Validation of the CART method. In Table 7, *Standard* error for CART method was similar with the one calculated by 10-fold cross validation which secures the validation. The comparison of validity results implied that regression method indicated more accurate results than CHAID and CART methods as shown in Table 8. Regression method can be used to estimate the Ideal Construction Duration over six factors in future studies. Standard errors of all three methods were similar.

Table 6. Validity of CHAID method.

Method	Estimation	Standard Error
CHAID	37227.186	3109.763
10-fold cross validation	40115.651	3524.340
Training Set (70%)	36616.334	5011.920
Test Set (30%)	42521.916	4823.904

Table 7. Validation of CART method.

Method	Estimation	Standard Error
CHAID	33379.264	3166.306
10 fold cross validation	41092.216	3860.222
Training Set (%70)	43341.801	5111.257
Test Set (%30)	41189.758	5133.594

Table 8. Comparison of validity results of regression, CHAID and CART methods.

Model	Number of Significant Variables	Estimation	Standard Error
Regression	6	36495.932	3039.935
CHAID	5	37227.186	3109.763
CART	3	33379.646	3166.306

The results obtained from decision tree methods showed similarity with the regression method. However, apart from the regression method, CHAID and CART methods can show more significant and more specific results in determining the Ideal Construction Duration.

Testing of Model

The data composed of 40 delayed housing projects that were selected for pilot study to test the model. These housing projects were chosen among 3500 projects listed in "TOKI Project Status Table" by random sampling method. These 40 selected projects consisted of recently completed housing projects with delay. The number of test data was kept above the minimum limit for

normality condition of 30 data (Field, 2009; Cevahir, 2020).

To test the selected data, regression equation was utilized. Variables showing statistical significance in regression method that were used for testing. It was observed that the results obtained for 40 housing projects by utilizing regression equation in the SPSS 26.0 was accurate and convenient. In other words, test results of model were reliable.

Table 9. Testing of model.

	Pre-test	Post-test
Number of Delayed Housing Projects	40	23
Delay Percentage	100%	57.50%
Reduction Amount of Delayed Housing Projects (%)	-	42.50%

As shown in Table 9, it was determined that regression method for test data reduced the number of delayed housing projects by 42.50%. It was also observed that the number of delays in housing projects decreased from 40 to 23. Post-test delay times of 23 delayed housing projects were also reduced.

Conclusion

It was shown that factors used by TOKI to determine Baseline Construction Duration were not sufficient. It was proven that additional factors from literature were required to achieve more accurate durations. Statistical analysis showed that all three statistical models were valid. Regression method indicated more accurate results compared to CHAID and CART. Therefore, the Ideal Construction Duration could be predicted over six factors by utilizing the regression method in the future. Despite CHAID and CART methods had lower performances compared to regression method, it was revealed that Ideal Construction Duration estimations can be achieved by utilizing less factors. Thus, it was proven that the Ideal Construction Durations could be calculated by all three methods. Indeed, it was argued that a factor that shown significancy within any model at least once shall be considered for Ideal Construction Duration estimation.

Testing of model showed that the model reduced number of delayed housing projects and delay times. In this sense, results implied that the model is useful and valid. The model also supports the optimization of total construction duration. It was possible to ensure that TOKI housing projects were completed on time by determining the Ideal Construction Duration, thus preventing delays which consequently will lead better cost management and less dispute among stakeholders.

A more practical and consistent project management tool was developed by the model that ensures the prevention of problems during tender phase and leads less risks during construction phase. In future researches, this proposed model can be transferred into a digital environment and converted into a computer program to increase the number of users, expanding to public and TOKI personnel. Thus, the proposed model can be utilized in a wider range.

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Construction Project Manager Selection for Superstructure Projects Using AHP and TOPSIS Multi-Criteria Decision Making Techniques

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Abstract

Construction projects involve very complex processes with the pressure and risks created by the multi-stakeholder structure of the sector due to high quality expectations, limited construction periods and large investment costs. Due to this high-risk nature of the sector, it is of vital significance for the project to keep the risks under constant control for the later stages of the project by foreseeing, organizing and planning them within the framework of a methodological project management. At that point, the project manager is the responsible one who will ensure that the project is completed within the framework of specified quality, budget and time. In this context, the selection of a qualified project manager has gained great significance for the sustainability of projects. In this study, the 5 most important risk factors and their sub-titles, that can be encountered in superstructure projects, has been obtained by expert opinions and grouped in themselves. These risk headings has been planned to be evaluated by 5 project managers to choose the most suitable project manager for the investor. While making the selection, it was aimed to reach the result in the TOPSIS method by weighting the risk factors with AHP (analytical hierarchy method), one of the multi-criteria decision making techniques. Thus, while choosing the project manager, it was aimed to reach a more rational result with a mathematical approach rather than emotionality.

Keywords: *analytical hierarchy, construction project manager, construction risks, manager selection, multi-criteria decision making*.

Introduction

A project is an effort to obtain a unique product or service with clearly defined start and end activities, under budget, time, resource and quality constraints, with well-defined goals and objectives (PMI, 2008). By another definition, a project is a set of activities in which the stages of the task are planned, performed, and all these activities are created to achieve a specific goal.

Project management is defined as the application of all knowledge, skills, methods, tools and techniques to project activities in order to meet project needs (PMI, 2013). It is likely to complete the projects produced in the construction sector by staying within the required time, quality and specific budget with a coordinated work. This coordinated work is formed within the concept of project management. Successful implementation of project management in

construction projects is carried out with the coordination of project management techniques and project management methodologies (Kömürlü and Toltar, 2018).

Project management is a discipline that has certain rules about how to manage projects, and its goal is to complete projects and reach the final point successfully (Newton, 2006).

The person authorized to complete the project successfully is called the project manager. The duties, authorization and responsibilities of project managers in construction projects can be listed as follows (İnşaat Tekniği, 2014);

- Ensuring that the project management policies determined by the senior management are understood by the construction sites connected to the project and that the activities are carried out within this framework

- Preparation, revision and follow-up of work schedules, master plans and budgets of the projects/projects for which he/she is responsible

- To ensure that the necessary measures are taken by detecting possible disruptions with labor, financing needs and projections in parallel with the reports prepared during the construction of projects

- Preparation of the 'Project Management Plan' and execution of the project within this plan

- Selection and approval of subcontractors, preparation of their contracts, management and performance monitoring

- Ensuring flow of information by establishing an effective communication and coordination network between the project and the central units

- Selection, approval, preparation of contracts and performance monitoring of suppliers

- Planning of project cash flow

- Preparation, control and approval of progress payments and final accounts by the employer in accordance with the contract and company interests

- Ensuring that all support and service units of the construction site work in accordance with the workflow

- Carrying out the occupational safety in accordance with the procedures by taking all precautions and controlling the activities.

- Representing the company in the best way by developing good relations with the employer, employer representatives, partners, site workers, union representatives, official institutions and the surrounding community.

- Conducting, coordinating and finalizing all the works related to the project delivery, such as temporary acceptance, final acceptance, with the employer/employer representative and central units.

- To take an active part in resolving disputes in cooperation with domestic/international technical consultants and lawyers

People undertaking the project management should have some technical and non-technical characteristics in order to fulfill all these authorities and responsibilities properly. The most important non-technical features of the project manager are; leadership, empathy, referral, management and orientation ability, follow-up, coordination, responding to customer expectations and being understood (Atabey, 2020).

Construction projects involve very complex processes due to the pressure and risks created by the multi-stakeholder structure of the sector, as well as high quality expectations, limited construction times and large investment costs. Due to this high-risk nature of the sector, it is of vital significance for the project to keep the risks under constant control for the later stages of the project by foreseeing, organizing and planning them within the framework of a methodological project management.

At that point, the project manager is the person who will ensure that the project is completed in the quality, budget and time desired by the investor by evaluating and managing every negative element that may occur in the project and will take the responsibility. In this context, the selection of a qualified project manager has gained great significance for the sustainability of the projects.

Personnel selection, which is a part of the principles and practices of human resources management, is an issue that should be emphasized in the construction sector, where labor is intense, as in other sectors (Anbarcı & Manisalı, 2012). Employees are the most significant key resource in an organization that determines the success of that organization today with their knowledge, ability and motivation (Karabesevic et al., 2018). The decisions to be made about hiring a person are very important for the sustainability and success of the organization. (Afshari et al., 2014). Selecting talented, ambitious and skilled candidates helps businesses achieve the success (Demirci & Kılıç, 2019). The purpose of the personnel selection process is to benefit from the techniques necessary to meet the personnel needs of the enterprise in the most accurate way and to provide sufficient number and quality personnel in a timely manner (İçigen & Çetin, 2018). Personel selection is a strategic issue for organizations, and it is necessary to use imprecise and uncertain data in the decision-making process (Dağdeviren, 2007). Organizations make use of many traditional or modern methods during personnel selection. Some of these techniques are interview and test methods. The training, skills and personality characteristics of the candidates are evaluated together by the company officials participating in the interview using the interview method, which is considered the most appropriate technique for selecting personnel. In this case, the evaluation results may differ depending on the authorities of the company performing the evaluation. In addition, there is no generally accepted scale for the characteristics to be evaluated. Therefore, the solution of the problem with known arithmetic operations may not be very healthy here (Anbarcı & Öz, 2015). Another method used to identify the right candidates with the qualifications and abilities to meet the needs of the business is MCDM methods (Ilgaz, 2018). The need to measure qualitative variables along with quantitative variables has made the data richness and the use of numerical techniques a necessity (Özdemir, 2015). More effective and efficient supportive decision-making tools that will contribute to the individual skills of decisionmakers in complex decision-making processes are a necessity (Yıldırım & Önder, 2015).

In addition to intuitions, experiences and limited information, an analytical evaluation of the decision process is required for rational decisions (Can, 2015).

Working conditions, which are constantly changing and getting harder over time, condition people, institutions and businesses to choose the good and successful ones in decision making (Forman & Gass, 2001). Numerical methods or decision technologies (decision analysis, models, algorithms and theories) have a positive effect on the decision making process (Carlson & Fuller, 1996).

The use of Multi-Criteria Decision Making (MCDM) methods in the decision-making phase helps managers evaluate alternatives and ensures more efficient use of business resources. MCDM methods are an analytical method that provides the opportunity to evaluate many strategic and operational factors that can be measured and not measured at the same time, and that can include many people in the decision-making process (Dağdeviren et al., 2005). MCDM method, such as group decision (Chu et al., 2007; Opricovic & Tzeng, 2007), quality (Tong et al., 2007), engineering (Liu & Yan, 2007) and enterprise resource planning (Büyüközkan & Ruan, 2008) used in various fields.

Multi-Criteria Decision Making; It consists of two main parts, namely Multi-Objective Decision Making and Multi-Attribute Decision Making (Phua & Minowa, 2005). MultiAttribute Decision Making method is used to solve problems consisting of more than one criterion. In this method, **AHP** (Analytic Hierarchy Process), **ANP** (Analytic Network Process), **TOPSIS** (Technique for Order Preference by Similarity to Ideal Solution), **PROMETHEE** (Preference Ranking Organization Method for Enrichment Evaluation) and **ELECTRE** (Elimination and Choice Translating Reality) are the most preferred methods (Timor, 2011).

In his study, Dağdeviren (2007) proposed an algorithm for solving the personnel selection problem with the Fuzzy Analytical Hierarchy Process (FAHP) method. The proposed algorithm was used to determine the personnel to be promoted in a business and priority values were determined for the candidate personnel. In the application of the proposed model, the factors and sub-factors in the decision-making process were decided by using fuzzy numbers, and in this way, the uncertainties in the process were evaluated more easily by the decision makers.

Samanlıoğlu et al. (2008) proposed a framework for the evaluation and selection of personnel for an information technology department. Personnel evaluation is a complex and multicriteria decision-making problem involving many qualitative and quantitative criteria. Due to the ambiguous and imprecise nature of the evaluation and criteria, an integrated AHP-TOPSIS method, in which the decision makers' decisions are expressed with fuzzy numbers, is determined here to rank the different information technology experts. After determining the weights obtained from fuzzy AHP by scope analysis, alternatives were listed with fuzzy TOPSIS.

Doğan and Önder (2014), in their study, aimed to present a model in which the most suitable candidate(s) can be selected by using multi-criteria decision making techniques in the human resources procurement and selection process. For this purpose, the qualifications of the candidates were obtained from the expert opinions, job advertisements of the companies and the literature. Then, the degree of importance of the characteristics that the candidates should have was analyzed with the Analytical Hierarchy Process (AHP) with the survey data obtained from the experts and faculty members. In line with the order of importance determined as a

result of the analysis, 10 experimental candidates were evaluated with the TOPSIS method and the most suitable person(s) was selected.

Koyuncu and Özcan (2014) re-evaluated six engineers who were hired in the last one year in the position of production manager of a manufacturing company, in line with the recruitment criteria. The personnel selection process in the company has been discussed with the AHP and TOPSIS methods, which are among the multi-criteria decision-making methods in the literature. The rankings obtained from the AHP and TOPSIS results were compared with the performance results of these individuals after at least 6 months of employment. AHP and TOPSIS methods gave the same ranking in the ranking, and the performance evaluation result observed that the first and last ranked candidates were consistent with these results.

In his study, Ilgaz (2018) used AHP and TOPSIS methods together for the selection of the operation personnel needed by a business operating in the logistics sector. In the study, five alternative candidates were evaluated according to thirteen criteria. The criterion weights were calculated by the AHP method. The ranking of the alternatives was made using the TOPSIS method and the most suitable candidate for the enterprise was determined.

İçigen and Çetin (2018) used AHP and TOPSIS methods for personnel selection of a five-star accommodation business. In the study, ten candidate personnel were evaluated according to fifteen criteria. The criterion weights were calculated using the AHP method. The ranking of the candidates was made using the TOPSIS method and the most suitable personnel were selected.

Widianta et al. (2018) conducted a comparison to discover how well each of the AHP, SAW, TOPSIS and PROMETHEE methods performed in solving the problem of evaluating employees and to place them in the position where they can play best according to their qualifications. These authors show that TOPSIS and PROMETHEE give more accurate results than some rankings conducted by recruiters earlier.

Nabeeh et al. (2019) integrated a neutrosophic AHP approach with TOPSIS through a case study to evaluate and select a number of candidates to fulfill a manager position in an Egyptian technology park.

Özdemir and Nalbant (2020) used the integrated fuzzy preference relations-fuzzy AHP method for the engineer selection problem of a company in Turkey. In the study, seventeen alternative candidates were evaluated according to twenty-two criteria under five sub-criteria. Alternatives were ranked according to the results of the integrated method and the most suitable candidate was determined.

Taş and Karataş (2021) used the neutrophisophic AHP and neutrophisophic TOPSIS methods for project manager selection in a software company. In the study, four alternative personnel were evaluated according to five criteria. Criterion weights were calculated using the neutrophilic AHP method. Alternatives were listed according to the results of the neutrophic TOPSIS method and the most suitable one was determined.

Material and Method

In our study, the 5 most important risk factors and their 23 sub-titles, that can be encountered in superstructure projects, has been obtained by expert opinions and detailed literature review and grouped in themselves. These risk headings has been planned to be evaluated by 5 project managers to choose the most suitable project manager for the investor. While making the selection, it was aimed to reach the result in the TOPSIS method by weighting the risk factors with AHP (Analytical Hierarchy Process), one of the multi criteria decision making techniques. Thus, while choosing the project manager, it was aimed to reach a more rational result with a mathematical approach rather than emotionality.

The AHP and TOPSIS methods have been preferred in this study as the TOPSIS shows that the closest alternative to the ideal solution and the farthest alternative to the negative ideal solution is the best alternative. One advantage of TOPSIS is that each alternative takes its own value. Therefore, it is possible to get a good view of the differences between the alternatives and how the criteria differ from each other (Spee, 2005).

In addition to this, AHP is concerned with the judgments people make on their feelings and intuitions as well as their thoughts. AHP relies on simple elaborated hierarchical structures to represent decision problems. With such an appropriate representation, it can deal with risk, conflict and forecasting problems. People find AHP easy and are often influenced by the method rather than being alienated (Saaty, 1994).

AHP (Analytical Hierarchy Process) Method

AHP, which is a quantitative and qualitative method developed by Thomas Saaty in 1977, performs the ranking of the important criteria and decision alternatives with pairwise comparisons of the effective criteria in decision making by including the knowledge, experience and intuitions of the decision maker in MADM problems under uncertainty (Chena & Wang, 2010). The following steps are used when making comparisons in the AHP method;

Step 1: The problems are determined and the main and sub-criteria to be used in the solution of the problem are determined.

Step 2: The hierarchical structure of the main and sub-criteria to be used is created.

Step 3: After the hierarchical structure is established, the relative importance of each criterion is calculated (Chandran et al., 2005). The relative importance of the criteria can only be found by making a pairwise comparison, that is, by comparing the two criteria with each other (Sharma et al., 2008). Pairwise comparison is based on the experience and knowledge of the decision maker (Chandran et al., 2005). Therefore, at this point, the decision maker is asked to create binary decision matrices by comparing the main and sub-criteria.

After the hierarchy is created, it is necessary to calculate how many times more important the criteria are (relative importance degrees) against each other. The decision maker determines the degree of importance between the criteria based on the 1-9 scale. The importance scale seen in Table 2, created by Saaty, is used when making a pairwise comparison.

Table 1. Creating a pairwise comparison matrix for criteria (Saaty, 1990; Chandran et al., 2005).

	Criterion 1	Criterion 2	Criterion ……..	Criterion j
Criterion 1	W_1/W_1	W_1/W_2	……	W_1/W_j
Criterion 2	W_2/W_1	W_2/W_2	……	W_2/W_j
Criterion ….	……..	…….	……	……..
Criterion i	W_i/W_1	W_i/W_2	……	W_i/W_j

Table 2. Saaty comparison scale (Saaty, 1990).

Importance	Definiton
1	Equally important
3	A little more important
5	Strongly important
7	Very strongly important
9	Absolutely important
2,4,6,8	Intermediate values

Step 4: This is the phase of checking the consistency of the pairwise comparison made in the previous step. After creating the comparison matrix and giving the numerical values to the criteria with the help of the scale in Table 2, it is necessary to calculate the relative importance levels. The best way to calculate relative importance in a pairwise comparison matrix is Saaty's eigenvector method (Hurley, 2001). The eigenvector is calculated by the formula (Ramadhan et al., 1999);

$$\mathbf{w_i} = \frac{\mathbf{1}}{\mathbf{n}} \sum_{\mathbf{j=1}}^{\mathbf{n}} \frac{\mathbf{a_{ij}}}{\sum_{\mathbf{j=1}}^{\mathbf{n}} \mathbf{a_{ij}}} \qquad (1)$$

Step 5: After calculating the eigenvector and determining the relative importance of the criteria, the consistency (CR) of the comparison matrix is calculated (Hafeez et al., 2007) (Zhou & Shi, 2009). CR= Consitency Ratio, CI= Consistency Index, RI= Randomness Index.

$$\mathbf{CI} = \frac{\boldsymbol{\lambda}_{\mathbf{max}} - \mathbf{n}}{\mathbf{n} - \mathbf{1}} \qquad (2)$$

$$\mathbf{CR} = \frac{\mathbf{CI}}{\mathbf{RI}} \qquad (3)$$

While calculating CI, the maximum eigenvalue (λmax) in the formula is calculated as follows (Peng & Dai, 2009);

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \qquad (4)$$

In order to calculate λmax, the "All Priorities Matrix" is obtained by multiplying the comparison matrix with the weights and priority vector found in the previous stages. All the elements of the calculated priorities matrix are divided by the priority vector values. The result obtained by taking the average of the obtained values is determined as λmax (Uzun et al., 2016).

Step 6: The RI values determined by Saaty are taken from Table 3 in order to find the consistency ratios.

Table 3. Random indicators (Saaty, 1994).

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,54	1,56	1,57	1,59

The purpose of calculating CR is to determine whether the decision maker acts consistently when comparing criteria. The upper limit of the Consistency Ratio (RO) is evaluated as 0.10. If the calculated consistency ratio is greater than 0.10, the criteria are considered to be inconsistent and the decision maker should reconsider the values entered in the matrix (Donegan et al., 1992; Stain & Mizzi, 2007). That is, the closer the CR is to zero, the higher the consistency of the decision matrix (Jian-Zhong et al., 2008).

TOPSIS (Technique for Order Preferences by Similarity to Ideal Solution) Method

TOPSIS is a method added to multi-criteria decision making techniques by Hwang and Yoon (1981). The main rule in this method is to find the best option among the alternatives by measuring the shortest distance to the ideal solution and the longest distance to the negative ideal solution (Dumanoğlu & Ergül, 2010).

The main reasons for the active use of the TOPSIS method are that it can be applied directly over numerical data and has a very limited subjectivity. The only subjective point in the method is the weights given to the criteria.

The stages used in the TOPSIS method are listed below (Ahi et al., 2008);

Step 1: Determination of decision matrices.

Step 2: Determination of normalized decision matrices by means of the following formula.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1, 2, \ldots m; \;\; j = 1, 2, \ldots . n. \qquad (5)$$

Step 3: Determine the weighted normalized decision matrices by the formula given below.

$$v_{ij} = w_j * r_{ij} \quad (6)$$

Step 4: Determining the distances to the positive and negative solution by measuring the separation by means of the formulas given below.

$$S_i^+ = \sqrt{\sum_j \left(v_{ij} - v_j^*\right)^2} \quad i = 1, 2, \ldots, m \quad (7)$$

$$S_i^- = \sqrt{\sum_j \left(v_{ij} - v_j^*\right)^2} \quad i = 1, 2, \ldots, m \quad (8)$$

Step 5: Calculating the closeness to the ideal solution using the formula given below.

$$C_i^* = \frac{S_i^-}{(S_i^- + S_i^+)} \quad i = 1, 2, 3, .., m \;\; 0 \leq C_i^* \leq 1 \quad (9)$$

The C_i^* value must be between $0 \leq C_i^* \leq 1$. The solutions obtained are sorted by their relative closeness (C_i^*) to the ideal solution and the most suitable option is determined (Azimifard et al., 2018).

Application

In this study, the choice of project manager, which is a very significant subject in the construction sector, was determined by means of 5 main risk factors and 23 sub-risk factors. The weights of the risk factors were calculated using the AHP method with the evaluations taken from the experts. The weights of the risk factors obtained with AHP were solved with TOPSIS. It is very difficult to evaluate which of the project managers, who are close to each other in terms of experience, age, expertise, education etc., are suitable for the company and the project. The 23 sub-risk factors were evaluated according to the order of importance that the project managers resolved and the order of importance given to the problems of the company and the project. Sub-risk factors of the **'Management/Organizational Structure Based'** main risk factor are; **1a)** Financial and operational management of the company, **1b)** Not established or non-operative communication, coordination and reporting lines, **1c)** Delays in investigations made by the employer, **1d)** Delays in payments and progress payments, **1e)** Reputation and reliability problems. Sub-risk factors of the **'Planning Based'** main risk factor are; **2a)** Deviation of material supply time predictions, **2b)** Failure to keep up with the work schedule during the construction process, **2c)** The risk of change in the amount of workquantity, **2d)** The ability of the project team to understand the scope of the project in planning. Sub-risk factors of the **'Design Based'** main risk factor are; **3a)** Insufficient architectural and engineering designs, **3b)** Insufficient communication between the customer representative and the project supplier, **3c)** The risk of the designer not being able to complete the necessary design stages on time, **3d)** Deficiencies in the design documents. Sub-risk factors of the **'Construction Based'**

main risk factor are; **4a)** Delays in employer decisions, **4b)** Experience in construction technique and applicability of technological developments, **4c)** Construction method not suitable for design, **4d)** Starting work at the construction site without obtaining work approval in accordance with the technical specifications and requirements of the employer, **4e)** Insufficient capacity of materials and equipment to be used in production. Sub-risk factors of **'Finance & Economics Based'** main risk factor are; **5a)** The effects of inflation/speculative movements in the country's economy, **5b)** Insufficient project financing, **5c)** Cash flow deviations, **5d)** Exceeding the project budget specified in the contract, **5e)** Exchange rate fluctuations.

The main risk factors presented to the project managers and the sub-risk factors among the main risk factors were asked to be ranked between 1 and 5 (best - 5, worst - 1). It was aimed to select the most suitable project manager for the company's ideas by using the TOPSIS method, based on the answers received from the candidate project managers consisting of 5 people.

Table 4. Weight calculations of sub-risk factors with AHP.

Main Risk Factors	Sub-Factors	w	General Weights
Management/Organizational Structure Based (w= 0,272)	1a)	0,100	0,0272
	1b)	0,176	0,0479
	1c)	0,077	0,0209
	1d)	0,353	0,0960
	1e)	0,295	0,0802
	CR Value = 0,059 (OK)		w=0,272
Planning Based (w = 0,120)	2a)	0,111	0,0133
	2b)	0,290	0,0348
	2c)	0,175	0,0210
	2d)	0,424	0,0509
	CR Value = 0,070 (OK)		w= 0,120
Design Based (w= 0,074)	3a)	0,424	0,0314
	3b)	0,090	0,0067
	3c)	0,199	0,0147
	3d)	0,287	0,0212
	CR Value = 0,039 (OK)		w= 0,074
Construction Based (w= 0,174)	4a)	0,283	0,0492
	4b)	0,068	0,0118
	4c)	0,382	0,0665
	4d)	0,171	0,0298
	4e)	0,097	0,0169
	CR Value = 0,046 (OK)		w=0,174

Finance & Economic Based (w= 0,360)	5a)	0,299	0,1076
	5b)	0,356	0,1282
	5c)	0,091	0,0328
	5d)	0,108	0,0389
	5e)	0,146	0,0526
	CR Value = 0,054 (OK)		w=0,360

As seen in Table 4, pairwise comparisons were made for the main risk factors and sub-risk factors using the AHP method. At this stage, expert opinions were used. Using the obtained data, the weights of the sub-factors were calculated and data were obtained for the TOPSIS method. Among the 5 main factors, the 'Finance and Economy Based' risk factor emerged as the most important factor with w=0.360. In the second place, the risk factor 'Management/Organizational Structure Based' came to the fore with w=0.272.

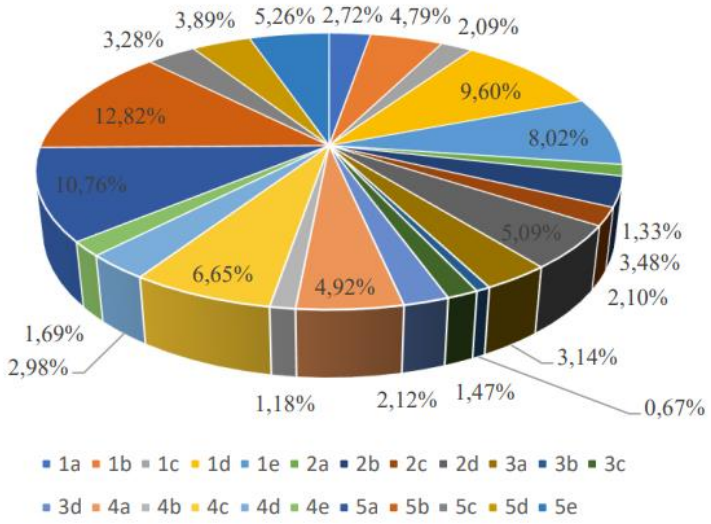


Figure 1: Importance weight chart of criteria.

Table 5. TOPSIS decision matrix.

	Max	Max	Max	Max	Max	Max	Max	Max	max
w	2,7200 %	4,7900 %	2,0900 %	9,6000 %	8,0200 %	1,3300 %	3,4800 %	2,1000 %	5,0900 %
Decision	1a	1b	1c	1d	1e	2a	2b	2c	2d
A	4	3	1	2	5	3	2	4	1

B	3	4	2	5	1	3	5	4	2
C	1	2	4	3	5	3	4	5	2
D	2	3	1	5	4	4	3	5	2
E	5	2	3	4	1	5	3	4	2

Table 6. TOPSIS decision matrix (continuing).

	Max	Max	Max	Max	Max	Max	Max	Max	Max
w	3,1400 %	0,6700 %	1,4700 %	2,1200 %	4,9200 %	1,1800 %	6,6500 %	2,9800 %	1,6900 %
	3a	3b	3c	3d	4a	4b	4c	4d	4e
A	5	2	4	3	1	5	3	2	4
B	5	2	3	4	1	2	4	5	3
C	2	1	3	4	4	1	5	2	3
D	4	1	2	3	4	1	5	3	2
E	3	1	2	4	5	4	1	3	2

Table 7. TOPSIS decision matrix (continuing).

	Max	Max	Max	Max	Max
w	10,7600%	12,8200%	3,2800%	3,8900%	5,2600%
	5a	5b	5c	5d	5e
A	5	3	1	2	4
B	3	2	5	1	4
C	4	3	2	5	1
D	4	5	1	2	3
E	2	4	3	1	5

The TOPSIS method was used by using the ranking data of the project managers consisting of 5 people about the main and sub-factors. With the weight data obtained by the AHP method, decision matrices were formed by switching to the TOPSIS method.

Table 8. Weighted normalized decision matrix.

	Max	Max	Max	Max	Max	Max	Max	Max	Max
w	0,0272	0,0479	0,0209	0,0960	0,0802	0,0133	0,0348	0,0210	0,0509
Weighted N.D.M	1a	1b	1c	1d	1e	2a	2b	2c	2d
A	0,0146	0,0221	0,0037	0,0216	0,0486	0,0048	0,0087	0,0084	0,0123
B	0,0110	0,0295	0,0075	0,0540	0,0097	0,0048	0,0219	0,0084	0,0246
C	0,0036	0,0147	0,0150	0,0324	0,0486	0,0048	0,0175	0,0106	0,0246
D	0,0073	0,0221	0,0037	0,0540	0,0389	0,0064	0,0131	0,0106	0,0246
E	0,0183	0,0147	0,0112	0,0432	0,0097	0,0080	0,0131	0,0084	0,0246
Ideal Solution Value	0,0183	0,0295	0,0150	0,0540	0,0486	0,0080	0,0219	0,0106	0,0246
Negative Ideal S.V	0,0036	0,0147	0,0037	0,0216	0,0097	0,0048	0,0087	0,0084	0,0123

Table 9. Weighted normalized decision matrix.

	max	max	max	max	max	max	max	max	max
w	0,0314	0,0067	0,0147	0,0212	0,0492	0,0118	0,0665	0,0298	0,0169
	3a	3b	3c	3d	4a	4b	4c	4d	4e
A	0,0176	0,0040	0,0090	0,0078	0,0064	0,0086	0,0228	0,0083	0,0104
B	0,0176	0,0040	0,0068	0,0104	0,0064	0,0034	0,0305	0,0208	0,0078

C	0,0070	0,0020	0,0068	0,0104	0,0256	0,0017	0,0381	0,0083	0,0078
D	0,0141	0,0020	0,0045	0,0078	0,0256	0,0017	0,0381	0,0125	0,0052
E	0,0105	0,0020	0,0045	0,0104	0,0320	0,0068	0,0076	0,0125	0,0052
Ideal Solution Value	0,0176	0,0040	0,0090	0,0104	0,0320	0,0086	0,0381	0,0208	0,0104
Negative Ideal S.V	0,0070	0,0020	0,0045	0,0078	0,0064	0,0017	0,0076	0,0083	0,0052

Table 10. Weighted normalized decision matrix.

	Max	Max	Max	Max	Max	Max	Max	Max	Max
w	0,1076	0,1282	0,0328	0,0389	0,0526	0,1076	0,1282	0,0328	0,0389
	5a	5b	5c	5d	5e	5a	5b	5c	5d
A	0,0643	0,0485	0,0052	0,0132	0,0257	0,0643	0,0485	0,0052	0,0132
B	0,0386	0,0323	0,0259	0,0066	0,0257	0,0386	0,0323	0,0259	0,0066
C	0,0514	0,0485	0,0104	0,0329	0,0064	0,0514	0,0485	0,0104	0,0329
D	0,0514	0,0808	0,0052	0,0132	0,0193	0,0514	0,0808	0,0052	0,0132
E	0,0257	0,0646	0,0156	0,0066	0,0321	0,0257	0,0646	0,0156	0,0066
Ideal Solution Value	0,0643	0,0808	0,0259	0,0329	0,0321	0,0643	0,0808	0,0259	0,0329
Negative Ideal S.V	0,0257	0,0323	0,0052	0,0066	0,0064	0,0257	0,0323	0,0052	0,0066

After the decision matrix was created in the TOPSIS method, normalized decision matrices were created. The weighted normalized decision matrix was obtained by multiplying the calculated normalized decision matrix with the importance weights of the criteria.

Positive and negative ideal solution values, which are the next stage of the TOPSIS method, were calculated.

Table 11. Distance from the positive ideal solution

	TOTAL	Si^{*+}
A	0,0045421	0,067395
B	0,0061343	0,078322
C	0,0034152	0,05844
D	0,0018558	0,04308
E	0,0055983	0,074821

Table 12. The distance from the negative ideal solution.

	TOTAL	Si^{*-}
A	0,0042978	0,065558
B	0,0034477	0,058717
C	0,0049508	0,070362
D	0,0067335	0,082058
E	0,0034519	0,058753

After calculating the distances from the positive and negative ideal solution, the relative distance value C_1^* from the ideal solution was calculated.

C_1^* is obtained by dividing the distance from the negative ideal solution by the sum of the distance from the positive and negative ideal solution.

Table 13. Relative distance values to the ideal solution.

CONCLUSION	Si*(+)	Si*(-)	Ci*
Person A	0,06739509	0,06555751	0,49308932
Person B	0,07832153	0,05871672	0,42846957
Person C	0,05843955	0,07036195	0,54628207
Person D	0,04307952	0,08205794	0,65574240
Person E	0,07482150	0,05875263	0,43985036

After calculating their relative distances to the ideal solution, the selection stage was made among the project managers consisting of 5 people. Person D, with the highest relative distance to the ideal solution, stands out as a suitable project manager for a company doing business in housing projects with Ci* = 0.65574240. Person C took the second place with Ci* = 0.54628207. Person B took the last place with the value Ci* = 0.42846957.

Table 14. Ranking Results.

Ranking Results	
1	D
2	C
3	A
4	E
5	B

Conclusion

In this study, it has been aimed to reach a solution by using multi-criteria decision-making techniques in the selection of the project manager, which is one of the most significant issues in the construction industry. In the system created using expert opinions and literature review with 5 main risk factors and a total of 23 sub-risk factors, the importance weights of the criteria were determined by the AHP method. Candidate project managers were asked to rank the main and sub-risk factors in order of importance. Using the TOPSIS method with the sequencing data obtained, it was investigated which project manager the company would be suitable to work with.

Among the 5 main factors, the 'Finance & Economics Based' risk factor came to the fore with the highest importance. While the 'Management/Organizational Structure Based' factor came to the fore in the second place, the 'Design Based' risk factor took the last place with a weight of w=0.074. Among the sub-risk factors, the factor of 'Insufficient financing of the project' took the first place with the weight of w=0.1282. The second place was taken by the factor of 'The effects of inflation/speculative movements in the country's economy' with a weight of w=0.1076.

It has been seen that the multi-criteria decision-making methods used to solve complex events and choices that may involve emotions using mathematical expressions could also be used while selecting the project manager in construction projects. Not only the age, experience and education of the project manager, but also the suitability of the company to the target and ideas that the company wants to achieve can be evaluated by means of a questionnaire that can measure the ideas of the project managers.

The survey results obtained as a result of the answers given by the A, B, C, D and E project manager candidates has been evaluated. Persons **C and D** took **the first two places** due to the importance weights of their answers obtained by the AHP method. The project manager candidate who does not match the ideas of the employer who will choose the project manager is the **B** candidate.

In the analyzes obtained using the TOPSIS method, it has been seen that '**Person D'** ranks the criteria **5a** and **5b**, **which have a high degree of importance, as the highest value**. It stands out as the project manager that the company may want, with the high values it gives to the criteria with high importance in the importance weights of the risk factors created by using expert opinions.

It is easy to make a choice by using multi-criteria decision making methods, which are widely used today. As a result of the analysis, it has been seen that it would be more consistent to move away from emotionality and make a choice with a mathematical approach.

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A Method for Determining the Probability of Achieving a Maximum Tender Price Score in Turkish Public Procurement Law Open Procedure

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Abstract

Public procurement investments attract many private companies due to its huge market volume. This results a huge competition among companies in the world and in Turkey during public procurement tenders. Given the notable competition, the fact that investments are made with taxes paid by citizens, and the involvement of government officials and politicians in the process, almost all countries have public procurement regulations. Obviously, Turkey is one of the countries with a public procurement law for the regulations to be followed by the government institutions for public procurement. Consequently, tenderers must cultivate strategies by calculating the probability of winning a contract within this public procurement law due to its competitive nature of the industry. In this study, tenderer's potential winning strategy under Turkish Public Procurement Law open procedure is examined by means of proposing a simulation model for probability calculation with the restrictions of relevant regulations of Turkish Public Procurement Law no. 4734, tenderer's perceived market conditions and their cost structure against various probability distribution to support tenderers in decision making under uncertainty prior to tenders.

Keywords: *decision support, probability distribution, public procurement, simulation model.*

Introduction

Public goods such as public infrastructure or national defense are the commodities in which users' individual consumption has no effect on the quantity or quality of the product or service obtainable by others (non-rival) and individual use of the commodity cannot prevent other's consumption (non-excludable) (Sloman et al., 2016). Consequently, this results no motive for private market to make public goods available for people due to lack of profit opportunity and, therefore, this is government's responsibility to provide these goods or services for resident's use by means of collected taxes from citizens. Similar to public goods, governments are also providing merit goods such as health and education despite the fact that those could be supplied privately (Fiorito & Kollintzas, 2004). While those commodities, public or merit goods, are being provided or invested by governments or state-owned enterprises for people's use, private market is the one who delivers the goods, services or works for the realization of those enormous volume of projects. Hence, public procurement (or government procurement) which

is the process of procurement of goods, services and works on behalf of public authorities from private market is inevitable.

As conveyed by Organization for Economic Co-operation and Development (OECD) (2017), general government procurement as a percentage of Gross Domestic Product (GDP) varies between 10-15% of a state economy in average. Whilst this percentage has increased as a result of COVID 19 response and overall falling of GDP due to economic crisis after 2019, public procurement compared to non-procurement government expenditures decreased in 2020 due to direct support packages by government (Organization for Economic Co-operation and Development (OECD), 2021). According to the estimate done by Open Contracting Partnership and Spend Network (2020), the size of global procurement market is 13 trillion USD per annum.

Given enormous volume of global public procurement and its share in state economies, source of this investments' being taxes collected by citizens and probable connection of government officials and representatives in the process, public procurement has to be and is regulated by law almost in all countries. By means of those regulations under the procurement law of states or international institutions, transparency, competition, equal treatment, reliability, confidentiality, public supervision, and fulfilment of needs appropriately, promptly, and efficient use of resources are tried to be promoted. One of the countries who offers a public procurement law to be complied by the government institutions and tenderers during public procurement is Turkey. The current public procurement act (Law No. 4734) was published in Turkey on 22 January 2002 (Republic of Turkey Public Procurement Authority, 2020). Under this act, open procedure (where all tenderers can submit a quotation), restricted procedure (only invited tenderers who are qualified following a prequalification procedure can submit their quotation) and negotiated procedure (to be used under special circumstances) are provided under article 18.

In this study, determination of the probability for achieving a maximum tender price score in Turkish Public Procurement Law Open Procedure is discussed. In order to determine the probability, a simulation model is proposed by taking into consideration, (i) the restrictions of Law no. 4734 with relevant regulations, (ii) assumption of tenderer's perceived market conditions, iii) tenderer's assumption on probability distribution and iv) tenderer's own quotation. It is assumed that the outcomes of the simulation model will provide a decision support to the tenderer whether to enter the bid or not or revise its quotation. Therefore, in coming section of this study, tendering procedure under Law no. 4734 with relevant regulations is summarized, then, in next section, simulation model is developed. Finally, outcomes with past tenders are tested with the proposed simulation model.

Open Procedure under Law no. 4734

Following steps under Turkish Public Procurement Law are provided for open procedure type of tenders in Figure 1

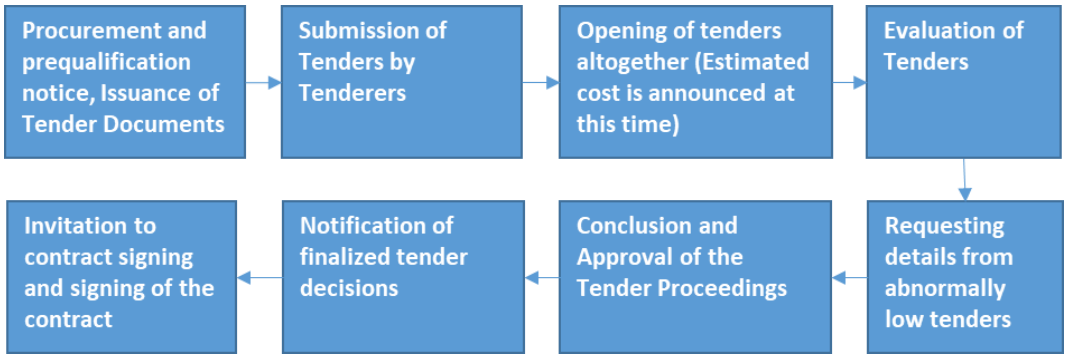


Figure 1: Steps for open procedure type of tenders.

Upon tender submission and evaluation by tender commission, the tenderer who submitted the *Economically Most Advantageous Tender* would be awarded by the contract. As conveyed under article 40 of Turkish Procurement Law, either only price base or the price base and non-price factors as cost of operation and maintenance, productivity, quality and technical aspects are defined as *Economically Most Advantageous Tender* (Republic of Turkey Public Procurement Authority, 2020). In this study, only price base score is taken into account for *Economically Most Advantageous Tender* for the proposed mathematical model. Article 45 (Identification of Limit and Abnormally low tenders) of Public Procurement General Notice published on 22 August 2009 determines the best tender price scored tender with the formulation given below:

T_n (Valid Offer): $(EC * 40\ \%) < T_n < (EC * 120\ \%)$ (1)

where *Estimated Cost (EC)* is the cost calculation undertaken by the contracting authority which is announced at the time of tender opening.

T_{ort1} : Valid offers (T_n) mean value ($T_{ort1} = \frac{\sum T_n}{n}$) (2)

σ : Valid offers standard deviation ($\sigma = \sqrt{\frac{\sum (T_n - T_{ort1})^2}{(n-1)}}$) (3)

σ is included to mean and deducted from mean.

$T_{ort1} - \sigma$

$T_{ort1} + \sigma$

The second arithmetic mean is determined by obtaining the average of the tenders within the zone of one standard deviation below and one standard deviation above the arithmetic mean value.

T_i : Tenders inside one standard deviation: T_i: $(T_{ort1} - \sigma \leq T_i \leq T_{ort1} + \sigma)$ (4)

T_{ort2} : Mean of Tenders inside one standard deviation: $(T_{ort2} = \frac{\sum T_i}{n})$ (5)

A value (C) is determined by dividing the second calculated mean by the estimated cost (EC).

C : T_{ort2}/EC (6)

A (K) value is found by substituting the value of (C) in the relevant one of the following equations.

If;

$C < 0.60 \rightarrow$ $K = C$ (7)

$0.60 \leq C \leq 1.00 \rightarrow$ $K = \frac{(3.2\ C - C^2 - 0.6)}{(C+1)}$

$C > 1.00 \rightarrow$ $K = \frac{(C^2 - 0.8\ C + 1.4)}{(C+1)}$

The limit value is found in the following equation:

$$\text{SD (Limit Value)} = \frac{K \times T_{ort2}}{C \times N} \quad (8)$$

Upon obtaining SD (Limit Value) with the formulation given above, the first offer, which is just above SD is the best tender price scored tender. While tenders given below SD is called *Abnormally Low Tenders*, other tenders above SD have price scores calculated proportionally. In this study, the main target of the proposed model is to find out the probability of getting the best tender price score of the given offer.

Model Development

The proposed model is based on acquiring average outcomes from randomly selected input variables among tenderer defined ranges through a number of iterations with respect to several probability distribution. In each iteration, outcome through above given formula is calculated and recorded. The possible results of those records are the mean of SD (Limit Value) and the mean of the best tender price scored tender. In addition, the value of user's tender price can be checked against the value of the best tender price scored tender in each iteration. If user's tender price match with the best tender price scored tender, it means the user's tender price wins and recorded as a win. Otherwise, it would be recorded as lost in that iteration. Hence, the mean value of total number of those wins against the number of all iterations gives us the probability value of the assumptions made by the user for this tender session.

In the model, the inputs assured to be known by the tenderer are number of tenderers (N) giving quotation to the tender including the bidder itself, range of estimated cost (min_cost and max_cost), range of quotation to be given by the tenderer (min_bid and max_bid), your bid (own_bid), probability distribution of the tender (dist) and the number of iterations (S). In each iteration, SD (limit value), best tender price scored tender (BTPST) and whether your bid wins or not (W) are found with respect to the randomly selected inputs as per the chosen probability distribution. Consequently, this sequence is repeated with the given number of iterations up to maximum number of tenderers (N) (Figure 2).

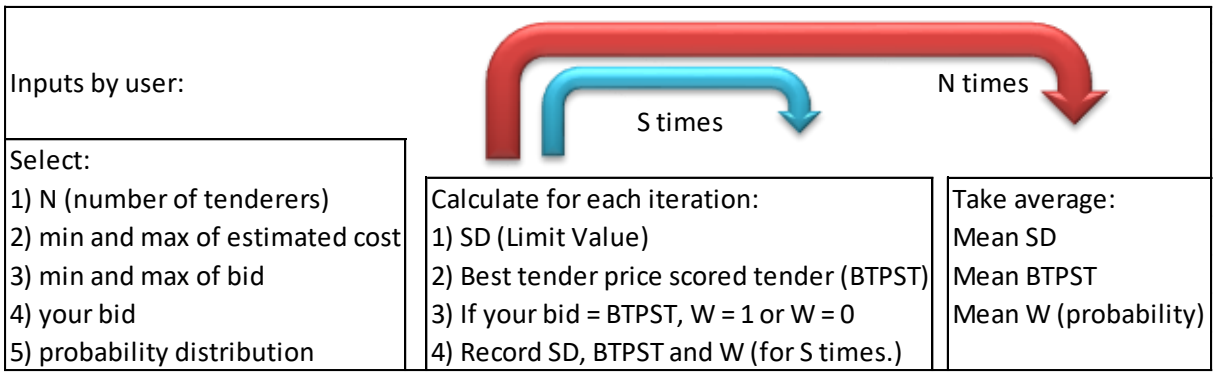


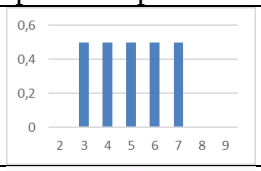
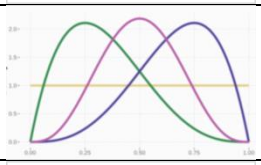
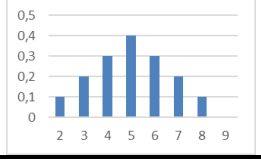
Figure 2: Steps of proposed model.

Proposed Probability Distribution

Although estimated cost is selected randomly according to a uniform distribution between user defined minimum and maximum of estimated cost, bids of each tenderer for N number of tenderers are selected randomly by means of an user defined probability distribution. The proposed probability distributions for bids are discrete uniform distribution, beta distribution and symmetric triangular distribution (Sinharay, 2010) as shown in Table 1. In discrete uniform probability distribution, all integers in a range of variables have equal probability. That is, all the bids have the same probability in the given tender. In symmetric discrete triangular distribution, integers in the range do not have equal probability and probability density function is shaped like a triangle. Lastly, we preferred beta distribution option with various parameter values in our model. Using two parameters of beta distribution function, the shape of the distribution can be controlled by the user.

The reason why those probability distributions are chosen is to support decision making to see different scenarios if all bids have equally likely outcomes (discrete uniform probability distribution), if all of the tenderers would have tendency to bid lower or higher bids compared to other bidders (beta distribution with different α and β parameters) or if all of the tenderers would like to bid around the mean value of the market conditions (symmetric triangular distribution). Although it is very hard to estimate which probability distribution is appropriate to use, the user would have a chance to compare and check the previous similar bids so that they would use this estimation for future tenders.

Table 1. Summary of probability proposed distribution.

Probability Distribution	Function	Graphical Representation
Discrete uniform probability distribution	f(x) = 1/k where k = the number of values the random variable may assume	
Beta distribution	$f(x,\alpha,\beta)$ = constant * $x^{\alpha-1}(1-x)^{\beta-1}$ where $\alpha,\beta > 0$	
Symmetric Triangular distribution	$f(x) = ((b-c)-abs(c-x))/(b-c)^2$ where b is max bid and c is the mean bid	

In our model, for Beta distribution, α & β coefficients from 1.5 to 5 are used in order to cover all distribution options for randomly selected bids of each tenderer as shown in Figure 3.

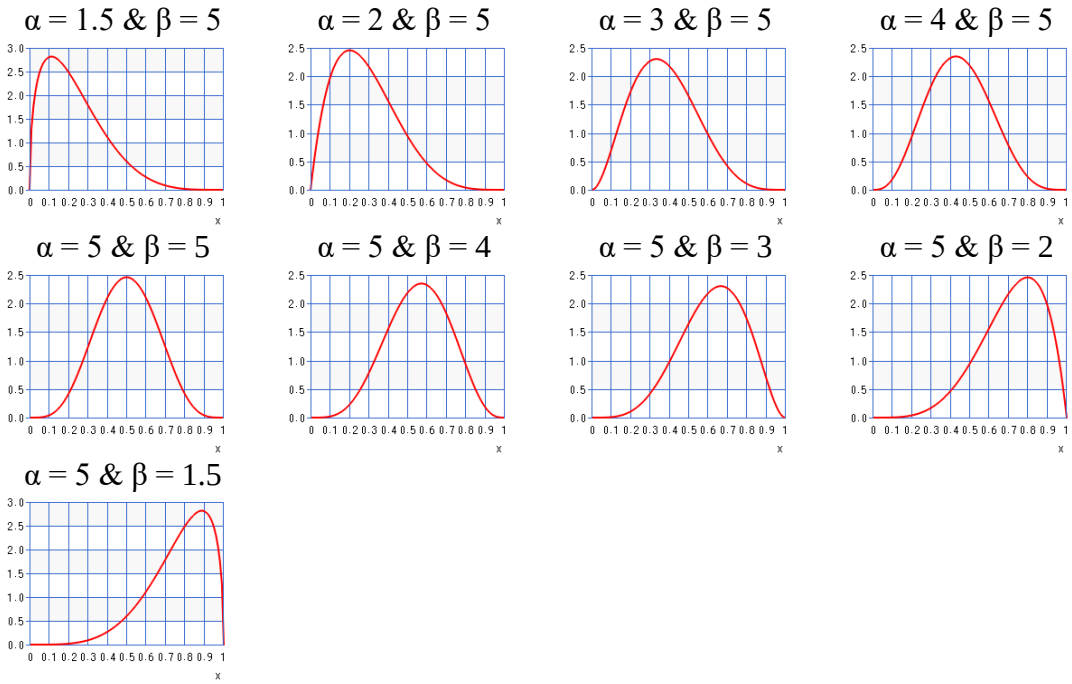


Figure 3: Beta distribution coefficients used in the model.

Detailed Model Steps

The proposed model includes fifteen steps as follows:

1: Set min_cost, max_cost, min_bid, max_bid, own_bid, S, dist

2: For n = 3 to N do

3: For i =1 to S do

4: bids = sample (n-1) number between min_bid; max_bid uniformly at chosen dist

5: cost = sample one number between min_cost; max_cost uniformly at random

6: valid bids = bids in the zone (greater or equal to cost*0.4 and smaller and equal to cost*1.2)

7: if number of valid bids < 2, stop and do next iteration

8: calculate T_{ort1}, σ, $_{Tort1}$+ σ, T_{ort1}- σ, T_i, T_{ort2}, K, C and **SD**

9: calculate BTPST = min (valid bids>SD) and record BTPST, cost and SD on list of "records" dataframe for n

10: If own_bid = BTPST, W =1, else W = 0 and record W on the list of "records" dataframe for n

11: End for.

12: Mean_BTPST = mean (records of BTPST), Mean_SD = mean (records of SD), Mean_Cost = mean(records of cost), Mean_W = mean (records of W)

13: End for.

14: Plot the data of Mean_BTPST vs N

15: Plot the data of Mean_W vs N

Using the steps given above, we tried a simulation with the assumptions: min_cost = 2,000,000 ₺, max_cost = 2,200,000 ₺, min_bid = 1,000,000₺, max_bid = 2,400,000₺, own_bid = 1,500,000 ₺, S = 2000, dist = uniform distribution and N is from 3 to 20. The results are shown in Fig. 4.

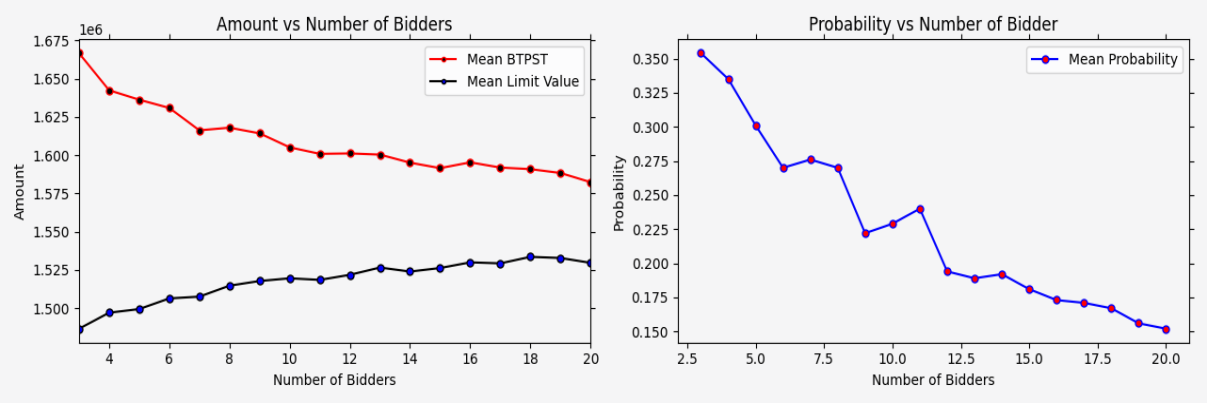


Figure 4: Estimated values and probability against number of bidders.

It is not astonishing that while the number of bidders increases, the mean BTPST is falling as a result of rivalry between bidders. Yet, the mean limit value is growing so that the abnormally low tenders can be disregarded. On the other hand, with the increase of the number of bidders, the mean probability of our own bid of being the best price scored tender is getting lower and lower. This is also not surprising. However, what is surprising in here, as the number of bidders is increasing, in order to increase the probability of getting a higher score, the bidder should increase their quotation. Notwithstanding, it is limited with other bidders' quotations. Therefore, estimating the correct number of bidders to enter to the bid is also vital.

Results of Simulation of Proposed Model

While the model is tested with above mentioned assumptions, we also tested the model with 30 actual tenders. In order to observe the error between simulations and the actual tenders, we used the Mean Absolute Percentage Error (MAPE) [11] approach as;

$$\mathrm{M} = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \tag{9}$$

In order to form the results table given in the Annex -1 by means of a software program coded in Python using the algorithm given above, probability with various probability distribution is tested to determine the highest probability against that probability distribution. After filtering the highest probability values for the corresponding distribution, the Absolute Percentage Error for Limit Value and BTSPT for each tender is calculated so that the overall MAPE can be demonstrated. Here, while actual minimum & maximum bid values, BTPST and Limit Values observed in each tender are used as input for the simulation, for estimation of interval of minimum and maximum estimated costs, 95% and 105% of tender's estimated cost are used as model inputs for minimum and maximum estimated cost. For all tender simulations, number of iterations (S) are taken as 2000 iterations. Consequently, models provided results are BTPST, Limit Value and probability. Therefore, using actual and model results of Limit Value, absolute percentage error is calculated.

Once the results table formed by using the assumptions and actual tender inputs, it is demonstrated that the mean probability of estimation of the best tender price scored tender of those 30 actual tenders with our model is 20.39 %. As seen in Fig. 5, it is not surprising that as the number of bidders are increasing the probability of having the BTPST is decreasing since the competition among companies are increasing.

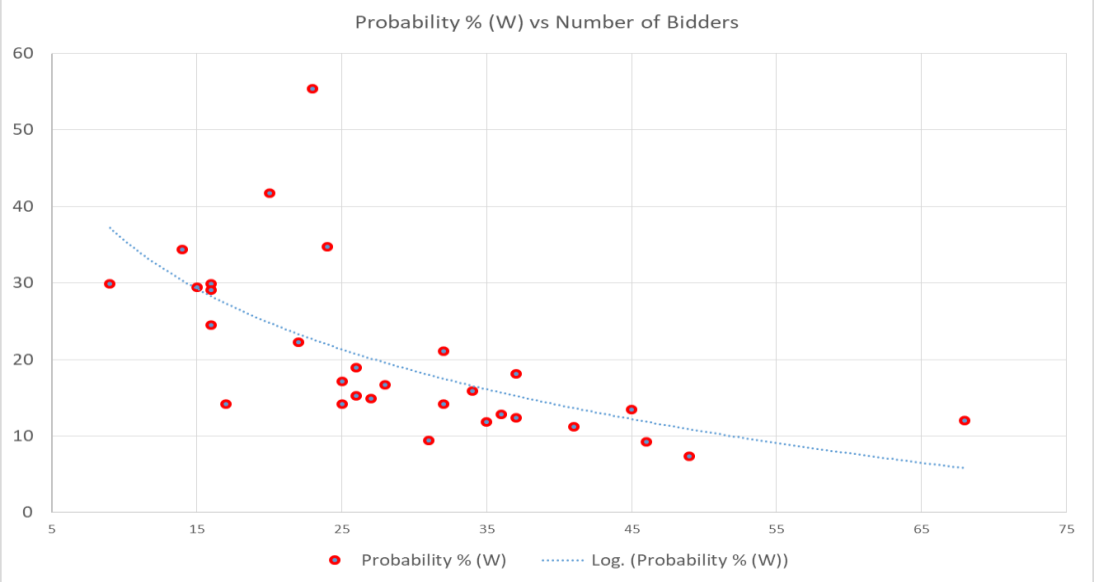


Figure 5: Probability vs number of bidders.

Among those 30 actual tenders, the results table shows that no probability distribution dominates against the number of bidders. Although it is found that 8 out of 30 observations (27%) is beta distribution with $\alpha = 3$ & $\beta = 5$ parameters and no triangular distribution is used in the table, we trust that the distribution is unique for each and every tender. Maybe, one may use previous tenders to estimate the correct parameters and distribution. However, it is sure that there is a room for further studies where the probability distribution can be estimated more precisely.

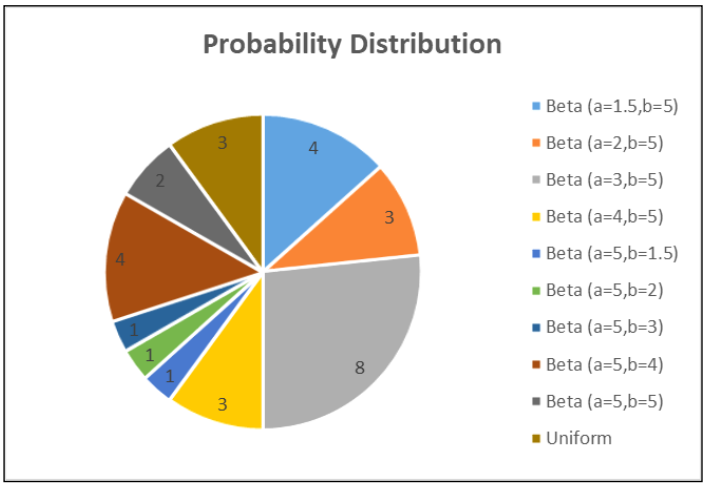


Figure 6: Probability distribution.

Lastly, the MAPE of Limit Value and BTPST are found as 1.01% and 0.93% respectively. Although those percentages seem very less, considering the huge volumes of the projects which are over millions of Turkish Liras, these may cause significant number of differences in certain cases. Even, those would impact who would be the winner. Notwithstanding, it should be noted that probability to getting the highest score require *minimum error* in estimation of Limit Value.

Conclusion

Trying to achieve a maximum tender price score in Turkish public procurement law open procedure is a problem of decision making under uncertainty. The model given in this study is developed in order to support the decision makers prior to submission of their tenders for the bids announced under Public Procurement Law of Turkey open procedure. By means of the proposed model, tenderers have the chance to see the probability of their bids to get the maximum tender price score. However, the proposed model requires that the inputs have high certainty so that outputs can be accurate. Although estimated cost to be given by the contracting authority can be estimated with the calculation of project quantities and possible unit costs in a certain extent, number of bidders to give quotation, their minimum and maximum bid values and possible probability distribution could be difficult to guess. Hence, there is a big room for further studies to develop methods to obtain more accurate inputs into the model so that maximum probability can be targeted.

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Annex 1 – Results Table

Tender No	Tender Observation						Model Inputs				Model Results			Absolute Percentage Error	
	# of Bidders	Minimum Bid	Maximum Bid	Estimated Cost	BTPST (Actual)	Limit Value (Actual)	Minimum Cost (Input)	Maximum Cost (Input)	S	Distribution	BTPST	Limit Value	Probability % (W)	Limit Value %	BTPST %
1	15	94.701.514	131.600.000	138.264.527	99.893.046	99.439.703	131.351.301	145.177.753	2000	Beta (a=3,b=5)	101.126.955	99.914.929	29,4	0,48	1,24
2	23	59.876.543	85.344.017	84.033.413	64.400.380	64.379.553	79.831.742	88.235.084	2000	Beta (a=5,b=5)	65.025.797	63.806.026	55,4	0,89	0,97
3	25	55.939.930	78.076.915	116.764.014	67.250.000	67.145.217	110.925.814	122.602.215	2000	Beta (a=5,b=5)	67.301.904	67.017.068	17,1	0,19	0,08
4	32	101.988.375	159.726.000	197.629.750	124.160.000	124.090.026	187.748.262	207.511.237	2000	Beta (a=3,b=5)	123.063.885	122.412.400	14,2	1,35	0,88
5	28	59.930.000	85.531.000	119.991.561	74.043.282	73.766.008	113.991.983	125.991.139	2000	Beta (a=5,b=4)	74.089.300	73.791.151	16,7	0,03	0,06
6	17	33.280.000	44.729.264	58.822.288	37.515.115	37.505.196	55.881.174	61.763.402	2000	Beta (a=4,b=5)	37.920.456	37.700.014	14,2	0,52	1,08
7	37	50.353.000	109.959.300	88.887.778	66.400.000	65.223.650	84.443.389	93.332.167	2000	Beta (a=3,b=5)	66.065.682	65.479.505	18,1	0,39	0,50
8	24	58.495.214	69.920.181	87.159.142	63.790.341	63.111.192	82.801.185	91.517.099	2000	Beta (a=5,b=1.5)	63.490.797	62.726.238	34,7	0,61	0,47
9	31	162.366.006	279.330.103	246.058.377	172.620.000	171.557.640	233.755.458	258.361.296	2000	Beta (a=1.5,b=5)	175.974.776	174.812.909	9,4	1,90	1,94
10	45	91.117.358	187.290.339	183.450.068	122.815.000	122.261.446	174.277.565	192.622.571	2000	Beta (a=3,b=5)	123.339.640	122.560.347	13,5	0,24	0,43
11	32	35.355.720	52.280.204	58.473.535	42.910.000	42.176.528	55.549.858	61.397.212	2000	Beta (a=5,b=3)	42.797.475	42.442.191	21,1	0,63	0,26

Tender No	Tender Observation						Model Inputs				Model Results			Absolute Percentage Error	
	# of Bidders	Minimum Bid	Maximum Bid	Estimated Cost	BTPST (Actual)	Limit Value (Actual)	Minimum Cost (Input)	Maximum Cost (Input)	S	Distribution	BTPST	Limit Value	Probability % (W)	Limit Value %	BTPST %
12	25	73.291.330	107.650.062	111.855.506	77.141.695	77.045.798	106.262.731	117.448.281	2000	Beta (a=1.5,b=5)	77.247.182	76.846.783	14,2	0,26	0,14
13	41	56.763.063	89.504.740	99.975.857	62.781.453	62.342.140	94.977.064	104.974.650	2000	Beta (a=1.5,b=5)	63.222.382	62.948.735	11,2	0,97	0,70
14	26	47.899.995	64.582.030	84.884.898	53.964.000	53.961.683	80.640.653	89.129.143	2000	Beta (a=3,b=5)	53.679.531	53.473.996	15,3	0,90	0,53
15	16	59.934.853	88.688.012	91.555.747	66.774.455	65.386.011	86.977.960	96.133.534	2000	Beta (a=4,b=5)	67.479.765	66.625.348	29,9	1,90	1,06
16	68	44.942.500	99.916.350	115.213.321	71.994.400	71.839.123	109.452.655	120.973.987	2000	Uniform	72.986.213	72.300.155	12	0,64	1,38
17	14	28.167.088	54.500.000	48.022.713	35.787.000	35.068.153	45.621.577	50.423.849	2000	Beta (a=4,b=5)	36.249.224	35.600.954	34,4	1,52	1,29
18	35	27.996.345	44.910.106	50.284.435	32.692.480	32.665.225	47.770.213	52.798.657	2000	Beta (a=2,b=5)	32.296.705	32.124.586	11,8	1,66	1,21
19	27	36.848.508	50.443.640	63.861.229	41.110.000	40.813.866	60.668.167	67.054.290	2000	Beta (a=3,b=5)	41.288.129	41.118.175	14,9	0,75	0,43
20	16	98.388.588	139.887.216	125.449.496	117.353.180	100.316.982	119.177.021	131.721.971	2000	Beta (a=5,b=2)	114.248.855	100.964.909	29,1	0,65	2,65
21	9	127.238.000	233.568.905	276.397.709	182.812.728	182.200.997	262.577.824	290.217.594	2000	Beta (a=5,b=4)	184.326.039	181.401.732	29,9	0,44	0,83
22	16	141.054.290	212.120.120	259.139.851	176.558.662	174.646.710	246.182.858	272.096.844	2000	Beta (a=5,b=4)	175.813.038	174.367.166	24,5	0,16	0,42
23	22	20.458.448	27.727.256	29.988.217	21.409.889	21.326.768	28.488.806	31.487.628	2000	Beta (a=3,b=5)	21.698.056	21.513.238	22,3	0,87	1,35
24	34	41.680.000	66.995.020	89.839.463	54.900.062	54.885.133	85.347.490	94.331.436	2000	Uniform	54.741.110	54.188.586	15,9	1,27	0,29
25	37	58.906.656	113.045.422	146.241.120	90.405.239	90.148.788	138.929.064	153.553.176	2000	Uniform	87.427.783	86.176.321	12,4	4,41	3,29

Tender No	Tender Observation						Model Inputs				Model Results			Absolute Percentage Error	
	# of Bidders	Minimum Bid	Maximum Bid	Estimated Cost	BTPST (Actual)	Limit Value (Actual)	Minimum Cost (Input)	Maximum Cost (Input)	S	Distribution	BTPST	Limit Value	Probability % (W)	Limit Value %	BTPST %
26	46	149.490.000	247.897.137	259.013.924	170.159.890	169.756.002	246.063.228	271.964.620	2000	Beta (a=2,b=5)	172.107.600	171.350.998	9,2	0,94	1,14
27	20	120.918.268	257.581.954	209.628.252	165.993.354	159.327.044	199.146.839	220.109.665	2000	Beta (a=5,b=4)	167.851.472	164.299.163	41,7	3,12	1,12
28	49	49.985.117	74.757.595	87.527.828	56.733.925	56.715.924	83.151.437	91.904.219	2000	Beta (a=2,b=5)	56.070.952	55.892.949	7,4	1,45	1,17
29	26	22.623.623	24.824.000	34.985.676	22.898.492	22.807.096	33.236.392	36.734.960	2000	Beta (a=3,b=5)	22.992.090	22.914.315	18,9	0,47	0,41
30	36	72.000.000	104.999.925	123.971.981	78.857.978	78.566.748	117.773.382	130.170.580	2000	Beta (a=1.5,b=5)	78.427.867	78.118.388	12,8	0,57	0,55
												Mean	**20,39**	**1,01**	**0,93**

Data Scraping for Corporate Identity Evaluation: A Stakeholder Engagement and Management Perspective

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Abstract

Stakeholder management is one of the vital topics of project management which is recently separated from communications management, forming the tenth knowledge area of project management discipline. The communication in-between all stakeholders and the organization as an entity is subject to this knowledge area, and include a wide range of forms, that can be written or verbal, as well as formal or informal. Different communication technologies can be used in this context, and there is a shift towards informal communication methods in construction industry, just as many others. One of the informal-written communication mediums is social networking site (SNS) with an increasing popularity. SNSs offer an interactive communication space that accommodates valuable information for the organization, and the information on these networks are open to the public to an extent. Considering corporate SNS accounts as a formation of corporate identity (CI), and SNS users as stakeholders, this paper tries to create a framework where publicly available data on an SNS is extracted using data scraping techniques and the extracted data set is used to evaluate the CI strategy by mining this data. This framework is expected to be assistive for providing valuable information how AEC firms build, develop and manage CI on social networks, to improve their CI strategies.

Keywords: *AEC, big data, data scraping, SNS, stakeholder engagement management*.

Introduction

In the construction industry, strategy can be defined as degree of diversification and geographic expansion, and how an organization adapts to environmental changes (Dikmen & Birgönül, 2003). These environmental changes refer to the conditions related to the competitive business environment the companies are in. However, that limited perspective considering company profits above all are being questioned more than ever due to the climate change and environmental catastrophes caused by the economic activities of human kind. For the construction industry, this means a challenge for a project based environment to look beyond the project environment and consider more about the ongoing effects of the built environment and the footprints that we leave behind for the next generations. Being one of the leading energy consuming, waste producing and carbon dioxide emitting industries, construction industry needs a change.

This inevitable shift in the line of sight appears in company activities and applies to a wider ground of public as stakeholders. Companies are showing their responsibilities not only for their shareholders and other parties in their projects from a close proximity, but also for the public as a stakeholder from a broader perspective. Corporate social responsibility (CSR) activities are widened with the emphasis on the topic of environment, and corporate social and environmental responsibility (CSER) activities and reports are assembled under the topic sustainability. On corporate web sites, sustainability statements became an essential part of the corporate identity, such as mission and vision statements. As sustainability becomes a core competency in strategic management framework, its existence and approval by the public domain becomes a key issue for corporate strategy, and core competencies cannot be measured in terms of dollars and market share (Chinowsky & Meredith, 2000).

Regarding these notions, this article tries to develop a theoretical framework in order to identify the position and effect of SNSs on corporate identity (CI), and its place in the strategic management of AEC firms. In this regard, concepts that form the theoretical framework of corporate identity evaluation through SNS activity are examined followed by a proposed model for using social media data for corporate ID evaluation. The paper then discusses the model and propose future research recommendations.

Theoretical Framework

Developments in IT are deeply affecting all the industries, forcing companies to invest, adapt and innovate new processes in their business environment, while the boundaries between business and private life is getting blurred by the SNSs. People are becoming increasingly aware of the relevance of environmental issues in their daily lives (Bartels & Hoogendam, 2011). Social media (SM) have completely redefined the interaction between companies, customers and all the stakeholders, creating a social network that enables instant communication. The availability of digital technologies, and the extent of available data are essential elements for exploiting innovative opportunities (Russo et al., 2022). However, companies' attempts to differentiate themselves using these technologies frequently fail due to the lack of integration with their corporate strategies (Dikmen & Birgönül, 2003). This lack of integration puts forward the importance of understanding key concepts and the need for more research to use these technologies to strengthen strategic perspectives.

Corporate Identity

Companies have a strategic perspective just as the personality of individuals, that is independent from its intentionally planned extent and this perspective is crucial for paving the way through competitive advantage (Dikmen & Birgönül, 2003). In a broad definition, corporate identity is how an organization reveals its philosophy and strategy through behavior, communication and symbolism (Leuthesser & Kohli, 1997).

While discussing the corporate identity, other phrases like corporate reputation or corporate image also come to mind. While image and reputation can be regarded as representing the same concept, the main difference between identity and image can be simplified as different perspectives depending on the side we are observing the organization from. From the internal perspective, the term corporate identity should be understood as its personality, and it refers to the essential features that differentiate the organization, meaning the behaviors a company

chooses to present itself to all the stakeholders, as well as the public (Dutot et al., 2016). Instead, company image is how customers or external stakeholders define the impression of the company, and, is more subjective. Moreover, executive managers' reputation accounts for a large extent of the company. This amount is 50% in US, and 63% in Germany according to the CEO magazine (Everett, 2017). On the other hand, the image that a firm creates on their stakeholders, depending on the information the firm disseminates on its internet based digital mediums is called e-reputation, which is also coined as digital reputation (Dutot et al., 2016). Although the means of expression for corporate identity are various in different mediums, leading categories are mission statements of the firms and annual reports that form a visible communication with stakeholders. These reports are also a good source for summarizing corporate image (Leuthesser & Kohli, 1997). Dikmen and Birgönül (2003) indicate that one of the most important objectives of construction companies that operate internationally is building a positive company image.

Corporate Social (&Environmental) Responsibility Reports

In the recent years, the concept of corporate social responsibility (CSR) or with its extended name, corporate social and environmental responsibility (CSER), increased in importance. Harvard Business School reports that 90% of the S&P 500 index companies published CSR reports in 2019, up from 75% in 2014, and 20% in 2011 (Cote, 2021). Although there is not a universally agreed definition of CSR, the European Commission mentions it as social and environmental factors taken into account by stakeholders, in contact with relevant other stakeholders on a voluntary basis (EU, 2001). Zhao et al. (2012) embraces a definition that distinguishes the firm's consideration and response towards issues beyond a narrow economic, technical and legal requirements of the company to accomplish social and environmental benefits balancing the concerns of various stakeholder, adding that CSR reports are an emerging component of corporate performance since the mid 1990's (Zhao et al., 2012). Tekçe (2014) links the emergence of CSR reports to the public demand in parallel to the progress of the sustainability concept and examines their presence in large scale, international construction companies. Research also shows that, leading motivations for releasing CSR reports are reputation and brand identity. The given messages in these reports can be classified under four main topics: benefits, values, focus, and self-image (Leuthesser & Kohli, 1997).

However, current progress in sustainability agenda seems to transform CSR reports a step further that goes beyond the target of opinion formers like pressure groups, politicians and media, towards the whole value chain from an enlarged stakeholder perspective. This progressive report type is called "sustainability report". Despite this focus change, CSR and sustainability are closely linked, and they are often considered as equivalent concepts (Rameshwar et al., 2020). Whether it is a CSR or Sustainability report, SM show a significant contribution to the construction of company's identity than the management of analytical aspects of sustainability performance (Russo et al., 2022).

Previous research suggests that, corporate culture featuring obligation towards social and ethical values are better in attracting best talent, increase productivity and maintain better connections with their stakeholders, also attracting more interest from investors (Moneva et al., 2007). Similarly, Zhao et al. (2012) indicate that CSR is increasingly valued in construction industry for its contribution on sustainable business development, and corporations develop CSR reports to maintain a positive corporate image (Zhao et al., 2012).

In order to achieve this, a firm should integrate its concerns on environmental, social, human or labor related issues with its strategy and policy by a voluntary commitment (Dutot et al., 2016).

Strategic Management Process

A typical management process consists initiation, planning, execution, monitoring and control, and strategic management process fits into this scheme within the same perspective. One of the most intact and cited model for strategic management is shown in Figure 1. In David's model (David, 1989), the initiation and planning stages are considered as 'strategy/formulation', where, the identity of the company is born and matured. As the process is cyclical and multi-dimensional, different stages and components, as well as the results of monitoring and control stage of strategy evaluation gives feedback to the other stages throughout the process lifecycle.

Figure 1. David's Model of the Strategic Management's Process

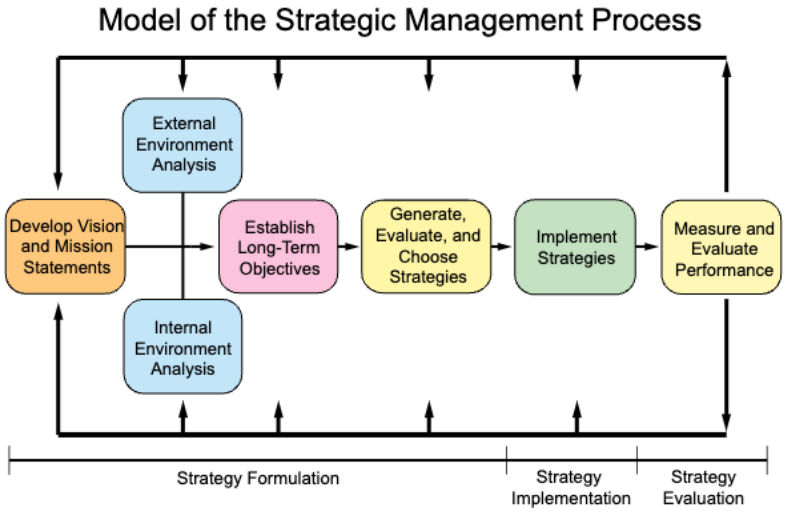


Figure 1: David's 'Strategic Management Process' model.

This model puts forward that, every kind of activity performed by a firm is a product of its strategic perspective, and rooted from its very own identity. Hence, it is also possible to 'reverse-engineer' the process and find out clues about the firms identity from its footprints, and try to understand the strategic management components. Identifying these components can help improve the process according to its objectives or make a company reassess the objectives itself.

Stakeholder (Engagement) Management

In the first instance, it may seem precarious to assess the public as a stakeholder, as the concept derived from the word 'stockholder'. The public may seem to be out of the managerial influence area, and far from administrative discussions. Some of the earliest work

about stakeholder management concepts suggested a narrow definition such as “the groups that enable the existence of the organization (Ackermann & Eden, 2011). However, the sustainability agenda changed such definitions and developed a definition that emphasize a mutual relationship between the two sides. Broadening the concept of strategic management afar from its economic roots, stakeholder can be defined as “any group or individual who is affected by an organization’s objectives as well as parties who can affect it (Freeman et al., 2005). After decades long discussions, it is inevitable to consider each economic activity with its impact on our environment and all the living habitat. In this perspective, the influence of public over corporate institutions cannot be ignored. Ramananda et al. (2020) underlines that public pressure effects corporate disclosure and companies voluntarily release CSR information in social media to respond various social and economic issues and to impress their stakeholders. Environmental issues are receiving an increasing public attention and they dominate the SM based disclosure (Akbas & Canikli, 2014).

Project managers spend a substantial amount of their time, more than 75%, for communication (Alten et al., 2020) and it is a critical part of project management (Turkulainen, 2015). On the other hand, previous research show that top level management teams find dealing with stakeholders problematic, both because of its difficulties as well as its ethically compelling sides (Ackermann & Eden, 2011). At this point, the legitimacy of stakeholder management rise to the surface, and the stakeholder versus stakeholder engagement management discussion emerges. Although these two phrases are being used interchangeably, there are slight differences between the two. As Association for Project Management defines it, stakeholder management approach depends on the prediction that stakeholder actions and behaviors can be predicted and in a way be manipulated, while stakeholder engagement approach focuses on relationship building for the practice of various outcomes through the project life-cycle (APM, 2022). Therefore, it is critical to consider these differences in order to set the aim of a research and adopt the findings from strategic management perspective.

What to Expect from SNS Data

As Feher (2015) indicates, all the companies and their employees, as well as all their partners and stakeholders are leaving digital footprints behind, on the internet. SNSs are not exempt from these digital footprints, and although they give an impression to be on the personal side, corporate presence on social networks is increasing exponentially. Besides, when the employee is considered as the main risk factor for the company’s reputation and safety (Feher, 2015), borders of the personal and corporate area of influence are getting blurred. Chinowsky and Meredith (2000) defined the business change and underlined the importance of the information access more than two decades ago. With the help of IT innovations, the boundaries in front of organizations that they had to place themselves in certain markets have changed drastically. Today any organization regardless of its size and geographical location can bid, design and even operate anywhere around the globe. Knowledge workers, new markets, and IT are part of everyday business life for AEC firms as well as other industries. Dutot et al. (2016) emphasize that the internet presence of companies has increased to such an extent that, it has become a fundamental pillar in communication strategy with its ubiquitous presence and attractive nature for the market, the ability to boost brand reputation with reduced costs, its capacity to offer real-time and easy to cross-check metrics (Dutot et al., 2016; Soydaş Çakır & Levent, 2021).

On the company side, the whole social media profile of the firm and its possible different uses should be managed by the management team distinctively according to different stakeholder profile and expectations. If this strategic process is considered as a simple exitance of a SM profile, companies will lose the opportunity to interact with their stakeholders and enhance their sustainability performance (Russo et al., 2022). SM can be considered more as simple texts and media like photographs or movie clips. Using photographs may help express ideas and experiences in different ways that words cannot and they have the power to influence the observers emotions. Also, it is not uncommon that, companies use images to create biased perceptions in their annual reports such as CSER which may lead to 'greenwashing' (Chong et al., 2019). However, SM presence of the firm creates a more open and traceable environment that is constantly in public eye, and enables verifications by performing crosschecks. In this context, Thompson (2018) positions SNS activities over the 'engagement' and 'connectivity' zones in her 'conceptual framework for the interaction of social media with the practice of project management' (Thompson, 2018).

According to a survey that questioned children in US, UK, and China, the percentage of children who want to be a 'YouTuber' is three times the number of children who wanted to be astronauts, a decade ago (Overstreet, 2022). In the era of content creators and influencers, it is quite appealing to think about a possible rise of 'architecture influencers'. As a medium with increasing importance, the data it produces is vast and available online.

A Data Scraping Model Proposal

Web scraping is a tool used to create structured data sets from unstructured data such as SNSs provide. Besides its popularity for SM research, it can be considered as a tool for collecting, storing and validating data from the internet for many reasons, such as online price comparison. Application Programming Interfaces (API) that many social media developers provide or custom made tools developed by programming languages like Python are being used for collecting data. Under the light of the theoretical framework of this research, two data scraping models are proposed aiming to evaluate the corporate identity of AEC companies from a stakeholder engagement and management perspective.

Data

Data used for firm selection and scraping are open to consideration depending on the framework researcher wants to use. Different databases can be considered as the data released by professional associations, academic institutions, media outlets, or blogs. These company databases should be selected depending on the aim of the particular research considering AEC industry. This research aims to develop a general data scraping model that can be applied for contractors, architectural design companies, or similar. For the trial runs, an international architecture company with active presence in Instagram, as noted by the media outlets is used.

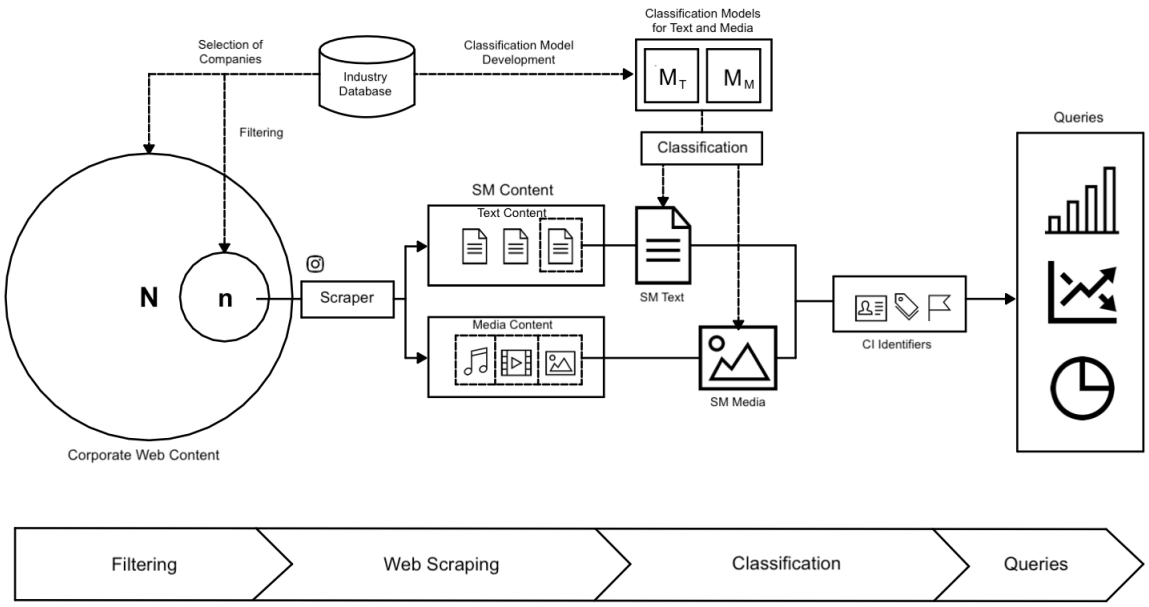


Figure 2: Proposed data scraping model for SNS activities.

Methods

The methodology for data scraping and classification methodology is adapted from (Kinne & Resch, 2018), and presented in Figure 2. In their research, Kinne and Resch (2018) discuss web scraping to obtain innovation indicators for manufacturing firms that are registered in an industrial database, preparing a Phyton programming language based tool, to map geographical locations of innovative firms at a predetermined location. Nevertheless, this research discusses a general SNS scraping model for SM posts, which will develop its own classification models for the text and media files obtained, in order to identify the characteristic items that help form their corporate identity. The model is adaptable to use with different databases, SNS types and uses a freeware, web-based scraping tool obtained from apify.com. The process starts after the database selection and proceeds as follows: (1) filtering the SNS accounts of the companies that will be scanned from the chosen database; (2) scraping the SNS activities form the corporate SM account; (3) Developing classification models for text and media data depending on the used industry database selected; (4) Querying the data for CI evaluation.

Moving further, this research proposes a second model that aims to identify the CI evaluation in comparison to the CSER documentation from corporate web sites of AEC firms. As the literature review suggests many clues about the CSER reports and corporate reputation (Dutot et al., 2016; Leuthesser & Kohli, 1997; Russo et al., 2022; Tekçe, 2014; Zhao et al., 2012), this second model intends to disintegrate text and image used in the reports and classify them using the proposed classification models, in order to both evaluate the CI further but also compare the consistency of these two different sets of data. This second model shown in Figure 3, has a similar workflow with the first model. However, at the web scraping stage, along the SNS data, CSR reports of companies are also scraped. At the classification stage they are dissected into text and pictures, and classified with the developed model. This two-way flow demands necessary adaptations for classifications models that will help reveal the CI identifiers.

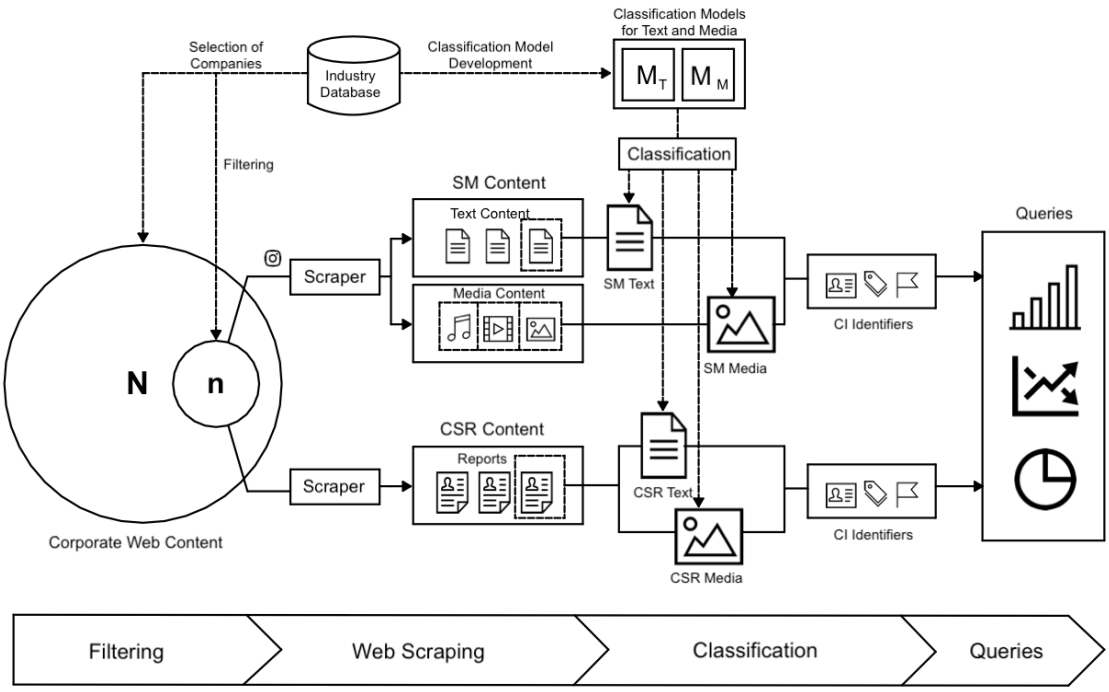


Figure 3: Proposed data scraping model with CSR report module.

Discussion and Conclusion

Stakeholder engagement and management process consists a vast majority of communication practice that are constantly shifting towards informal ways of engagement. As today's highflier of informal communication, SM is an under examined yet powerful tool that can enable big impacts in quite a short time. As business enterprises are paying more attention and trying to secure their position on SM, each SNS activity leaves traces of the firm's corporate identity, that forms a corporate reputation from the stakeholder's perspective. With its possible impacts, SNS activities deserve exploring as a strategic management tool. Different kinds of stakeholders should be considered for SM activities. However, with the rising environmental sustainability concerns, the public became one of the major stakeholders, for the companies who share a common vision for the planet, and want to utilize innovations of IT for their competitive advantage.

This research tries to set the theoretical framework for further research. These two models proposed in this research are developed in order to evaluate corporate identity characteristics of AEC companies that are actively present in SNSs. An SNS scraping process is completed for two major design firms. Further research is being planned for developing the necessary classification models in the near future. Both models will be subject to application for an extensive research that will put forward the corporate identity characteristics of the firms, while testing and developing the models further. Although there are obvious limitations, further research will be utilized to minimize them.

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Optimum Solution of Resource Leveling Problem

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Abstract

The reduction of the fluctuations observed in the resource histogram to the possible minimum level without any delay in the completion time of the construction project is called the resource leveling problem (RLP). The objective of the resource leveling process is to keep the resource utilization rates constant to ensure that the change in resource demand is kept at the minimum throughout the project. Moreover the activities are scheduled in order to ensure that the project completion time does not exceed the one obtained by the early start time of the activities. In this study, software is developed in Visual Basic which generates the construction schedule with the minimum resource fluctuations for small scale construction projects. The software solves the RLP by evaluating all of the scheduling options. Minimum moment resource fluctuation metric is utilized to measure the amount of fluctuations in the resource distribution throughout the construction project. The algorithm evaluates all of the possible scheduling alternatives and records the schedule which gives the minimum resource fluctuation. The executable file is tested to solve the resource leveling problem of a two story construction project. The problem is solved within one hour of computation time. The case study showed that the developed executable file can be implemented by the small scale contractors for the optimum solution RLP.

Keywords: *complete enumeration, optimization, resource leveling problem.*

Introduction

Construction projects may consist of large number of activities, may request large volume of resource use, and may provide high financial turnover. However highly competitive business environment makes impossible to compete without effectively managing the utilization of the resources. In order to manage projects properly in competitive conditions, project managers need to prepare a plan that foresees how resources will be used. In construction works, this planning is usually based on construction schedules. However, planning by focusing only on time causes the other project goals to be ignored, as well as causes an increase in costs. In planning, the goal is to evaluate the project elements together and to balance all elements effectively to get the maximum benefit from the project. Starting activities at the earliest start times may cause undesirable fluctuations in the resource histogram. These fluctuations affect the total budget of the project. Therefore, resource usage should be organized to have a better resource profile (Hiyassat, 2001, 2002).

One of the resource planning tools in projects is resource leveling. The main goal in resource leveling is to improve the resource usage by reducing the fluctuations of the resource demand and the peak resource demand without changing the project duration. Resource fluctuations may cause financial problems, penal sanctions in contracts, increased costs of temporary facilities-resources, and increased demand for the limited resources (Erzurum & Bettemir, 2021).

Exact methods, heuristics and meta-heuristics are applied to solve the RLP. Heuristic and meta-heuristic methods do not guarantee an optimal solution. Exact methods, on the other hand, can provide the guaranteed optimum solution for small-sized problems of RLP, which is NP-Hard (Rieck & Zimmermann, 2015). The computation time and memory requirement of the exact methods for the solution of RLP increase very rapidly if the number of activities of the project increases (Demeulemeester & Herroelen, 2002). Therefore, mathematical methods are insufficient for large-scale problems. However, it should be noted that it is inevitable that exact solutions are needed for the performance analysis of heuristic and meta-heuristic methods.

Heuristic methods require low computational demand. Because of the mentioned convenience, the solution performance is quite low compared to other methods. Because the main focus of the heuristic methods is to solve the problems in a reasonable time. In the problems solved with heuristic algorithms, it is generally aimed to produce a fast solution knowing that the solution is not guaranteed. Even if these algorithms search for solutions that are close to optimum, they are focused on reducing the solution time. Burgess and Killebrew (1962) proposed one of the first heuristics to solve the resource leveling problem. This method is based on a network-based solution that changes the start dates of non-critical activities by shifting the activities until they find the best result. Much of the later work has also focused on priority-based shifting techniques (Harris, 1978, 1990; Martinez & Ioannou, 1993; Hiyassat, 2000, 2001).

Due to the complex resource relationship and the large number of work items in the construction industry, intuitive solutions have become more and more inadequate in resource leveling in the construction industry. Because of the computational burden and time required by exact methods, researchers mostly turned to meta-heuristic algorithms. Meta-heuristic algorithms can direct the search process in the solution space, they can guide the problems to find the best points, reduce the solution time, and the memory requirement, and the effort to avoid local extreme points. In fact, the basis of all these positive features is the artificial intelligence created in the structure of meta-heuristic algorithms. Some of the most common meta-heuristics algorithms utilized for the solution of RLP are; genetic algorithms, simulation annealing, taboo search, particle swarm optimization, ant colony, petri nets, evolutionary development (Hegazy, 1999; Hegazy & Kassab, 2003; Iranagh & Sonmez; 2012; Son & Skibniewski, 1999; Wang & Zheng, 2001; Zheng et al., 2013; Bettemir, 2009; Ponz-Tienda et al., 2017; Lin & Gen, 2018; Qi et al., 2007; Wang & Qi, 2009; Li et al., 2010; Geng et al., 2011).

The solution space of RLP varies according to the number of activities, activity precedence relationships, and total float durations of the activities. Performances of the meta-heuristic methods are likely to reduce if the search space is too large. To avoid this, a deeper search strategy and effective learning algorithms can be developed and used. This will increase the memory requirement considerably because as the search space grows. In addition to this, population size must increase to obtain a near-optimal solution. With the processors produced

today, this negativity can be reduced. In cases where these negativities cannot be eliminated, precise methods are used, which have a high computational load and a longer solution time compared to other methods. Despite these negativities, it is clear that there is a need for problems that can be solved with exact methods and algorithms to be developed. Some of the exact methods are; dynamic programming, branch and bound algorithm, and linear integer programming (Younis & Saad, 1996; Agin, 1966; Demeulemeester & Herroelen, 1992; Mutlu, 2010; Yeniocak, 2013; Karaa & Nasr, 1986; Easa, 1989; Son & Mattila, 2004; Rieck & Zimmermann, 2015; Gather et al., 2011). The largest problem whose exact solution is obtained in a guaranteed manner is 50 activities.

Due to the limitations of the RLP solution methods currently used in the literature, a new solution method is needed. In this study, a method is developed that determines the search space by delaying the non-critical activities of RLP and obtains the guaranteed optimum result by scanning the entire search space. The second part of the study explains how the entire search space of RLP is determined and scanned. In order to measure the performance of the developed method a two-story building project is analyzed in the case study part, and finally the results are concluded.

Proposed Complete Enumeration Algorithm

The first stage of implementation is to create the network diagram of the project. One of the most common methods used for project planning is the activity on arrow diagrams. After the network is created, forward and backward pass calculations are made to obtain the early and late start times as well as float durations of the activities. In RLP delay of an activity cannot be more than its total float duration. In RLP delay times of the noncritical activities are the variables of the problem. The delays of the activities are assigned from 0 to its total float duration in sequence to execute complete enumeration. At each step only one delay time of an activity is incremented.

The construction schedule is formed after the assignment of the delay times. The start and end times of the activities should not violate the early and late start-finish times. Resource usages of the activities are determined by considering the start and finish times and the resource requirement of the activity. The daily resource demand is computed by summing the all of the resource demands of the activities which are executed on that particular day. The resource histogram is prepared by computing the daily resource usages for all of the project days.

The resource fluctuations are measured by resource leveling metrics which will be the objective function of the optimization process. The choice of objective function is very important in order to obtain a properly leveled resource histogram. The basic principle of the objective function is to measure the fluctuations of the resource usages. Minimum moment metric is used in for the measurement of the resource fluctuations. There have been studies in the literature dealing with the use and comparison of objective functions tried with different methods (Damci & Polat, 2014; Damci et al., 2016; Bettemir & Erzurum, 2019a, 2019b). The preferred objective functions are specific to the examined project. In other words, an objective function that gives a good resource profile in one project may not be efficient in another. Before this study, common metrics used in the critical path method were compared and the MM scale was preferred by evaluating the improvement of the resource profile (Bettemir & Erzurum, 2019a, 2019b). The formulation of the minimum moment scale proposed by Burgess and Killebrew (1962) is presented in Eq. 1.

$$MM = \sum_{i=1}^{S} \sum_{j=1}^{k} w_j r_{i,j}^2 \quad (1)$$

In Eq. 1, s is the project duration, k is the number of different resources, $r_{i,j}$ is the j^{th} resource amount needed on the i^{th} day, and ω_j is the weight value assigned for the j^{th} resource. The daily required amounts of each resource are collected in the construction schedule. Then, the total moment calculation is made by applying the objective function.

All of the feasible schedules are evaluated by implementing Eq. 1 and the obtained minimum moment value and the corresponding construction schedule is recorded. In this way, by trying all possible delay combinations, the entire search space of the resource leveling problem will be scanned and the best solution to the problem will be found.

The proposed method is implemented by software developed with the Visual Basic programming language. The advantage of the developed method is that it obtains the most suitable work program in small and medium-sized projects by scanning the entire search space. The software calculates all possible scheduling alternatives using the minimum resource metric and saves the alternative that gives the minimum resource. The details of the preparation and application can be found in (Erzurum & Bettemir, 2017, 2018, 2021; Erzurum, 2019). The computation details of the search domain are given in the case study part to ensure the completeness of the study.

Case Study

The implementation and the benefits of the developed application are illustrated with an example. The presented example consists of the analysis of a two-story building with 36 activities. In the problem only a single resource is defined. The project is completed in 106 days. Actually, other sources are needed for the activities, but in order to show the recommended practice, a review on a single source was preferred. The arrow diagram of the problem with CPM is shown in Figure 1. The amount of resource requirements are presented in Table 1.

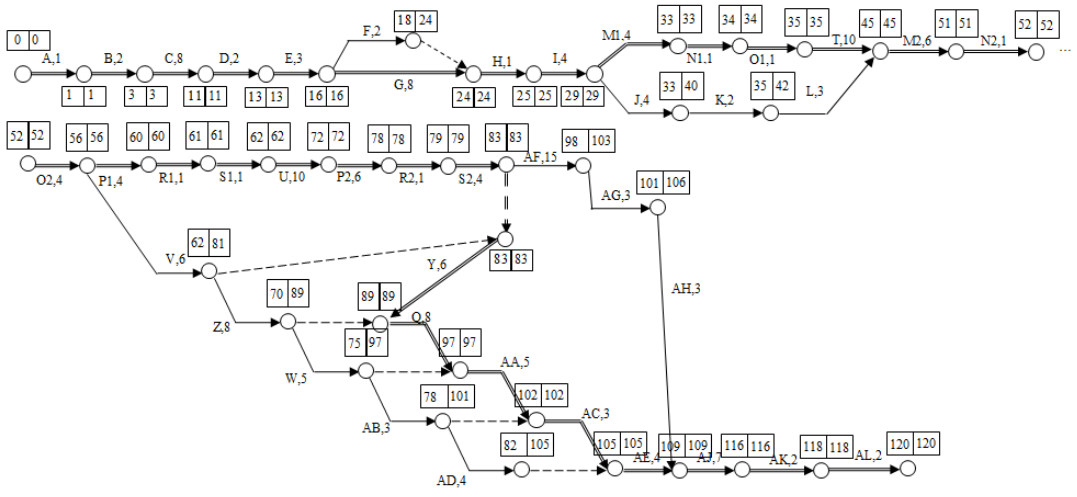


Figure 1: Network diagram of the analyzed two story building construction.

Table 1. Activity names, start times, and float durations.

Definition of the Activity	Activity	Dur.	Pred.	EET_i	LET_i	EET_j	LET_j	Resource	Free Float	Total Float
Grading	A	1	-	0	0	1	1	2	0	0
Mobilization	B	2	A	1	1	3	3	5	0	0
Excavation	C	8	B	3	3	11	11	3	0	0
Lean concrete	D	2	C	11	11	13	13	3	0	0
Water Insulation	E	3	D	13	13	16	16	7	0	0
Mechanical Works	F	2	E	16	16	18	24	4	0	6
Formw. & Reinf. (Foundation)	G	8	E	16	16	24	24	10	0	0
Concreting (Found)	H	1	F-G	24	24	25	25	6	0	0
Cure (Found)	I	4	H	25	25	29	29	1	0	0
Drainage	J	4	I	29	29	33	40	5	0	7
Connection to Rain Drainage	K	2	J	33	40	35	42	5	0	7
Backfill	L	3	K	35	42	45	45	4	7	7
Formwrk & Reinf. Of Columns (Ground F)	M1	4	I	29	29	33	33	10	0	0
Concreting of Columns (Ground F.)	N1	1	M1	33	33	34	34	6	0	0
Cure of Columns (Ground F.)	O1	1	N1	34	34	35	35	1	0	0
Formwrk & Reinf. Of Slab & Beams (Ground F)	M2	6	T	45	45	51	51	10	0	0
Concreting of Slab & Beams (Ground F.)	N2	1	M2	51	51	52	52	6	0	0
Cure of Slab & Beams (Ground F.)	O2	4	N2	52	52	56	56	1	0	0
Formwrk & Reinf. Of Columns (1st Floor)	P1	4	O2	56	56	60	60	10	0	0
Concreting of Columns (1st Floor)	R1	1	P1	60	60	61	61	6	0	0
Cure of Columns (1st Floor)	S1	1	R1	61	61	62	62	1	0	0
Formwrk & Reinf. Of Slab & Beams (1st Floor)	P2	6	U	72	72	78	78	10	0	0
Concreting of Slab & Beams (1st Floor)	R2	1	P2	78	78	79	79	6	0	0
Cure of Slab & Beams (1st Floor)	S2	4	R2	79	79	83	83	1	0	0
Masonry (Ground F.)	T	10	O1	35	35	45	45	8	0	0
Masonry (1st Floor)	U	10	S1	62	62	72	72	8	0	0
Fittings (Ground F.)	V	6	O2	56	56	62	81	5	0	19
Fittings (1st Floor)	Y	6	S2-V	83	83	89	89	5	0	0
Plastering (Ground F)	Z	8	V	62	81	70	89	7	0	19
Plastering (1st Floor)	Q	8	Y-Z	89	89	97	97	7	0	0
Door& W. Frames (Ground F)	W	5	Z	70	89	75	97	4	0	22
Door& W. Frames (1st Floor)	AA	5	Q-W	97	97	102	102	4	0	0
Floor Covering (Ground F)	AB	3	W	75	97	78	101	5	0	23
Floor Covering (1st Floor)	AC	3	AA-AB	102	102	105	105	5	0	0
Painting (Ground F)	AD	4	AB	78	101	82	105	4	0	23
Painting (1st Floor)	AE	4	AC-AD	105	105	109	109	4	0	0
Roof	AF	15	S	83	83	98	103	9	0	5
Roof Insulation	AG	3	AF	98	103	101	106	4	0	5
Rain gutters	AH	3	AG	101	106	109	109	3	5	5
Landscape	AJ	7	AH-AE	109	109	116	116	5	0	0
Control & Tests	AK	2	AJ	116	116	118	118	2	0	0
Cleaning	AL	2	AK	118	118	120	120	5	0	0

The network diagram shown in Figure 1 consists of 42 activities. The analyzed project is a hypothetical but a realistic construction project of a 2 story building which is constructed by traditional techniques. The building is reinforced concrete but the masonry walls are also load bearing walls. Initially the formworks and reinforcements of the columns are prepared and concreted. The masonry walls are constructed without waiting the final set of the concrete. Then formworks and reinforcements of the beams and the slabs are prepared and then they are

concreted. In this technique, the masonry walls also carry some of the loads on the structure. As a result of this, less bending moments on the beams and columns will occur and less reinforcement is required. This construction technique is slower but more economical than reinforced concrete technique. The same project is analyzed by Erzurum and Bettemir (2021) but with modern construction technique which is constructed in 104 days. However, this time the construction duration is 120 days.

First, the search space of the problem is determined. In order to divide the problem into manageable sizes, the diagram is examined in terms of the paths that constitute the whole diagram. In this problem, apart from the critical path there are 4 noncritical paths which are J-K-L, F, AF-AG-AH and V-Z-W-AB-AD non-critical paths. The details of the number of feasible schedule computations are presented in the Tables 2 to 4.

Table 2 illustrates that if the delay of activity V is kept constant at 0 day, the delay combination of the remaining noncritical activities of the path V-Z-W-AB-AD makes 17495 delay combinations. If the activity V is delayed 1 day then the activity Z has to be delayed by 1 day. In this case 2599 feasible scheduling alternatives are eliminated which makes the number of feasible schedule 14896. If the activity V is delayed 2 days, then the activity Z has to be delayed 2 days. The computation is not shown in Table 2 but in this case the reduction of the feasible schedules will be equal to the sum of the number 276, 253, 231, … , 3 which is equal to 2299. This makes the number of feasible schedule evaluations 12597 when the activity V is delayed 2 days. The total schedule evaluations become 97280 when all of the delay possibilities of the activity V are investigated.

Table 2. Feasible search space of the path V-Z-W-AB-AD.

V	Z	W	AB	AD	Feasible Search Space	
0	0	0	[0,23]	[AB,23]	300	
		1	[1,23]	[AB,23]	276	
		2	[2,23]	[AB,23]	253	
		…	….	….	…	
		22	[22,23]	[AB,23]	3	(2599)
0	1	1	[1,23]	[AB,23]	276	
		2	[2,23]	[AB,23]	253	
		3	[3,23]	[AB,23]	231	
		…	….	….	…	
		22	[22,23]	[AB,23]	3	(2299)
0	19	19	[19,23]	[AB,23]	15	
		20	[20,23]	[AB,23]	10	
		21	[21,23]	[AB,23]	6	
		22	[22,23]	[AB,23]	3	(34)
Total					17495	

Table 3 illustrates the computation details of the number of schedule evaluation of the path J-K-L. In the first line the activity J is not delayed and the activity K can be delayed from 0 day to 7 days which makes 8 different delay alternatives. The activity L must be delayed at least the delay time of the activity K. Therefore the delay alternatives of the activity L is from delay of K to 7 days. If the activity K is delayed by 0 day the activity L can be delayed from 0 day to 7 days which makes 8 delay alternatives. If the activity K is delayed by 1 day, the activity L can be delayed from 1 day to 7 days which makes 7 delay alternatives. As a result of this the number of delay alternatives becomes the sum of the numbers from 1 to 8 which is 36. This situation is shown in the first line of Table 3. If the activity J is delayed 1 day, the activity K has to be delayed at least 1 day. In this case 8 delay alternatives occurred by the

delay of K activity by 0 day is eliminated and 28 delay alternatives are formed. The rest of the delay alternative computations are given in Table 3 and the total delay alternatives which can be formed from the path K-L-J becomes 120.

Table 3. Feasible search space of the path K-L-J.

J Act	K Act	L Act	Number of Feasible Schedules
0	[0,7]	[K,7]	8 +7 + 6 + 5 + 4 + 3 +2 + 1 = 36
1	[1,7]	[K,7]	7 + 6 + 5 + 4 + 3 +2 + 1 = 28
2	[2,7]	[K,7]	6 + 5 + 4 + 3 +2 + 1 = 21
3	[3,7]	[K,7]	5 + 4 + 3 +2 + 1 = 15
4	[4,7]	[K,7]	4 + 3 +2 + 1 = 10
5	[5,7]	[K,7]	3 + 2 + 1 = 6
6	[6,7]	[K,7]	2 + 1 = 3
7	[7,7]	[K,7]	1
Total			120

Table 4 illustrates the computation of the number of feasible schedules that can be formed by delaying the activities in the path AF-AG-AH without violating the precedence relationships. The path has 5 days total float duration. If the activity AF is delayed 0 day, than the activity AG can be delayed from 0 day to 5 days. The activity AH can be delayed from the delay duration of AG to 5 days. In this case if the activity AG is delayed 0 day, AH can be delayed from 0 day to 5 days which makes 6 delay alternative. If the activity AG is delayed 1 day the activity AH can be delayed from 1 day to 5 day which makes 5 delay alternatives. Finally if the activity AG is delayed 5 days then the activity AH has to be delayed 5 days. This situation makes the number of feasible schedules equal to the sum of the numbers from 1 to 6, which is shown in the first line of the Table 4. If the activity AF is delayed 1 day, then the activities AG and AH have to be delayed at least 1 day. In this case the delay alternatives become from 1 day to 5 and reduce to 5 delay alternatives. In case AF is delayed 1 day, the number of feasible schedules becomes equal to the summation of the numbers from 1 to 5. The mentioned situation is shown in the second row of the Table 4. The rest of the delay situations are shown in Table 4 and 56 feasible schedules can be produced by delaying the activities of the path AF-AG-AH.

Table 4. Feasible search space of the path AF-AG-AH.

AF Act.	AG Act.	AH Act.	Number of Feasible Schedules
0	[0,5]	[AG,5]	6 + 5 + 4 + 3 + 2 + 1 = 21
1	[1,5]	[AG,5]	5 + 4 + 3 + 2 + 1 = 15
2	[2,5]	[AG,5]	4 + 3 + 2 + 1 = 10
3	[3,5]	[AG,5]	3 + 2 + 1 = 6
4	[4,5]	[AG,5]	2 + 1 = 3
5	[5,5]	[AG,5]	1
Total			56

All of the examined paths are not parallel to each other. To illustrate, the path J-K-L are parallel with the critical path so its schedule does not permute with the other paths. On the other hand, paths AF-AG-AH and V-Z-W-AB-AD are parallel and their feasible schedules permute. Therefore the numbers of feasible schedules of the paths AF-AG-AH and V-Z-W-AB-AD are multiplied to compute the number of feasible schedules of the project. The path J-K-L does not permute and examined independently. Therefore, the number of schedule evaluation of path J-K-L is added and the total 5.447.800 schedule evaluation is obtained as shown in Table 5.

Table 5. Computation of total number of feasible schedule.

Paths	Number of Feasible Schedules
J-K-L	120
AF-AG-AH	56
V-Z-W-AB-AD	97280
Total	5.447.680 + 120 =5.447.800

Table 6. Activity delay durations of the optimum solution.

Delay of J	4
Delay of K	4
Delay of L	4
Delay of V	2
Delay of Z	2
Delay of W	6
Delay of AB	6
Delay of AD	6
Delay of AF	5
Delay of AG	5
Delay of AH	5
Early start value	12568
Optimum value	12094

All of the feasible schedule evaluations are examined and the obtained guaranteed optimum result is given in Table 6. The objective function is reduced which means that the fluctuations in the resource usage is minimized. The Gantt diagram of the schedule obtained by the early start of the activities and the Gantt diagram of the optimized schedule are given in Figures 2 and 3 respectively.

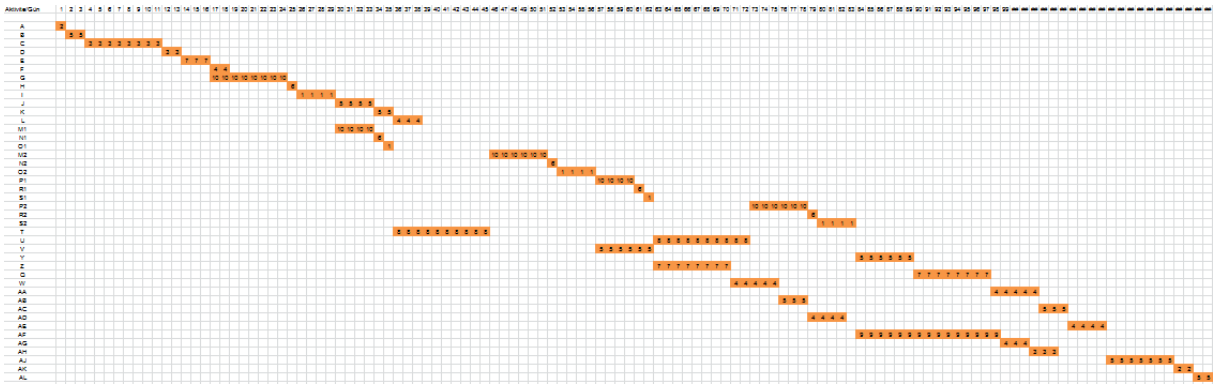


Figure 2: Gantt diagram of the initial schedule.

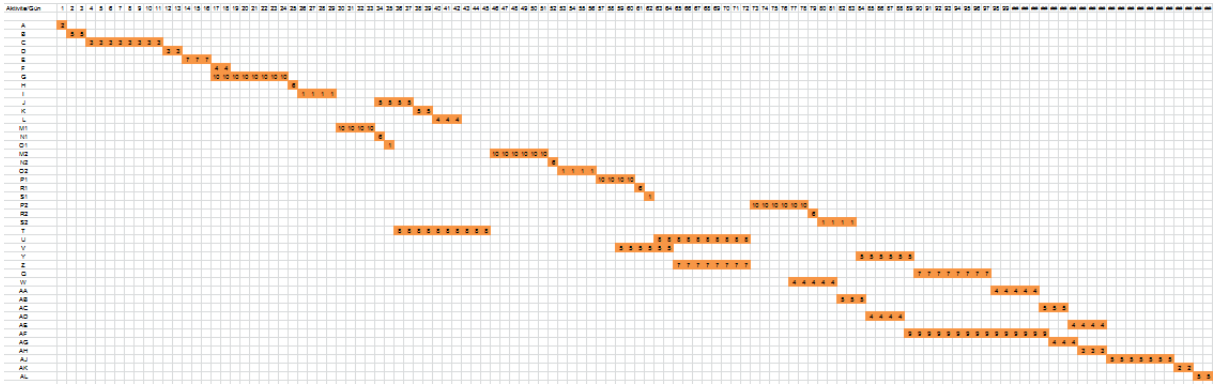


Figure 3: Gantt diagram of the optimized schedule.

The obtained moment values are less than the ones obtained by Erzurum and Bettemir (2021) because the duration of the project elongates without increasing the total man-hour. Therefore the daily resource requirement is reduced and consequently the sum of the square of them also reduced. The obtained schedule is the guaranteed optimum schedule with the minimum moment value because all of the feasible schedule alternatives are tried. Since there is not any feasible untried scheduling alternative it is sure that the optimum solution is achieved.

Conclusion

In this study, construction schedule of a two story building which consists of 42 activities is examined. The examined case problem is the largest project in terms of number of activities. This can be the contribution of this study. The fluctuations of the resources are minimized by utilizing the minimum moment resource distribution metric. The optimization process is handled by exhaustive schedule evaluation. The feasible schedule alternatives are formed by dividing the project into unique path. Each path is examined by adopting the combinatorial analysis and the numbers of different scheduling alternatives are obtained. The paths are combined and the number of the feasible schedule evaluation of the project is obtained and complete enumeration is performed by a Visual Basic code. The obtained solution is guaranteed optimum because all of the schedule evaluations are examined. The computational demand of the implemented technique is high but the computation time can be reduced by parallel computing as future study. The complete enumeration technique can be adopted to obtain the optimum value and the performances of meta-heuristic algorithms can be evaluated by comparing them with the known exact solution.

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Heritage Building Information System (HBIM) in Project Management of Cultural Heritage Buildings

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Abstract

Project management is the application of planning, organizing, directing, coordinating and controlling by using project resources to meet the requirements of a project and achieve the project goal and objectives. Companies have systematic efforts aimed at successful completion of projects that gradually become more and more complex in Turkey, just like in the developing countries. The project management system that consists of implementation of the project, time, cost, quality, contract and occupational safety management systems during the project process in a manner complementing each other considerably affects the individual achievement of companies. Project management system is generally associated with the construction sector.
In our country, which is very rich in terms of cultural heritage, there are many conservation project is being carried out for the cultural heritage buildings in the area. Although cultural heritage building information management (HBIM) is a highly studied field, cultural heritage management studies and research on project management processes in the field of conservation projects and applications of heritage buildings are limited. Project management process is well understood, however the concept of project management for architectural heritage projects is different because of uniqueness of every project. When we deal with architectural heritage, historic buildings etc., we need to spend more time and resources to understand what we have and to access its physical condition. In this study, the evaluation of Heritage Building Information System (HBIM) in project management are related with cultural heritage buildings.

Keywords: *construction sector, cultural heritage management, heritage building information management (HBIM), project management.*

Introduction

Cultural heritage management approach, the conservation concept has shifted from technical practice to a factor that increases the quality of life. Therefore, it is possible to perceive cultural heritage management as the most social and public form of conservation action. Cultural heritage management is an integrated conservation approach based on a management mechanism. An integrated conservation process can only be achieved by establishing a management mechanism. There has been an increasing public awareness of cultural assets around the world (Smith, 1999). The cultural heritage management is a complicated and changeable process and it should be modified according to the changes in the political, economic and physical settings (Vacharopoulou, 2005).

Those who work in the field of cultural heritage, are also working on how to manage the cultural heritage, how to research new methods to achieve analysis, how to find the wright material to use collection in order to develop the heritage management. Protection principles are prioritized in determining the methods (Çırak, 2022). Cultural heritage management also include a risk and crisis management plan. At this point, SWOT analyzes and PEST (political, economic, social and technical) auditing and risk assessment should be done. In risk assessment, apart from the period in which the cultural heritage was constructed, all parameters such as the physical environment it is in today, the psychological and sociological conditions of its users, and the economic balances should be considered holistically (Urtene, 2000). Project management can solve the problems of bureaucratic processes, hierarchy within government structures, balances between public and private investments control, creating a cost-benefit balance and risks.

Project Management in Cultural Heritage Buildings

Project management is important for organizing, planning, controlling the project, identifying and clearing issues, managing risks and changes, managing integration and using knowledge. Project management process is well understood, however the concept of project management for architectural heritage projects is different because of uniqueness of every project. However, the implementation of the project management in this area is possible with the facts that, in particular, the project manager is experienced in this area, knows the value of the architectural heritage project, is able to persuade all stakeholders in this regard, knows what needs to be done at each phase of the process; time management, budget updating, risk management, resource management etc., are carried out in the right phases (Güner & Benli, 2019).

In managing cultural heritage values, the qualities of cultural heritage values must be considered. For predictability, the cultural heritage challenges must be assessed so that technologically challenging and costly adjustments or repairs do not arise. Basic project management theory provides that flexibility is generally at its greatest in the early phases of a project, so there is no need to postpone the assessment of cultural heritage in a project (Stendebakken & Olsson, 2018).

The project's front-end phase is when the project exists conceptually, before the final decision about financing the project is made. The most important decisions regarding cultural heritage management are made in this phase. At this stage, the possibility of influencing the final outcome is at its highest (Stendebaken & Olson, 2017).

The main aim of project management is to evaluate the importance of the role of cultural heritage buildings to achieve sustainable refurbishment from the perspective of project managers and team members for the decision-making process, through providing guidance for, first, the flow of work between the stakeholders and, second, the arrangement of the tasks.

The role of project management to make sustainable refurbishment for cultural heritage buildings is important. Therefore, it is essential for the field experts to choose the convenient methods of refurbishment that best suit the situation and reduce the gaps between stakeholders in the management process. This will help the project managers and team members in the decision making process through providing guidance for the flow of work between stakeholders and the arrangement of tasks (Khodeir & Soliman, 2017).

Stakeholders involved in each process/phase of managing sustainable refurbishment for heritage buildings should achieve long-term benefits Guidance for the role of project management on heritage refurbishment (Figure 1). The most appropriate method of protection that cultural heritage experts will use in managing the situation will also guide the conflict between the shareholders. This will help the project managers and team members in the decision making process through providing guidance for the flow of work between stakeholders and the arrangement of tasks (Khaled et al., 2021).

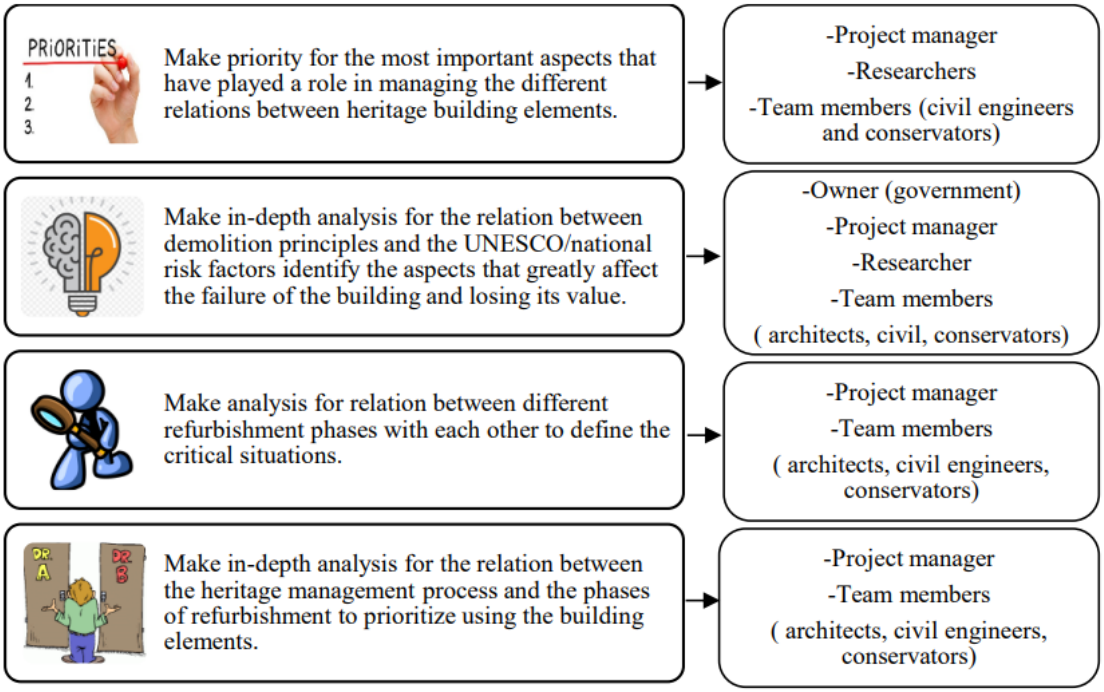


Figure 1: Guidance for the role of project management on heritage refurbishment (Khaled et al., 2021).

Heritage refurbishment aims to maintain and restore the original form of cultural heritage buildings without modernizing them. According to the Sustainable Local Heritage Conservation (2006), a conference was held with the aim of merging Project Management Body of Knowledge (PMBOK) and the National Historic Preservation Act (NHPA). It also recommended more management schemes for cultural heritage projects in terms of operations and resources (Hajialikhani, 2014).

Building information modelling (BIM) within renovation of buildings of significant architectural, historic or cultural values can evaluate the possibilities about renovation or restoration projects of historic buildings can be more demanding, challenging and complex than traditional renovation of for instance within housing. BIM is the tool used for holistic approach on project management and for repetitive data collection, design, simulation and verification processes, and in that sense seen as a tool to use in optimization of this process (Mazzola et al., 2017). As a multidisciplinary design, engineering and project management consultancy have extensive experience of applying BIM and geospatial techniques at all scales, from the restoration of important historical buildings up to major infrastructure projects and cultural landscapes (Kemp, 2014).

In order to improve the framework for 3D modeling, an accurate virtual model of a historic building is digitally constructed, using BIM (Building Information Modeling), where the building is being maintained through its entire lifecycle, including demolition. This integration of heritage recording and BIM is now a method to document and manage historic buildings, in which parametric objects are built, taking into account historical data, and layered-in plug-in libraries representing building components (Dore & Murphy, 2012).

Its integration in environmental design projects is proven to help design teams to make informed decisions from the early design stages and during the whole building life – cycle (Wu, 2010). This dissertation explores the potentials and challenges of BIM application in environmentally sustainable heritage reuse. For that purpose, two aspects are to be explored: applying BIM for heritage management, and applying BIM in environmentally sustainable building projects. Lately, many developments in the BIM field have been established, where the developed technology and methods challenged the cultural heritage community in the documentation framework. BIM has been a growing development within the past decade in the field of cultural heritage documentation, paving the way towards a future in the virtually built environment. In addition, BIM can also enhance the application of sustainable retrofitting of such buildings in particular, as HBIM provides review of the building's exterior and interior, and it also eases the availability to survey renovations and changes that either took place through different time periods or changes that will take place upon applying sustainable retrofit (Logothetis et al., 2015).

Heritage Building Information System (HBIM) in Project Management of Cultural Heritage Buildings

BIM use in the field of cultural heritage documentation. The diversity and complexity of BIM technology is obvious in many different fields; identification of environment, documentation of buildings, examination of construction or structure. (Logothetis et al., 2015). Building Information Modelling (BIM) is progressively being used in managing the complex processes within architecture, engineering and construction industry. Its application for heritage management is called Historic Building Information Modelling, or HBIM (Luggo et al., 2020).

The field of Heritage Building Information Modelling from heritage building management, maintenance and improvement perspectives, including the meaning of conservation, understanding and managing significance, surveys and inspections, energy efficiency and sustainability, building maintenance and repair, managing buildings and project management, managing quality and appropriateness of work and consent applications (Atıcı et al, 2017).

Where work is to be undertaken to an historic building, project management should be integrated with heritage management. This emphasises that understanding and managing significance is essential and needs to be incorporated into the HBIM. Arayıcı describes the situation as follows “There should be a process in place to ensure all people working on the project are aware of the significance of the historic building’’ (Arayıcı et al., 2017).

The interest for adoption of BIM for managing heritage is not on a great level. HBIM usage has demonstrated benefits in managing heritage projects, but the need for further research, and standards of cultural documentation is displayed in the published literature on this subject. It has been found that existing processes to develop our built environment are confusing, poorly

co-ordinated, with design information difficult to find and with many repeated activities, thus raised costs (Brookes, 2017).

In HBIM the parametric objects are built from historic data (surveys, assays and literature) and layered in plug-in libraries aimed to map the elements onto point clouds data and image survey data (Dore & Murphy, 2012). The HBIM process involves a reverse engineering solution whereby parametric objects representing architectural elements are mapped onto laser scan or photogrammetric survey data. The HBIM process generally includes a number of phases, starting with collecting and processing of laser/image survey data, identifying historic details from architectural pattern books, building parametric historic components/objects and finally correlation and mapping of parametric objects onto scan data and the final production of engineering survey drawings and documentation (Murphy et al., 2013).

Creating an as-built BIM is considered the first step of applying the HBIM process. It includes a number of steps as follows: 1. Data collection: in which dense point measurements of the facility are collected using laser scans taken from key locations throughout the facility. The product of the laser scan takes the form of a point cloud that represents the coordinates of the scanned building. 2. Data processing: through this phase of the HBIM process, the sets of point measurements (point clouds) from the collected scans are filtered to remove artefacts and combine into a single point cloud or surface representation in a common coordinate system (Tang & Huber, 2010).

The whole process is clearly represented as HBIM life – cycle diagram, as shown in Figure 2. The starting point of the HBIM process is the survey of the asset. Practically, knowledge and understanding of the historic assets' existing state translates into initial input of information into the HBIM. After the options and detailed surveys are performed, the intervention type is decided so it can be physically performed. When the work is done, the handover and operation phases can be realized, after which the information is stored for the future intervention strategies (Brooks, 2017).

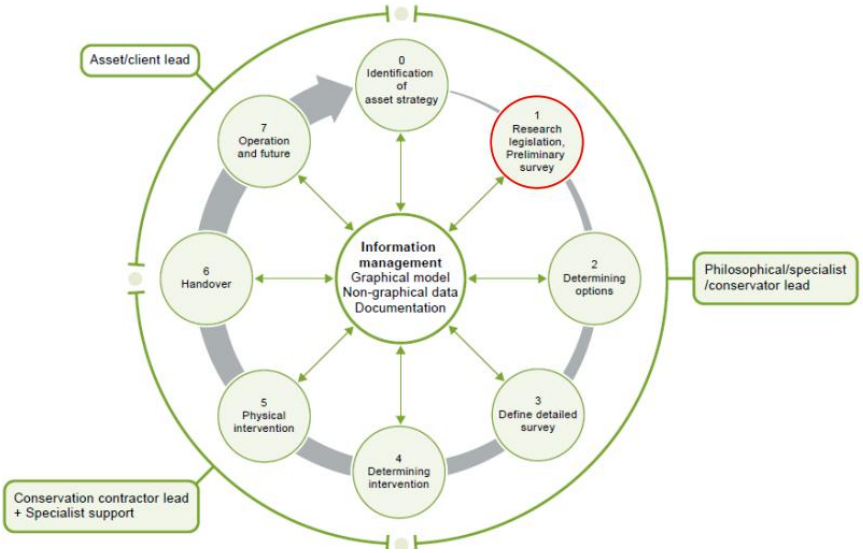


Figure 2: HBIM life – cycle diagram (Brooks, 2017).

Historical building management and planning conservation raise two important issues: the restoration and improvement of historical areas features and adopting a framework of sustainable development in heritage regions. Recently a number of processes have arose to aid in the aforementioned problems, namely the heritage building information modelling (HBIM) and the cyber-physical systems approach (CPS), where the latter is believed to achieve great potentials hereby integrating virtual models and physical construction and enabling bidirectional coordination (Khodeir et al., 2016).

On one hand, HBIM, a plug-in for Building information modeling (BIM) (Khodeir et al., 2016), was introduced as a process for modeling historic buildings from laser scan and photogrammetric data. Thus HBIM is specially tailored to the application on heritage buildings and on the long term management of the built environment (Dore & Murphy, 2012). On the other hand, employing the "cyber-physical systems" approach achieves more potential by integrating virtual models and physical construction, enabling bidirectional coordination (Akanmu et al., 2013). This will serve as a digital archive to help in conserving the heritage buildings and to test future development proposals within the context of these historic buildings.

The present study considers it from different angles by exploring the cyber-physical systems (CPS) approach to innovatively integrate Heritage building information modeling (HBIM) and physical construction (Khodeir et al., 2016).

Introducing Cyber-Physical Systems (CPS) have attempted to link virtual models and the physical construction using different data acquisition technologies (e.g. digital cameras, laser scanners, radio frequency identification tags). However, the existing approaches do not offer opportunities for two-way integration or communication between the virtual models and the physical construction. This two way integration/communication is important for enhancing feedback or controlling the constructed facility. To maintain bi-directional coordination, computational resources are required to tightly integrate the virtual models and the physical construction, such that changes in one environment are automatically reflected in the other. This is termed a cyber-physical systems approach. Cyber-physical systems approach has long been adopted in information systems research, and in other industry sectors (Akanmu et al., 2013). The analysis also proved uncovered the main difference between HBIM and CPS, where the later offers more potential by integrating virtual models and physical construction; achieving bidimensional coordination, enabling better communication between the design and in site teams with accurate documentation of the as-built condition. However convergence is increasingly prevalent for both processes, as for maintaining consistency between the virtual model and physical construction components, enabling preventative maintenance throughout the life cycle of the facility and finally the require of many potential applications in building enclosure and components (Khodeir et al., 2016).

Although HBIM shows a great potential in heritage buildings and in comprehensive preservation approach, as it could achieve the characteristics of resilience and it works as a documentation, visualization, simulation tool for project management of cultural heritage buildings, as shown in Figure 3. However, there is a need for smart tool/software that could be installed in the building to detect any hazards or unsafe actions, then develop reports/mitigation plans to mitigate these clashes automatically, besides ensuring more connection between building and user.

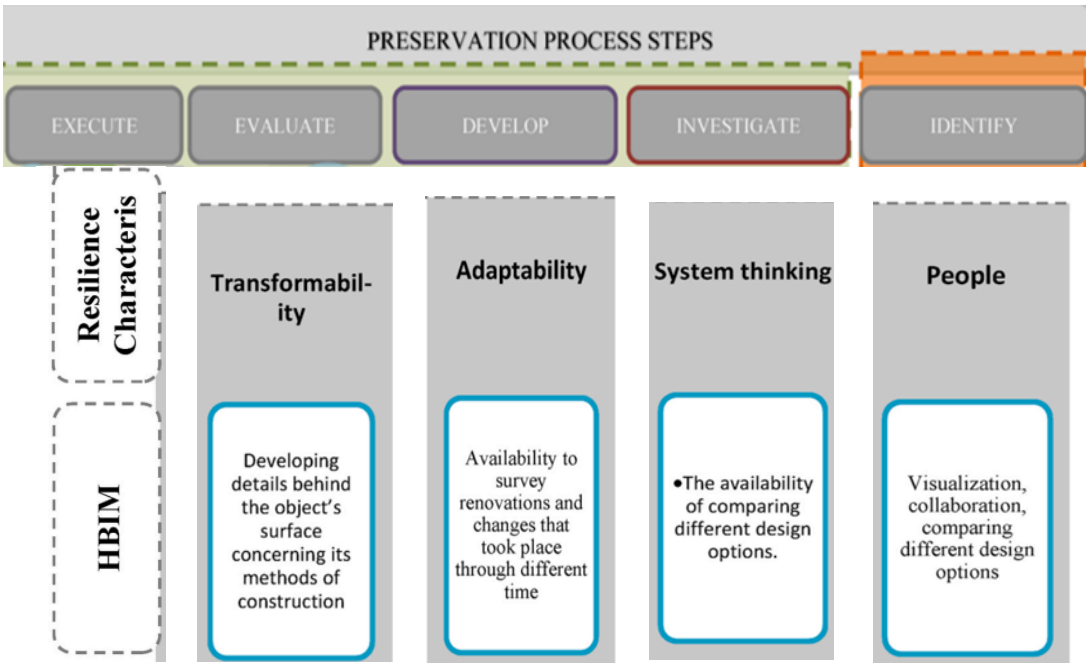


Figure 3: HBIM could achieve the characteristics of resilience and it works as a documentation, visualization, simulation tool with preservation process steps (Elabd et al., 2021).

Conclusion

Overall, BIM implementation workflow requires deep technological skills, precision and discipline from the begining through the whole process of creating the HBIM model. Moreover, economical and time investments need to be made for developing complete custom workflows for the commercial use of the proposed BIM tools. HBIM-based digital model that enables not only to visualize the physical and functional attributes of a building, but also to quickly identify major problems and explore potential issues associated with the conservation/management process of the construction, allowing a priority-based scheduling of maintenance actions and supporting decision-making procedures. Basic project management theory provides that flexibility is generally at its greatest in the early phases of a project, so there is no need to postpone the assessment of cultural heritage in a project.

CPS and HBIM, which could guide decision makers working in the field of heritage buildings management. This analysis showed that HBIM plays an important role in achieving conservation of heritage buildings producing full engineering drawings for the conservation of historic building and environments. Guidance for the role of project management on heritage refurbishment is important for stakeholders involved in each process/phase of managing cultural heritage buildings should achieve long-term benefits.

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Statistical Analysis of Cost Overrun Causes in Construction Projects: A Demonstration of Selection and Implementation Statistical Tests

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Abstract

Nowadays, clients in the construction industry are becoming increasingly concerned about the incapacity of executors to complete projects within the specified time and budget. Generally, time and cost variations versus the project's objectives represent the performance of the project. Eventually, to evaluate the project performance and hence the financial risks involved in project execution, it is vital to measure the cost variation in construction projects. Cost variation or overrun which became a typical occurrence throughout the world refers to the deviation between the planned budget and the actual cost of the project. Recently several studies strived to evaluate the causes of cost overruns to explore probable explanations for this phenomenon. One of the commonly adopted methods of withdrawing useful information from the collected data is the application of different statistical tests. However, most of the researchers failed to distinguish between the purpose and applicability of these tests which may lead to inaccurate results and interpretation. Therefore, this study focused on demonstrating the procedure for the selection and application of the aforementioned tests. This study was performed in Iran since the potential of cost overrun occurrence in construction projects in Iran is significantly high. Hence a survey is conducted among different parties including clients, contractors, and consultants who were involved in the construction projects to collect their responses based on probability, impact, and manageability for 38 identified causes of cost overrun. Accordingly, several statistical tests including the Mann-Whitney U test, Kruskal-Wallis H test, and Post hoc test were performed to evaluate the level of agreement between parties from different sectors (Public and Private) as well as different positions (Clients, Contractors, and Consultants). Moreover, Spearman rank-order correlation is adopted to evaluate the ranking of 38 causes of cost overrun based on their probability, impact, and manageability according to the opinion of respondents from different sectors and positions. The results revealed that firstly evaluating the assumptions leads to the selection of non-parametric tests. Secondly, there was a significant agreement between different parties concerning the probability, impact, and manageability of most of the causes of cost overrun except for a few. Finally, the correlation between ranking the causes indicated a strong and positive association between owners and contractors as well as public and private sector respondents in terms of ranking the causes based on their probability and impact.

Keywords: *cost overrun, parametric test, statistical analysis, non-parametric test*

Introduction

Rapid population growth and urbanization development in Iran have created a wide socioeconomic gap. This transformation converts the urban areas into engines of growth and beacons of opportunity and therefore demonstrated immediate construction necessities. Particularly in major urban areas, the construction process accounts for substantial economic output (Alizadeh & Irandoost, 2017). Given the significant development in urban construction projects, cost overrun is one of the major issues that influence construction projects' success dramatically. (Ahady et al., 2017) described cost overruns in the construction industry as a global phenomenon, even though the situation varies from country to country. According to the statistical Center of Iran during the years 2002 to 2012, cost overrun in construction projects was estimated at USD 21 billion (Hamed et al, 2016). Within the area of cost overrun analysis, utilization of statistical tests is considered a common approach. It is because they provide a mechanism for making quantitative decisions about a particular process. Statistical methods are essential for scientific research. In fact, statistical methods dominate scientific research as they include planning, designing, collecting data, analyzing, drawing meaningful interpretations, and reporting research findings. Furthermore, the results acquired from the research project are meaningless raw data unless analyzed with statistical tools. Therefore, executing statistics in research is of utmost necessity to justify research findings. Statistical analysis techniques could provide researchers with several means. Their function could be classified into three major groups descriptive, inferential, and associational statistics. Descriptive statistics is the simplest form of statistical analysis that employs basic mathematical functions such as measures of central tendency, measures of dispersion, and so on to summarize the data from a sample or represent a whole sample in a research population. Inferential statistics on the other hand employs tools such as statistical tests to make inferences or draw conclusions about a larger population based on findings from a sample group within it. Inferential statistics is performed through hypothesis testing to validate generalizations made about a population from a sample due to its ability to account for errors in conclusions made about a segment of a larger group. Finally, Associational statistics is a tool researchers use to make predictions and find causation. It is utilized to find relationships among multiple variables. Associational statistics is the most advanced type of statistical analysis and requires sophisticated software tools for performing high-level mathematical calculations. The analyses in this group are namely regression, structural equation modeling, correlation, and so on. In the area of cost overrun analysis, particularly where the data are collected based on a survey from different respondents' opinions, the aforementioned statistical techniques are widely employed. For instance (Al Hosani et al., 2020; Bekr, 2015; Herrera et al., 2020; Zafar et al., 2016) utilized descriptive statistics to summarize collected data. As far as associational statics are concerned, studies such as (Ahiaga-Dagbui et al., 2017; Asiedu & Ameyaw, 2021; Ubani et al., 2013) utilized causal analysis to explain the direction of association between different causes of cost overrun. In the case of regression analysis as well studies such as (Odeyinka et al., 2006; Zahmak et al., 2020) utilized this technique for assessing the impact of cost overrun causes on the amount of cost overrun in construction projects. Finally, for the case of inferential statistics which is the subject of this study, despite their wide application in cost overrun analysis, through an extensive literature review, common shortcomings are witnessed. Several studies (Akogbe et al., 2013; Cindrela Devi & Ananthanarayanan, 2017; França & Haddad, 2018; Gunduz & Maki, 2018; Rachid et al., 2019; Ramanathan et al., 2012) within the cost overrun analysis are performed statistical tests to generate more detailed insight from their collected data. These statistical tests are normally utilized to withdraw conclusions from different perspectives of respondents. However, the evaluation of the assumptions for the applicability of statistical tests in these

studies is majorly overlooked and subsequently led to inaccurate and unreliable outcome. Therefore, this study intends to demonstrate an appropriate procedure for selection and application of statistical tests to provide more robust outcome for accurate interpretation of the results.

Methodology

This section presented an epitome of the designed methodology for demonstrating the application of required statistical tests to evaluate the level of agreement and ranking correlation between different parties involved as respondents in the survey.

Identification of The Causes

Through an extensive literature review, 20 documents were identified to identify cost overrun causes. From the selected documents, the top 10 factors causing cost overrun were extracted. A total of 200 causes of cost overrun were investigated based on their redundancy, conceptual overlapping, and similarities. Finally, this process resulted in extracting 38 unique causes of cost overrun which according to previous literature influenced urban-related construction projects. Table 1 presents 38 causes of cost overrun that will furthermore have utilized to construct the questionnaire.

Table 1. Cost overrun causes.

S/N	Factors causing cost overrun
1	Variations of clients
2	Change in the foreign exchange rate
3	Change in project design
4	Change in the scope of the project
5	Contract related issues
6	Delay preparation and approval of drawings
7	Delays in the construction schedule
8	Errors or inconsistencies in project documents
9	Errors or omissions in construction work
10	Financial difficulties related to the contractor
11	Financial difficulties related to the owner
12	Improper construction methods
13	Inaccurate project cost estimation and control
14	Inaccurate scheduling and planning
15	Inadequate contractor's experience
16	Incomplete design at the time of tender
17	Insufficient geotechnical investigation
18	Lack of identification of needs
19	Lack of material, equipment availability, or failure
20	Lack of requirement specifications in tender documents
21	Lowest bidding procurement method

22	Material quality change
23	Number and level of competitors
24	Poor financial control on site
25	Poor site management and supervision
26	Project complexity
27	Subcontractor related issues
28	Reworks or additional works during the construction stage
29	Mistakes and defective works in the design and construction stages
30	Lack of preliminary examination before design or tendering
31	The long period between design and time of bidding/tendering
32	Labor productivity-related issues (labor shortage, unskilled labor, etc.)
33	Lack of communication and coordination and agreement between project parties
34	Inflation in prices of (labor, material, equipment, services, land, permissions, and so on)
35	Governmental policies related issues (corruption, legislation, political…)
36	Financial difficulties related to the cash flow (including mode of financing, bonds, and payments)
37	special issues related to unforeseen site conditions, adverse weather conditions, or other unpredicted conditions on the construction site
38	Force Majeure causes include outbreak of war, projectile missile, hostilities, contamination, and other such risks

Questionnaire Development

The preliminary questionnaire was developed and prior to the original survey administration, the contents of the questionnaire were verified through a pilot study. The results from the pilot study demonstrated high relevance and affinity of the questionnaire contents and the final questionnaire was approved based on the expert's opinion. In the final questionnaire along with Socio-demographical information, each respondent requested to score the Probability of occurrence (P), Impact (I), and possible Manageability (M) of each provided cost overrun cause based on a 5-point Likert scale.

Target Population and Sample Size Determination

The target population for the survey decided to be selected from the 3 main construction parties Client, Contractor, and Consultant who participated in urban-related construction projects in Iran. The contractor and consultants' groups were formed of site engineers, cost estimators, quantity surveyors, cost control engineers, construction managers, and project managers. The required sample size for the survey administration was 64 which was determined using Equation 1 (Bartlett et al., 2001):

$$n = \frac{t^2 s^2}{e^2} \quad (1)$$

Where; n = required sample size, t = corresponding statistic based on chosen significant value α, s = Estimate of variance deviation for the data collecting scale, e = margin of error (number of points on the principal scale).

Reliability Test

The reliability of the data collected through the questionnaire will be established through Cronbach's alpha method. Since the questionnaire is supposed to measure the responses for 3 different sub-items as the P, I and, M of each cost overrun cause, therefore, it is advised to perform separate reliability tests for each one of the prospective. In addition, a general reliability test will be performed to ensure the overall questionnaire responses (Gliem & Gliem, 2003). Cronbach's alpha will be calculated by Equation 2 (Bartlett et al., 2001):

$$\alpha = \frac{N \times \bar{c}}{\bar{v} + (N-1) \times \bar{c}} \quad (2)$$

Where: N = the number of items, $\bar{c}$ = average covariance between item pairs and $\bar{v}$ = average variance.

Hypothesis Development

The main objective of this study is the implementation of statistical tests. In this stage, two different types of statistical tests were considered to first measure the level of agreement between the responses from different sectors (public and private) and different positions (contractors, consultants, and owners) in scoring P, I, and M for each cost overrun cause. Eventually, for testing the level of the agreement following hypotheses are developed:

H_1: There is significant agreement among the responses from Public and Private projects concerning the P for each cause of cost overrun.
H_2: There is significant agreement among the responses from Public and Private projects concerning the I of each cause of cost overrun.
H_3: There is significant agreement among the responses from Public and Private projects concerning the M of each cause of cost overrun.
H_4: There is significant agreement among the responses from Owners, Contractors, and consultants concerning the P for each cause of cost overrun.
H_5: There is significant agreement among the responses from Owners, Contractors, and consultants concerning the I of each cause of cost overrun.
H_6: There is significant agreement among the responses from Owners, Contractors, and consultants concerning the M of each cause of cost overrun.
The rule for testing each hypothesis is if the acquired P-value for the selected test > 0.05, then the null hypothesis cannot be rejected which indicates there is a significant agreement between private and public respondents. Secondly, evaluating the strength and direction of association between the respondents' opinions from different positions and sectors regarding ranking cost overrun causes. To perform a correlation test following hypotheses are developed.
H_7: There is no significant relationship among the responses from different pairs of job positions concerning the ranking order of the cost overrun causes based on their P.
H_8: There is no significant relationship among the responses from different pairs of job positions concerning the ranking order of the cost overrun causes based on their I.
H_9: There is no significant relationship among the responses from different pairs of job positions concerning the ranking order of the cost overrun causes based on their M.
H_{10}: There is no significant relationship among the responses from different sectors concerning the ranking order of the cost overrun causes based on their P.

H_{11}: There is no significant relationship among the responses from different sectors concerning the ranking order of the cost overrun causes based on their I.
H_{12}: There is no significant relationship among the responses from different sectors concerning the ranking order of the cost overrun causes based on their M.

The rule of interpretation for the correlation test is, that if the correlation coefficient is negative, it indicates a negative correlation and vice versa. Also, since the correlation coefficient changes between -1 and +1, therefore, closer the correlation coefficient gets to +1 or -1 indicates more correlation strength. For hypothesis testing, when a calculated P-value > 0.05 means, it fails to reject the null hypothesis.

Statistical Tests

Statistical tests in general are categorized into parametric and non-parametric groups. Parametric statistics is a branch of statistics that makes inferences about the parameters based on the assumption that the data came from a certain sort of probability distribution (normal distribution). Once the assumptions verify the applicability of parametric tests, they could yield a more accurate estimate and as a result, they're frequently considered robust (Uchechi, 2020). On the other hand, non-parametric tests are sometimes known as assumption-free or distribution-free tests. It means they could be applied to nominal or ordinal data and also on the scales that don't follow the normal distribution, such as interval or ratio scales (Uchechi, 2020). Regardless of parametric tests' robustness, in comparison to non-parametric tests, they offer other advantages such as adaptability to all sample sizes, applicability on different data types (nominal, interval), and practicability with the dataset including outliers, or data that has been measured imprecisely (Spiegel, 1972). Table 2 presents the most common type of parametric and their equivalent non-parametric tests. It is notable that before implementation of either of the below-mentioned tests a detailed examination of collected data is necessary to verify the test's assumptions. It is due to the fact that violation of any of these assumptions may lead to an erroneous selection of tests and hence, for interpretation or generalization of sample results to the entire population the test produces unreliable or inconsistent outcomes (Lix et al., 1996).

Table 2. Statistical tests' groups.

Parametric Tests	**Non-parametric Tests**
Unpaired T-test	Mann-Whitney Test
Paired T-test	Wilcoxon Signed Rank Test
One sample T-test	Signed-rank test
One-Way ANOVA	Kruskal Wallis Test
Pearson's R	Spearman's R

Statistical Tests Assumptions

As previously mentioned, the evaluation of the assumption for selecting an appropriate test is required. This process should be performed in two stages. In the first stage, the test group should be determined. The most important assumptions for selecting the test from either the parametric or non-parametric group are to identify the data type and data distribution. Parametric tests rely on the assumption that the variables are either ratio or ordinal and

normally distributed. However, once the test group is determined each particular test relies on its assumptions. To test the level of agreement between the responses from different sectors (public and private) the test should be designed for two groups. On the other hand, for the responses from different positions (contractors, consultants, and owners) the test should be designed for more than two groups. Table 3 provides the most important assumption to be examined for each statistical test once the test group is determined (Verma & Abdel-Salam, 2019). After the determination of the required statistical tests, the tests will be performed and accordingly the results will be interpreted.

Table 3. Statistical tests' assumptions.

Aim of the Test	**Required Test**	**Test Group**	**Significant Assumptions**
Level of the agreement for 2 groups	Unpaired T-test	Parametric	Homogeneity of variances
Level of the agreement for 2 groups	Mann-Whitney Test	Non-Parametric	Independence of observation
Level of the agreement for more than 2 groups	One-Way ANOVA	Parametric	Homogeneity of variances, Independence of observation
Level of the agreement for more than 2 groups	Kruskal Wallis Test	Non-Parametric	Independence of observation
Correlation in ranking	Karl Pearson	Parametric	Linearity
Correlation in ranking	Spearman's R	Non-Parametric	Monotonic relationship

Results And Discussion

Reliability Test

Reliability tests were established using Cronbach's alpha approach. As summarized in Table 4, calculated Cronbach's alphas for all perspectives and the overall questionnaire were above 0.9 indicating excellent internal consistency and reliability of the questionnaire.

Table 4. Reliability test results.

Scale	Cronbach's alpha	No of items
P	0.961	38
I	0.970	38
M	0.965	38
Overall	0.987	114

Test Group Selection

The statistical tests in this study were performed using IBM Statistics Version 24. Kolmogorov-Smirnov and Shapiro –Wilk tests were performed to evaluate the normality of all collected responses for the cost overruns causes from their P, I, and M perspective. The

results yield p-values less than 0.05 for all the causes. It means in all the cases the null hypothesis for the normality test which indicated H_0: The population is normally distributed, will be rejected and therefore normality assumption is violated. Hence, violation of this assumption indicates that all the tests should be selected from the non-parametric test group. In conclusion, considering the fact that all the assumption for each particular test is performed, to implement the test for evaluating the level of agreement between the respondents from the public and private sectors Mann-Whitney Test is employed. For evaluating the level of agreement between the respondents from different positions as contractors, consultants, and clients Kruskal Wallis Test along with Dunn's post hoc test is performed. As far as the correlation test was concerned Spearman's ranked order test is performed to evaluate the strength and direction of association for ranking the causes between respondents from public and private sectors as well as the respondents from different positions as contractors, consultants, and clients.

The Level of Agreement for Different Sectors

The results of the Mann-Whitney U test revealed that except for a few cases there is not a significant difference between responses from the public and private sectors for scoring the P, I, and M of the causes of cost overrun. The total numbers of respondents were 89 and from the total for each cause 21 responses were from public project while 68 were from private projects. Table 5 summarizes the results for the only cases of disagreements based on P, I, and M between public and private projects.

Table 5. Sources of disagreement between different sectors.

Disagreement in cost overrun causes based on (P)						
Cause	U	Z	P-value	r	Mean Rank (Public)	Mean Rank (Private)
C1	510.	-2.052	0.04	0.217	35.29	48.00
Disagreement in cost overrun causes based on (I)						
C7	508.5	-2.041	0.041	0.216	54.79	41.98
Disagreement in cost overrun causes based on (M)						
C7	505	-2.082	0.037	0.216	54.95	41.93

The Level of Agreement for Different Positions

The results from the Kruskal-Wallis H test revealed that out of a total of 89 responses 25 responses are from owners while 26 are from consultants and 28 are from contractors. Table 6 summarizes the results for the cases of disagreements based on P, I, and M between owners, contractors, and consultants.

Table 6. Sources of disagreement between different positions.

Disagreement in cost overrun causes based on (P)			
Cause ID	Chi-Square	df	p-value
C2	6.205	2	0.045
C3	9.642	2	0.008
C4	13.561	2	0.001
C7	6.235	2	0.044

C9	7.715	2	0.021
C12	6.143	2	0.046
C16	7.268	2	0.026
C20	6.265	2	0.044
C31	10.248	2	0.006
Disagreement in cost overrun causes based on (I)			
C4	6.788	2	0.034
Disagreement in cost overrun causes based on (M)			
C3	8.250	2	0.016

To identify the source of disagreement, the post hoc test using Dunn's procedure was performed and the results are summarized in Table 7. The adjusted p-value through Bonferroni correction indicates which pair of the three subgroups (owners, contractors, and consultants) had a significant disagreement in the mean ranking of the scores.

Table 7. Post-hoc test results.

Disagreement in cost overrun causes based on (P)		
Cause ID	Sub-groups	Adj.sig
C2	Owner- contractor	0.043
C3	Owner- consultant	0.006
C4	Owner- consultant	0.001
C7	Owner- contractor	0.039
C9	Owner- contractor	0.044
C9	Owner- consultant	0.042
C12	Owner- consultant	0.049
C16	Owner- contractor	0.022
C31	Owner- consultant	0.004
Disagreement in cost overrun causes based on (I)		
C4	Owner- consultant	0.045
Disagreement in cost overrun causes based on (M)		
C3	Owner- consultant	0.017

Testing the Rank-Order Correlation of Different Sectors and Positions

Since the collected data violated the normality assumption eventually the Spearman rank-order correlation was adopted to statistically test the association between ranking the causes of cost overrun based on their P, I, and M perspectives among the respondents from different sectors and positions. The result from the Spearman rank-order correlation as summarized in Table 8 verifies the significant correlation for all the items. That means the obtained p-values concerning H_{10} to H_{12} are less than 0.05, therefore, they should be rejected. It is also indicated that there is a strong positive correlation in ranking the causes between the responses from private and public sectors based on their P (rho = 0.756) and I (rho = 0.656) of the causes. However, according to the result for M (rho = 0.476), there was a medium positive correlation in ranking the causes.

Table 8. Correlation for ranking the causes between different sectors.

		Public		
		P	**I**	**M**
Private	**Spearman rho**	.756**	.656**	.476**
	Sig. (2-tailed)	0.000	0.000	0.000

For different positions, however, the results presented in Table 9 indicated, except for just one case of correlation between consultants and contractors in ranking the causes based on their I (p-value = 0.1) for the rest there is a significant correlation between other pairs. Therefore except for H_8 the rest of hypotheses H_7 and H_9 will be rejected. In terms of the strength of correlation in ranking the causes with respect to probability and impact, owners and contractors demonstrated a strong positive correlation respectively with rho = 0.786 and rho = 0.616. Other correlations as presented in Table 9 are either medium or weak.

Table 9. Correlation for ranking the causes between different positions.

		Owners			Contractors		
		P	**I**	**M**	**P**	**I**	**M**
Contractors	**Spearman rho**	.786**	.616**	.374*			
	Sig. (2-tailed)	0.000	0.000	0.021			
Consultants	**Spearman rho**	.585**	.448**	.540**	.455**	0.271	.389*
	Sig. (2-tailed)	0.000	0.005	0.000	0.004	0.100	0.016

Conclusion

Through an extensive literature review, a major gap regarding statistical assumption evaluation prior to their application in cost overrun analysis is witnessed. The aforementioned issue majorly led to the selection of inappropriate statistical tests which resulted in unreliable outcomes and in certain cases where the assumptions are severely violated the results get completely reversed. Therefore, this study aimed at demonstrating the selection and application of statistical tests for cost overrun analysis. A survey has been conducted among different stakeholders in the Iranian construction industry. Along with their socio-demographical information, the respondents were requested to score using a 5-point Likert scale regarding the probability of occurrence, impact, and manageability of 38 identified cost overrun causes. 89 valid responses are received, and a reliability test validated the responses. The following conclusions are withdrawn from the results:

- Since Likert scale data are considered the ordinal level of measurement also, the normality assumption is violated in all the cases regardless of parametric tests' power the required tests should be selected from the non-parametric tests group.

- Each required statistical test has its own assumptions which must be assessed before application of the test. This study utilized Mann-Whitney Test, Kruskal Wallis Test, and,

Spearman's rank order correlation test hence, before applying of aforementioned tests all assumptions as provided in Table 3 are accurately examined.

- The results indicated that among public and private sectors C1 and C7 were the only sources of disagreement. However, among contractors, consultants, and owners concerning scoring the cost overrun causes based on their probability of occurrences there were significant disagreements in C 2, 3, 4, 7, 9, 12, 16, 20, 31. On the other hand, for scoring the impact and manageability except for C3 and C4 all the parties significantly agreed.

- The results also indicated that in terms of ranking the causes between the public and private sectors as well as contractors, consultants, and owners the highest correlation was belonged to ranking the causes based on their probability of occurrence. It could imply a better comprehension of the concept of probability of occurrence of cost overrun causes in comparison to their impact and manageability among the respondents.

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Construction Productivity Improvement: A Case Study of Turkish Republic of Northern Cyprus

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Abstract

Productivity in the construction industry cannot be over emphasized, as it is a very essential factor that can contribute to the entire growth of the construction industry. Particularly in Turkish Republic of Northern Cyprus, the benefits of productivity have not been harnessed completely and it falls short in standard as compared to other parts of the world. Therefore, this paper seeks to evaluate productivity problem in T.R. Northern Cyprus, by exploring ways in which productivity can be enhanced using management planning skills and by highlighting the various causes of un-productivity by identifying the key drivers that can cause productivity decline. Data is obtained, by the aid of a questionnaire, which comprise of various sections to collect general information about the respondents, current status of construction industry and Construction productivity in T.R. Northern Cyprus. After which SPSS was used to analyze the result(s). Findings indicate that in T.R. Northern Cyprus there is an extensive delay in construction completions for new projects. Thus, there has to be improvements in the areas of construction labor job security, work conditions and skill retention within the company, along with, improvement of construction methods/procedures and building codes.

Keywords: *construction, Northern Cyprus, productivity improvement.*

Introduction

Construction is a fast-paced work with a plethora of interconnected elements that influence construction procedures and decisions. The construction industry is frequently facing challenges with obstacles to its long-term growth, notably in terms of complexity and uncertainty. It is frequently threatened by lower-than-expected productivity, excessive project costs, and the need to make optimal use of limited resources. This industry is described as a large, dynamic and often times, multifaceted industry which creates processes leading to development of new structures, which includes engineering projects and also all forms of renovations (Celik et al., 2017). It is an industry, which has contributed about 5.9% of the total gross value of European Union member states (Nazarko & Chodakowska, 2015). It plays a major role in the development of any economy including T.R. Northern Cyprus. There was a construction boom after the Annan peace plan which resulted in the emergence of several small companies between the periods of 2004 – 2010 but as a result of no proper regulation of the construction activities, it gave rise to delays, high cost of projects, poor quality of work, low productivity and subsequently inefficiency (Balkiz & Therese, 2014). Therefore, this

paper, as a contribution to existing body of knowledge, seeks to evaluate productivity problem in T.R. Northern Cyprus, by exploring ways in which productivity can be enhanced using management planning skills and by highlighting the various causes of un-productivity by identifying the key drivers that can cause productivity decline.

Literature Review

According to TRNC Statistical Institute's Urban Construction Statistics, between the years of 2015 and 2019-latest year available) total number building construction has increased from 619 (266,560 m^2) to 1306 (650,476 m^2) (Table 1) which means amount of building construction has more than doubled along with an increase in problems related to applicability of current construction methods and standards. A trend that has started after Annan Plan 2004-2007 according to Celikag and Naimi (2011) and continued until 2019.

Table 1. T.R. Northern Cyprus urban construction statistics (Source: TRNC Statistical Inst.).

		2019	2018	2017	2016	2015
Genel Toplam	A	1.306	1.537	964	739	619
General Total	B	650.475	719.598	412.065	411.788	266.560
	C	1.619.724.182	1.618.416.006	922.762.165	635.175.122	370.083.437

A – Number of buildings B- Floor Area (m^2) C – Value (TL)

Also, according to the TRNC Statistical Institute's statistics data, number of people employed in construction companies in T.R. Northern Cyprus was in average 7.5% of the working population (Figure 1), where as in European Union countries, this number was around 3% (Nazarko & Chodakowska, 2017). As a result of the increase in the construction work done and employment by the sector, the success or the failure of the construction projects/industry, as well as the worker productivity, became much more important for the T.R. Northern Cyprus's economy and the livelihood of its residents.

Productivity has been one of the most researched topics in the construction industry in the last few decades where it can be defined in many ways depending on the user (Hanna et al., 2008). According to Hanna et al. (2008) productivity is defined as the ratio between total inputs of resources which include Money, Materials, Machinery, Manpower and Minutes (Time); and the total output of the product within cost, time and specification (Nasirzadeh & Nojedehi, 2013). In general, construction tasks are complex and not easily quantifiable during the assessment and measurement of productivity (Janssen & McLoughlin, 2008). According to (Eriksson & Westerberg, 2011) in many countries, the construction industry attracted criticism for poor quality and low productivity. Towards the improvement of productivity in construction, it is essential to improve the productivity effecting factors in general, like, enhance workers motivation, improve strategic management, and improve procurement management (Rojas & Aramvareekul, 2003). Factors affecting productivity may have a short-term or long-term effect on the project. Various studies in different countries have been carried out to identify the factor affecting construction productivity.

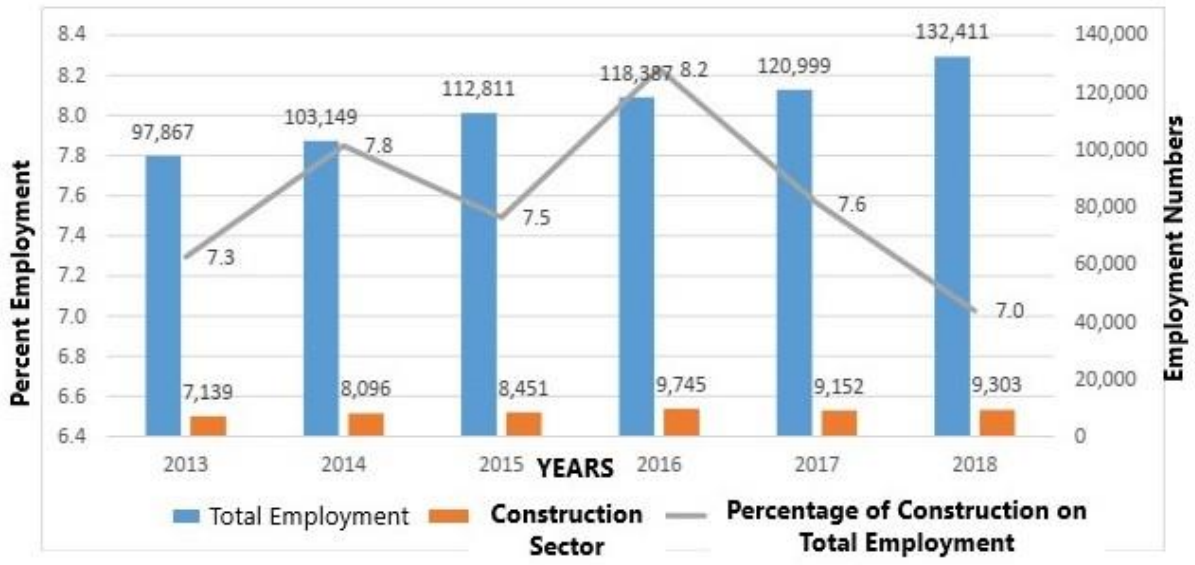


Figure 1: T.R. Northern Cyprus construction employment data (Source: TRNC Statistical Inst.).

One such study done by Shehata and El- Gohary (2011) suggested to group factors that affect labor productivity as Industry related, Management related and Labor related factors (Shehata & El-Gohary, 2011). Some of the factors that affect the construction productivity, which identified through literature review for this research, were grouped into three main areas: Construction Labour productivity, Government Policies/Building codes and applicability of professional Construction Management methods.

Methodology

For this research paper, a quantitative research approach was used to identify the factors influencing the productivity of Construction industry in Northern Cyprus. The data was gathered using Question survey (Convenience sampling). 150 questionnaires were distributed and 110 was gotten back in return, amongst which 100 was valid. All of those responded to the survey had prior experience working on Construction projects. Questions were designed to identify factors and gather data to answer the following main research questions.

RQ1) To what level does the conventional practices affect the productivity in Construction industry of Northern Cyprus?
RQ2) What are the possible effects of, if any, integrating more detailed pre-planning stage in to construction projects to achieve better productivity rates.

Data collection: Design of questionnaire was as following: The questioner was in two sections. First section (A) included questions regarding demographic data about the participant. Second section (B) consisted of close ended question with definite answers. Section B gives options to measure the degree at which a respondent or participant agrees, neutral or disagrees with a point of view. Section A consisted of 10 questions and, Section B consists of 12 questions, making 22 questions in total.

Reliability: The questionnaires were distributed in construction firms around the provinces of T. R. of Northern Cyprus. The received responses by the respondents were summarized in an Excel data sheet and the data analyzed using SPSS software. The reliability of the Section B was examined using Cronbach's alpha if item deleted which represents the scale's Cronbach's alpha reliability coefficient for internal consistency if the individual item is removed from the scale. The reliability of the Section B of this study ranges from .890 to 0.898 (Table 2), which suggest internal consistency.

Table 2. Cronbach's alpha reliability results.

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
QB1	55.35	176.917	.536	.898
QB2	55.10	175.162	.606	.895
QB3	55.19	172.984	.586	.896
QB4	54.79	176.895	.574	.896
QB5	54.64	176.455	.621	.894
QB6	54.97	168.130	.691	.890
QB7	55.05	173.907	.634	.893
QB8	55.16	173.065	.654	.892
QB9	54.90	171.566	.670	.891
QB10	55.32	171.816	.573	.897
QB11	55.25	170.715	.653	.892
QB12	55.27	168.805	.688	.890

Results and Discussion

Results of the survey, from demographic data, shows that 88% of the participants were male and only 12% were female. 73% of the participants were between the ages of 18 and 35, which suggest construction industry is dominated by young work force. 87% of the population had some form of education where 50% had college/university degrees. Also, it can be seen that the ongoing projects are mostly (37%) new construction and 35% were maintenance/renovation of existing buildings. Construction staff size of the ongoing projects were largely concentrated 100-200 staff with 32% and 50-100 staff with 26% where 77% of the survey participants were Managers/Supervisors in these companies/projects. Lastly, 77.0% of the participants have said they worked in a failed construction project where they defined the failed projects as the ones that have spanned 3 to 4yrs over the expected time of completion or abandoned projects.

To answer RQ1 primary data (Table 3) was used (QB2, 4, 5, 8, 9, 10, 11, and 12). Participants (66%) reported that temporary nature of employment (job security), and the working conditions are two major factors that significantly affect the worker productivity. In addition, current T. R. Northern Cyprus Buildings Codes (64%), faulty construction procedures/sub-standard construction methods and materials used (82%) and failure to adhere strictly to specified standards (un-professionalism) (83%) were the three major factors identified that have adverse effect in the successful completion of Construction projects in T. R. Northern Cyprus.

Table 3. Summary of survey results.

QB	Statement	Disagree	Neutral	Agree
2	Transition of acquired skills is limited in the construction industry due to its temporary nature of l aying off workers after every project.	18 (18.0%)	8 (8.0%)	74 (74.0%)
4	Faulty construction procedure is a major challenge in maximizing productivity in North Cyprus.	16 (16.0%)	2 (2.0%)	82 (82.0%)
5	Failure to adhere strictly to specified standards is highly due to un-professionalism	12 (12.0%)	5 (5.0%)	83 (83.0%)
8	The construction procedure for every particular project goes a long way in minimizing waste and enhancing efficiency on site.	20 (20.0%)	8 (8.0%)	72 (72.0%)
9	Productivity on site is largely dependent to the main site supervisor in charge of the project.	17 (17.0%)	8 (8.0%)	75 (75.0%)
10	There will be a significant boost in productivityif the workers have a certain level of job security?	27 (27.0%)	7 (7.0%)	66 (66.0%)
11	The working condition of the workers goes along way in determining the efficiency of the project?	25 (25.0%)	9 (9.0%)	66 (66.0%)
12	A review on North Cyprus building code with the aim to update and regulate it according to new standards will go a long way in ensuring productivity	25 (25.0%)	11 (11.0%)	64 (64.0%)

Table 4. Anova analysis (dependent var.: QB1 & independent var.: QB3, QB6, QB7).

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
QB1								
	QB3	.457	.087	.485	5.275	.000	.285	.630
	QB6	-.016	.091	-.017	-.175	.861	-.197	.165
	QB7	.190	.103	.184	1.842	.069	-.015	.395

To answer RQ2, statistical significance was tested (Table 4), using ANOVA analysis, where QB1 (Integration of pre-planning as a key part of Management method) was dependent factor, QB3 (Effect of integrating pre-planning on construction productivity) was statistically significant (B = .485, t = 5.275; p = .000 <.05), QB6 (Effect of better Government policies on

construction productivity) was not statistically significant (B = -.017, t = -.175; p = .861 > .05) and QB7 (Effect of better integration of advanced management techniques on construction productivity) was also not statistically significant (B = .184, t = 1.842; p = .069 > .05). Therefore based on the participant replies, in Northern Cyprus, improved government policies and application of advanced management techniques will not necessary have a positive effect on construction productivity.

Conclusion and Recommendations

The current study identifies the impact of significant factors on construction productivity and successful project completion in the Turkish Republic of Northern Cyprus using a structured questionnaire survey approach. The Northern Cyprus authorities, like the Ministry of Works and Housing, the Engineering professional, the Cypriot Contractors Union and the other concerned authorities are recommended to promote and encourage contractors to improve their standards and organizational system of working. In addition, these authorities should put in place necessary rules and regulations that will aid in the development of local contractors capabilities, which will eventually reflect higher percentage of productivity/successful completion in local construction sector.

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The Need for Stakeholder Management and Engagement in Projects

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Abstract

The focus of this study was to investigate the influence of project communications and project stakeholder management on the success of projects. The study aimed to highlight some of the areas in project communications and project stakeholders' processes that increase project success, utilizing the case example of Gauteng's SANRAL e-toll project. To achieve its goals and objectives, the study exploited the body of knowledge developed in the field of project management and used communications and stakeholder management in combination with a number of complementary theories. The research design of this correlational and exploratory study entailed a positivist research philosophy using a deductive approach. This implied the need for both narrative and numeric data. The so-called quantitative research was conducted by means of a survey questionnaire which was designed and used to determine the level of influence of communication to stakeholders in the case example of Gauteng's SANRAL e-toll project. The qualitative part of the research was conducted by means of a semi-structured interview. Notable findings of this study include the significant link between communications and stakeholder management on the outcome of a project, specifically with reference to Gauteng's SANRAL e-toll project, and the need for organizations to value the importance of communication to stakeholders in determining the success of a project according to the PMBOK ® (Project Management Body of Knowledge).

Keywords: *communication management, failure, PMBOK, project management, project success, stakeholder management.*

Introduction

The discipline of project management is on the rise. Projects increasingly play a crucial role as the innovation engines, value creation and strategic change tools of the future in both project driven and non-project driven organizations (Killen et al., 2012). Some cases of project failure, reported over decades (Serrador, 2009; Nicholas & Steyn, 2012), relate to project communication, while many problems relating to stakeholder issues have also been observed (Dalcher, 2009). The stake and scope of projects imply the constant need for understanding the causes of project failure, as well as the need for realizing how important variables like project communications and project stakeholder management affect project success (Davis, 2014).

The problem statement therefore focuses on the project communication phenomenon, the need for effective project communication and the specific research gap that needs to be addressed. The Gauteng e-toll project by SANRAL was used as the specific case in this research project. It was selected due to the importance of project communication and the specific media reports and public common knowledge of the controversies surrounding the e-toll project. Although the project had been a technical success, various reports indicated severe complaints, dissatisfaction and grievances voiced about the communication barriers between the e-toll project and its stakeholders (Rennie, 2013). Several aspects of the Gauteng e-toll project by SANRAL were problematic (Clarke & Duvenage, 2014) and led to widespread public disapproval of the project (Rennie, 2013). The author illustrates this as an important aspect, central to project success (Nicholas & Steyn, 2012), noting that successful projects are characterized by good communication and high-quality information sharing and exchange.

It was anticipated that the findings of the study would contribute valuable information to the knowledge base for project managers and professionals working in the field of project communications and stakeholder management by increasing their awareness of the issues that may have caused complications (such as the non – payment of users in the SANRAL e-toll project in Gauteng). Nicholas and Steyn (2012) lists inadequate project communication as a level three cause for project failure due to factors related to inadequate information quality and inadequate information distribution. The author illustrates this as an important aspect as mentioned above (Nicholas & Steyn, 2012). Thus, the researcher's contribution through this article is the provision of project management strategies for improving the link between project communication, stakeholder management and project success through the case example of the Gauteng e-toll project by SANRAL.

The Importance of Stakeholders in a Project

Too many projects fail due to a misconception of projects and the type of management approach they require. The definition offered by PMI® states that a project is "a temporary group activity designed to produce a unique product, service or result" and that project management is the "application of knowledge, skills, tools and techniques to project activities to meet the project requirements" (PMI, 2017). Nicholas and Steyn (2012) indicate the following ways in which the introduction of project management should benefit any organization:

- increase the likelihood that the desired outcome of the project will be attained;
- ensure the best use of the resource allocation;
- meet the needs of the stakeholders associated with the organization; and
- comply with the trends in the global market to ensure a competitive advantage for the organization in question.

The major causes of project failure are ineffective stakeholder management, poor project communications between the project manager and the stakeholders, and a lack of participation on the part of the project stakeholders (Eskerod & Jepsen, 2013). In the majority of project scenarios, the correct stakeholders are not included in the necessary phases of the project, particularly during the early stages. In such cases, the end users are approached only once the project has been implemented and they are then forced simply to accept and use the finished product. However, this may cause major resistance to the project implementation and may even result in the organization concerned suffering major financial losses and a loss of

turnaround time (Chou & Yang, 2012). Evidently, the communication process is important. According to the PMBOK® Guide (PMI, 2013), effective communication serves as the bedrock for business

Organizations that are effective in communication perform well, with 80% of them reaching their goals (Joslin & Müller, 2014). Leading authorities such as Cleland and Kerzner (1985), Larson and Gray (2018), Nicholas and Steyn (2012) and Slack, Chambers and Johnston (2010) define project management as the art of directing, coordinating and integrating human and other resources throughout the unique life cycle of a project. The importance of project communication is therefore evident as critical to project success. It is included as a separate knowledge area of the PMBOK® because it is one of the primary roles of the project manager. By using a project management methodology, one is better equipped (guided) to provide continuous communication to acquire project requirements and to identify and handle the scope of the project. This helps in laying out expectations and early identification and engagement of stakeholders. Through incorporation of the ability to produce realistic project estimates & activity schedules with effective risk and problem management, one now has the ability to handle project constraints (Rowe, 2015).

The different phases of a project can be distinguished in various ways. Kerzner (2013) states that each phase has certain deliverables that need to be completed before the next phase commences. He also states that in some projects, phases tend to overlap. Baars (2006) identifies six different phases of a project, namely the definition phase, design phase, developmental phase, implementation phase and follow-up phase.

Nicholas and Steyn (2012) provide a useful summary of the integration role of the project manager in terms of providing direction (leadership), decision making, being an entrepreneur, being an evangelist (conveying faith in the project), and being the project communication hub.

Nicholas and Steyn (2012) lists inadequate project communication as a level three cause for project failure due to factors related to inadequate information quality and inadequate information distribution. The author illustrates this important aspect as central to project success (Nicholas & Steyn, 2012), noting that successful projects are characterized by good communication and high-quality information sharing and exchange. The project manager will therefore need several communication mechanisms for effectively integrating the efforts of all project participants (and stakeholders) for facilitating the entire project life cycle process. These multiple mechanisms include formal meetings, informal review meetings, frequent ‘teach-ins’, hard copy reports, and electronic updates, among others.

Project stakeholders are often mentioned as essential players in projects (Cleland, 1985; Miller & Olleros, 2001; Office of Government Commerce (OGC), 2003; Olander & Landin, 2005). Cleland (1985) introduces stakeholders and stakeholder management processes to the project management umbrella by highlighting the importance of stakeholder identification, classification, analysis, and management approach formulation. In Table 1, a list of various definitions of stakeholders is compiled which have been analyzed from various articles.

Table 1: Definitions of stakeholders (Littau et al., 2010).

Author	**Definition**
Cleland (1985)	Stakeholders “have a vested interest in the outcome of the project”
Cleland (1989)	“Stakeholders are those persons or organisations that have, or claim

	to have an interest or share in the project undertaking."
Dinsmore (1990)	A stakeholder is someone "who has a stake in project outcome?"
Wright (1997)	"Stakeholders are any individuals who have an interest in the outcome of the project."
McElroy & Mills (2000)	"A project stakeholder is a person or group of people who have a vested interest in the success of a project and the environment within which the project operates."
Freeman (2002)	Stakeholders are "groups or individuals who can affect or are affected by the accomplishment of an organisation's mission."
PMBOK® Guide (2013)	Stakeholders are "individuals and organisations that are actively involved in the project or whose interest may be affected as a result of project execution or project completion."
Boddy & Paton (2004)	"Stakeholders are individuals, groups or institutions with an interest in the project, and who can affect the outcome."
Andersen (2008)	Stakeholders are defined as "a person or a group of persons, who are influenced by or able to influence the project."
Bourne & Walker (2006)	"Stakeholders are individuals or groups who have an interest or some aspect of rights or ownership in the project, and can contribute to, or be impacted by, the outcomes of the project."
Olander (2007)	"A person or group of people who has a vested interest in the success of a project and the environment within which the project operates."
Walker et al., 2008)	"Stakeholders are individuals or groups who have an interest or some aspect of rights or ownership in the project, and can contribute to, or be impacted by, either the work or the outcomes of the project."
Edum-Fotwe & Price (2009)	Stakeholders are "individuals or groups who are directly and/or indirectly involved in the selected scales and beyond and whose lives, environment or business are affected by the three spatial scales and beyond the adopted constructs."
Couillard et al., 2009)	Stakeholders are "entities or persons who are or will be influenced by or exert an influence directly or indirectly on the project."

After considering the definitions of stakeholders and their importance, the definition of stakeholders can be summarized below which the one is adopted in this study:

"Effective stakeholder engagement necessitates an understanding of dealing with host communities and key stakeholders, particularly those who represent a perceived threat to a project, in both the planning and implementation phases. Establishing dialogue and building strong and genuine relationships with local communities and other stakeholders is now recognized as a vitally important part of any project. From large-scale resource projects and transport infrastructure to the development of local community facilities, stakeholders matter. In terms of stakeholder classification, a stakeholder analysis should also be conducted to evaluate the expectations of the stakeholders in order to understand what they expect to gain from a project and, thereby, to understand how to influence the stakeholders to ensure that they support and contribute fully to the project (Yang et al., 2009). There are various systems available to assist in this regard."

Several scholars affirm that the success or failure of a project depends primarily on the management of the project (Chou & Yang, 2012; Kloppenborg et al., 2014; Mohan & Paila, 2013). According to Ó Conchúir (2012), it is essential that the project leader or manager possesses the following project management skills in order to manage projects successfully:

- negotiation skills to reach agreement on the necessary resources and the resolution of conflicting demands for such resources;
- skills to produce the envisaged end results with the available resources and in accordance with the prescribed performance requirements;
- leadership skills so as to direct the project efforts; and
- decision-making skills for the crucial strategic decisions that will lead the project towards a successful end.

It is incumbent on project managers to identify the project stakeholders, determine their requirements and expectations, and manage their influence over the requirements and outcomes of the project to ensure the success of a project. Thus, according to Beringer et al. (2012), the behavior of stakeholders and the techniques of stakeholder management are key factors in either the success or failure of a project. Long et al. (2004) group projects into four principal components, namely comfort, competence, commitment and communication. They argue that the comfort component emphasizes a monetary and leadership resource for the project to run smoothly. This needs to be balanced with stakeholder involvement. The component of competence emphasizes the need for a capable work force to carry out the tasks in the project if success is to be attained ultimately. The component of commitment points to the fact that all stakeholders should be interested in the goals of the project

Project failure is deemed to have occurred when projects do not achieve their intended scope within the predetermined budget and time frame, or else, while implemented within budget and on time, they are not embraced by the end users and/or project stakeholders (McLeod et al., 2012). Thus, if a project is not embraced by an end user/project stakeholders a project failure has occurred.

The South African National Road Agency Limited (SANRAL) Gauteng e-toll project was launched in 2013. It involves an electronic process to collect the tolls. This project is subject to the SANRAL Act 27 of 1998 (South Africa, 1998). One of the often-utilised claims made by the government and its agencies to 'entice' other stakeholders, was that e-tolling needed to be accepted (S.A. Department of Transport, 2012), because:

"The improvements have been made and the benefits of these improvements are being enjoyed by road users. […] Therefore, the funding of this project through the "user-pay" principle is required. This is an equitable way of funding the project, since the benefits will be enjoyed by those who pay for it."

It was therefore necessary to include the e-toll system for the entire e-toll project to be implemented. SANRAL attempted to appease Gauteng motorists using e-tolls by offering discounts on e-tagging fees. However, this strategy was not successful. In fact, SANRAL has been reluctant to reveal the amount of revenue it has collected using the 60% discount scheme. This highlights the lack of stakeholder engagement in the project (Fin24, 2018b).

It was necessary to ensure the definite engagement of SANRAL, the e-toll project managers and government leadership in order to overcome the moral and the ethical disengagement of the stakeholders involved at the time of the launch of the project. Communicating the prior estimation of the cost of the e-tolling to the decision-makers would have enabled an ongoing research process that would have assisted the progress of the project. Another problem associated with the execution of the project related to the definite measuring points installed on the freeways and the lack of alternative routes for users. As pointed out by Matsiliza

(2016), alternative routes for those motorists who are either not able to pay the high toll fees, or who are unwilling to do so, is a requirement.

As mentioned, the e-toll system was expected to ease the traffic flow in South Africa, and this would have been beneficial to the movement of both people and goods. In other words, it was anticipated that SANRAL's e-toll project would stimulate the urban economy by facilitating the easy movement of traffic in Gauteng, the urban hub of the country. On the contrary, the automatic e-toll revenue collection has been found to constitute a significant obstacle to the movement of goods. The Chief Executive Officer (CEO) of SANRAL has stated that there was a stringent plan for collecting e-toll payment from motorists who are refusing to pay their tolls (BusinessTech, 2016). Matsiliza (2016) asserts that the billing system needs to be revised with the help of a competitive pricing model. It is incumbent on SANRAL to involve the stakeholders in instituting various grades of payment to ensure that the users are satisfied with the billing system. With such stakeholder engagement, the project could have been successful in the field of e-tolls (Matsiliza, 2016).

Research Methodology

A mixed methods approach was followed in this research. Additionally, in order to further assist the researcher, a convergent parallel mixed methods design was followed. With this approach, the researcher collects both quantitative and qualitative data, analyses the data separately, and then compares the results to determine if the findings confirm or disconfirm the data sets (Creswell, 2018; McKim, 2017).

According to Bush (2016), a target population is the overall number of people from which insightful responses can be collected. SANRAL e-toll went live in Gauteng on December 3, 2013, when the province had some 3.5 million registered vehicles (Matsiliza, 2016). The target population for this research was therefore the Gauteng motorists as well as the project manager, in this case referred to as SANRAL (SANRAL - Northern region).

Various techniques that were considered in this study under the probability sampling technique (Creswell, 2018). These are simple random, systematic, cluster and stratified random sampling. To select the research respondents that were to fill in the questionnaires, the simple random technique was used. The sample size for those who filled the questionnaire was 400.

In this research, a questionnaire was the data collection method, with its content guided by the literature review. Assistance from the Statistics Department at the University of South Africa was sought, particularly to get advice with regard to the validity of items for statistical purposes. The questionnaire, which was comprised of structured questions was administered to 400 Gauteng road users. Questionnaires were handed to the respondents when they filled up with fuel at Engen garages situated on the national highways of Gauteng.

Semi-structured interviews were used in this research to obtain narrative data to be thematically analyzed. Interviews were planned with the project sponsor (i.e. SANRAL – Northern region) based on the availability of the project managers. An interview schedule was compiled in which the interview questions were outlined.

To obtain the narrative data through a structured interview involved interaction between the researcher and the respondents, which needed to be documented. The interviews were therefore recorded, and the researcher took notes at the same time. After the interviews, the recordings were sent to a data transcriber to develop a content analysis. The recordings and notes are kept as records for future reference.

In brief, the process to obtain numeric data through questionnaires entailed the following process: Questionnaires were distributed at each Engen garage on the N1 (south and north), M1 (south and north), and R21 (south and north). Field workers assisted in distributing the questionnaires to the respondents. The supervisor and another academic colleague were observers at the R21 (south) Engen garage.

From the above it is evident that mixed, integrated or combined methodologies have many advantages. Many authors tend to move away from the conventional approaches.

Discussion of Results and Findings

Thematic analysis was conducted as the essential information gathering strategy to recognise, analyze and distinguish subjects inside the information set. This approach was used because it "permitted the analyst to sort out and portray the information in rich detail to arrange and decipher the numerous viewpoints of the investigated subject" (Braun & Clarke, 2006). The themes were:

- Meeting stakeholder expectations: The expectations of all stakeholders should be determined early in the project through consultations to ensure that they are met at the end.
- Stakeholder engagement in project decision making: Stakeholders are vital when decisions are being made throughout the project in order to achieve a successful outcome.
- Stakeholder identification throughout the project life cycle: The severity of influence of a stakeholder largely depends on the type of stakeholder, which has to be identified, along with ensuring that the right stakeholders are identified at all stages of a project.
- Stakeholder involvement and commitment: Stakeholders need to be involved throughout the process and all stakeholders need to be on board.
- Lack of communication in the project: The soft skill of communication is usually neglected in projects; a lack of communication emerged as the biggest shortfall in project success.

The findings of the interviews confirm that an organization must consider all groups or individuals who can influence business activities, and that the organization must concentrate on bringing in value for stakeholders, as also suggested by Freeman (2004). The themes identified are in line with the idea, which implies that stakeholders are crucial for the existence of any organization (Eskerod & Jepsen, 2013). Overall, the outcomes of the interviews seem to suggest that in order to achieve a successful outcome, stakeholder consultation and communication is required at every stage of the project life cycle.

A value of +1 signifies a perfect positive linear correlation, which means that two variables are precisely related, and as the value of the one variable increases, so does the value of the other. This also means that a value of -1 signifies a perfect negative linear correlation, which means that two variables are precisely related, but as the values of one variable increases, the

values of the other decreases. Spearman's correlation (Cohen, 1990) was used to reflect the correlations between all the significant statements in the questionnaire and the variables of the three scales. Of the twenty statements in the questionnaire, the following were related to stakeholder management:

- Gauteng motorists were involved during the initiation of the project (Statement 4). The majority of the respondents indicated that they were not involved during the initiation of the project.
- The needs of the stakeholders were assessed during the project initiation (Statement 5). The majority of the respondents indicated that their needs were not taken into consideration during the initiation of the project.
- The stakeholders/community had an opportunity to give inputs and make suggestions during the project (Statement 6) The majority of the respondent indicated that the stakeholders/community were not allowed to provide an input during the project.
- The government was involved during the initiation of the project (Statement 7) the majority of the respondents agreed that the government was involved during the initiation of the project.
- The government was involved during the planning of the project (Statement 8). The majority of the respondents agreed that the government was involved during the planning of the project.
- When there were challenges, the government was involved in addressing the challenges (Statement 9). The majority of the respondents indicated that the government did not play a role in addressing the challenges of the e-toll project.
- The e-toll project misled the stakeholders due to a lack of communication with the stakeholders (Statement 10). The majority of the respondents agreed that there was a lack of communication about the e-toll project.

In summary, the twelve statistically significant correlations described above (whether positive or negative) seem to suggest that relationships do exist between project stakeholder management on the one hand, and project communications management and project success on the other hand, as demonstrated in the case of the SANRAL Gauteng e-toll project.

This research finding is in line with previous research by Mawela et al. (2015), mentioned previously, that there were numerous stakeholders related to the SANRAL e-toll project and all of those stakeholders were crucial in the project. Further, according to Achterkamp and Vos (2008), "salience is described as the degree to which managers give priority to competing stakeholder claims".

Secondary research sources are very direct and specific about this issue. Bond-Barnd (2017), Steyn and Fletcher (2015), for instance, argue that the quality of communication triggers the process of achieving success, trust and collaboration. They further indicate that communication sustains the process as it is the only factor identified in the literature that is required as a direct input/predictor of the level of trust, degree of collaboration and success achieved (Bond-Barnard et al., 2015). Bond-Barnard (2017) and Butt and Savolainen (2016) put forward the view that any project must have three levels of success, namely project success, project management success and constant project success. Yet, to achieve these three levels of success, Davis (2014), Joslin and Müller (2014), Goetsch and Davis (2016) and Rose (2013) found that effective communication is necessary to enhance all the links between the various relationships that exist within a project management set-up to satisfy the needs of stakeholders. Stakeholders are individuals and organizations who are actively involved in the project directly or indirectly, and whose interest may be positively or negatively affected

because of project execution or successful project completion (Zulch, 2014). Yang et al. (2014) add that assessing both the attributes and behaviors of stakeholders are critical success factors in a project. They emphasize that important practices in the successful management of a project comprise engaging the stakeholders, communicating with the stakeholders regularly, and establishing long-term stakeholder relationships.

Conclusion

Five themes considered important for project success were identified after interviews were conducted with the two project managers from SANRAL. From the project manager's perspective, one theme dealt with project communications management, and indicated that communication was a soft skill that was usually neglected. The remaining four themes dealt with project stakeholder management, pointing out that stakeholders' expectations should be met, stakeholders should be involved in decision making, stakeholders should be involved throughout the project life cycle, and stakeholders should be on board from the beginning and demonstrate commitment towards the e-toll project.

In addition to several issues which may be seen as constraints on the project, such as the cost of the project, the unskilled labor force, the materials and the handling fees, as well as the lack of support of the stakeholders (Matsiliza, 2016), it is evident from the above that the respondents were of the sentiment that there was minimal communication and engagement with the Gauteng motorists, being one of the key stakeholders for the e-toll project.

The research was aimed at assessing the impact of project communications management and project stakeholder management on project success through a case study of the SANRAL Gauteng e-toll project. It was also aimed at answering questions regarding whether there is a relationship between project success and communications management, as well as between project success and project stakeholder management. In conclusion, it can be stated that effective communication is crucial for project success. Stakeholder management also affects project success. This is measured by the level of engagement with stakeholders, who must be engaged at all costs to ensure successful projects in the future.

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Preliminary Estimation of Natural Gas Pipeline Construction Costs with Regression Analysis

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Abstract

Natural gas pipeline construction (NGPC) projects are inherently includes high changefulness like any other construction works. Considering that variability, it can be stated that to make an accurate cost estimation is difficult. The main objective of this paper is to achieve a coherent mathematical equation to be able to make a preliminary cost estimation of NGPC costs. To this end, a number of pipeline cost data, which is in US dollar currency, was obtained for the period 1986-2010. With this data, a simple regression equation was tried to be revealed by working through statsmodels, one of the libraries used for the Python programming language. It was concluded that a significant part of the NGPC cost could be explained with the diameter and length variables. In this respect, this paper has the potential to assist the institutions responsible for the execution of the NGPC processes of the Turkey or the contractors considering investment or at the decision-making stage. Moreover, the paper presents a first attempt at both predicting of NGPC costs in Turkey and executing that operation by using Python programming language.

Keywords: *natural gas pipeline, preliminary cost estimation, python.*

Introduction

An accomplished cost estimation is one of the key factors of project success in construction sector (Kim et al., 2004). It plays a vital role for each part of a construction project. It is crucial for owners to be able to create a systematic investment program in the meantime, while it is lifesaving for contractors for calculation of profitability and forecasting of cash flow. It should be noted that a real-like cost estimation would also set the designer's limits. Especially, preliminary cost estimation (PCE) techniques with limited project information are very helpful for partners of construction works like owners, designers, contractors and so on (Arage & Dharwadkar, 2017). The earlier successful cost estimation before beginning of the project brings early decisions among those partners. Thus, an environment arises in which each partner of construction works can foresee the future and people can make more solid decisions. Just as an accurate PCE may increase the profitability of the contractor, an improper one may affect the profitability of contractors negatively and lead indispensably project failure (Cheng & Hoang, 2014). It is a well-known fact that a high level of detail does not exist at PCE stage. That is why we need an amount of data of similar previous projects to make estimation. When we take the competitive environment of construction sector into consideration, it is very clear to see the necessity of a fast and efficient estimation method for

the people who are employee in cost and planning department of construction companies (Uğur, 2007).

Natural gas pipeline constructions (NGPCs), like other construction works, have pretty much uncertainty in terms of project cost because of its nature. To be able to make an accurate cost estimation is thereby considerable not easy. In the literature, there are a small number of research scrutinizing costs of NGPC projects. Those studies, almost all of which were studied in United States, indicate that there are several cost components in NGPC like labor, material (pipes), miscellaneous and right of way (ROW) (Parker, 2004; Rui et al., 2011a, 2011b, 2012; Thaduri, 2012; Ulvestad & Overland, 2012; Zhao, 2000). In these studies, details of which will be shared in literature part, while some researchers try to obtain an equation that gives total estimated cost with those four cost components, others contributed the descriptive statistics of the total costs of pipeline projects in the past to the literature. In Turkey, unfortunately, there is no a database where the costs of the NGPCs are kept by dividing them into components unlike in the United States. Therefore, it is not possible to study with aforementioned cost components and to obtain an equation, which is result of those. Under these circumstances, this research has focused on constructional independent variables that are inherent for NGPCs instead of general cost components like labor, material, miscellaneous and ROW. Details of constructional independent variables will be presented in later sections. The research suggests an early estimation technique of NGPC costs via an equation created with statsmodels library of Python. Since the maximum possible number of data is reached during the data acquisition phase, it was necessary to comment that the research on a whole count, not a sample, for our study. This is the most important limit of the research and that is why further statistical evaluations were not executed such as normal distribution of residuals.

Literature

There are many studies covering cost estimation techniques in construction sector via various methods (Erdal, 2021; Sueri & Erdal, 2022; Ugur et al., 2019). However, few of them focus on the NGPCs. Lack of the information in detail about NGPCs or arrangement difficulty of existing complex database may be the main reason of that deficiency. In this part, a few studies addressing only cost estimations in NGPCs or other pipeline systems have been explained. In addition to these, although not directly aimed at estimating natural gas pipeline construction costs, a few related studies are also included in this section.

Zhao (2000) reported the distribution and cost variation of natural gas pipelines in Europe, Asia and United States. Researcher stated in her study that material and labor costs cover 80% of the NGPC costs for onshore while it is 84% for offshore (Zhao, 2000). Parker (2004) investigated the cost differences in hydrogen transmission lines based on the costs of natural gas, fuel oil and oil pipelines. Author concluded that NGPC costs consist of 26% material costs, 45% labor, 7% miscellaneous expenses (research, inspection, insurances, permits, etc.) and 22% ROW (Parker, 2004). Rui et al. (2011a) developed five different regression models and tried to estimate the costs of 412 onshore natural gas pipelines built between 1992 and 2008 in different regions in the United States. In the study, the authors determined that large-scale natural gas pipeline projects have more affordable unit costs (Rui et al., 2011a). In another study in same year by Rui et al. (2011b), researchers stated that learning the job by repetition reduces the labor costs over time (Rui et al., 2011b). In his study, Thaduri (2012) collected data on 180 natural gas pipelines and 136 pressure stations completed within the borders of the United States and Canada between 2000 and 2008 and presented descriptive

statistical data. Because of the evaluations, it was stated that the cost items with the highest share in the costs of natural gas pipelines were labor with 40% and material costs with 31% (Thaduri, 2012). Ulvestad and Overland (2012) examined the cost analysis of two different natural gas transmission options, pipeline and liquefied natural gas (LNG). Authors concluded that pipeline transport is a better option for larger natural gas volumes and shorter distances while it is LNG for smaller volumes and longer distances (Ulvestad & Overland, 2012). Bai et al. (2013) estimated the annual cost for the pipelines required for CO_2 supply, with the support of the existing literature in their studies. In the study, where two different routes with similar characteristics were selected in two different regions of China, they estimated the annual costs to be 52.52 RMB/t on average (Bai et al., 2013). Matthews et al. (2015) evaluated infrastructure projects within the scope of the concept of "social cost". Especially in infrastructure construction or rehabilitation projects where excavation is applied, calculation methods are proposed for each social cost category because of the inability to use the road, noise, pollination due to excavation, etc. Researchers determined that the social cost could be calculated between 1% and 9% compared to the project cost (Matthews et al., 2015). Zhang et al. (2016) conducted a research on interregional natural gas supply and infrastructure expansion in China by 2035, using an optimization model. In the study, in which four different scenarios were evaluated, it was stated that natural gas wholesale price and import cost are the most important points for China. In addition, it was evaluated what kind of natural gas supply changes/problems these scenarios will create in the country (Zhang et al., 2016). Kaiser (2021) examined the costs of onshore and offshore oil and gas pipelines in the United States. The author also mentioned pipeline requirements, cost estimation procedures and normalization processes in his study, where he presented the similarities and differences in the construction and demolition processes of onshore and offshore pipelines (Kaiser, 2021).

Preparation of Dataset

Data of available approximately 100 NGPCs in Turkey were reached by a not easy way. The information of all projects made between 1986 and 2010 was examined manually and dataset was finalized. After the examinations, in first stage the independent variable candidates that can be used in our regression model were pipe diameter (inch), length of pipeline (km), excavation amount (m^3), ideal depth (m), line valve (number), take-off valve (number), pigging station (number) and project duration (day). In examined papers, information of some projects were missing. Therefore, number of data decreased to 57 because of lack of information that can be used as a variable like project duration, cost etc. As an example, information of first five projects of 57 natural gas pipeline projects were showed in Table 1 which was created with codding *df.head()* (df is name of the dataset) in *Pandas* library which is one of the most popular modules in Python.

After finalizing the dataset some descriptive statistics of variables and correlation between variables were calculated with codding *df.describe().T* and *df.corr()*. Descriptive statistics including important explanatory statistical information such as mean and standard deviation are presented in Table 2. Table showing correlation values between variables and formatted as a heat map is presented in Figure 1.

Table 1. First five data item of the dataset.

Number	Diameter	Length	Excavation	Depth	Line	Take-off	Pigging	Project	Cost

	(inch)	(km)	(m^3)	(m)	valve (number)	valve (number)	station (number)	duration (day)	($)
0	16	1.57	1992.31	1.41	0	0	0	343	1478615
1	40	110.96	385488.94	2.32	3	0	1	747	47364121
2	12	12.64	12375.07	1.22	0	2	2	14	860314
3	40	102.47	355973.83	2.32	3	0	1	771	44619968
4	16	25.00	31644.00	1.41	0	2	1	46	2640478

Table 2. Descriptive statistics of 57 NGPC costs.

Parameters	**Mean**	**Standard Deviation**	**Min**	**25%**	**50%**	**75%**	**Max**
Diameter (inch)	21.68	13.51	6.00	10.00	16.00	36.00	48.00
Length (km)	77.89	68.97	1.57	32.22	59.62	100.15	320.00
Excavation (m^2)	185415.93	280057.34	1992.31	31255.85	101466.29	204683.31	1311421.46
Depth (m)	1.59	0.53	0.97	1.07	1.41	2.11	2.52
Line valve (number)	2.33	2.42	0.00	0.00	2.00	3.00	10.00
Take-off valve (number)	2.16	4.58	0.00	0.00	1.00	3.00	34.00
Pigging station (number)	1.14	0.61	0.00	1.00	1.00	1.00	3.00
Project duration (day)	456.00	325.77	14.00	205.00	435.00	662.00	1205.00
Cost ($)	24988742	36524306	860314	2966139	12061949	27678047	174505208

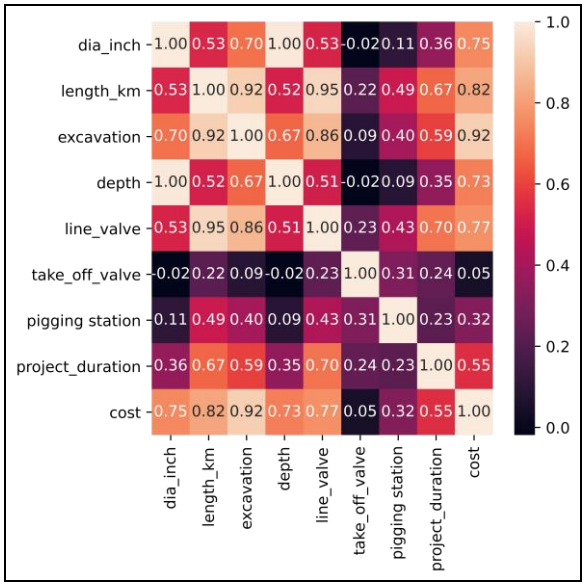


Figure 1: Heat-map of correlation between variables.

Data Preprocessing

To increase the quality of data is the first step of executing of any model because it can lead fallacious results (Pyle et al., 1999). At first blush, it is easy to see that dataset includes cost data taking places in a wide range by looking at Table 2. Even in Table 1, which shows only first five data of all dataset, there is a considerable amount of variability. Data set with an average of about $25M has a standard deviation of about $36M by the way. However, a correlation problem of independent variables was determined. In Figure 1 one can easily say that excavation and depth parameters look like a result of a mathematical equation due to the fact that correlation higher than 0.9 value. Same comment is available for line valve variable

by the way because of its high correlation value. That means we do not need those variables to be able to explain the variability of cost data as the diameter and length parameters are enough. It is most probable that excavation and depth parameters are calculated values by length and depth respectively. Therefore, it is a better way to eliminate these parameters from dataset. On the other hand, we should be awake to differences between 75% quartile cost value and maximum cost value. The gap between those two values makes one think about existing of outlier values. At this stage, it was decided to define and eliminate outlier values by creating a boxplot of cost data. The boxplot created with *seaborn library* in Python in which 25% quartiles can be seen is given in Figure 2.

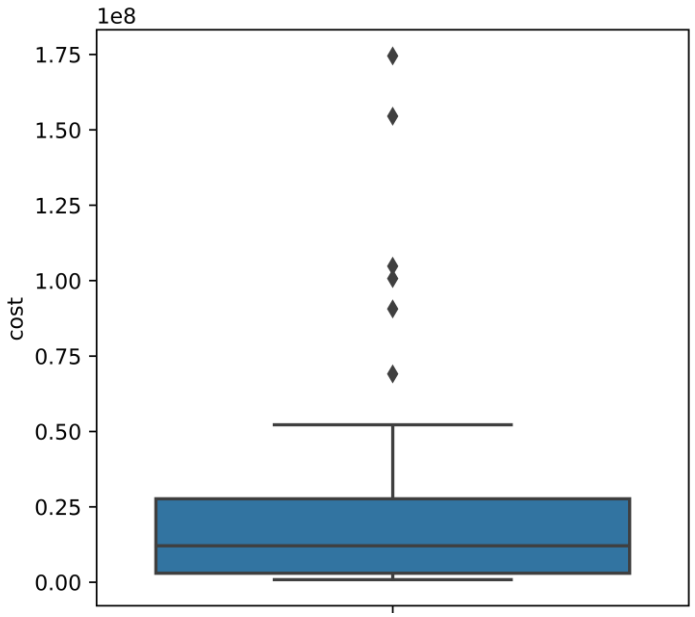


Figure 2: Boxplot of cost data.

According to plot, cost values higher than approximately $60M are outlier values and should be subtracted from dataset because it is thought that those values would affect negatively the final equation. After all these arrangements number of cases decreased to 51 and 3 independent variables were taken out of the dataset. After these processes, descriptive statistics and correlation matrix of variables were created and shown in Table 3 and Figure 3.

Table 3. Descriptive statistics of 51 NGPC costs.

parameter	**mean**	**standard deviation**	**min**	**25%**	**50%**	**75%**	**max**
Diameter (inch)	19.22	11.96	6.00	10.00	14.00	24.00	40.00
Length (km)	59.89	36.06	1.57	30.98	58.28	74.89	164.50
Take-off valve (number)	2.06	4.82	0.00	0.00	1.00	2.50	34.00
Pigging station (number)	1.06	0.54	0.00	1.00	1.00	1.00	2.00
Project duration (day)	399.12	285.81	14.00	174.00	358.00	585.50	1205.00
Cost ($)	14317338	15111751	860314	2799282	8350746	22154375	52219433

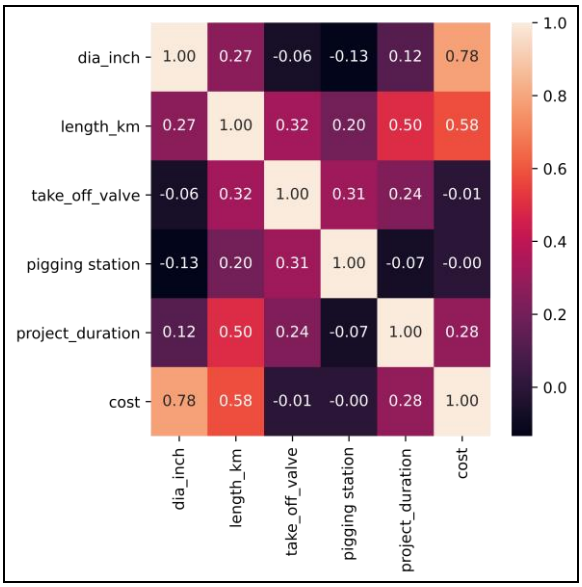


Figure 3: Heat-map of correlation between variables after parameter elimination.

Regression Analysis by Statsmodels Library

In this part of the research, a regression analysis were executed by using statsmodels library. Statsmodels library is one of the useful modules of Python for statistical models, hypothesis tests and data exploration (Seabold & Perktold, 2010). It is beneficial in terms of information it gives and the time it saves. Actually, exiguousness of data was a supreme challenge for this kind of an analysis. In this research, to have just about 50 data to be able to use in creating regression model is an example of that challenge. The more data actually the more learning and the more deep analysis. We conducted the operations under these conditions with statsmodels library by using least squares methods. After data preprocessing, dataset finalized and regression model was executed by statsmodels library and its functions. Codes showing how to create model with statsmodels are given in Figure 4.

```
import statsmodels.api as sm
import statsmodels.formula.api as smf

df.drop(df[df.cost > 60000000].index, inplace = True)
df1 = pd.DataFrame(df)
df1.drop(columns=["depth", "excavation", "line_valve"], inplace=True)
df2 = pd.DataFrame(df1)

X = df2.drop(columns =["cost"])
y= df2["cost"]
```

```
X = sm.add_constant(X)
lm = sm.OLS(y, X)
model = lm.fit()
model.summary()
```

Figure 4: Codes for creating model by statsmodels.

A regression model using ordinary least squares method was created by means of statsmodels. Results of this code and details of the final model, including important metrics such as R-squared, adjusted R-squared and Prob (F-statistic), are given in Table 4 and Table 5.

Table 4. Ordinary least squares regression results.

Dep. Variable:	cost	R-squared:	**0.777**
Model:	OLS	Adj. R-squared:	**0.752**
Method:	Least Squares	F-statistic:	31.39
No. Observations:	51	Prob (F-statistic):	1.30e-13
Df Residuals:	45	Log-Likelihood:	-876.66
Df Model:	5	AIC:	1765.
Covariance Type:	nonrobust	BIC:	1777.

Table 5. Ordinary least squares regression results.

parameters	coef	std err	t	P>|t|	[0.025	0.975]
const	-1.347e+07	3.43e+06	-3.922	**0.000**	-2.04e+07	-6.55e+06
dia_inch	8.419e+05	9.48e+04	8.884	**0.000**	6.51e+05	1.03e+06
length_km	1.781e+05	3.76e+04	4.741	**0.000**	1.02e+05	2.54e+05
take_off_valve	-3.833e+05	2.46e+05	-1.557	0.126	-8.79e+05	1.12e+05
pigging_station	1.156e+06	2.16e+06	0.536	0.595	-3.19e+06	5.5e+06
project_duration	1266.9667	4433.852	0.286	0.776	-7663.269	1.02e+04

In first trial, independent variables except diameter and length had p-value higher than 0.05. It statistically means that those variables are inadequate to be able to explain the variability of target cost value. At this stage, an equation can be formed with the values in Table 5 and the model can be terminated, or the independent variables with high p-values can be removed from the model and a trial can be made again. On the purpose of presenting some real statistical result, those variables were removed from the dataset. Therefore, only diameter and length variables were left for the regression model. Results of this final trial were presented in Table 6 and Table 7.

Table 6. Ordinary least squares regression results.

Dep. Variable:	cost	R-squared:	**0.765**
Model:	OLS	Adj. R-squared:	**0.755**
Method:	Least Squares	F-statistic:	78.15
No. Observations:	51	Prob (F-statistic):	8.00e-16
Df Residuals:	48	Log-Likelihood:	-878.01
Df Model:	2	AIC:	1762.
Covariance Type:	nonrobust	BIC:	1768.

Table 7. Ordinary least squares regression results.

parameters	coef	std err	t	P>|t|	[0.025	0.975]
const	-1.223e+07	2.41e+06	-5.071	0.000	-1.71e+07	-7.38e+06
dia_inch	8.549e+05	9.17e+04	9.324	0.000	6.71e+05	1.04e+06
length_km	1.689e+05	3.04e+04	5.555	0.000	1.08e+05	2.3e+05

As it can be seen from the Table 6 that created model has a $R^2 = 0.765$ value. It may be accepted as a not bad result specific to engineering problems. In the model, two independent variables have p-value less than 0.05, which means it is an appropriate choice to be able to explain the variability in dependent variable with those parameters. At this stage, as a PCE option that Eq. 1 emerged:

Cost ($) = -12226990.71 + 854865.97 × “Pipe Diameter” + 168936.70 × “Pipeline Length” (1)

where cost is in US dollars, pipe diameter in inch and length in km. To simplify the equation “D” can be used instead of Pipe Diameter and “L” for Pipeline Length. The revised Eq. 2 is given below.

Cost ($) = -12226990.71 + 854865.97 × D + 168936.70 × L (2)

The constant of the model was located in equation unpleasingly. Moreover, it is clear to see that some misestimations may come true because of such a huge constant value. Even if no one can say negative constants are awkward for regression analyses, it is normal to boggle because of having a constant lowering the result about $12M. It will be beneficial to look at the predicted costs and real costs. Some helpful statistics were presented in Table 8 to measure success of the final model. Explanations about details of the table are below the table.

Table 8. Real cost – predicted cost relationship.

Cost ($) = -12226990.71 + 854865.97 × D + 168936.70 × L		
Predictions	**Number of projects**	**Average real project costs of these projects ($)**
Negative cost results	6	1751854.27
Underestimation	25	11455554.97
Overestimation	26	17069053.52
Error range under $1M	12	6388981.00
Error range between $1M and $2M	5	16424855.22
Error range between $2M and $3M	7	9122743.09
Error range between $3M and $4M	8	3383372.35
Error range between $4M and $5M	2	24305072.25

The model made negative cost estimation 6 times as projected after creating the equation. Average real project costs of those six ones was about $1.75M and none of them higher than $2.4M. The model made 25 underestimation while it is 26 for overestimation. For 12 ones of 51 projects, model can be presented as successful because of estimation with an error under $1M. In addition, it estimated the cost with an error range between $1M and $2M for five projects while the average real project cost of which was nearly $16.5M. On the other hand, to have an error range between $3M and $4M while the average of real costs was just $3.83M

looks like a failure for PCE. Nevertheless, the model can be seen as partially successful in view of limitations and challenges about getting and arranging the data besides missing and lack of the useful data.

Conclusion

This research has been conducted to produce an equation for a PCE method of NGPC costs. Much as lack and acquisition of information tended to demotivate, the studies carried out in United States encouraged the authors about workableness of that subject. To prepare the dataset manually and missing of a number of values of cases were the main challenges of the research. After all this process, an equation was obtained that can reveal the NGPC cost estimates while the projects are still in the preparation stage, with a not bad coefficient of determination which is $R^2 = 0.765$. This study covered only a basic regression model. The proposed method can be used in the construction sector considering the statistics presented in last paragraph before conclusion part. In our future research, we intend to concentrate on increasing the number of the data and running analysis by machine learning techniques. In addition, in such large works in terms of cost, it would be desirable to conduct a study that will reveal how much of a mistake would be considered tolerable by the investor in a preliminary estimation that can be made with limited information.

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Evaluation of Update Rates of the Contracting Certificates and Work Experience Certificates

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Abstract

While choosing the contractor there have been several criteria. Demanding a work experience certificate of similar working groups with the determined rate of commitment value of the work is the main point. According to the data from TUIK 2022 construction cost index of March has shown an annual increase of 101,57 percent. The 2022 updating indexes in the bulletin, which has been used to classify the contractors and announced by the public authority, has been lower than this rate. The volunteers who want to participate in a tender have updated the total amounts of work experience certificates based on domestic producer price index through electronic public procurement platform. However, the updated numbers have failed to satisfy the increases due to the inflation. In such an atmosphere, construction investment costs have highly increased above the total amounts of work experience certificates. Under these circumstances, contractor companies have less opportunities to bid on new jobs. In this study, the updated amounts of work experience certificates and construction costs in free market have been compared and the difference between them have been searched in terms of the ability of the contractors to bid in the future.

Keywords: *construction costs, construction management, index, work experience certificate.*

Introduction

The market makers in public and private sectors use bidding to carry out their current jobs under best circumstances. Bidding brings the opportunity to a fair competition for the volunteers who have similar conditions in terms of public. On the other hand, it brings a cost advantage for the private sector, too. In a study conducted in 2010, Erdoğan defined "bidding" as contractually leaving the cost responsibility of the production and the presentation of a service whose circumstances are formerly determined to a private person/entity.

The concept of "bidding" expresses the "process" through which the management chooses a volunteer for a certain job under certain procedures (Demircioğlu, 2014). According to Binmora and Klemperer (2001), "bidding" has been advised as the method to value the sources in the best way.

In Turkish Administrative Law, bidding has been defined as “the formation process of contracts to purchase necessary good and services, whose cost would be paid by the administration, in order to carry out the services that fall into the administration’s area of responsibility”. Bidding is also “the formation process of contracts to make a private person, who offers the best among volunteers, conduct a job within a competitive environment which is formed by obeying the codes of practice stated by law” (Yıldırım, 2016).

The market makers in public and private sectors have been sharing and decreasing their risks by bidding construction investments. Construction sector carries various risks depending upon the costs, resource utilization and organization. By giving a job to a volunteer through bidding means risk sharing for the administration.

In their study in 1990, Al-Bahar and Crandall have determined “risk” as the realization probability of being exposed to events that would negatively or positively affect the aim of the project due to an uncertainty. Similarly, Turkish Language Association also defines “risk” as the danger of being exposed to any damage.

By determining the applicant through bidding, it is expected the contractor to take the risks. The owners are generally assumed to be in the group who does not like risks or ignores the risks depending upon the scale and complication of the project. On the other hand, the contractors might have an attitude as taking risks, ignoring risks, or disliking risks according to the scale and complication of the project and market conditions. While owners generally tend to expect the contractors to take all risks that might come from any source, the contractors hope to secure themselves by trying to increase the bid price (Zaghluol & Hartman, 2003).

Each constructional project is specific and unrepeatable, is huge in number and requires to combine various fields of specialization. Besides, each project emerges at the end of a long, complicated and compelling production process from the idea stage to the construction stage. All these specialties have been basic and determinative factors in construction sector. Meanwhile, these specialities make this sector riskier compared to other sectors. When a general classification is done for the risks in the sector, it is seen that there are different categories such as prepare for bidding risks, political risks, market risks, financial risks, natural disasters, cultural risks, company risks, construction risks, design risks, contract risks, legal risks, and environmental risks (Kaplan, 2014).

After the pandemic, there have been a deterioration in expectations and supply demand equilibrium due to the loose monetary policies all over the world. As the central banks in countries have fallen behind with the precautions, an inflationary atmosphere has occurred. When recent conditions have been taken into account, it can be said that the most important risk that the contractors who want to participate into a bidding would take is to determine the bid price depending upon construction costs. The inflationary pressure over the costs reduces the determination of the participants and increases financial risks. And this condition negatively affects the duration of the completion of the projects.

The volunteers who want to participate into the bidding both in public and private sectors have to provide certain conditions. Work experience certificate, in other words the completion of a similar job certificate is one of the most important conditions. According to the public procurement law, it is essential to choose from the participants who are able to bear the cost in

the optimum way, have a same or similar experience and references that show they are capable of doing the job subjecting to tender (Yıldırım, 2018).

There is an idiom in our culture means "give the job to the competent person". This comes out in public affairs too as giving the job competent contractors. Through public procurement law, a condition which includes having a certificate that shows certain capabilities and competences related to the job subjecting to the tender has become a must for the volunteers who want to participate into the bidding. As a result, the concept of "work experience certificate" has occurred (Bozkurt et al., 2015). In a study in 2014, Demircioğlu has interpreted that in a certain area, if there are more professional volunteers who have proven themselves as competent, they will be more preferable than the ones without any experience and this will be on behalf of the public weal.

"Work experience certificate" has a special importance among the certificates required to determine the professional and technical competences in construction works biddings. Because in construction works biddings, it is compulsory for the volunteers to own a work experience certificate in order to encourage to be experienced without taking into consideration the approximate cost (Yıldırım & Gelişen, 2017).

Work experience certificate gives a clue about the contractors about whether they are capable of completing the job or not by evaluating the previous works (İnan, 2015). It is a kind of reference and as it is a legal must, it can be understood that it is a crucial certificate. In order to take part in a public bidding, the participants have to own this certificate. Besides they need to have a work experience certificate that is similar to the work area and will meet the required rate. Therefore, the work certificate determines the scope, quality and size of the work that the contractor might take part in (Yıldırım, 2018).

However, in view of current circumstances, it is great importance for such an important certificate to maintain its value that the market conditions should correspond to the parameters determined in a bulletin by the Ministry of Environment, Urbanization and Climate Change. In this study, these parameters and current market conditions have been compared and the results and suggestions have been presented.

The Concept of Work Experience Certificate and Varieties

In the literature, there have been various definitions for "work experience certificate". However, it is defined in the regulation for implementation of construction works, in article 3, subclause (d) that "work experience certificate expresses the certificate of work conduct, certificate of work inspection and certificate of work management that shows the experience of the participant on the work subjecting to tender or on similar works".

In the same regulation, in article 3, subclause (b), "similar works" is defined as "the works that is similar to the work/parts of work subjecting to tender in respect of quality and quantity and that requires the same or similar construction engineering, facility, machine, equipment, financial capability, specialization, organizational needs. Although the regulation has drawn a line for the definition of "similar works", the main point is that the experiences should be close to the size, construction engineering, machine, equipment, and organizational structure of the work subjecting to tender. It is vital to determine the working groups in order to choose the contractors who have the technical competences and who have the most reasonable tender.

If it is possible to choose volunteers who have similar work experiences in the past, it will prevent the waste of public and private sector funds. Thus, it will be possible to save labour, time and funds.

Under the heading of the conditions for drafting document, in the regulation for implementation of construction works, in article 44, the requirements for this certificate have been determined. Based on this article, for the pledged works depending upon a single contract, the certificates are prepared as;

a) "Contractor's work completion certificate" in works with substantial completion,
b) "Contractor's work conduct certificate" in ongoing works, if the first contract price is completed and if the rate reaches at least 80% of the total contract price, precisely.
c) "Subcontractor's work completion certificate" on condition that the pledged work part is completely finished and subjecting work part is partly accepted by the management, or substantial completion is done related to the initial contract through an agreement which includes a cost for the contractor who has made a commitment to the institutions and organizations which are authorized to prepare a work experience certificate.
d) "Work inspection certificate or Work management certificate" in ongoing works, given to the architects and engineers who have conducted task of inspection and management with the rate of at least 80% of the first contract price, on condition that the first contract price is completed and if the rate reaches at least 80% of the total contract price, precisely.

"Similar work groups list" has been formed to provide fair competition conditions, to define and to classify the works subjecting to tender in accordance with the public procurement law no. 4734. In this list, similar works are classified under five main headings as; "infrastructure works", "superstructure (building) works", "sanitary installations and mechanical installation works", "electric work" and "electronic and communication works". These main headings are divided into sub categories in the details of the list. The management can examine the list and prepare a pre-condition to the bidding for similar works subjecting to tender.

The Evaluation of Parameters of Assessment for Work Experience Certificates According to Current Construction Costs

In Turkey, construction sector, with its greater work load, is a leading sector among others compared to developing countries. Whether the employment rates or investment amounts are evaluated, it can be seen that the sector is huge in terms of numbers. Especially, the majority of investments in a developing country like Turkey are directly related to construction sector. Developing countries have to improve their standards and cope with many different compulsory actions such as completing deficient infrastructures, conducting industrial activities, increasing production, maintaining logistic activities through ports, airports, and highways for ultimate outputs. For this reason, all the items of work mentioned are directly or indirectly related to the construction sector (Kazaz et al., 2019).

As a result, the recession or the mobility in construction sector directly affects the financial situation in the country. Likewise, the developments in macro economy also directly reflects in construction sector. Recently, inflation has been rising up globally which has an important influence in construction costs. In relation to rising costs, individual investors, who want to preserve their savings, tend to housing and institutional investors speed up the work for their industrial constructions by moving their capacity increase plans to an earlier time. These

attempts deteriorate the supply and demand equilibrium in the sector. This can be seen in the data from TUIK March 2022 data, too. While current consumer price index has increased by 73,50% annually, construction cost index has increased by 101,57% and building materials index has increased by 128,11% annually. As its understood from the statistics, construction cost increase is far above the inflation rate.

Considering these data, for the investments whether through public or private sector, the work experience certificates have become crucial for the volunteer companies to bid. It is important to own updated certificates for companies to be classified as competent for similar or upper-level works.

In order to determine the current values of the work experience certificates, a bulletin called "Assessment parameters of contracting certificates used for construction, facility and repairment works and work completion certificates in 2022" by the Ministry of Environment, Urbanization and Climate Change is being used firstly to classify the contractors. Work experience certificates are being updated through EPPP depending upon domestic producer price index if companies want to bid on. In an inflationist atmosphere, it is possible for a company to preserve its required competences to bid on only through updating the rates according to current conditions. However, lately, the updated rates remain under the prices that are occurred in the market conditions. In this study, the current values of investments in Konya Organized Industrial Zone and the work experience certificates that the contractors own have been compared and it is tried to be evaluated whether they are suitable for current market conditions or not.

Investment 1

The project evaluated under the title of Investment 1 includes rain water, drain water and road infrastructure works of Konya Organized Industrial Zone expansion area. Via this investment it has been aimed to remove the waste during the production phase of industrial facilities that is going to be set up in the expansion area, to remove the rain water in order not to have rain water floods and to form an infrastructure for a healthy transportation.

Within the scope of the investment, about 60.000m. reinforced concrete pipes in different sizes and 6.000 m. glassfiber-reinforced pipes in different sizes have been used. Due to the geographical conditions of Konya, as the natural ground in the working area does not have enough slope, digging height has been increased. This has been resulted in a cost increase.

The cost of this investment is approximately 130.000.000 TL and it was contracted out for 124.526.945,41 TL on 10.11.2017. On 18.12.2017 the contract was signed; construction site was delivered and construction works started. The investment was made with the set amount and was put in service.

When work experience certificate is updated through EPPP depending upon the bid date, it is seen that the total amount becomes 629.881.573,53 TL. For this calculation, basic domestic producer price index (ppi) was 306,04, and current index was taken as pre-June 2022 index-1548,01- as it was the date of inquiry. When the same amount is updated with the rate of 3,428 according to the bulletin called "Assessment parameters of contracting certificates used for construction, facility and repairment works and work completion certificates in 2022", the result is 426.878.368,86 TL.

However, if this project was put into practice at the present time, the amount of the investment would be much higher than the one calculated above. It can be seen that, when items of work in the same project, by keeping the sizes same, is re-calculated according to the market conditions, the amount rises up to 785.277.019,38 TL. In order to explain this increase, it will be enough to examine the increases in some basic materials. Contract values and current values of some basic materials are given in Table 1.

Table 1. Contract values and current values.

Material	Unit	Length in metres	Unit price (tl)	Contract sum (tl)	Current unit price (tl)	Current sum (tl)	Increase rate (%)
Ø3800 mm glassfiber-reinforced pipe	Meter	1370	8.750,00	12.075.000,00	52.500,00	71.925.000,00	596
Ø2800 mm glassfiber-reinforced pipe	Meter	1960	6.000,00	11.760.000,00	27.632,05	54.159.170,00	461
(making) 15cm plant mix base layer	Ton	3500	140,00	350.000,00	430,00	1.505.000	430

As it can be seen in Table 1, the prices of different materials used in the work have been increased in different rates. These rates are above the total amounts compared to whether the bulletin or the updated work experience certificate done through EPPP. A summary of information belonging to Investment 1 is given in Table 2.

Table 2. A summary of information belonging to investment.

Job name	Rain water, drain water and road infrastructure works
Bid date	10.11.2017
Bid amount	124.526.945,41 TL
Updated amount according to the bulletin	426.878.368,86 TL
Updated amount according to EPPP	629.881.573,53 TL
Updated amount according to the market conditions	785.277.019,38 TL

Investment 2

The project evaluated under the title of Investment 2 includes the work of the road that is 26 km. long and has different platform width and road top layers in Konya Organized Industrial Zone 4th expansion area. With this project, the last pledged investment of the expansion area has been completed and it is aimed to provide industrial facilities to have modern and permanent transportation.

Within the scope of the investment, totally 210.000 tons of asphalt concrete have been used in bituminous treated base, binder and wearing courses. Moreover, rainwater grates, road strips and pavement regulations in restricted areas have been done.

The approximate cost of road top layer work calculated by the management was 49.000.000,00 TL. It was contracted out for 44.984.350,00 TL on 16.07.2020. The investment was completed on time and was put in service.

When the investment amount is updated through EPPP depending upon the bid date, it is seen that the work experience certificate given to the contractor becomes the value of 143.355.574,68 TL. For this calculation, basic domestic producer price index (ppi) was 485,37 and current index was 1548,01. When this amount is updated with the rate of 2,058 given in 2020 according to the bulletin, the result is 92.536.632,30 TL.

It can be seen that, when items of work in the same project, by keeping the sizes same, is re-calculated according to current market conditions, the approximate cost rises up to 209.627.071 TL. Especially, the high prices of the production including petroleum-derived raw materials such as bitumen can be explained by the increasing prices of global commodity. When this project was contracted out, brent petrol was about 20 dollars and this supports the condition mentioned above. Contract values and current values of some basic materials are given in Table 3.

Table 3. Investment 2, contract values and current values.

Material	Unit	Length in metres	Unit price (tl)	Contract sum (tl)	Current unit price (tl)	Current sum (tl)	Increase rate (%)
Doing bituminous base course work with 11 cm thick pressed asphalt concrete	T	95.000	177,00	16.815.000,00	885,00	84.075.000,00	500

Doing binder layer work with 8 cm thick pressed asphalt concrete	T	70.000	184,50	12.915.000,00	960,00	67.200.000,00	520
Hot mixture wearing course and patch work (with robot)	T	3.000	425,00	1.275.000,00	2.150,00	6.450.000,00	506

As it can be seen in Table 3, with the increase in petrol prices and exchange rates and the increase in prices due to the inflationist atmosphere, road top layers investment has shown a much higher increase than the rates determined in EPPP and the bulletin. A summary of information belonging to Investment 2 is given in Table 4.

Table 4. A summary of information belonging to Investment 2.

Job name	4th part road top layers work
Bid date	16.07.2020
Bid amount	44.984.350,00 TL
Updated amount according to the bulletin	92.536.632,30 TL
Updated amount according to EPPP	143.355.574,68 TL
Updated amount according to the market conditions	209.627.071,00 TL

Investment 3

The project evaluated under the title of Investment 3 includes the work of surrounding walls and parcel walls in order to ensure general security of 160 industrial parcels and the region in Konya Organized Industrial Zone 5th expansion area. Totally, 67.000 metres long walls have been produced in different heights. The approximate cost of the project calculated by the management was 21.000.000,00 TL. It was contracted out for 19.144.451,65 TL on 04.11.2020. The investment was completed on time.

It is seen that, when the work experience certificate that the contractor has deserved updated with current indexes through EPPP, it reached a value of 55.556.018,67 TL. When this amount is re-evaluated with the numbers in the bulletin by the Ministry, it is only 39.399.281,50 TL. However, after the current market researches, it is seen that if the investment was desired to be re-done, the price would become 99.821.682,16 TL.

The increasing costs of energy cost after the COVID 19 pandemic have made the prices of raw materials for concrete much higher compared to the average inflation numbers. The estimated numbers above prove this situation as the work of building walls is a concrete and iron-based production. Contract values and current values of some basic materials are given in Table 5.

Table 5. Investment 3, contract values and current values.

Material	Unit	Length in metres	Unit price (tl)	Contract sum (tl)	Current unit price (tl)	Current sum (tl)	Increase rate (%)
C25 / 30 concrete; pouring with a concrete mixer (sulphate resisting cement product)	M^3	27.000	250,00	6.750.000,00	830,00	22.410.000,00	332
Concrete steel	T	1.200	4.210,00	5.052.000,00	13.600,00	16.320.000,00	323
0-25 mm broken stone filler work	T	112.000	20,00	2.240.000,00	60,00	6.720.000,00	300

Table 6. A summary of information belonging to Investment 3.

Job name	5^{th} part surrounding walls and parcel walls work
Bid date	04.11.2020
Bid amount	19.144.451,65 TL
Updated amount according to the bulletin	29.399.281,50 TL
Updated amount according to EPPP	55.556.018,67 TL
Updated amount according to the market conditions	99.821.682,16 TL

Results

During Covid 19 pandemic, expansionary fiscal policies that are applied by Central Banks in countries not to lower the demand and to sustain their economies has created a demand and supply gap after the pandemic. Taking into consideration of the base effect of energy prices, as they have been rising up in high rates, the world has to come up against the concept of inflation which has been forgotten for a while. As the precautions have been delayed in many developed countries, a price instability has occurred.

Recently, the inflation has been rising up in our country, too. On the date that this study was conducted, the annual consumer price index was 73,50. As it is given in details in the study, the inflation in the construction industry is much higher than this rate.

When the economic conditions in our country is based as an opinion, the construction sector has always been a trigger. As it can be understood from the economic growth performance of Turkey, the construction sector has always become extended relatively more than the average numbers in the country. However, the latest increases in prices affect construction costs negatively and many contractors have difficulty in determining a price for the works they want to bid on. Both in housing and other construction investments, especially within the last year, there has been an uncontrolled increase.

Both public and private investors give their construction investments out by contract and determine certain criteria for their contracts. In this study, one of the most important criteria in these contracts, work experience certificate has been examined and the consistency of the amounts have been questioned. As samples, three different projects with different goods have been chosen. In each project, the amounts of updated work experience certificates have been lower than the current amounts of the investments.

Investment 1 is an infrastructure project. The main entries are reinforced concrete and glassfiber-reinforced pipes. If the contractor of this project wants to use the work experience certificate for other projects in the future, the amount will be 629.881.573,53 TL. However, if the contractor wanted to do the same job again, when the current market conditions are taken into consideration, the amount for that investment would be 785.277.019,38 TL. In this case, it would be impossible for the contractor to bid on a new contract in private sector which requires an exact amount of work experience certificate. The work experience certificates updated through EPPP will be 20% lower than the price determined for a new job, according to the market conditions.

Investment 2 is a road top layer project. However, while examining this investment it should be kept in mind that it was the pandemic year and petrol prices drew back to 20 US dollars. The main entry of the investment is petroleum-derived bitumen and when the work experience certificate has been updated the amount is 143.355.574,68 TL. The same investment can be done for 209.821.682,16 TL with updated prices. Despite the fact that there has been a base effect of the pandemic, the amount of work experience certificate is 32% lower than the current value. In this case, the work on asphalt negatively affects the competence of the contractor.

Investment 3 is the work of surrounding walls and parcel walls. Main entries for the job are furnace materials, mould manufacturing, iron manufacturing, and concrete manufacturing. These headings directly concern the housing industry and are accepted as the main items of

construction works. With the increasing risks due to the Russian-Ukrainian war, the increase in energy prices have made the prices of raw materials in concrete manufacturing rise much higher than the inflation rate. Specific to our country, when the increases in foreign exchange rates have combined with these risks mentioned, the prices of fuel oil have risen up to 300%. This situation has been negatively affecting the manufacture and transportation processes of the materials and the concrete. As a result, the updated amount of the work experience certificate of the contractor has become 55.556.018,67 TL. If the same investment was desired to be re-done, the cost would be 99.821.682,16 TL. As it can be understood from the numbers, the value of work experience certificate is 44% lower than the current amount.

Considering the evaluations above, it is seen that work experience certificates do not reflect the real competences of the contractors. In this case, for the contractors, an offer opportunity for new contracts is negatively affected.

As the amount of work experience certificates vary from the market conditions, building contractors have an obstacle to grow their extend of work. If the global inflationist atmosphere becomes permanent, the approximate costs that are calculated by the managements will increase more compared to the value of work experience certificates, and the number of volunteer contractors will be lower in time.

Several precautions must be taken in order to prevent this. Firstly, it can be suggested that a different platform might be prepared to update work experience certificates not according to domestic producer price index but according to differential index. Indexes should be determined according to similar work groups and the certificates should be updated according to them. As a result, in an atmosphere where the prices of concrete become much higher than the prices of bitumen, a job that includes concrete as a main entry should have a higher updating rate.

Secondly, it can also be suggested that until this inflationist atmosphere becomes an end, the managements might reduce their demand about work experience certificate rates. As a result, the contractors will have the right to bid on more works with their current certificates, and they will have the chance to own new certificates. It is assumed that, the second suggestion is easier, faster and more applicable because to prepare the substructure will be quicker.

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Subcontractor Management in Construction Projects: A Literature Review of Research Trends

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Abstract

Subcontracting has become a frequently used position in the construction industry to work on projects in a more organized manner, to create new employment for different groups or individuals, to share risks and to complete work in a limited time frame. Administrative situations and problems related to subcontracting should be well identified in order to establish and manage organizations such as tender, contract and execution between main contractor (MC) and subcontractor (SC). This literature review was carried out with the aim of researching and bringing together the studies related to SC management in recent years and to serve as a guide for researchers. In line with this goal, the studies encountered in the literature related to the SC management side of the managerial issues between the MC and SC were examined. The studies were categorized under six groups as follows; 'subcontracting practices in construction', 'general subcontractor management' 'evaluation and selection processes', 'collaboration with main contractor', 'subcontractor performance appraisal on-site' and 'subcontractor risk management'. 'Evaluation-selection processes' came first among the subjects that the researchers focused more on, it was determined that there are still few studies and the subject that needs more research and study is 'Subcontractor performance appraisal on-site'.

Keywords: *Subcontracting, subcontractor management, selection, evaluation, performance appraisal*

Introduction

Subcontracting in the construction industry has become an increasing need or habit with each passing year. MCs divide the entire work they receive from the employer into parts and have others undertake these parts, both reducing the workload and sharing the risks. The use of SCs has been adopted in the construction sector, which requires special expertise, has large-scale costs and requires advanced equipment. (Yoke-Lian et al, 2012) Selecting SCs, making contracts, managing them, managing their relationships, maintaining their organization can be the summary of a project's success or failure.

Certain responsibilities fall on both MCs and SCs for the common good of the project. The main success factors in a project can be listed as mutual trust of the parties, transparency, well-defined scope of work, clear definition of responsibilities and cooperation. The success of a project in which many SCs will work together will emerge as a product of joint effort. In the construction industry, where cooperation is very important, trust, loyalty and reliability are the factors that ensure cooperation. (Deep et al, 2019) Trust-based relationships allow for better teamwork, which is believed to increase productivity. (Chalker and Loosemore, 2015) Relationships between MCs and SCs are one of the types of relationships that are affected by issues that can create situations of distrust. (Manu et al, 2015) If the relations between MCs and SCs are not managed properly, the performance of construction projects is directly or indirectly affected negatively, and the relations between these parties become more and more important in achieving the desired goals of the construction projects. (Tan et al, 2017)

Although formal commitment is established with the contracts, it is desired that the project be carried out at the desired standards with a more effective cooperation between the SC and the MC. While subcontracting and SC management is so important for the construction industry, there has been a need for continuous research on this subject. The aim of this study is to identify trend SC management studies in recent years and to identify gaps in this subject. With this literature review carried out for this purpose, the study areas were determined and the study densities were shown.

Methodology

An in-depth literature review was conducted to gain a comprehensive insight into the SC management researches in construction industry. This literature review was carried out using Google Scholar and Scopus databases. By examining the studies on the topic of SC management, especially the last 15 years (2006-2021), it is aimed to reduce it to a more understandable level by categorizing the subjects related to SC management, which can be a guide for researchers who want to do research. Studies related to SC management, with the keywords 'subcontracting', 'Subcontractor', 'Subcontractor management', 'Subcontractor performance evaluation', 'Subcontractor selection', 'on-site subcontractor performance', searched and investigated. 322 documents that may be relevant to the subject were examined. Afterwards, the titles and abstracts of the studies were checked and elimination was carried out. A total of 62 documents were examined in depth through this scan. By examining these studies, trend researches in SC management were categorized in six different groups. The number of documents of each group is written and their percentages in the total studies are shown.

The Research Trends on Subcontractor Management

This literature research is based on the concept of subcontracting in the construction sector and was conducted on the question of which dimensions or areas of subcontracting have been carried out. As a result of the studies examined, when we group the subcontracting studies in the construction sector in the literature, the following titles are formed: ’Subcontracting practices in construction’, ’general subcontractor management’, ’subcontractor evaluation and selection processes’, ’collaboration with main contractor’, ’subcontractor performance appraisal on-site’, and ‘subcontractor risk management.’

Subcontracting Practices in Construction

In the construction industry, the subcontracting system is a common practice dating back to ancient times. (Sun et al, 2020). When this is the case, it is necessary to have a good grasp of the definition of subcontracting. According to Abdullahi (2014), a SC is a person or a commercial firm that is contractually agreed with him/her to fulfill some or all of the obligations of the contracts of another person or firm.

After thoroughly adopting the definition of subcontracting, we can talk about its practices in the construction sector. Memili et al. (2011) compare the management preferences of family and non-family companies according to their subcontracting tendencies. Yoke-Lian et al. (2012) conducted a literature review on the types of SCs, the problems posed by SCs, and current methods proposed to improve subcontracting practice, and indicated that the success of a construction project depends on the MCs ability to select the appropriate SC during the bidding process and the proper management of the SC during construction. Lew et al. (2020) conducted a study to investigate the multi-layered subcontracting practice in the Malaysian construction industry, to identify the problems arising from this type of subcontracting system, and to identify methods for improving quality performance.

General Subcontractor Management

By keeping the SC potential wide in the works, the contractors want to complete the projects in the desired time and share their responsibilities. While they share most responsibilities and risks with SCs, managing, administering and monitoring them is an important management or business area. It is obvious that problems may arise in any subject in a construction site or project, as well as problems related to SC management. It has been seen that building information modeling (BIM), which has been used for a long time and its use is increasing rapidly, with the inclusion of developing information technologies in the construction sector, is also used in the field of SC management. Gurevich and Sacks (2014) created a BIM-based information system to be used in the task selection of SCs and worked on a system that shows processes accurately and reliably.

In the researches, it is seen that the SC management policies are examined and there are studies that are of a developmental nature. Biruk et al. (2017) stated that previous researches dealt with SC management and planning separately and aimed to create a decision support mechanism that integrates the steps of SC selection, coordination and determination of the appropriate division of labor with timing. Akinwale and Olusanya (2020) examined the impact of contracting and working processes with SCs in Nigeria on wages and workloads. They have determined that wages and workloads are not suitable, especially by making evaluations on the basis of workers.

Collaboration with Main Contractor

In a construction project, the MC is both a responsibility to the customer/employer and is obliged to manage the SCs. The construction market, which is an environment where relations can deteriorate quickly or very successful projects can be produced with good relations, can easily be affected positively or negatively by MC-SC relations. Manu et al. (2015) by dealing

with the issue of trust in the MC-SC relations in projects, examines the factors affecting this situation, which is of great importance in terms of relations in projects. A healthy cooperation in projects creates power in the project. Therefore, in cases where cooperation weakens, the execution of the project becomes more and more difficult.

According to Mudzvokorwa et al. (2020), with the increasing need for and dependence on SCs in the construction industry, improving the operational relationship between MCs and SCs increases the probability of the project's success and the overall project performance. Korb and Sacks (2020), by developing a simulation, conducted a study based on the relationships between the main and SCs on how to direct the control strategies of the MCs and the labor resources of the SCs. In order for a harmonious relationship to be established, relationship types must be defined and adopted. For this, Tan et al. (2017) in their research examining the relationships between MC-SC based on a survey study, named the types of relationships and divided them into four groups as oppositional, competitive, collaborative and partner.

Subcontractor Evaluation and Selection Processes

Researchers have often emphasized that SC selection is the most important and first step in SC management in a project. Prior performance data is usually taken into account when making this selection. It is desired by everyone to have a fair selection that will provide more objective results for the selection of SCs, and will provide profit in terms of cost, time and quality. Many different decision support systems have been proposed by researchers from past to present that facilitate the decision-making of MCs. Ko et al (2007) conducted a study aimed at improving existing practices to evaluate the performance of SCs. The appropriateness of adopting the Evolutionary Fuzzy Neural Inference Model (EFNIM) to ameliorate the disadvantages was examined.

In the SC selection model that Ulubeyli and Kazaz (2016) developed, it has been seen that it can be used as a consultation system for MCs to reduce the risk in the selection of SCs. In this model, it is aimed to understand the MC's strong and weak points of each bidder, and as a result, to make informed and correct decisions. Abbasianjahromi et al. (2014) in their research, found that previous studies evaluated the selection of SCs on the basis of criteria, but did not consider the number of tasks assigned to SCs. Considering this situation, they proposed a hybrid model applying the continuous ant colony and fuzzy set theory.

In the construction sector, where costs are at the forefront, the price offers they give when choosing a SC often precede their other features. Polat (2016) stated that MCs generally tend to choose SCs that offer the lowest bid price, and that working with unqualified and underfunded SCs can lead to inefficiencies and failures. For this reason, it proposes a decision approach in which AHP and PROMETHEE are used together, which considers the financial capacities and qualifications of the SCs in the SC selection process. Shivam and Khasiyani (2018) developed a conceptual model for SC selection in different construction projects by proposing an integrated decision approach that uses the relative importance index (RII) for the SC selection issue and the preference ranking organization method for enrichment assessments (PROMETHEE). Keshavarz-Ghorabaee et al. (2018) have proposed a new approach by defining the SC evaluation process as a dynamic multi-criteria group decision-making problem. This is designed based on the EDAS method, which is a new and efficient MCDM approach. Koçak et al. (2018) have adopted an approach to create a new alternative to

SC selection with the Additive Ratio Assessment Method, which is one of the multi-criteria decision-making techniques that can be more scientific, instead of traditional practices in the construction industry.

The MCs need to set out with the right strategies in order for the works in the project to go well, and as the first step of this, they should pay attention to the selection of the appropriate SCs. Nov and Peansupap (2020) stated that the MCs have wrong practices in selecting SCs. Thereupon, they developed a new model using artificial neural networks to determine the type of relationship between main and SC. Vo et al. (2021) presented an overview to assist MCs by presenting a study targeting the development of appropriate SC evaluation and selection factors in their projects in the construction industry. Karaman and Sandal (2021) aimed to develop a selection criteria model that could contribute to the pre-qualification conditions for SCs in the future SC selection process and to measure their impact on project success.

Subcontractor Performance Appraisal On-Site

The literature reviewed is mostly on the measurement of performance in the bidding period and the selection of SCs according to this performance. There are deficiencies in measuring and evaluating the performance of SCs during construction execution. NG and Tang (2008) have defined performance evaluation criteria that will form the basis for the development of a new SC performance evaluation system and facilitate the viewing and comparison of performances. NG and Skitmore (2014) then propose an approach to develop a balanced scorecard SC evaluation model through a survey study in which baseline and target performance levels are determined for large-scale skilled SCs. Yang et al. (2015) in their research based on the concept of Total Quality Management, focused on the performance evaluations of employees and SCs. Chamara et al. (2015) by investigating the performance of SCs in the project in terms of time, cost and quality, which are crucial issues in the sector, aimed to bring their current performance to the desired levels. With the right organization, the difficulty level of managing multiple SCs involved in a project can be reduced. In this context, MCs have important duties. MCs should consider how to develop different relationships with different SCs and how to protect cooperating SCs for the success of the project. (Tan et al. 2017) For this, SCs can contribute to the project by developing a dynamic and effective management model with continuous performance evaluations during the construction process.

Subcontractor Risk Management

Risk identification before and during the project lifecycle can significantly determine the success of project risk management. (Wu et al, 2017) The management of the identified risks is also one of the situations that requires an organization or a new management style in itself. While most of the works are transferred to SCs, their performance in the project is very important in terms of achieving the desired quality. Many construction projects either fail to meet deadlines or exceed the budget allocated for the project. (Maria Krechowicz, 2017) MCs have to manage a significant risk in terms of the success of the project, depending on the performance of the SCs in these matters. As it is known, construction projects are complex structures in which many SCs work together or in different time periods. It is risky to predict the future with the previous data of the SC. In this regard, Cheng (2016) has also considered risk assessments to improve the accuracy of the estimates of the possible performances of SCs

before starting the construction phase of a project. While creating products in construction projects, the effects of risks on quality performances are one of the most important issues to be considered. Adinyira et al. (2020) have published their study aiming to examine the impact of the management of risks arising from the use of SCs on the quality performance of building construction projects.

Results

Table 1 provides information about the authors, years and frequency of the documents. Accordingly, it has been observed that the researches carried out by the researchers with the help of different methods on the selection of SCs at the bidding stage are intense. The importance of selecting the appropriate SC has been frequently mentioned by the authors in general. While the studies in other groups were close to each other, it was understood that attention was paid to the studies showing the importance of cooperation between MC and SC. For MCs in construction projects, the success of the SC while the current work is in progress is critical, but this issue has not been mentioned very often in the literature.

Table 1. Summary table of the subcontractor management topics, authors, years and frequency

Subcontractor Management in Constructıon	The Authors' Researches on Subcontractor Management Between 2006-2021	Frequency
Subcontracting practices in construction	Yoke-Lian et al. (2012), Choudhry et al. (2012), Abdullahi A.H. (2014), Lew et al. (2020), Rostiyanti et al. (2020), Memili et al. (2021)	6/62 (%9,70)
General subcontractor management	Flynn C.J. (2008), Thomas and Flyinn (2011), Gurevich and Sacks (2014), Biruk et al. (2017), Jazayeri et al. (2018), Mambwe et al. (2020), Akinwale and Olusanya (2020)	7/62 (%11,30)
Collaboration with main contractor	Wood and Ellis (2005), White and Marasini (2014) Loosemore (2014), Manu et al. (2015), Chalker and Loosemore (2016), Liu et al. (2017), Tan et al. (2017), Adeyekun (2019), Fagbenle et al. (2018) Deep et al. (2019), Mudzvokorwa et al. (2020), Korb and Sacks (2021),	12/62 (%19,40)

Subcontractor evaluation and selection processes	Ko et al. (2007), Hartmann and Caerteling (2010), Fagbenle et al. (2011), Abbasianjahromi et al. (2013), Cheng and Huang (2012), El-Kholy (2019), Ulubeyli and Kazaz (2016), Marzouk et al. (2013), Abbasianjahromi et al. (2014), Shahvand et al. (2016), Polat (2016), Basu et al. (2017), Abbasianjahromi et al. (2018), Shivam and Khasiyani (2018), Keshavarz-Ghorabaee et al. (2018), Kocak et al. (2018), Palha et al. (2019), El-khalek et al. (2019), Nov and Peansupap (2020), Abdullah et al. (2021), Afshar et al. (2020), Vo et al. (2021), Karaman and Sandal (2021)	23/62 (%37,00)
Subcontractor performance appraisal on-site	NG, (2007), NG and Tang (2008), NG (2010), NG and Skitmore (2014), Yang et al. (2015), Chamara et al., (2015), Tesha and Luvara (2017), Poovitha et al. (2018)	8/62 (%12,90)
Subcontractor risk management	Krechowicz (2017), Arrto et al. (2008), Cheng (2016), Wu et al. (2017) Artan İlter and Bakioğlu (2018), Adinyira et al. (2020)	6/62 (%9,70)

Conclusion

This research has been prepared to examine the development of studies on SC management in recent years. The administrative issues of the MCs on the SCs were categorized and the studies were divided into different groups. When this categorization is examined, it is seen that much more attention has been paid to the 'evaluation and selection processes'. Considering the needs of the sector, the evaluation of SCs before they are employed in the project and the selection processes within the framework of the selection criteria will provide an environment where the risks are reduced for the MCs in the following processes. In this context, the subject that the literature focuses on more frequently has taken shape in line with the needs of the sector. On the other hand, establishing a SC performance appraisal process by measuring the performance of the SCs on-site and making the necessary evaluations according to these data during the project implementation phase will again have positive results for the MCs. However, the issue of performance measurement and evaluations in on-site has not attracted much attention in the literature. It is thought that future work will be carried out in this direction.

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Organizational and Team Resilience: Construction Industry Survival in the Pandemic Crisis

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Abstract

Organizations have to navigate difficult, uncertain, rapidly changing times of crisis. They need resilience capacities to survive in uncertain environments, bounce back from crises, adapt to change, and foster future success. Organizations have been structured more team-based lately. Therefore, understanding and developing the contribution of team resilience to organizational success is important for the organization to move forward. Organizational and team-level resilience supports organizations' development towards success beyond surviving in challenging times. With the outbreak of the COVID-19 pandemic, many industries faced an unexpected crisis and uncertainty. The construction industry and organizations have also been significantly affected by the challenges posed by the pandemic. Many construction companies have had difficulties in business continuity due to quarantines. In this changing and uncertain adversity, teams had to change the way they do business and faced many difficulties in maintaining their performance. Therefore, building organizational and team resilience is vital for organizations' business continuity and future success in a pandemic such as the COVID-19 pandemic. This paper aims to examine organizational resilience and focus on team resilience to encourage organizations to build resilience in the face of crises such as the pandemic.

Keywords: *construction industry, COVID-19, organizational resilience, pandemic, team resilience.*

Introduction

It is not new for people to work together as a group to increase their odds of survival. Teams consist of individuals who are interconnected and have common goals (Salas et al., 2015). As the complexity of the work increases, utilizing teams in most sectors is becoming widespread. Teams provide more potential in the face of complexity, both by enabling efficiency and creativity for organizations and by dividing responsibility and decision-making among their members (Conti & Kleiner, 1997). Teamwork reduces the need for coordination and simplifies the organizational structure. Moreover, teamwork can improve productivity and lead to lower costs over time. Team members can share experiences and knowledge with each other as a learning opportunity, which can increase the team's overall creativity. However, not every industry may have effective teamwork due to its own obstacles since efficient teamwork depends on management structure, leadership styles, and organizational flexibility (Tarricone & Luca, 2002). Teamwork efficiency in the construction industry is not high as the

productivity in the effort put into the construction industry and the resulting product value is low. The construction industry mainly focuses on technical skills such as the iron triangle of time, cost, and quality to achieve project success. Moreover, the social skills in teamwork and resilience are neglected in the project success because the projects heavily focus on the factors such as low bid prices, which creates fragmented teams and results in poor team performance in the industry. Due to the nature of the industry, construction project teams are usually assembled at the project location, sometimes with local individuals, for a certain amount of time. Teaming up people who may have never met before and putting project responsibilities on the team can be problematic and come with challenges.

Projects are becoming more and more complex and challenging, requiring the ability to deal with challenges at the individual, team, and organizational levels (Varajao et al., 2020). In recent years, a lot of research has been done on resilience in management and business. One of the meanings of resilience is the ability of the system back to its original state (or to adjust itself to the new state according to the new situational demand) from an adverse event (Xue et al., 2018). Although some researchers argue that resilience is a process that ultimately leads to resilient results, it is the process of how organizations react when facing adversities to achieve resilient results (Hillmann & Guenther, 2021). Organizational resilience includes the organization's ability to face adversities, maintain its sustainability, and move forward on track with its future goals (Bui et al., 2019). However, construction projects are open to being affected by external factors, have uncertainties, and the risk is high, which makes them complex. Therefore, construction organizations need to be resilient in order to provide stability and survive in a competitive environment. Since organizations have been structured more team-based lately, resilience has become a team-level concept rather than being an individual-level capacity. Moreover, teams are implemented in organizations with their strengths as well as their weaknesses, thus team resilience can affect organizational resilience. In order to achieve organizational resilience, its teams as units can be investigated by focusing on team resilience and on strategies to develop team resilience.

Organizations operate in a dynamic environment, yet, with the development of technology, the global economy is now inevitably more volatile, uncertain, complex, and competitive. Internal and external factors such as weather, geopolitics, pandemic outbreaks, scientific and technological innovation, and other non-human factors lead to “black swan” and “grey rhino” incidents more frequently and affected global business (Liang & Cao, 2021). Most recently, the sudden outbreak of the Covid-19 pandemic has affected the global economy more than any other crisis in the history of mankind.

Apart from concerning health issues, the Covid-19 pandemic forced lockdown all over the world, which caused economic shutdowns and heavy losses. Since the construction sector was interdependent with many sectors both directly and indirectly, the industry has been one of the sectors most affected by the pandemic. Global restrictions caused supply chain issues, delays in activities, revenue losses, increased cost of construction outputs, contractual issues, and many other issues (Assaad & El-adaway, 2021). Therefore, the industry had to absorb these financial shocks just like every other business. However, while other sectors can develop innovations with modern managerial methods after the crises, the construction sector lags these developments. Remote teams have been used in many sectors for years, but the Covid-19 pandemic has globally required organizations to adopt them for self-isolation purposes. Therefore, the development of remote collaboration has made teamwork in the construction industry more complex.

The construction industry suffers from tight timeframes, task complexities, poor working environments, complex business relationships, poor teamwork, and other factors. This paper aims to explore how the Covid-19 epidemic affects teamwork in the construction industry and emphasize the importance of organizational and team resilience. In this context, it is hoped that this study will increase awareness of the subject by revealing the importance of effective teamwork and developing organizational and team resilience in the industry.

COVID-19 Pandemic and Construction Industry

In December 2019, in Wuhan (China), the epidemic started and has been a major global threat to human health. As of 11 March 2020, The World Health Organization (WHO) announced this outbreak as a pandemic (Sierra, 2021). Since the disease can be transmitted by respiratory droplets in direct contact with the mouth, nose, or eyes and by direct contact with infected people or indirect contact with infected surfaces, containment measures introduced have included recommending people stay at home and quarantining outbreaks regions (Pirzadeh & Lingard, 2021). Therefore, most governments around the world have enforced strict lockdowns, including restricting people's movements and gatherings, to decrease the spreading of the virus (Sierra, 2021). Both human health and the operational health of businesses were affected because of the pandemic. Work health and safety issues have also become a challenge for organizations and industries to carry on business operations during the pandemic (Caligiuri et al., 2020). Governments and employers have encouraged workers to work at home (also can be referred to as teleworking). Moreover, 88% of worldwide organizations implemented home-based work according to the survey that 800 globally leading human resources attended (Pirzadeh & Lingard, 2021). However, dramatically decreased demands and production have impacted most sectors of the economy. Covid-19 has had major effects on the global economy through forced lockdowns and economic shutdowns - beyond easy recovery (Ogunnusi et al., 2021). For instance, the US economic activities by GDP have shrunk by 5% in the first quarter, and 32% in the second quarter of 2020 resulting in one of the most severe economic shocks in modern times (Meyer et al., 2022). The construction industry was not immune to the impacts of the pandemic either and had to absorb these financial shocks just like every other business.

The construction industry is one of the biggest industries in the world and it makes for about 13% of the global gross domestic product (GDP) (Biorck et al., 2020). Moreover, the construction sector has relationships with many sectors both directly and indirectly. Therefore, the construction industry is considered an important operator of economies (Assaad & El-adaway, 2021). Even without Covid-19, the construction sector has always been battling time and cost overruns as one of the major setbacks (Ogunnusi et al., 2020). With the restrictions, as in most industries, many construction projects also stopped. Being behind schedule and the exceeding costs of idling equipment made it an expensive issue for the sector (Alkhalouf, 2020). Due to supply chain issues, delays in planning, operational restrictions, and inspections the construction industry was affected heavily by the coronavirus (Biorck et al., 2020). While the sector was being affected by restrictions, many companies were facing collapse and going out of business and some of them resumed working with disrupted workflow. For instance, construction organizations had to either shut down both domestic and/or international sites or continue their projects at a lower capacity resulting in labor, material, and equipment supply issues (Chih et al., 2022). According to the survey conducted by Build UK on behalf of the Construction Leadership Council, from September 2020, the construction company would most likely face a 7.7% reduction in the workforce

while the industry anticipates a 26.7% decrease in agency workers and self-employed (Ogunnusi et al., 2020). Since all these issues such as unemployment and downsizing in organizations are interconnected and have led to a lack of cash, manpower, and resources in general, it created a chain of delays, loss of labor productivity, and contractual issues (Assaad & El-adaway, 2021). Due to the pandemic, the construction industry was not able to adopt telecommuting as easily as other sectors to lessen the safety issues without disrupting productivity (Al-Mhdawi et al., 2022). Furthermore, the construction sector in developing countries was more vulnerable to the challenges caused by the pandemic. Due to financial issues such as rising exchange rates, inflation, fluctuations in material costs, and escalated interest rates the negative effects of the pandemic were more significant in developing countries (Al-Mhdawi et al., 2022).

With the pandemic, it is important for the construction industry to address the challenges in many ways. According to Assaad and El-adaway (2021), the pandemic has many future research areas and one of them could be the implications of teamwork during the pandemic. Moreover, the significance of the organizational context for psychological factors concerning their connection to teamwork can be identified as a subject for future research (Rasmussen & Jeppesen, 2006).

Teamwork Challenges in Pandemic Era

Construction industry workers face many difficulties in teamwork. They were faced with new teamwork challenges with the pandemic. The challenges experienced by teams during the pandemic process can be grouped under the following headings.

Workplace Loneliness

With the implementation of restrictions, many employees, including project-based construction professionals and managers started working from home for self-isolation purposes - creating virtual teams. Therefore, employees are removed from their colleagues hence, their social life at work. During the Covid-19 pandemic, workers may have been impacted negatively by the lack of social interaction and connections through work. Some level of social interaction with co-workers is necessary for almost all jobs. Although utilizing virtual teams through teleworking has been operating for decades, one of the main disadvantages of virtual teams is the lack of physical interactions since the lack of these interactions may create the feeling of isolation and being left out (Kirkman et al., 2002). Moreover, teleworkers feel lonelier, worried, and guilty compared to their office-working colleagues (Mann & Holdsworth, 2003).

Disturbed Life-Work Balance

The adaption of digital technologies has made it possible to use time more efficiently and productively, yet reduced social engagement has also impacted individuals' work and life balance (Lingard et al., 2021). It is reported that social isolation causes psychological issues and reduces the satisfaction of the job among people who work from home (Bentley et al., 2016). Similarly, it is also reported that increased stress which related to social isolation such as not being able to separate work from family, or ending up working longer hours (Montreuil

& Lippel, 2003). For example, according to a survey of 436 teleworkers in Lithuania during the COVID-19 pandemic, the difficulties of new ways of working remotely impacted some employees negatively in terms of self-organization and separating work from personal life (Raišienė et al., 2020). In addition to the challenges of working from home, some construction professionals also may choose to work even though they should be resting (Ogunnusi et al., 2021).

Reduced Engagement

Conventionally, it can be thought that teams that work face-to-face are more productive and satisfied compared to virtual teams that have feelings of isolation and disengagement towards their job (Ogunnusi et al., 2021). Adopting remote working to utilize remote meetings or enabling remote site inspections are beneficial for many construction organizations (Lingard et al., 2021). However, along with the benefits of home-based teleworking for individuals and organizations, the negative aspects are sometimes overlooked. For instance, it is reported that home-based teleworkers in the US experience less social support and increased uncertainty about their roles at work (Pirzadeh & Lingard, 2021). As a part of the negative impacts of Covid-19 on the construction industry, some people working home-based reported that they did not have enough space at home and due to distractions at home, had challenges focusing on their work (Ogunnusi et al., 2021).

Lack of Communication

Sharing knowledge, coordination and communications are the keys to expecting the effectiveness of the team, therefore, in virtual teams, the coordination decreases as it is harder to communicate (Garro-Abarca et al., 2021). Decreasing social interactions may result in reduced commitment and performance. Lack of direct communication with managers and team members due to virtuality, in general, may cause confusion, miscommunication, and uncertainty among team members (Raišienė et al., 2020).

Lack of Trust

Trust provides stronger leadership, communication, and cohesion to the teams. Therefore, it can be considered that trust has one of the most important roles especially in increasing virtuality because of the Covid-19 pandemic (Garro-Abarca et al., 2021). In the creation of successful virtual teams and organizations, building trust can be the greatest challenge, therefore, barriers such as traditional attitudes are needed to be transformed into thinking cooperatively (Kumaraswamy et al., 2005). The level of trust among teams working remotely is generally lower compared to ones who work face-to-face (Raišienė et al., 2020). With reduced communication with social isolation, some challenges may arise such as concerns and jealousy among employees which may lead to mistrust (Bentley et al., 2016). Moreover, lack of trust becomes an issue in the execution of work effectively for teams. Many organizations require constant social interactions to build trust which virtuality eliminates (Raišienė et al., 2020). However, trust within teams can be built when people deliver what they promised and meet the results.

Overwork

Some studies show that working remotely is more beneficial for employers than for employees because it requires teleworkers to put more hours and effort beyond normal office working hours (Pirzadeh & Lingard, 2021). According to the study of Covid-19 effects on the UK construction, reduced workforce on-site affected schedules, and required employees to manage sites without a margin of error, thus, increasing working stress among employees. Moreover, conditions like these increased the risk of fatigue from overworking and negatively affected well-being (Jones et al. 2020). Even though online interactions may reduce teleworkers' feelings of isolation, overworking remotely and constant communication due to limited other social activities because of Covid-19 may also cause individuals to spend too much time at work (Pirzadeh & Lingard, 2021). In addition, teleworkers may experience being 'out of sight, out of mind' and concerned about opportunities they may miss, which can lead to overworking more to impress managers among other employees (Bentley et al., 2016).

Organizational Resilience

The word “resilience” comes from the Latin word “resilire” which can be characterized as the capacity to recover rapidly from troublesome and possibly hurtful circumstances (Xue et al., 2018). Resilience is based on "bouncing back" from the stressful experiences people gain throughout their lives (APA, 2013). Moreover, the idea of resilience can be applied to any functional system (Turner et al., 2017). When the resilience concept is applied to society, it becomes defined as being able to protect itself from harmful events such as wars, natural disasters, or revolutions (Vale & Campanella, 2005). In an economic concept, resilience means the ability of a business organization to be able to endure risks and seize opportunities even in unfortunate events (Delli Carri, 2019). Therefore, over time, the concept of "organizational resilience" has been studied as a characteristic of the organization to cope with internal or external shocks arising from disturbances and unexpected situations in the organization (Bui et al, 2019).

The main definition of organizational resilience is described as the organization's ability to recover from hardships or challenging events, by responding to endangering situations (Varajao et al., 2021). Moreover, this ability not only includes the organization to endure challenging circumstances but also bounce back from them to continue staying on track for its needed future objectives safely (Fleming, 2012).

From the perspective of human resources, the main objectives for a resilient organization are to be flexible, agile, and dynamic, thus, to have a better chance to survive against external factors mostly arising from the competition (Bui et al, 2019). From another perspective, organizational resilience can be described not only as bouncing back from unexpected challenges but also as an opportunity to absorb adverse situations and enabling organizations to exploit more opportunities for the future (Lengnick-Hall et al., 2011). Bouncing back definitions assume a single desirable outcome for resilient organizations. However, if crisis situations are considered a cascading process, the organization must be able to evolve by constantly responding to challenges (Darkow, 2019).

Organizational resilience is generally thought of as being able to anticipate risks and avoid potential difficulties. However, for practicality, it may be simpler to develop immunity by confronting what has happened before than to avoid risks that are unlikely to happen - perhaps

never happen (Andersson et al., 2019). Additionally, an organization may try to expect possible future risks, however, these anticipations may cause a weakness towards other unpredicted circumstances (Hillmann & Guenther, 2021).

Having resilient systems that are both strong and able to adapt quickly simultaneously brings a paradox to organizational resilience (Zolli & Healy, 2012). This means needing high-quality operations without requiring too many resources as well as balancing between planning long-term development and short-term effectiveness of operations (Andersson et al., 2019). Thus, structural efficiency issues come from rigidness problems that resilient organizations have to deal with (Linnenluecke et al., 2012).

Organizations have been structured more team-based lately (Hollenbeck et al., 2012). Thus, resilience has become a team-level concept, not only by managing the challenges effectively but also by enabling teams to adapt to adversity and manage pressures, rather than being an individual-level capacity (Hartwig et al., 2020). For the success of the organization, it is of great importance to investigate its units - teams, and how they work, process, and learn (Rodríguez-Sánchez & Perea, 2015).

Team Resilience

Team resilience can be defined as the capacity of a team to cope with difficulties, absorb them, and maintain positivity against challenges (Carmeli et al., 2013). From one perspective, when team resilience is defined as being able to cope with difficulties, it is considered an observable ability only in the face of difficulties and can be studied in the post-difficulty phase (Hartwig et al., 2020). However, from another perspective, team resilience can actually be defined as a dynamic process in which adversities are effectively overcome continuously (Morgan et al., 2013).

As projects become more complex day by day and their degree of adversity increases, it becomes necessary to cope with these mostly environmental challenges on an individual, team, and even organizational level (Morcov et al., 2020). Due to these increasing complexities, projects require more teamwork and the roles of teams in organizations are becoming more important (Amaral et al., 2015). Teams are included in organizations with their strengths and weaknesses. Therefore, the decisions of the organization can directly affect the resilience of the team (Rodríguez-Sánchez & Perea, 2015). With the help of resilient thinking, managers can improve performance and reliability through flexible and systematic approaches to challenges. Moreover, they can provide stability by solving problems by creating new conditions (Varajao et al., 2020).

According to researchers, the presence of only resilient individuals in the team is not enough to create a resilient team (Hartwig et al., 2020). Having a resilience capacity does not necessarily mean having a resilience capability (Lengnick-Hall et al., 2011). In other words, a group of individuals with high resilience may not be able to cope with adverse conditions or communicate effectively in an organized manner as they should (McEwen & Boyd, 2018). Therefore, in order to develop team resilience, it is necessary to provide individuals with a team structure that has common rules and values, transformative leadership, and is in constant interaction with each other, even in unexpected times of difficulty (Morgan et al., 2015). Resilience in challenging situations can be achieved with a team with common goals, interdependence, and result-oriented work (Hartwig et al., 2020).

Just like the behavior of individuals, teams have similar behavior and working systems (Stewart, 2010). Teams, like individuals, have knowledge of what they think, skills about what they do, and attitudes about how they feel. Moreover, they can be adversely affected in times of stress even though the negativities are on an individual basis, their effects will be reflected in the team's functioning (Dietz et al., 2017). It is important for teams to develop their resilience, as well as individuals, against adverse situations. For example, employees in a more resourceful work environment (such as supportive co-workers) increase their own resilience. This suggests that the quality of relationships is important for team resilience (Meneghel et al., 2016). In addition, while resilience reduces psychological stress, it has the effect of increasing task performance and job engagement (Hartwig et al., 2020). Strategies are factors that help develop resilience, moreover, it is necessary to understand the skills and support for building resilience required (Holdsworth et al., 2019).

Conclusion

The construction sector, which is one of the largest sectors affecting the economy of countries, is prone to be adversely affected by unexpected events. It is crucial for construction organizations to develop resilience to the unexpected. This paper emphasized the significance of team resilience in improving the resilience of construction organizations against unexpected situations such as Covid-19.

The Covid-19 outbreak has adversely affected construction organizations. It has made it compulsory for the sector to switch to working conditions that it is not accustomed to. This necessity has changed the way teams in construction organizations work and has faced many difficulties. The challenges were grouped as workplace loneliness, disturbed life-work balance, reduced engagement towards work, lack of communication, lack of trust, lack of motivation, and overwork. These challenges highlighted the importance of building resilience at the team level. Team resilience enables individuals in the team to cope with difficulties, absorb them and maintain a positive attitude at the same time. Thus, the difficulties caused by Covid-19 can be overcome and the resilience of the organization can be ensured. Therefore, it becomes important to promote the development of team-level resilience to increase the resilience of organizations.

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A Model for Exploring the Overconfident Behavior in Construction Organizations

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Abstract

Construction business executives, like any other business executives, make various types of decisions. The concept of decision making has been a popular research topic for decades. There is no evidence that this interest will decrease in years to come. The question of why business executives are making again, and again poor or wrong decisions has been fully resolved. The concept of overconfident behavior is considered one of the most promising approaches to address this challenging question. The concept of overconfident behavior refers to a biased way of acting at a given situation. Overconfident behavior may have positive or negative performance outcomes. It becomes more apparent when construction business executives have to make decisions under the conditions of "low control" and "relative performance". The research presented here proposes a conceptual model to guide construction business executive to address the challenge of decision making. The proposed model builds on concepts of "overconfident behavior", "low control" and "relative performance".

Keywords: *low control, overconfidence, overconfident behavior, relative performance.*

Introduction

Construction business executives, like any other business executives, make different kind of decisions as a part of their routine managerial activities. These decisions can have important consequences not only for their organization but also for the whole construction industry. It is very common to observe unfavorable results of these decisions. Studies of the psychology area have been developing explanations to explain unfavorable behaviors in the decision-making process. Pioneering studies, such as Simon (1955) and Tversky and Kahneman (1973), introduced a number of path breaking concepts such as 'bounded rationality' or 'heuristics' respectively, to study decision making process.

One of the commonly known decision-making heuristics is overconfidence. Overconfidence is a broad term which refer to mention irrational behaviors causing high levels of confidence which is not parallel with reality (Moore & Schatz, 2017). It is a very ordinary to observe

overconfident behaviors in daily life. For instance, many people believe that they are better drivers than other drivers. Likewise, students reason their failures as a result of the subjectivity of lecturers.

Overconfidence as a concept and as a term is widely used in decision making studies to cover a variety of irrational behaviors. However, overconfidence is not a single unitary distortion in decision making processes (Moore & Schatz, 2017). Research studies define the types of overconfident behaviors by adopting varying terminology. A quick internet search with the use of keyword of "overconfidence" yields results such as "better-than-average effect", "illusion of control", or "miscalibration". Moore and Schatz (2017) classify this confusing terminology into three types of overconfident behaviors: (1) overestimation, (2) overplacement and (3) overprecision. Overestimation is the belief of an individual evaluating herself or himself as better than she or he is. Overplacement is related with comparison with rivals and locating yourself in a better position to rivals exaggeratedly. Overprecision is the trust on own knowledge sophistically.

There is a growing body of knowledge about heuristics or similar psychological causes of irrational behavior including overconfidence in decision making processes. Yet research studies in business management area express that managers are failing to eliminate the negative consequences of overconfidence in decision making process. Rosenzweig (2013) argues that the underlying reasons of such failures is not paying attention to the context of decisions making process. Rosenzweig (2013) suggests that the context of decision making process can be conceptualized in two dimensions; namely (1) the level of control and (2) the relativity of and performance. Rosenzweig (2013) develops a four quadrant model using two diemsnions. Each quadrant uncovers differing effects on the consequences of decisions. In parallel, he underlines that to prevent from consequences of irrationality in decision processes, decision makers have to act accordingly with the context of the decision that is being made.

Heuristics are commonly evaluated as the main causes of poor performance and undesirable results in the area of business management. Overconfidence is not an exception. Yet more recent research studies argue that overconfident behavior is needed in some special cases such as entrepreneurship or new product development activities (Moore & Healy, 2008). Similarly, some research studies report the positive outcomes of overconfidently made decisions due to the motivational influence of overconfidence. This study develops a conceptual model explain the effects of overconfident behaviors in varying levels of control and relativity of performance and also discusses its possible benefitable or destructive outcomes.

Types of Overconfident Behaviors

Overconfidence is used as a broad term covering differing behaviors distorted from rational behavior. According to different research streams, different meanings are associated to the overconfidence. For instance, studies in the behavioral finance such as Lovric et al. (2010) mention calibration errors of own data as overconfidence. Other studies concentrate on the ambitious behaviors of top managers as overconfident behavior (Malmendier & Tate, 2005a, 2005b). Some researchers express the necessity to classify overconfident behaviors (Glaser & Weber, 2007; Moore & Schatz, 2017). Accordingly, this section aims to describe this diversity in more detail. In this perspective, definitions and classification in Moore and Schatz (2017) is used as a foundation for the review present herein. Moore and Schatz (2017) classify

overconfident behavior under three sections: (1) overestimation, (2) overplacement, and (3) overprecision.

Overestimation

Overestimation in individuals' judgement processes is linked to self-evaluation of personal capabilities. The key element in overestimation is the belief of an individual that locates herself or himself as a more ambitioned than her or his real situation. Moore and Schatz (2017) explain this behavior by referring to the individuals' distorted judgement that stating she or he has more control over consequences of actions than her or him in reality. Overestimation is an internal process, and it is not linked to the comparison to others' performances. According to the authors, this irrational judgement may trigger over-optimistic behavior that is damaging for the individual. For instance, an athlete evaluating herself or himself in a desirable situation although she or he is not in reality, may reject to practice adequately for a tournament and may perform poorly. Similarly, a student may prefer to study under low performance and receive relatively low grades for her or his capacity.

However, the concept of overestimation is not as smooth as expected in all cases. Decision makers do not tend to expect positive outcomes in all cases. Moore and Schatz (2017) state that task difficulty is a determinant which may reversely effect self-evaluation. According to the authors, easy tasks direct decision makers to feel that their performance will be better than reality. In contrast, decisions related to the tough tasks uncover the concept of 'underestimation'. When the task is relatively difficult, the decision-maker evaluates her or his self-capability as lower than reality.

Overplacement

Overplacement is a distorted view of an individual's self-capability evaluation. The main difference between overestimation and overplacement is the addition of others' performances in the judgement process of decision makers. The term "better-than-average effect" is used for the overplacement effect in some texts (Beer & Hughes, 2010). Very briefly, overplacement is the mental distortion that cause an exaggeration in an individual's performance evaluation relatively to others' performances (Moore & Schatz, 2017).

In contrast to overestimation, task difficulty plays an opposite role in overplacement. The relatively evaluation of own performance by adding others' performances to the judgement processes, leads to underplacement when the task is easy (Moore & Schatz, 2017). Individuals perceive easy tasks as easy for all. According to the decision maker, others are able to carry out the evaluated task easily, so her or his capabilities are not adequate. However, relativity between individual's capabilities and others' capabilities is still the same. As a result, 'underplacement' of own capabilities may occur in easy tasks' decisions.

Overplacement is sensitive to confusion with the concept of 'egocentrism'. In this behavioral attitude, decision makers deny others' capabilities (Moore & Cain, 2007). Egocentric behavior is rejection of others' performances although evaluation of performance is relative. Egocentric decision maker ignores competitors and only focus to own personal evaluation. Camerer and Lovallo (1999) define egocentric behavior as "reference group neglect". In

egocentric behavior, the cause of distortion is not related to self-performance evaluation, so the concept is not evaluated as a point of overconfident behavior.

Overprecision

Some empirical and experimental studies on overconfidence design their research methodology to measure individuals' confidence intervals of own data about a subject and compare its accuracy with the reality (e.g., Lin and Bier (2008), Hoffrage (2016)). Excessive trust to own data is defined as overprecision (Moore & Schatz, 2017). As expected, overprecision is a distortion in the internal judgement processes of individuals. Similar to overestimation and overprecision, alternative terminology is also used for overprecision. Most commonly, term "miscalibration" is used in the area of behavioral finance rather than overprecision (Lovric et al., 2010).

Overprecision is effective when decision makers use past data to make future predictions. An investor's previous stock performance, an organization's previous product introduction performance are examples of past data for decision-makers. A contractor's past bidding results is an example to past data of construction organizations. Past data is a precious information for the decision makers. However, the decision under consideration may show variety to the past cases. Furthermore, attractivity of the possible outcome can trigger the desire to undervalue the possibility of negative consequences. As a result, decision maker may ignore the level of variance in the past data and concentrate to the mean if it supports the ambitioned choice.

Studies researching overprecision are not only based on empirical data but also on experimental data. In virtual simulations, overprecision is represented by manipulating standard deviation of past records (like distortions in confidence intervals in empirical studies) and observing its consequences as results of mathematical models. In addition to revealing effects of overprecision at individual level, these studies enable researchers to observe whole environment such as stock markets.

Contexts of Decisions

The major causes of unfavorable consequences of decisions have been studied for a long time. In a variety of research disciplines such as psychology to business management, there are plenty of studies those are focused on exploring the reasons of undesirable outcomes of decisions. Similarly, many normative studies develop models to assist managers to prevent from adverse decisions. In the domain of construction project management, causes of adverse decisions have been explored from the perspective of technical errors. However, there is a growing body of knowledge about the behavioral aspects of decision-making in particular insights about the explanation of irrationality in decision making processes. Heuristics (biases) and in some cases deliberate political distortions similar to Flyvbjerg (2008)'s "strategic misrepresentation" explain negativity in the consequences of decisions which cannot be expounded by technical errors.

There is a growing body of knowledge about technical and behavioral aspects of bad decision-making process. This body of knowledge can offer more insights to managers to improve the process of decision making and in turn eliminate unfavorable decision outcomes.

However, research studies in business management or similar areas that suggest that failures in decision processes are still effective. Normative studies cannot protect decision-makers from adverse consequences. Rosenzweig (2013) clarifies the causation behind the unimprovement of the decision-making process without criticizing the growing body of knowledge about decisions. Rosenzweig (2013) explains the mechanism of poor decision making by taking attention to context of decisions. In order to clarify this context, author defines two dimensions: (1) control and (2) performance.

Rosenzweig (2013) states that control dimension is the ability of decision-maker to influence the outcomes of decisions. For instance, decision of selecting which model of an automobile is going to be bought is a low control decision as the performance of the decision (satisfaction from the selected choices) cannot be influenced by the decision maker. It is determined by the selected product. In contrast, if the performance of the outcomes of the decision can be shaped by the decision-maker, the decision offers high level of control. A student's decision to apply to a university program is an example to high control decision. According to the decision-makers performance the consequence can be a valuable graduation or failing out.

Performance dimension is determined by the way how the success is measured. If the decision's outcome is compared with other decision-maker's performance, it is a relative decision. In contrast, if the success of the decision is independent from rivals' decisions, it is an absolute decision. At the first scenario, in order to get a satisfying result from a decision, decision-maker has to be in a better position from her or his rivals. In construction, bidding process is a good example to decisions with relative performance. If the contractor submits the most desirable tender to the client organization, it gets the privilege to sign the contract. In contrast, performance of a selection of a finance instrument to invest in is an absolute performance decision. Profit from the instrument is independent from other investment tools' performances.

Two dimensions divide context of decisions into four areas (Figure 1). In first quadrant decisions, decision-maker does not have the ability of improving the outcome once the decision is made (Rosenzweig, 2013). Furthermore, performance of the decision is constant, it is not affected by what rivals do. Rosenzweig (2013) states that this field of decisions are sensitive to systematic biases. For instance, 'gambler's fallacy' can be harmful in this area. This bias is related to unrealistic evaluations of possibilities in consecutive cases. When the decision-maker face frequent negative outcome, the belief to positive outcome in the next step increases without proof. This bias can easily affect first field decisions. In this field of decisions, once the decision is made, any enhancement in consequences of the biased decision is impossible because of the disability of effecting outcomes.

Second quadrant decisions provide opportunity to the decision-maker to influence the outcomes of the decision (Rosenzweig, 2013). The success of decisions is not related to others' performance. For instance, if a student decides to apply to a proficiency exam in a foreign language, she or he can affect the result by studying more or less. Decisions in this field may be affected by biases, but the decision-maker has the ability of lowering negative consequences as she or he can affect outcomes of the decisions. Furthermore, as the decision-maker still has the ability to affect the outcome of the decision after the decision-making, motivating biases such as optimism can force the decision-maker endeavor to improve performance of decisions.

In the third quadrant, performance is relative, but control is low. Relativity in performance evaluation increase the importance of rivals' performances. In order to get successful results from this kind of decisions, decision-maker has to perform better than competitors (Rosenzweig, 2013). This triggers competitiveness. Like first quadrant decisions, a vital issue about third field decisions is the inability of affecting outcomes once the decision is made. This field reveals the need for strategic thinking. Concepts such as game theory explain and prescribe decisions in this field.

In the fourth quadrant, the decision-maker has the ability of improving the results after the decision is made. The performance of the decision is determined relatively to competitors' performances (Rosenzweig, 2013). Rosenzweig (2013) takes attention to strategic management concepts in fourth field decisions. Enlargement of service locations of a contractor organization can be an example of fourth field decisions. The organization can affect the outcome by hard competition and the success is performing better than rivals. Complicated nature of this field makes decisions more sensitive to biases and technical errors. Decision-makers have to act with sufficient measures (such as Kahneman (2017)'s two system thinking) in order to prevent from behavioral and technical errors.

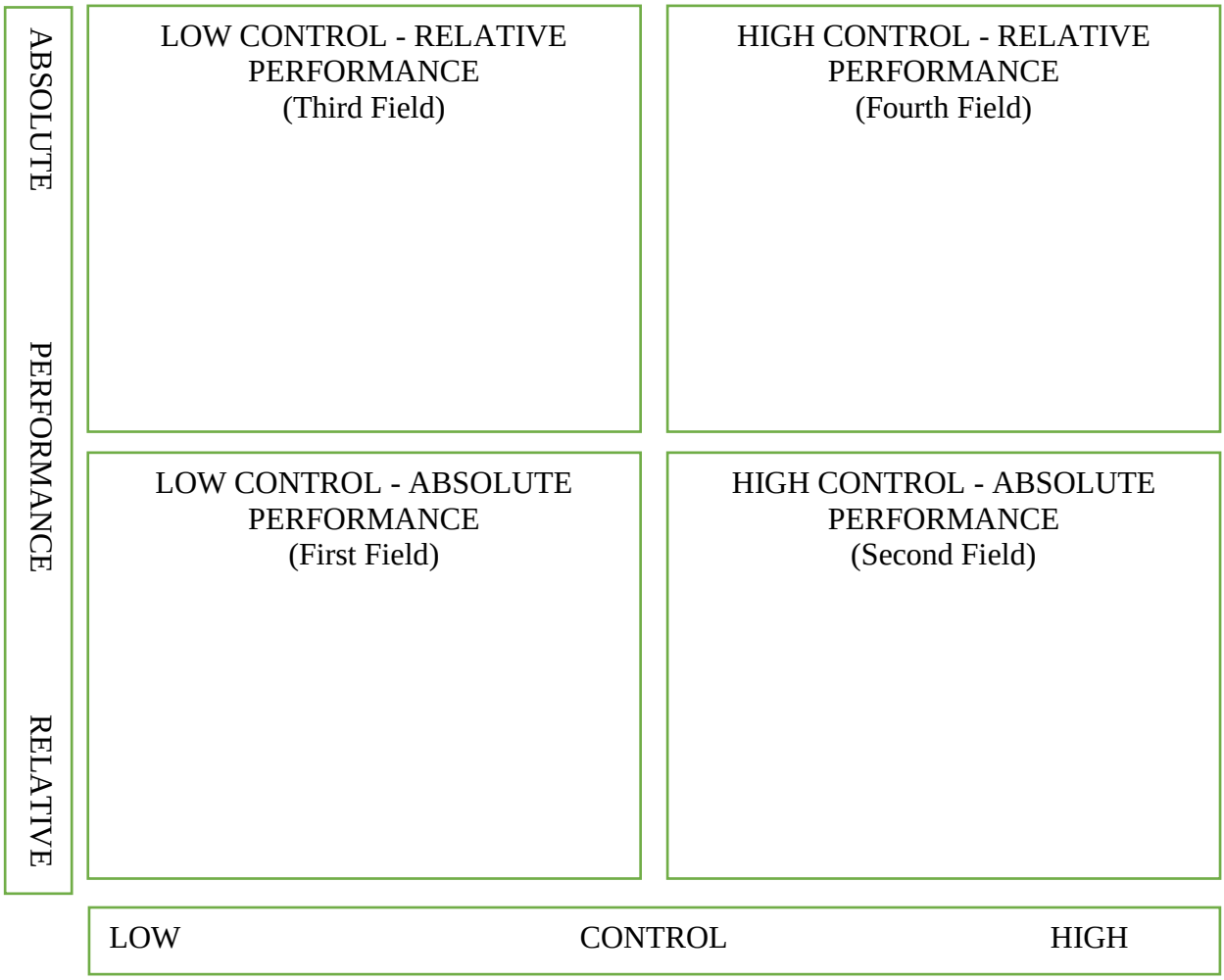


Figure 1: Four fields of decisions (Rosenzweig, 2013, p. 91).

Discussion

In the perspective of behavioral studies, heuristics including the overconfidence effect are evaluated as causes of undesirable negative consequences of decisions. Illusive inferences of overconfident judgements may lead individuals to make unrealistic decisions. Moore and Healy (2008) remark possible negative outcomes of overconfident judgement including even catastrophic events in the history such as World Wars. However, in their evolutionary study Johnson and Fowler (2011) criticize negative opinions on overconfidence by pointing to its existence in evolutionary continuum. Some biases are not eliminated by evolutionary selection. According to authors, unbiased decisions are not the best option in all cases. Similar studies support the possible positivity of overconfidence. For instance, Vitanova (2021) mentions that overconfidence supports leadership of chief executive officers (CEOs) in organizations. As a result, this overconfident behavior in CEOs' actions develops positive outcomes. In a similar vein, Moore and Cain (2007) concluded supportive effects of overconfident behavior on market entries.

Lowering impacts of loss-aversion is an example to benefitable points of overconfidence. Loss-aversion is a quite common behavioral reaction to the risk or uncertainty. Negative behavioral impacts of losses are more influential than positive behavioral impacts of gains (Kahneman & Tversky, 2012). For this reason, individuals feel reluctant to act in risky situations such as market entry or new product introductions. Moore and Schatz (2017) highlight that, overconfident behaviors such as overestimation and overplacement may minimize the effect of loss aversion. Here, it is needed to be reminded that not all the new product introductions or market entries bring success as a result. However, to gain competitive advantage in strategic areas, appropriate entrepreneurial movements are necessary.

Johnson and Fowler (2011) help clearing the idea behind the dilution of effects of loss-aversion by overconfident behavior. In their model, authors define an award (a scarce resource), and two individuals who may decide to compete for gaining it. Capabilities of individuals for achieving the award are not same. As the situation is uncertain, both the more capable and less capable individuals may make decision to struggle for gaining the award. When its rival decides not to attend to the competition, other individual gets the award without the necessity of being more capable. If two of the individuals decide to compete, more capable one gets the award. Individuals with overconfident behavior are more expectable to join the competition. So, they have more possibility to win without being more capable than their rivals.

Furthermore, an effective impact of overconfidence becomes visible when the decision-maker has control over consequences of the decision. Behaving under effect of overestimation or overplacement motivates decision makers to endeavor for improvement of results. Similarly, Flyvbjerg (2021) mentions that overplacement triggers an ungrounded optimism that increases managers' efforts for getting favorable outcomes from a decision. In the same vein, Hilary et al. (2016) state that over-optimistic (can be both overestimated or overplaced) behavior of managers trigger extra effort to meet targets.

Malmendier and Tate (2005b) state that the belief of having control of actions makes decision makers more optimistic. In contrast, when the decision-maker's control on the outcomes of the decision is low, previously mentioned positive effects of overconfidence lose effect. Under low control decisions, decision-maker has to select the best possible alternative as she

or he is not capable of effecting consequences of the decision. As a result, distorting effects of overconfidence will become damaging in low control decisions.

Accordingly with preceding discussion, overconfidence cannot be classified as harmful or unnecessary in all cases. Rosenzweig (2013) states that varying characteristics of decisions necessitates different measures of action. Accordingly, a model for possible effects of overconfident behavior in different fields of decisions is discussed and developed.

Harmfulness of overconfident behavior can be defined as the difference between the cost of the actions to accomplish the objective and the value of the gained award. In cases ensuring more benefit from cost of overconfident actions, overconfidence causes positive outcomes. In contrast, when the overconfident actions cost more than the benefits gained from the actions, overconfidence causes negative outcomes. As mentioned in Johnson and Fowler (2011), motivating effects of overconfidence make individuals struggle more to accomplish to the objectives. As presented in Figure 2, some level of overconfidence rescue individual from loses and enable gaining benefits. However, increase in the effort is not expected to have a linear shape and become disadvantageous after a point as the level of increase in the benefit as a result of increase in the effort decreases.

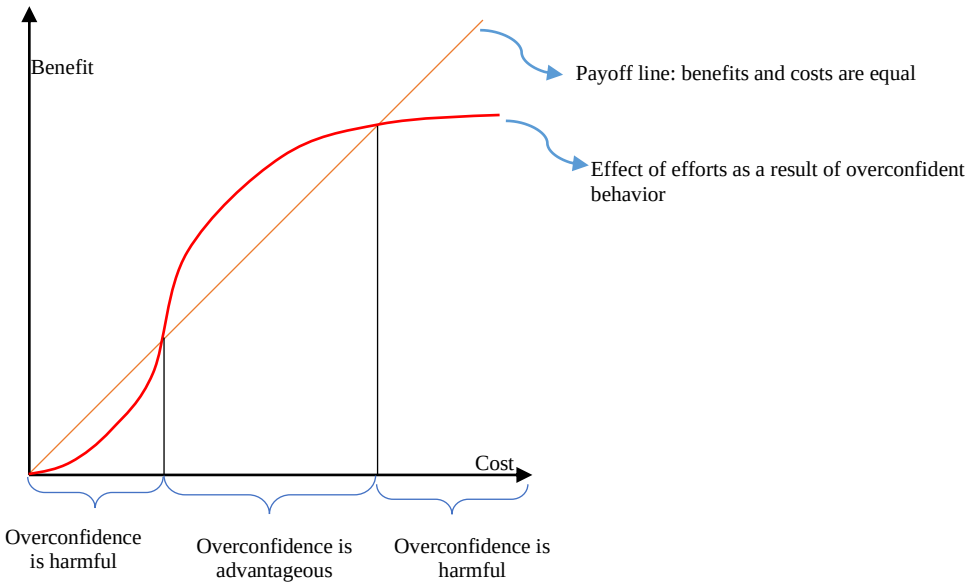


Figure 2: Effect of overconfidence over cost and benefit in decisions (generalized).

The generalized effect of overconfident behavior described in Figure 2 is not valid in all cases. Ability of controlling outcomes or relativity of performance support the positivity of overconfident behavior. However, if the decision does not provide opportunity to the individual to influence the outcome or the performance evaluation is absolute, efforts as a result of motivation of overconfidence becomes ineffective. Figure 3 presents the possible effects of overconfident efforts for the four quadrants of decisions described in Rosenzweig's (2013) model.

Conclusion

Cognitive biases and other causes of failures have been the subjects of research studies for a long time. These studies offer precious insights for decision makers on how to achieve their predefined goals. Yet, general business management studies report that failures caused by poor decision-making process are still plague organizations. Rosenzweig (2013) proposes that the poor decision-making process can be improved by paying special attention to the context of decision-making process.

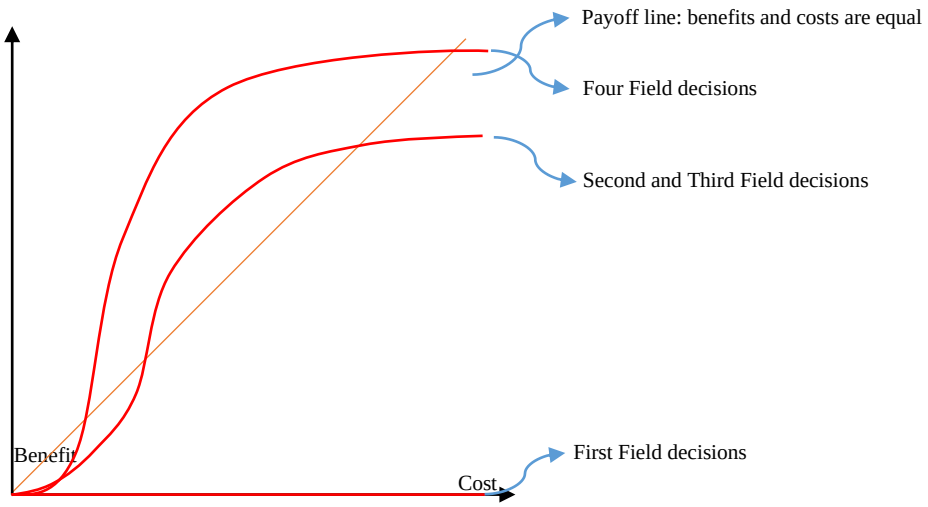


Figure 3:Changing effects of overconfidence in Rosenzweig's (2013) four field of decisions.

Overconfidence, like all kinds of behavioral biases, has negative connotation for decision making process. Yet more recent research studies reject the negative connotation about the overconfidence and argue that the elimination of all types of overconfident behaviors in all contexts of decisions is not a constructive behavior. When the decision maker has ability to influence the outcome or the performance is relatively evaluated, overconfident behavior holds possibility to improve the outcome. In some cases, such as entrepreneurial decisions or competitive decisions are positively affected by overconfidence. In contrast, decisions in the context of absolute performance evaluation and low control are sensitive for negative impacts of overconfidence.

As a further research study, the impacts of overconfident behavior can be explored and validated explored by using empirical and/or experimental studies. Future research studies based on empirical or experimental studies may offer more guiding results to decision makers. Accordingly, this model does not provide a normative model for decision makers. The objective of the research presented herein is to propose the possible overconfident behaviors in differing decision-making contexts and informing decision-makers about its possible negative and positive consequences. Overconfidence is not a curse that the decision-maker has to eliminate in all cases. Further comprehensive research may give opportunities for developing a normative model supporting decision-makers for eliminating negative impacts of overconfident behavior.

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The Changing Role of Project Professionals in a Digitally Disrupted Environment

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Abstract

Industrial revolutions (IRs) have brought to the world a massive change in the political, social and economic environment, greatly influenced by technological advancements, altering the way we work and deliver projects. Yet, evidence suggest that digital transformation goes beyond the mere implementation of disruptive technologies. The aim of this paper is to investigate the leadership skills required at project level to lead transformation in an increasingly disrupted digital environment. The paper examines the elements and skills that are required to lead the necessary change. Based on literature reviews, a conceptual model is developed and presented to illustrate the dynamics of project leadership of this industrial revolution 4.0. The major facets of digital transformation demonstrated the crucial role of leadership as well as enabling aspects such as culture and strategy. The primary data analysis collected from professionals involved in projects has examined the degree of awareness and acknowledgement on the enabling aspects that shape the project leader 4.0. The analysis suggests that project professionals put more emphasis on the strategic nature of project leaders' roles. Furthermore, the mixed research method revealed how project leadership is seen to be crucial in delivering transformation.

Keywords: *culture, digital disruption, leadership skills, project management, strategy, transformation.*

Introduction

The backbone of the global economy relies on industrial revolutions. Technologies such as Artificial Intelligence (AI), Internet of Things (IoT), nanotechnology or cloud computing are creating opportunities, foreseen and unforeseen, with an increased competition allowing businesses to thrive in ways never seen before. The increased competition is putting pressure on organisations and inducing them to adopt and adapt to changing technologies in a surviving attempt to remain in business with barriers to entry being virtually none. In fact, technologies are forcing organisations to address the broader strategy, the 'why' of their business, the *'what'* to produce or offer and the *'how'* to do it. This game changing business environment has brought disruption. Christensen (2020) described disruption as a *"process by which a product or service powered by technology enabler takes root in simple applications at the low end of a market, typically by being less expensive and more accessible, and then relentlessly moves upmarket, eventually displacing established competitors".* Digital

transformation therefore is about *"how companies are adapting to the new reality created by digital disruption"* (Kane, 2019). The imperative of digital transformation is an insistent subject matter for many executives, virtually in every industry, even the most unexpected ones. And, as disruption is becoming the new normal, organisations are required to embark on a transformation journey. Forbes Insights (2018), on behalf of the Project Management Institute (PMI), conducted a survey of executives across the globe and found out that nearly 80% of the organisations have undergone a significant transformation using disruptive technologies, yet only 25% of the projects at those organisations generated tangible benefits realised against the original goals and business intent. Accenture (2018) mentioned leadership as one of the factors in embracing a culture that would bring change and drive digital transformation. It seems obvious that while dealing with disruption, it is important for executives and project professionals to understand the disruptive trends affecting their business. On the other hand, in embracing the digital journey, it is also crucial for project leaders to have more than just the technical skills. It implies that new technologies involve new skills set, new mindset requiring a new perspective for project and programme management. Organisations therefore have to rely on project professionals to take advantage of disruption, and not simply be reactive of it. Kane (2017) put forward that the key problem faced by organisations when it comes to digital disruption is not the technology but rather is a people issue. Similarly, amongst the challenges identified by Forbes (2018), it is seen that people related challenges in the form of fear, resistance to change, responsibility or capacity to drive change represent the main constraints to a culture of change towards digital transformation. In fact, the McKinsey Global Institute report (2017) analysing 46 countries estimated that 60% of occupations have at least 30% of constituent work that could be automated and that by 2030, between 400 million and 800 million individuals could be displaced by automation and would need to find new jobs. The economists Brynjolfsson and McAfee (2014) referred to this phenomenon as the *'second age machine'*, that is, technologies spreading to areas that used to be exclusively handled by humans. The Covid-19 pandemic has showed the value and necessity of digital transformation with organisations accelerating this transition. The pandemic has had some immediate negative impacts on organisations as well as some positive impacts with some companies seeing a peak in their activities while it was also observed (Iansiti & Richards, 2020) that *"this need to virtualise work due to Covid-19 is driving digital transformation and deepening differences across people and across firms at an incredible rate".* The research further stated that any process that could be '*rapidly digitised has been virtualised'*, from video conferencing to telemedicine. However, the *'trap'* to avoid as put forward by Carr (2003) is to focus on technology as *'an end in itself'*. A study conducted by *MIT Sloan Review Management* and Deloitte (cited by Kane et al., 2015) to understand the challenges and opportunities associated with the use of social and digital business, identified *'Strategy'* as the key driver in the digital field and further mentioned that the power of digital technologies does not lie in the technologies individually. Kane et al. (2015) stated that *"the ability to reimagine the business is determined in large part by a clear digital strategy supported by leaders who foster a culture able to change and invent the new".* In fact, the research conducted by the authors found out that organisations at an early stage of digital transformation have a decidedly operational focus with improving efficiency and customer experience as digital strategies rather than seeing transforming the business as the digital strategy. The research further concluded by stating that leaders must be able to tackle the following questions in their journey towards transformation. They should ask themselves whether their organisation has a *'digital strategy that goes beyond implementing technologies'*, that is, does it transform how the business works. The authors also raised the question of whether the *'culture fosters digital initiatives'*, changing mindsets to stimulate greater digital progress. And finally, whether the

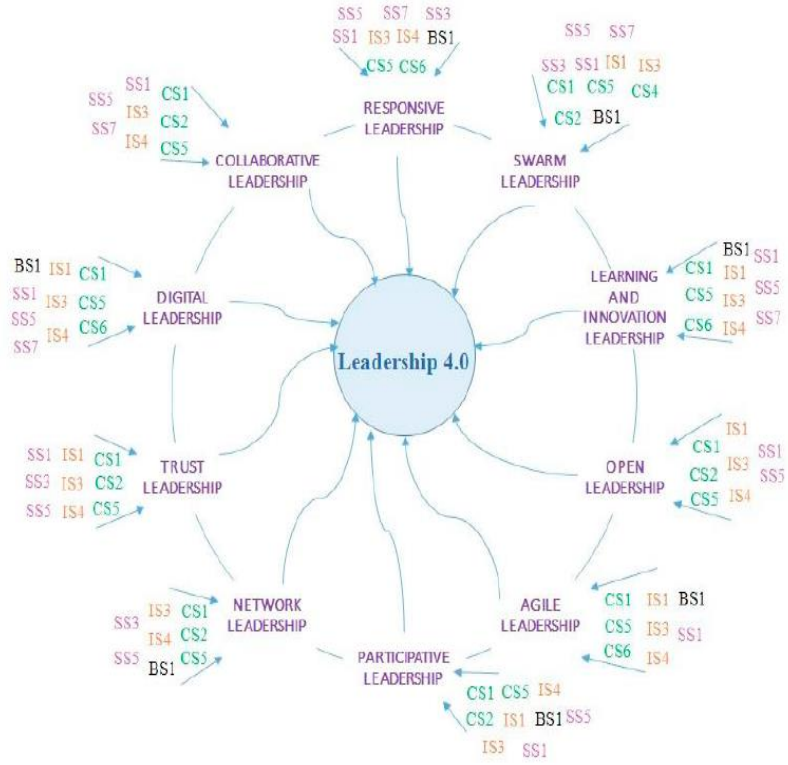
organisation is confident in its leadership in paving the way for transformation. In fact, while organisations may articulate strategies for disruptive technologies and digital transformation, they may however face challenges to execute against that strategy and the intended results. APM (Association for Project Management, 2019) stated that the *"project profession should play an important role in shaping the future…projects are how successful change happens: they are the way that businesses and governments deliver social, economic, business, and environmental outcomes, so it will be in the form of projects, programmes, and portfolios that change is delivered"*.

Leadership

In this digital age, it is important for organisations to reinvent themselves, moving from the traditional project leadership to leading the transformation, requiring new skills to adapt, guide and navigate into the digital world for effective strategy delivery. Leadership refers to the behaviours of an individual and processes applied while directing and coordinating the activities of group members. There exist different theories on leadership from defining it by traits, contingency approaches, and situational styles or through behavioural or participative theories and more recently popularised, emotional intelligence. Leadership is an important quality in any organisation as it drives organisational effectiveness and competitive edge. Digital leadership therefore requires leaders to adapt and augment some of their core skills to face the challenges and embrace the opportunities of the disruptive business world. The study of Guzmán et al. (2020) resulted in 10 leadership characteristics found for the industry 4.0 and their relationship with 4 leadership skills groups which are *(i) cognitive (ii) interpersonal (iii) business and (iv) strategic skills* which they recommended leaders to consider in their transformation journey. Guzmán et al. (2020) cited Kelly (2018) regarding his analysis of phases to characterise leadership for each industrial revolution (IR). Kelly (2018) referred to the 1st IR as *'charismatic'* leadership relating to how leaders perform through actions and personal characteristics. The 2nd IR was influenced by scientific management with a top-down approach reflected in a *'directive'* leadership. The 3rd IR recognised the achievement of goals and is characterised by *'transactional'* leadership but also as *'transformational'* as autonomy, ideas and collaboration are empowered. Guzmán et al. (2020) suggested that both existing and new leadership characteristics are required for the 4th IR. They further referred to the term *'leadership 4.0'* requiring investment and openness to culture change with leaders not only able to deliver value through technologies and innovations but also having the ability to a create a friendly environment, further stating that a *'swarm (moving crowd)'* leadership is needed and is responsive as leaders act in an agile environment. The model below (Table 1) was developed by Mumford et al. (2007) and acknowledged 4 groups of leadership skills. In addition, Guzmán et al. (2020) cited the work of Ashkenas and Manville (2018) who identified 6 leadership skills based on interviews of successful leaders *(i) 'shaping a vision for focusing and challenging the team' (ii)) 'translating the vision into clear strategy about what action to take and what not' (iii) 'recruiting, developing and rewarding a team of great people' (iv) 'focusing on measurable results' (v) 'promoting innovation and learning to sustain the team or organisation' and (vi) 'leading yourself'.* Guzmán et al. (2020) then created the model (Figure 1) that demonstrates the 10 leadership characteristics with the required skills (Table 1). Each skill group highlights the relationship with the characteristics skills *(in purple).* For instance, the model shows that for strategic skills, visioning and identification of key causes were important skills while for business skills, the relationship with leadership characteristics were lower.

Table 1. 4 Groups of leadership skills by Mumford et al., 2007 (Guzmán et al., 2020).

Cognitive Skill (CS)	Business Skill (BS)	Interpersonal Skill (IS)	Strategic Skill (SS)
CS1: speaking	BS1: operations analysis	IS1: social perceptiveness	SS1: visioning
CS2: active listening	BS2: management of personnel	IS2: coordination	SS2: systems perception
CS3: writing	resources	IS3: negotiation	SS3: system evaluation
CS4: reading	BS3: management of financial	IS4: persuasion	SS4: identification of downstream
comprehension	resources		consequences
CS5: active learning	BS4: management of material		SS5: identification of key causes
CS6: critical thinking	resources		SS6: problem identification
			SS7: solution appraisal



Skill Group	Code	Skill description	Frequency
Cognitive Skills (CS)	CS5	active learning	10
	CS1	speaking	9
	CS2	active listening	6
	CS6	critical thinking	5
	CS3	writing	0
	CS4	reading comprehension	0
Interpersonal Skills (IS)	IS3	negotiation	10
	IS4	persuasion	10
	IS1	social perceptiveness	7
	IS2	coordination	0
Business Skills (BS)	BS1	operations analysis	7
	BS2	management of personnel resources	0
	BS3	management of financial resources	0
	BS4	management of material resources	0
Strategic Skills (SS)	SS1	visioning	9
	SS5	identification of key causes	9
	SS7	solution appraisal	5
	SS3	system evaluation	3
	SS2	systems perception	0
	SS4	identification of downstream consequences	0
	SS6	problem identification	0

Figure 1: The network of characteristics and skill requirements for Leadership 4.0 (Guzmán et al., 2020).

Ready et al. (2020) identified 3 reasons why leaders are not as ready as they think they are in embracing change and these are (i) *'a deficiency in digital savviness coupled with outdated mindsets'* (ii) *'a series of blind spots; cultural, strategic, human and personal that prevent them from seeing a clear path forward'* and (iii) *'multiple embedded tensions that undermine strategic execution'*. Among the findings of Kane et al. (2019), it was observed that it is also important to understand the technology that is the digital literacy of leaders as well as team members. The authors further stated that digital literacy of leaders would help to position themselves as agent of change and support the transformation. Adaptability is another factor that is to be considered in the change process for a more fluid and flexible workplace. These transformations can be achieved via continuous training, formal education, cross-generational reverse-mentoring programmes or online programmes (Kane et al., 2019). The demand for digital leaders is strong with a need for organisations to develop the right talents. Kane (2018) analysed the top 4 trends that digital leaders should have, and these are (i) provide vision and

purpose to drive the digital transformation (ii) create conditions to experiment new ideas, new models (iii) empower people to think differently by adopting inclusive leadership, and (iv) enable collaboration across boundaries. Anthony and Putz (2020) stated that in embracing digital transformation, leaders must first transform themselves in an environment where growing technologies render old technologies obsolete, that is, their inner capacities, awareness and mindset to *"combat basic biases that make it hard to make decisions in uncertainty and toggle between different frames"*. They further argued that there are four flawed assumptions that leaders tell themselves (i) *'We are safe'* - taking comfort in data thinking everything is going fine (ii) *'It is too risky'* - investment in innovations is a bold risky bet (iii) *'My shareholders won't let me'* - managing the short term returns rather than maximising shareholders' value (iv) *'My people are not up for the task'* - people resist change. Kegan Robert (cited by Anthony & Putz, 2020) described a self-transforming mind as the 5th order of consciousness whereby one sees beyond himself, others, and systems and develop an understanding of how all people and systems interconnect, the cognitive flexibility which most leaders lack. Anthony and Putz (2020) put forward that this is so because most leaders grew up either in a *'disciplined or entrepreneurial'* world but *'rarely or never both at the same time'* to cope with the *'emerging needs'*.

Implications on Project Management

"Traditionally, project managers operate at the surface, where they are predominantly concerned with the delivery of a product or an outcome through the completion of tangible actions, tasks and activities" (Madsen, 2015). PMI (2018) reported that *"innovators believe that the role of the project manager will evolve to one that advocates for the technology, motivates teams to implement, supervises course corrections, and becomes an authority on disruptive technologies".* PMBOK (2017) stated that *"leadership skills involve the ability to guide, motivate, and direct a team"* and in addition, the skills include capabilities of project leaders to negotiate, show resilience and critical thinking, communicate, be solution oriented as well as to demonstrate interpersonal skills. Similarly, Svejvig and Andersen (2015) talked about a *'rethought'* version of project management whereby they suggested project management to be viewed as beyond completing a project on time and within the budget. They positioned project management as a more holistic approach managing complexity, uncertainty, and change and value creation. The traditional approaches to project management focus mostly on planning and managing risk. However, the influence of the PM is not to be neglected. PM plays an important role in not only leading the team in delivering the strategic objectives of the organisation, but the PM also has a crucial role in directing and communicating the *'vision of success of the project'* (PMBOK, 2017). PMI (2018) stated that *"just over one in four respondents mentioned the ability to learn, understand, apply, and keep up with technology as the most-needed skill for project managers to respond to the impacts of the digital transformation.* Other skills include communication; leadership and management skills; change management, adaptability, and flexibility (PMI, 2018). The success of projects is no more encapsulated by the traditional *Iron Triangle* and stated that *'if project management is to be tasked with transformation',* the *Iron Triangle* then goes beyond efficient projects (APM, 2019). It also acknowledges the value of relationships as well as the importance of change and recognises that project management has evolved and that in this digital era, it has started to reflect in the profession.

Conceptual Framework

An extensive review of the relevant literature has revealed a number of prevalent themes as summarised below.

- Leadership: Project managers require a certain level of digital savviness (Ready et al., 2020; Kane et al., 2019).
- Strategy: Shaping a clear digital strategy and vision endorsed by leaders who encourage and translate a culture of change and inventing the new (Kane et al., 2015; Guzmán et al., 2020).
- Culture: Creating an innovative and learning culture and mindset that engage all levels in the organisation with a more holistic and strategic approach to transforming and delivering value (Accenture, 2018; Forbes, 2017; Kane et al., 2015).
- Project Team: Project professionals must broaden their skills, superseding the basic project management skill (PMI, 2018; APM, 2019; Kane, 2018).
- Project: Project is a vehicle for change and practitioners must reflect on the profession by adopting a continuous learning culture, a more holistic and strategic approach to transforming and delivering value (APM, 2019; Svejvig & Andersen, 2015).
- Skills: Reskilling programmes are required with investment in training, formal processes, and transfer of knowledge (Anthony & Putz, 2020; PMI, 2018; Kelly, 2018).

Based on the above, the following conceptual framework was developed (Figure 2).

Enablers refer to the backbone within the organisation that facilitates the transformation of the leader. The two enablers that are identified in this framework are (a) Business Strategy and (b) Culture. Elements of the **enablers** have also been identified as actions or input that could be considered at organisational level to create this environment for the leadership 4.0. As reviewed in the literature, reimagining the business depends greatly on a clear strategy that supports and invests in leaders' transformation. Hence, the importance of an organisational culture that embraces change and innovation and encourages people to lead the transformation. Some of the enablers identified include the business model of an organisation, how the organisation may be structured to create an environment that allows for innovation or approaches to managing and leading talents towards an empowering and learning culture that would help to navigate the VUCA (Volatile, Uncertain, Complex, Ambiguous) environment. The challenge today, is the increasing pace at which economies are being disrupted. Transformation is therefore required through sets of new skills, initiatives and actions that would transform businesses and people.

Skills Group represents the skill categories identified in the literature reviews as predominating and/or emerging in the digital industry. Four categories of skills are suggested in the conceptual framework and is as follows:

a) Strategic / Transactional Skills Group refers to the project leader 4.0 to demonstrate the ability to build in strategies and make strategic choices in addressing digital disruption and transforming business and people. The leader is transactional in that it requires a structure and a directed environment to achieve goals, reshape and lead the organisation in a way of thinking and doing.

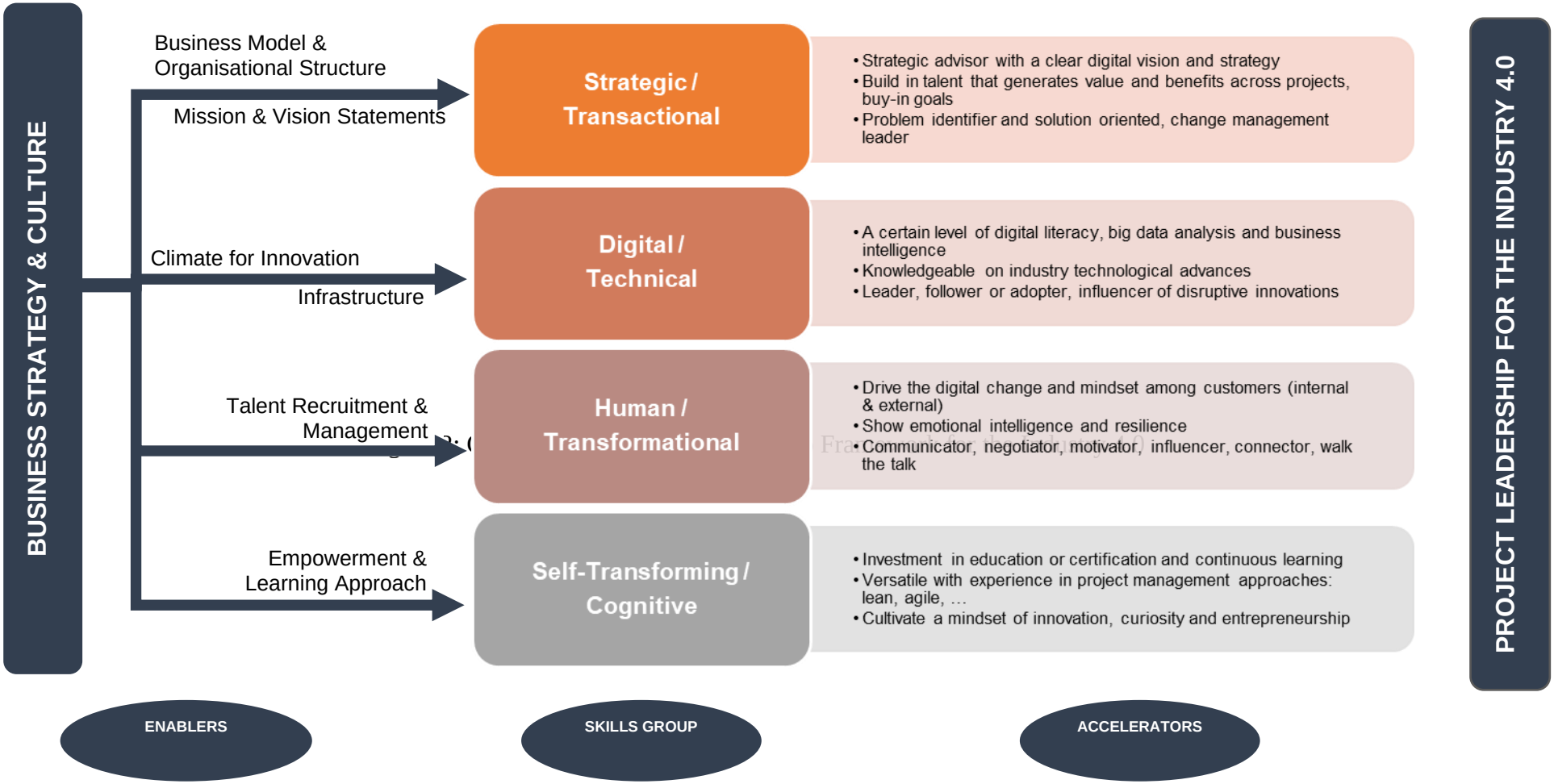


Figure 2: Conceptual framework.

b) Digital / Technical Skills Group suggests that the leader has to be up to date with the latest trends or technologies of the industry. As put forward by Kane (2019), *"it is a lot easier to teach executives the technology knowledge they need than to teach technologists the leadership skills they need."* This group skill involves the leader to develop an understanding or working knowledge of technologies and how to capitalise or apply to the organisation or areas of business in delivering value.

c) Human / Transformational Skills Group implies that digital transformation is led by people and the need to understand and embrace the purpose behind the transformation. The skill group requires leaders to develop and articulate the right mindsets and behaviours that influence, engage and connect with people.

d) Self-Transforming / Cognitive Skills Group indicates that the leader has to be a reflective practitioner and build on skills that bridge the knowledge gap. It suggests that leaders must become aware and invest in their own learning and development and demonstrate agility and entrepreneurship in navigating through digital disruption.

Accelerators shows the drivers or characteristics that contribute to each **Skill Group** that are to be developed and nurtured by leaders. For instance, the conceptual framework suggests that project leaders developing versatility regarding different project management approaches and methods contribute to the Self-Transforming / Cognitive Skills. It further shows the ability and capability of the leader to adapt through VUCA situations.

Research Methodology

Mixed methods research was undertaken through self-administered questionnaire and interview survey with individuals working on projects. Saunders et al. (2016) stated that survey strategies using questionnaire are *"popular as they allow the collection of standardised data from a sizeable population in a highly economical way, allowing easy comparison"*. It also allows for a multitude of information from participants and enable the researcher to analyse quantitatively using descriptive and inferential statistics. The targeted population for this study concerned individuals working on projects in the UK regardless of the sector. A simple random sampling was used, and individuals were contacted via their companies randomly and through professional networks to gather data. Another approach that was used to collecting data for this study includes online interviews with individuals working on projects. A list of questions based on the conceptual framework were sent to the participants prior to the interview. Upon their consent to participate to this survey, an online interview was then carried out. However, it was decided that the conceptual framework developed is shown to the participants only at the end of the interview to collect further feedback. This was done to avoid any bias or influences in responses or feedback. We must also acknowledge some limitations to this study. It is to be noted that the survey was conducted in a time of global pandemic disrupting work environment and jobs, and due to time constraint, the targeted population being quite large, only 58 questionnaires were collected. Another limitation also concerns the qualitative feedback whereby only one professional consented to be interviewed, therefore suggesting further research on the developed conceptual framework. The skills were searched to support the leadership characteristics and, subject to an abductive analysis, the relation and construct were made. However, Maxwell (2012) explained that a conceptual framework changes, both because the

information gathered lead to new ideas and understandings, and because the process of doing this may lead to more awareness of, or question parts of the previous conceptual framework.

Findings

The data analysis showed that overall, respondents are aware of the impact of digitisation and new technologies. Some responses may suggest that depending on companies, the importance of some skills or the implementation of those skills might differ. This, however, requires further analysis in terms of maturity of companies (which was not covered in this survey).

Organisation Culture and Strategy

The *'enablers'* developed in Figure 2 identified elements or inputs that define the business strategy and culture of an organisation for a leadership 4.0 in this disruptive environment. This part of the survey assesses the perception of the participants regarding the importance to which their organisation has embraced digitisation. The data obtained demonstrate that from the perspective of the respondents, their organisations acknowledge the importance of adopting new technologies, embracing a culture of change, creating a climate for innovation, developing the appropriate skills, and reinventing the business model, that is, the *'enablers'* that help in defining and positioning an organisation in its digital transformation journey. In fact, the mean results for the statements *'Investing in technologies to better enable project success', 'Creating a culture receptive to change', 'Instilling a climate for innovation'* and *'Empowering and developing talents with the necessary technical skills'* are all above 4 which implies that most respondents consider that their organisation has embraced digitisation and acknowledged those statements in their transformation process as *'important'*. However, the mean result of the statement *'Creating a business model responsive to new technologies, digitalisation and market conditions'* is 3.97 which is slightly below 4 but nevertheless close to *'Important'*. The standard deviation results from the participants seem to be consistent, implying that the results converge towards the average.

Strategic and Transactional Skills

This section examines the data collected regarding the *'skills group: strategic / transactional skills'* as described in the conceptual framework. As suggested, this skills group involves the leader's ability to act strategically in decision making, directs and leads to achieve goals, shape, or reshape the project's organisation and environment. The statements set for this section analyses the perception of the respondents as to how they assess the importance of the mentioned skills for a PM role in a disruptive environment. From the data obtained, it is observed that the statement *'The PM is a strategic advisor to the company'* has a mean result of 3.43 which is closer to 3, that is, the respondents assessed this skill requirement as '*moderately important*' for a PM. The next statement *'The PM has a clear digital vision and strategy and is capable of inspiring such vision and strategy to the team'* has a mean of 3.76, nearing 4 *(Important)*. On the other hand, the statements *'The PM is forward looking and solution oriented'* and *'The PM is capable of developing talents that generate value and benefits across projects'*, indicated mean results above 4 *(Important)* but however, the mean result for the former statement is higher, which implies that more respondents tend to agree that this required skill is important to the PM role. Similarly, we observed a lower standard

deviation for the statement *'The PM is forward looking and solution oriented'* compared to the other statements, which means that the lower the standard deviation, the values tend to be closer to the mean. The 3 other statements have a standard deviation result above 0.9 which is explained by greater disparity in the responses. Further analysis show that 52% of *'Project Manager'* responses deemed that the PM being a strategic advisor to the company is of low or moderate importance with only 7% considering this statement as *'very important'* in the transformation process while 29% of *'Project Team Member'* respondents checked this as *'very important'*. Similarly, 34% of the *'Project Manager'* responses believed that having a clear vision of the digital strategy and being capable of inspiring such vision and strategy to the project team is of low or moderate importance. It is to be noted that 31% of the participants who answered *'low importance'* or '*moderate importance'* for this statement are from the Construction sector, 36% from Financial Services and Banking Results and 38% from Technology. The data collected showed that there is a certain degree of awareness amongst the PMs and project team members in recognising the strategic and transactional importance of the role of the PM. Hence, it can be said that the role of the PM in delivering change and transformation is expected to be of strategic nature.

Digital and Technical Skills

This section evaluates the responses of the participants regarding how they would rate the importance of digital and technical skills to the role of the PM. It is seen from secondary sources that some level of digital literacy is required but however, it also includes subject matter expertise and ability for professionals to demonstrate agility in the transformation process. It is observed that the statement *'The PM is versatile with experience in different approaches: lean, agile, hybrid… and methods that give flexibility and better results in delivering projects'* has a mean result of 4.22 and a standard deviation of 0.727 which implies that there is a convergence towards the mean result. Respondents tend to agree that this is an *'important'* requirement to the role of PM. The 2 other statements *(i) 'The PM has business analytics expertise, is able to analyse big data and apply business'* and *(ii) 'The PM is knowledgeable on industry technological advances'* have mean results below 4 *(important)* which may suggest greater disparity in responses as seen by the standard deviation of 1.110 for the statement *'The PM has business analytics expertise, is able to analyse big data and apply business'*. This may be interpreted as the profession does not yet fully integrate such dimension into the role of project management. Crosstabulation statistics between the sector of operation and this statement show that 38% from the Construction sector considered this statement of no, low or moderate importance while in the Financial and Banking sector, 54% thought so and 77% in the Technology sector.

Human and Transformational Skills

Industry insights showed the importance of engaging individuals and stakeholders to address the gaps and challenges such as skills, resistance to change and foster an innovation mindset and culture. This section examines the feedback from respondents concerning the importance of transformational skills required for the PM role. 3 statements were rated by the respondents and the statement *'The PM demonstrates emotional intelligence and interpersonal skills that contribute to projects*' performance' has the highest mean with a result of 4.64 and a standard deviation of 0.583, the lowest amongst the 3 statements. This implies that responses for this statement converge towards the mean and therefore, the respondents considered this as an

'important' aspect required for PMs in contributing to project performance. Similarly, the respondents also deemed *'important'* (mean result of 4.38) the necessity for PMs to be able to create the culture for change and lead accordingly. However, the other statement *'The PM is capable of instilling a digital and innovative mindset across stakeholders, both internal and external'* has mean result of 3.86 which is slightly below *'important'*. Furthermore, it is to be highlighted that only 18% of the 'Project Manager' respondents ticked as *'very important'* the statement *'The PM is capable of instilling a digital and innovative mindset across stakeholders, both internal and external'* as opposed to 29% among the *'Project Team Member'* respondents. Project Management is strongly influenced by hard paradigms (Pollack, 2007) associated with factors that focus on *'efficient, expert-led delivery, control against predetermined goals and an interest in underlying structure'*. These roots, however, require a shift to more *'softer'* aspects with emphasis on the people side of project management, emotional intelligence, roles that would encourage innovative mindsets, influence, and engage stakeholders.

Self-Transformation and Cognitive Skills

This section examines the *'accelerators'* elements of the skills group *'Self-transformation / Cognitive'* and gathered the opinions of the respondents on the importance of learning and development for the PM role. It is observed that for all the 4 statements *(i)* '*The PM should have ongoing project management training' (ii) 'There is a need for PM to acquire more knowledge and subject matter expertise beyond the standard certification' (iii) 'The PM should cultivate a mindset of innovation, curiosity, and entrepreneurship' and (iv) 'The PM should demonstrate the ability to learn, understand, apply and keep up with technology'*, the mean results are above 4 *(important).* In terms of standard deviation analysis, it is seen that the last statement *'The PM should demonstrate the ability to learn, understand, apply and keep up with technology'* is the one with the lowest result which implies that respondents tend to agree more on its importance, the result in fact, converges towards the average. Overall, the findings for this section show that there is an acknowledgement amongst the respondents that learning, training, development, and investing in self are important elements that also form the leadership skills of PMs.

Qualitative Findings

For this part of the primary data collection, only 1 individual *(*Participant *P1)* provided his consent to participate to the online interview. *P1* has a civil engineering background with 7 years of experience in the construction industry. He holds the position of Project Co-ordinator in one of the major construction players in the UK. The feedback from *P1* revealed that there is an understanding and awareness of the impact of digitisation, new technological advancement on the workplace and professional activities. The addressed questions provided an insight in the interviewee's industry and the main themes and interpretations were around culture, leadership, learning skills, knowledge, and adaptability. However, the dominant factor during this conversation concerned the organisational culture. *P1* stressed on the culture developed within the organisation that sets the guidelines and structures the approach and behaviour of the PM and decision makers. It is also interesting to note that the interviewee emphasised on external elements such as legislations, and professional institutions in defining and structuring the construction industry. *P1* mentioned the voice of leaders are powerful in communicating and influencing players in the industry. Therefore, if construction players are

looking for a strategic and competitive advantage they might as well adopt, follow, and keep up to date with the industry advances. Another focus of this interview was around learning skills, that is, the importance according to *P1* to invest in people. On one side, *P1* suggested that it must be part of the company's culture to offer training to its people but on the other side, it is important for professionals to invest in self, through certification, and other courses. Regarding the framework, the interviewee described it as the *'ideal'* required skills, which might suggest that this is not the case in real world. In addition to that, *P1* mentioned that often, new technologies and developments are owned by other departments or stakeholders which may not necessarily urge project professionals to acquire those skills but rather adopt a more *'execution'* role.

Conclusions and Recommendations

This study tackles a contemporary challenge in practice. Firstly, project professionals have to take advantage of disruptions to re-skill, up-skill and lead the transformation. It has been seen that it is crucial for project leaders to have more than just the technical skills. The study revealed that there is an acknowledgement on the importance the role of the project leader to expand to other aspects such as forward thinker and the human side in response to rapid evolutions. However, this study also suggests the importance to define and view the role of the PM as of strategic nature. The ability to reimagine project management and project delivery in a digitally disrupted environment is largely determined by a clear digital strategy, supported by project leaders who foster a culture enabling change. In fact, we have seen in the literature review chapter that academics as well industry insights suggest that transformation requires a clear strategy. Secondly, technology is only as valuable as the new business strategies and practices it enables. Culture hence is essential in leading transformation. Leveraging on disruptive technologies requires companies to embrace a culture of change that encourages transformation that is, engaging in a process of change management and therefore presenting opportunities to evolve to the next best practices. As seen in the framework developed, culture can be identified through the approaches implemented such as empowerment, learning, talent management or the climate for innovation. This study also showed that having strong leadership figures influence the strategy and the culture of the company, providing for direction and identity to its people and fostering (digital) initiatives. Finally, the conceptual model was developed to identify the themes and patterns and was further tested and explored through data collection. The purpose was to examine characteristics and skills required by leaders to interact and operate in a digitally disruptive environment. The findings of this study contribute to understanding the linkages in the construct of the project leader 4.0. Indeed, the findings revealed that overall, this study is consistent with research that indicate that digital transformation is not only about technologies, but that leadership is also a major facet in the transformation. The *skills groups* identified and tested demonstrated that there is a degree of awareness among people involved in projects on the importance of the 4 *skills groups* categories (a) Strategic / Transactional (b) Digital / Technical (c) Human / Transformational and (d) Self-Transforming / Cognitive. Some recommendations can be made for academics and project management practitioners:

a) Further tests on the developed framework (Figure 2) may benefit academics in developing the set of leadership skills required for PMs. The tests may explore more variables such as mature organisations, small or medium enterprises, countries or more project positions/different experience on projects.

b) The project management discipline should emphasise more on the strategic nature of the profession rather than portraying a '*hard'* version, an 'execution' role.

c) Self-awareness amongst practitioners is essential in order to leverage on disruptive technologies to reinvent their role, learn and acquire more subject matter expertise.
d) PM should recognise that they have the power to lead change and transform processes not only through technical knowledge but through their capability to exploit their human skills, for instance, through emotional intelligence, communication and negotiation skills with stakeholders.
e) Organisations should not view disruptive technologies as an operational challenge but rather define a clear strategy, strong culture and leadership to navigate through.

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Implementation of Geert Hofstede's Cultural Dimensions to Multinational Construction Management

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Abstract

Since the dawn of enlightenment era in seventeenth century, understanding human behavior has become the major concern of social sciences. Particularly philosophers and later scientists devoted their efforts to comprehension of patterns, shaping human actions and reactions in and across societies. This approach yielded in another field of study namely Behavioral Science, differentiating from social sciences in respect of implementing empirical data to decision making processes as well as business strategies, taking into account impacts of society on the individuals or groups which can be named broadly as "culture". Geert Hofstede, during 1970s, managed to collect an immense data set from IBM employees in worldwide offices, to compile into meaningful figures, which reflect cultural deviations of societies; later referred to as Hofstede's Cultural Dimensions. This model found a large implementation area in multinational business practice in last decades. Current study will cover, to what extend a cultural model can be implemented in various areas of multinational construction management.

Keywords: *behavioral science, culture, multinational project management, strategy.*

Introduction

Influential thinkers and philosophers -even being followers of empiricist school- were well aware that there is space beyond human experience forming basis of human understanding, which would be named as innate powers of human mind, are actually the main factors that varies our interpretations of the external world and essentially how we react to it. This subconscious space is the factor behind deviations of human behavior; actions, non-actions, reactions, responses, decisions etc. from individuals to individuals or groups to groups. Inquiries on cultural parameters affecting individual and social behaviors go back to ancient times; sixth century BC Kleistenes and Solon in Greece and Servius Tullius in Rome (Oskay, 2015), who tried to re-organize social structuring of their societies noticing deep inter-relation between societal institutions and process of civilizations. Since then, efforts for understanding the cultural patterns of societies and intervention to the natural route of the evolution of the society never ceased.

Culture, is a main gate to the understanding of multi-national business environment, especially when there is close interaction of entities. One way to categorize groups of people behavioral-

wise is using nations as samples, though it may not essentially reflect the real case about particular individuals. Geert Hofstede was among the first few to systematically categorize the deviations of behavioral patterns of different cultures relative to each other and in his initial study (Hofstede, 1980) based on IBM's employee data, relieved four major cultural aspects, which he called "*dimensions"*. These dimensions identified by Hofstede were; Power Distance (PDI), Uncertainty Avoidance (UAI), Individualism-Collectivism (IDV) and Masculinity (MAS). Hofstede later developed his model adding a fifth dimension, of *Long versus Short Term Orientation* (LTO) in 1991 taking into account surveys in China and a sixth dimension in 2010, Indulgence versus Restraint (IVR) generated from World Value Survey (Hofstede, 2010).

Modern studies regrading interactivity of sociology and business practices started with Abraham Maslow's culture-independent work about "hierarchy of needs" (Maslow, 1943). Anthropologist George Murdock (1957), first time introduced a worldwide cultural varieties classification. Anthropologist Mary Douglas was the first to utilize a two-dimensional Cartesian framework to illustrate cultural variations incorporating *individualism/public* classification and *social boundaries* (Douglas, 1970) setting a methodological ground for Hofstede's 1980 work. Following Faucheux et al. (1982) who pointed out the importance of cultural variations in organizations, the subject initiated more concern. Aaron Wildavsky's (1989) prescription of four varieties of cultures (*hierarchy/collectivism; apathy/fatalism, competition/individualism and equity/egalitarianism*) followed them. Another alternative to Hofstede's dimensional categorization came from Fons Trompenaars, who proposed a seven dimensional cultural diversity model applicable in business practice (Trompenaars, 1993), which included *universalism vs particularism, individualism vs communitarism, neutral vs emotional, specific vs diffuse* and *achievement vs ascription* dimensions together with *orientation of time* and *attitudes to the environment*. This new model proposed was criticized by Hofstede (1996) for not positioning countries distinctively in dimensions; not validating country scores with respect to independent parameters and confusion of using deductive conceptual categories based on approaches of *sociologists and anthropologists of 1950s and 1960s.* Debate continued with the answer (Hampden-Turner & Trompenaars, 1997) criticizing Hofstede to categorize cultures linearly in "True-False" type of logic with a universalist approach, neglecting shades of gray; presenting his findings in not very meaningful cross-axis diagrams and his reductionist approach to include as minimum as possible dimensions of factors to model wide varieties among cultures. In 1994, Shalom H. Schwartz –to facilitate cross-cultural research- introduced a new set of dimensions working on 41 cultural groups in 38 countries (later 72 countries), taking into account individual values *of the sample on psychological and social variables* (Schwartz, 1994). Schwartz Value Survey (SVS) was conducted among limited samples, composed of students and teachers while further analysis (Fischer et al., 2010) found similarity between individual level values of SVS and Hofstede's country scores. However, this similarity was far from a *near-perfect* match except scores of IDV. As Hofstede in a joint study with US psychologist Robert R. McCrae, rightfully concluded, personalities are not independent from cultural factors (McCrae, 2010). By 2000, Hofstede's 1983 work had become already *more than a classic* (Baskerville, 2003). Baskerville's literature survey illustrated that, in 18 years, "Culture's Consequences" was cited by journal articles in business, psychology, and anthropology/sociology topics 712, 540 and 48 times respectively with an overall citations reaching to 1706; but noted the relatively low citations in anthropology and sociology fields. Baskerville argued this relatively low citations' reasons as: Hofstede's work was based on only one company's data far from being representative and its insufficiency against George Murdock's wider work "Ethnographic Atlas". In his Atlas, Murdock (1957) had examined 565

different cultures referring to variety of cultures within the same countries, which was deemed to be neglected by Hofstede while reducing them all into nation states.

Regarding the structures of organizations in multi-cultural environments, there is a vast amount of literature accumulated after the second half of the twentieth century; but until 1980s, scholar works on organizational development like Bennis (1969), Friedlander and Brown (1974), Alderfer (1977) were based on American practice and did not take into account cultural diversity as criticized by Adler (1983). The global awareness on the failure of Western styles of management approaches in different cultures, started simultaneously with the Chinese economic reforms in 1980s, when Western style project management was tried to be implemented in China in a broad sense especially in construction sector (Chen & Partington, 2004). Wang and Liu (2007) provided empirical evidence from china indicating the cultural barriers to the use of Western project management values in China; their analysis relieved major deviations in Western and Chinese values over *Horizontal – Vertical* management, *Team-Family* consciousness together with *Task-Boss* orientation. A research study (Özorhon, 2007), demonstrated the specific importance of cultural varieties in International Construction Joint Ventures. Prado et al. (2017) illustrated the detrimental effects of cultural varieties on organizational strategies.

Regarding the relation of project management and effects of cultural differences, the contributions followed organizational development issues. Upon, Laurent's (1983) work, which pointed out process of management was in significant correlation with biases of managers and revealing significant diversities among managers in ten different European countries, Hofstede (1984) published another work to implement his cultural dimensions in management and planning denoting the fact that "*no management activity can be culture free"*. Archibald (1991) pointed out the significance of adjustments in attitudes and understanding to overcome cultural barriers in project management function. Archibald's "barriers" were closely related to PDI and UAI. Kendra and Taplin (2004) pointed out the significance of cultural framework's importance in a collaborative work about project success within an organization. Prabhakar et al. (2008) in a study regarding culture and conflict management topic carried out on 150 telecom sector project managers from France, Great Britain and India found significant correlation between Hofstede's IDV and MAS dimensions and some with UAI dimension for project managers adopting an approach to avoid conflicts. Bredilet et al. (2010) found direct correlation between Hofstede's IDV dimension and project deployment while PDI and UAI dimensions were reported to be supportive cultural factors.

This limited scope study intends to cover coherence or divergence of Hofstede's cultural dimensions with respect to multinational construction management applications based on the observations of the author. For those who are alien to the subject, a brief introduction to the cultural dimensions is also provided.

Term "Culture"

Prior to moving further with Hofstede Dimensions, a common understanding of the term "culture" should be discussed. For centuries, interpretation of culture varied drastically with respect to time and incorporated disciplines, but a consensus has not been reached among scholars. The etymological background of the term goes back to Latin, as Cicero, in first century

BC, referred to it as "*Cultura animi philosophia est* -Philosophy is the cultivation of soul-". This definition of culture relating it to "progress via cultivation and settlement" later evolved into a parallel understanding of *culture* with *civilization*. Cicero's analogy essentially bonded culture to human activities, thus *civil life in the city*. This self-generation of the **self** was explained later by French historian Jules Michelet; as "***the decisive shaping of self by self"*** or as Karl Marx put it*; **"the production of people by people"*** (Braudel, 1995). This parallelism between culture and civilization has become a common understanding and Encyclopedia Britannica describes anthropological definition of culture as "*a concept, called attention to the non-biological, nonracial, non-instinctual dimension of human life, the basis of what is called civilization: its values, techniques, and ideas in all spheres*."

Combining all above definitions, we can simply compile the common characteristics of the term "culture" into the following benchmarks; *implies a society sharing the same environment, acquires knowledge via morals, custom, habits, beliefs, behavior patterns, routine practices, and it is an evolving institution reproducing itself, essentially parallel to civilization and its economic activities.*

Hofstede's Interpretation of "Culture"

Without understanding particular definition of Hofstede for "culture", an effective understanding of his dimensional model would not be comprehended. In his 1991 work (Hofstede, 2010) Hofstede, evaluated definition of "culture" as "civilization" or "refinement of mind" as a narrow approach. For him, culture is a "*mental software*" which has a broader use that is common to sociologists and especially anthropologists. In this respect, he discriminates human nature from culture, using a computer world analogy; while human nature is an operating system (which all human beings inherited via their genes;), culture is not something innate, and implies that culture is an application which, main inputs collected from the environmental factors of the society one borne into. In that respect, human beings use their innate nature to interpret the external world but express or reflect their feelings thru the software called "culture". Figure 1 is a visual representation of "practices" (rituals, heroes, symbols) as the software of the mind running on the operating system of "values", altogether shaping the society's behavioral patterns.

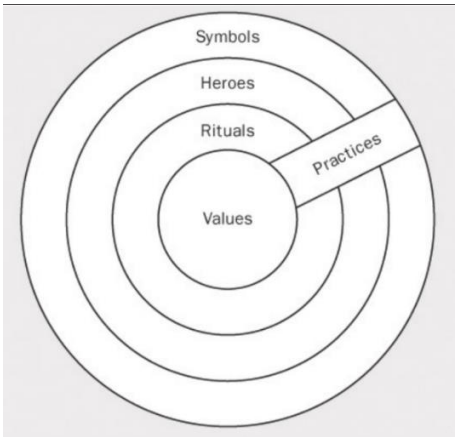


Figure 0: Hofstede's (2010) "onion" manifestations of culture.

Hofstede, tries to provide significant factors how human beings response to external world, and why there are deviations in these responses from nation to nation. Therefore, Hofstede's cultural model is based on nation-states where such measurements of deviations can be handled more easily. This approach is essential (though Universalist) in multinational business practice where entities cannot run particular psychological and sociological surveys for each case. Shortly, as Hofstede (2011) expressed in his YouTube interview; "*what makes us different is, the forest we were born in*." That is the reason why nationwide characteristics merge, as the public is the byproduct of that typical "*forest"* they live in. From the viewpoint of business economy; nation-wise cultural factors have a broad influence, as they constitute "*a stable set of values, perceptions, preferences, and behaviors*" that have been learned by the individual in a particular environment.

Hofstede's Interpretation of "Dimension"

Hofstede (2010) defines dimension as "*an aspect of culture that can be measured relative to other cultures*". Using a dimensional model, made it easier to group together "*a number of phenomena in a society that were empirically found to occur in combination, regardless of whether there seems to be logical necessity for their going together*." Therefore, the heart of the dimensional study rests in this inductive argument; the dimensions produced themselves based on the survey used, instead of a logical and biased pre-determination. In this respect, one can –at the first sight- might have difficulties in interpreting these **self-relieving** cultural dimensions of the study, as it might deviate from classical classifications.

A Review of Hofstede's Cultural Dimensions

Hofstede, upon encountering with a similar survey –Chinese Value Survey (CVS)- in 1971 by a Canadian researcher, Michael Bond, a new dimension which was not correlating with Hofstede's initial dimensions was relieved and Hofstede added that dimension to his model as "LTO-Long-Term versus Short-Term Orientation" being the fifth dimension in 1984. And finally, Michael Minkov's drilling into World Values survey data relieved the final (sixth) dimension of "IVR- Indulgence versus Restraint" in 1991.

Sample Data

In post-World War II economic booming years; IBM was among the few multi-national companies, which employed thousands of employees worldwide. During 1970s *IBM employee survey data comprised the largest cross-national collection of comparative value statements anywhere in the world* (Hofstede, 2010). The work, which started with 40 countries extended to 72 in a short. Although the surveys conducted initially were generally misinterpreted to be pertaining to managers only, Hofstede (2011) points out that they covered all levels of employees' dataset. The sampling and its outcome indices should be interpreted as relative weights of nations (countries) with respect to each other, rather than being absolute figures. While computation, mix of occupations surveyed were kept constant for all countries, as Hofstede (2010) pointed out, *Spanish engineers were not compared to Swedish secretaries*.

Validation of Dimension Indices with Other Measurable Parameters

When the question is about deviations of cultures, the major difficulty will be about commensurability. One has to find ways to make abstract and relative measurements, put them into one coordinate system where values of the axis which is also subjectively defined by the researcher. So, interpretation of the relative values designated to the factors should be checked for coherence using measurable country specific parameters like, GNI (Gross National Income), violence rates, income inequality, religion, savings etc. Some of Hofstede's correlation factors are given Table 1. Referring to his initial study (1980), Hofstede points out that these cultural dimensions were validated using four hundred significant correlations with other independent country-specific parameters and additionally points out that the indices scores are not time dependent, i.e. the relative rankings of countries in 2010 were close to the rankings of 1970.

Table 1. Correlation of cultural dimensions with country parameters.

Dimension	Corr. Type	Independent Correlated Country Parameter
PDI	(+)	Use of Violence, Income Inequality
IDV	(+)	Level of GNI
MAS	(-)	Share of GNI for government aids to poor countries
UAI	(+)	Roman Catholicism
LTO	(+)	National savings rates

In his interviews (Hofstede, 2011), he also points out the fact that, *"though the indices figures might change in time, relative positions (rankings) of countries with respect to each other remain stable"*.

Understanding Hofstede's Dimensions

The remarks hereon, are based on Hofstede's latest work of 2010. However, for the scope of this study in multinational construction management, specific intention will be given on PDI, IDV, UAI and LTO dimensions, which supposedly provide more significant distinction factors. The data interpretations are made on the summary data obtained from Geert Hofstede web site, made publicly available for researchers. However, for the sake of homogeneity, the countries where some dimensions not measured, were excluded from this study; so the data used comprises of 61 countries plus the Arabic, East Africa and West Africa regions.

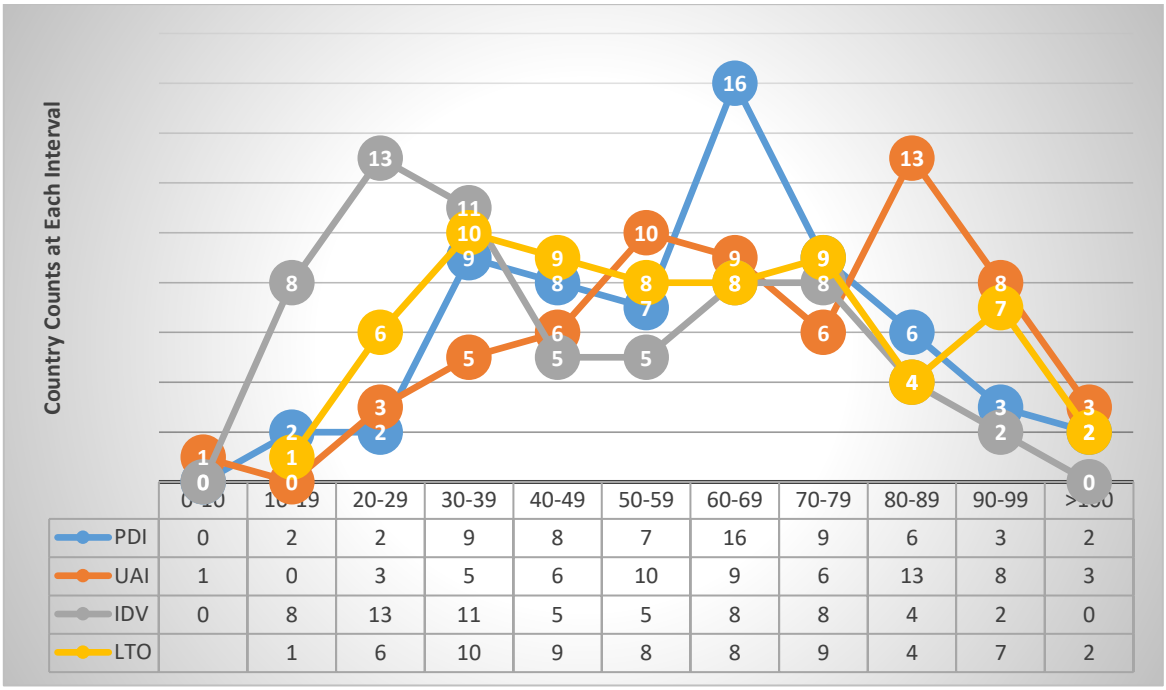


Figure 0: Distribution intervals of country scores by dimensions.

In some of the below interpreted data, several country scores are exceeding 100, which indicates that, the country data is added later, upon finalization of the normalization process. Figure 2 represents distribution intervals of country scores with respect to four dimensions chosen for this study.

Power Distance Index (PDI)

The dimension referring to PDI aims to measure the degree of inequality between members of a society. IBM's employee survey included questions regarding how subordinates were feeling free to express their ideas or counter-arguments in front of their superiors. As the index value increases, the power-distance between subordinates and superiors are increasing. i.e. 0 for small power distance and 100 for large. Figure 2 demonstrates the variation of PDI scores (in blue) worldwide corresponding to the lowest standard deviation (20.44) among all other dimensions. The mode of the distribution is 60-69 interval, and a slight tendency to a lower PDI score can be observed. Highest and lowest five PDI scoring countries and respective behavioral differences specifically related to business practices are listed in Table 2. More "democratic" oriented business practices were observed in Scandinavian countries, whereas authoritarian approach increases in East Europe and Far East.

Table 0. Highest and lowest PDI scores.

	Country	PDI	Some behavioral differences noted by Hofstede
Top	Malaysia	104	Children more obedient to parents, both parents worked fulltime, educational process is teacher centered, budgets spent for higher
	Slovakia	104	

	Philippines	94	education, at work superiors and subordinates are existentially unequal, state authority tends to be traditional and symbolic elements used to show power, have tendency of using centralized power, subordinates expect to be told what to do, power and wealth coincide, weak check and balance mechanisms
	Russia	93	
	Romania	90	
Bottom Five	Norway	31	Children learn to say "no" and to contradict, one parent works fulltime, educational process is student centered, budgets spent for secondary wide-spread education, at work flat hierarchy exists, tendency for power use is decentralized, subordinates expect to be consulted, power and wealth need not to coincide, strong check and balance mechanisms
	Sweden	31	
	Ireland	28	
	N. Zealand	22	
	Denmark	18	

Hofstede's striking finding on PDI is about geographic correlation of the scores; approaching to the equatorial zones, power distance increases and for him this fact is caused by prehistoric migrations of people; equatorial zones require hard work to grow crops necessary for survival. British Historian Ian Morris (2010) had described a similar geography effect on civilizations as "Lucky Latitudes", which provided more suitable environmental conditions for agriculture / horticulture and yielded to development of division of labor together with vertical hierarchy.

Individuality versus Collectivity Index (IDV)

The dimension referring to IDV aims to measure the degree whether the interests of the group prevails over interest of the individual in a society. The separation is initially generated from family structures; in collectivist nations, families are in extended forms to include grandparents to grandchildren, whereas in individualist nations families are nuclear (core). Hofstede (2010) found a strong relationship between a country's national wealth and degree of individualism in that nation; higher the individualism higher the wealth of that nation. This finding is not surprising as long as wealth is measured in terms of commodities; so, in the countries where private ownership is praised, wealth in that respect will be naturally higher. Private ownership by definition, entails individuality following the assumption of Adam smith that; *each individual is motivated by self-interest and self-interests of individuals are for the benefit of the whole society*. Anglo-American governance of high IDV scores confirms this assumption.

Figure 2 demonstrates the variation of IDV scores (in grey). The left side shifted IDV distribution in Figure 2 demonstrates a general tendency towards collectivism against individualism in world scale (σ=23.14). This is denoted by Hofstede as "*collectivism is the rule in our world, and individualism the exception*" (2010, p. 97). To have closer look, Highest and lowest IDV scoring countries and respective behavioral differences are listed in Table 3.

Table 2. Highest and lowest IDV scores.

	Country	**IDV**	**Some behavioral differences noted by Hofstede**
Top	U.S.A.	91	Higher national wealth, children encouraged to develop own opinions, longer and explicit contextual approach (contracts),
	Australia	90	

	Great Britain	89	encourage independent self, prefer to live in detached houses, more life insurance policies sold, weaker labor unions, management is understood as management of individuals, trust is to be established with organizations rather than individuals, confronting views welcome, preference of freedom over equality, employer-employee relationship is calculative
	Canada	80	
	Hungary	80	
Bottom Five	Peru	16	Lower national wealth, children forced to obey, shorter contextual relations (contracts), encourage interdependent self, prefer to live in communal apartments, hiring family members in businesses, stronger labor unions and labor conflicts, management is understood as management of groups, trust is to be established among individuals, confronting views not expressed, preference of equality over freedom, employer-employee relationship is moral
	Trinidad and Tobago	16	
	Indonesia	14	
	Colombia	13	
	Venezuela	12	

Uncertainty Avoidance Index (UAI)

The dimension referring to UAI aims to measure the degree of anxiety levels of a society under contingent or ambiguous situations. The relative values of nations were measured via survey questions reflecting one's stress level at work, ideas about breaking company rules and whether they intend to work for the company (IBM in this case) for a long time or not. High stress levels, fear of breaking company rules (as they endanger one's future expectations) and plan for keeping the work for a long time are indicators of anxiety levels. Higher the anxiety, higher the UAI. Figure 2 shows the distribution of UAI scores shifting to right (with σ=22.71), which is a clear indication that, nations worldwide have a general tendency of avoiding uncertainties. Hofstede (2010), in his interpretation of uncertainty avoidance, gives particular attention to the fact that, this dimension should not be confused with risk avoidance. As he points out; "*uncertainty is to risk as anxiety is to fear. Fear and risk are both focused on something specific: an object in the case of fear, and an event in the case of risk. … Uncertainty has no probability attached to it.*" Uncertainty avoidance is avoidance of one from a *complete unknown*. Table 4 summarizes behavior characteristics of high and low UAI scores of countries selected for business-oriented events.

Table 3. Highest and lowest UAI scores.

	Country	UAI	Some behavioral differences noted by Hofstede
Top Five	Greece	112	High stress and high anxiety, personalities are more neurotic, strong superegos, what is different is dangerous, more worries about health and money, in shopping search is for purity and cleanliness, new cars expert repairs, conservative investments, time is money and urgency prevails, top managers concerned with daily operations, need for precision and formalization, more corruption, conservatism governs, principles governs over practice
	Portugal	104	
	Uruguay	100	
	Malta	96	
	Russia	95	
Botto	China	30	Uncertainty is a normal feature of life, low stress and low anxiety, personalities are more agreeable in nature, weak superegos, what is
	Vietnam	30	

Hong Kong	29	different is approached curiously and tolerantly, fewer worries about health, money and time, in shopping search is for convenience, prefer used cars DIY repairs, risky investments, time is framework for orientation, top managers concerned with strategy, tolerance for ambiguity, less corruption, liberalism governs, practice governs over principles
Sweden	29	
Denmark	23	

Very high UAI scores of Greece, Portugal and Russia in Table 4 is not surprising. As they have scored even more than 100, evidently the data for these countries were collected later most probably after 2008 economic crisis, which affected these countries most. On the other hand Scandinavian and Far Eastern countries differentiate from the rest of the world with lowest scores most probably due to trust in future and particular philosophical teachings respectively. This finding is strongly correlated to the LTO dimension below.

Long Term versus Short Term Orientation (LTO)

Hofstede explains the appearance of this dimension which appeared from CVS, with the influence of Confucian teaching in the high LTO countries. Major Confucian ideas reflected are; stability of the society to be based on un-equal status relationships, a person is primarily a member of society (relating to IDV), not treating others as one would not like to be treated oneself, main work virtues to be acquiring skills, hard work, patience and preservation. So almost four out of eight values of the CVS was directly related to Confucius' teachings as Hofstede (2010) denotes; "*culture rises from its ashes like a phoenix*." A new dimension's discovery in a survey pertaining to Far Eastern countries relieved another fact regarding methodology; surveys directed by Western "minds" would not be reflecting the truth in the Eastern societies or vice versa; in Hofstede's (2010) words: "*a questionnaire invented by Western minds produced a fourth dimension dealing with Truth (refers to UAI); a questionnaire invented by Eastern minds found a fourth dimension dealing with Virtue.(refers to LTO)"*. Hofstede's conclusion is; scientific research very well copes with analytical thinking ***but organizational capacities like management or government requires synthetic thinking***.

Figure 2 shows the uniform distribution of LTO scores (in yellow) with several modes ending up in the highest standard deviation (σ=23.22) among other dimensions. Table 5 illustrates highest and lowest LTO countries together with selected behavioral differences regarding business operations.

Table 4. Highest and lowest LTO scores.

	Country	LTO	Some behavioral differences noted by Hofstede
Top Five	Korea South	100	Support entrepreneurial activity via persistence or tenacity, sustained efforts for slow results, subordination of oneself for a purpose, respect for circumstances, main work values of hard work, learning, honesty, adaptation, accountability, and self-discipline; importance of profits ten years from now, investment on lifelong personal networks, matter and spirit are separated, synthetic thinking, investment in long term real estate, disagreement does not hurt
	Taiwan	93	
	Japan	88	
	China	87	
	Germany	83	

Bottom Five	Morocco	14	Quick results expected, concern with social status and obligations, respect for traditions, main work values of freedom of expression, individual rights, achievement and thinking of oneself; importance on this year's profits, meritocracy –reward by abilities-, matter and spirit are integrated, analytical thinking, investment in short term mutual funds, need for cognitive consistency
	Iran	14	
	Colombia	13	
	Trinidad and Tobago	13	
	Africa West	9	

LTO champions of South Korea, Taiwan, Japan and China are also the world industrial growth leaders in the final quarter of twentieth century; named among Five Dragons. Although major scientific inventions of twentieth century took place in the "analytical" western world, Far Eastern countries managed to adapt themselves with their hard work, perseverance and tenacity to cope with those inventions and even to take them to further level as observed in automotive and electronics sectors. Germany shines being the highest LTO country among Europe and not surprisingly, it was the European Union's growth leader by 2010 scoring twice the average of EU countries (World Bank, 2022). It is evident that, LTO index provides coherent data for reflecting a country's sustainable growth rate.

Incorporation of Hofstede's Cultural Dimensions in Multinational Construction Management

Multinational construction has become a major field of business activity starting from the post-World War II period, significantly after 1960s. Upon reconstruction of Europe, the workforce and related resources accumulated there had to be shifted to third world countries to ensure to sustainability of growth in the West. Establishment of United Nations (UN), World Bank and International Monetary Fund paved the routes of that growth. By the end of 1950s international forms of British Construction contracts (JCT -originated from RIBA-, FIDIC -originated from ICE- etc.) were made available to be used all around the world, based on their local forms prepared under Common Law and using British legal jargon; and naturally conflicts were inevitable. 1958 New York Convention by UN, prepared the infrastructure for resolution of international conflicts by allowing the recognition of international arbitral awards by local governments making international contracting business more feasible for Western companies. Upon saturation of Western construction giants' appetite, other countries started taking their part in worldwide game making use of their competitive advantages of factor conditions (human and physical resources), developing firm strategies (Porter, 1990).

As per Deloitte's Global Construction Powers Report 2019, with respect to Top 100 Global Construction Companies sales (GPoC ranking) China has become by far the world leader holding almost 44% of worldwide construction revenues, Japan follows with 13% and South Korea is the fifth one with a share of 5%. From the Western world US keeps the highest position with a market share of 9% followed by France and Spain with shares 8% and 5% respectively. Turkish companies in GPoC 100 shares 0.3 % of construction revenues by 2019 (Deloitte, 2019).

Expected Cultural Conflicts

This new global environment turned the world into one large "forest". Slowly but surely, understanding the needs of the environment, the international construction giants started to transform themselves into multinational giants, making more use of local human resources to take the advantage of their skills in the particular regions. Business entities were not struggling anymore only with the suppliers and employers of other nations but also with wide range of nationalities within their own organizations; therefore reshaping organizational strategies was essential. In this context, Hofstede's cultural dimensions model would be a rather convenient tool for avoiding conflicts within and interacting entities.

Hofstede's country scores are grouped in ten major regions in this study, presumably reflecting similar characteristics originating from historical facts in Figure 3, which illustrates the worldwide cultural deviations, compiled from averages of country scores involved. The much lower standard deviations of dimensions (10-12) among countries within regional groups defined, than the overall standard deviations (20-23), indicating a coherent grouping. Putting aside Scandinavian countries, there is a convergence of scores in MAS dimension, i.e. almost all the world is equally masculine; that dimension is inherent to nature of human beings; thus might have little differential effect in multinational business.

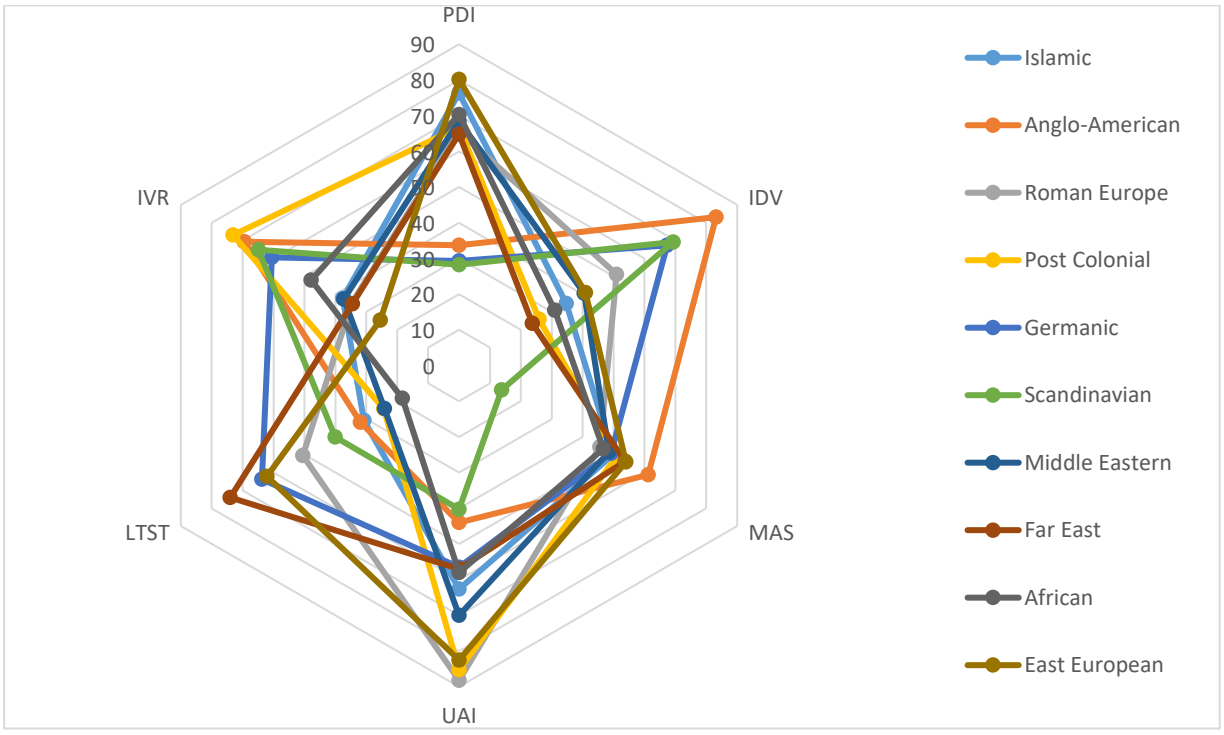


Figure 1: Worldwide cultural dimension deviations in representative regions.

Expected Effects of Power Distance (PDI)

As seen from Figure 3, low and high PDI countries concentrate in two poles; generally indicating the wealth level. It is interesting to note that, lower PDI cultures (wealthier ones) are those, who made advantage of trade concessions they gained historically from the higher PDI

cultures. Both sides of these countries have very long-term historical business relations with each other. Closure of borders to foreigners did not contribute to wealth of neither Japan nor China historically; besides they had lost their positons in front of the Western countries.

Power Distance is an important factor especially in multinational companies where managers and subordinates are from diverse cultures. A manager from a high PDI culture might find the expressions and attitudes of lower PDI culture subordinates offensive and conversely for a low PDI culture manager, non-confronting behavior of high PDI culture subordinates might risk business. Lower PDI culture employees prefer to be listened and their advice taken for important issues; this should not be taken as an offense by their managers of a high PD culture. High PDI cultures are more dependent on centralized power. In this respect, implementation of Western management recipes like Management by Objectives (MBO) (Drucker, 1955), might not be effective in high PDI countries (Hofstede, 1984). While conducting business, this factor will make quite difference; especially when negotiating with members of a high PDI culture, highest rank officials are required, as subordinates will not be provided with authority to give away any item during bargaining, and this is a tricky situation when the other side is represented with full authority.

Expected Effects of Individualism versus Collectivism (IDV)

Figure 3 demonstrates an important the separation of wealth between Anglo American, Scandinavian and Germanic countries with higher IDV scores compared to the rest of the world. 1960's had become the turning point for a paradigm shift from collectivism to individuality. Effects of cold-war between socialist and capitalist countries should not be underestimated in this paradigm shift. Propaganda tools to show especially socialist countries as "evil empires" played a great role in changing consumer behaviors as well; individualism came with an explosion of consumption; smaller houses, more appliances, more automobiles and growth of related industries. A significant negative correlation between IDV and PDI scores can be seen in Figure 3.

As Hofstede (1984) pointed out; "*in individualist cultures, the relationship between the employee and employer is a business relationship based on the assumption of mutual advantage: it can be called a calculative relationship.*" A lower IDV score culture making business with a higher score IDV culture should be prepared for clearly defined long contractual agreements and a more organizational behavior. In high IDV cultures, trust is expected to be achieved only at organizational levels instead of establishing good relations with individuals. High IDV culture entities while making business with lower IDV cultures should be prepared for willingness of their local managers to work with extended family members and first circle friends; thus the risk of nepotism will be higher. Strong labor unions in lower IDV countries may be the sources of conflicts with local workforces in multinational projects. Therefore, contingency factors regarding local workforce and contractual risk mitigation should be carefully distributed especially under Force Major, Suspension and Termination clauses of contracts.

Expected Effects of Uncertainty Avoidance (UAI)

Figure 3 represents a clear negative correlation between UAI and IDV dimensions; higher the IDV lower the UAI. Generally, discussions made above for IDV holds right considering the negative side in UAI scores. However, some specific care should be given to the delivery methods incorporated in construction contracts. A high UAI culture's representatives should avoid making contracts -when they are employers- under Cost Plus or Unit Price terms with open ends. Best selection of contracts in that respect will be lump sum turnkey basis and if there is sufficient time and funds, EPC type delivery will work better. High UAI culture contractors will face tension under Design-Build contracts as the party responsible for design will be struggling with higher contingencies. In this respect, it has to be kept in mind that high UAI culture representatives are *not good negotiators when outcome of the negotiation is very ambiguous* (Hofstede, 1984). Once the risks are defined and followed together with consequential effects, stress and anxiety level of high UAI culture representatives might be taken under control. So following a Risk Register (like in NEC) during works might help.

When multinational lower UAI entities or corporations are working with higher UAI culture managers, they have to give specific importance to follow corporate long-term strategies, as their managers will be busier in dealing with daily matters more. A striking finding of Hofstede was the increasing level of corruption together with increasing UAI score and representatives or corporations of lower UAI cultures should be prepared for consequential effects of corruption especially in contingency factors in high UAI countries.

Expected Effects of Long Term vs Short Term Orientation (LTO)

As can be seen from Figure 3, LTO is not correlated with the other dimensions relieved from IBM survey, however, it generates quite a useful tool in understanding *eastern* minds while conducting business relations with the rest of the world. When getting into business relations with Far East cultures, others should be aware that inner harmony and slow but sure steps forward would prevail. Business strategies should be established considering long-term arrangements and profit expectations in short periods might not realize. Patience will be the key factor for a successful business partnership. Corporations with lower LTO scores when engaged with subordinates of high LTO cultures, can trust their hard work, adaptation, honesty and accountability as long as required respect is shown for their cultural values. Acceptance of other options than a single unilateral truth is another key factor. However, a high level of consultation or confrontation even for the benefit of the business relation might not be expected from high LTO cultures. Far Eastern cultures are very good business partners especially on PPP or BOT type long-term engagements, where results would be obtained slowly but surely. That is the reason; Chinese and Japanese giant construction companies are widely involved in BOT type contracts with long-term engagements with governments.

Sample Cases

In the following cases, observations of the author who was involved in Turkish, Polish, American, Russian and German construction companies in various positions among Middle Eastern, European, post-Soviet Union, American and African cultures, will be illustrated in

reference to Hofstede's cultural dimensions. It should be noted that the arguments below reflect the subjective opinions of the author. There exist a wide opportunity for future empirical work.

Case I- Russia and Turkey

Since the resolution of Soviet Union in1990, Russia and Turkey have become important business partners. CIS countries opened numerous opportunities to Turkish contractors especially in modernization of infrastructure and building advanced trading centers and industrial facilities.

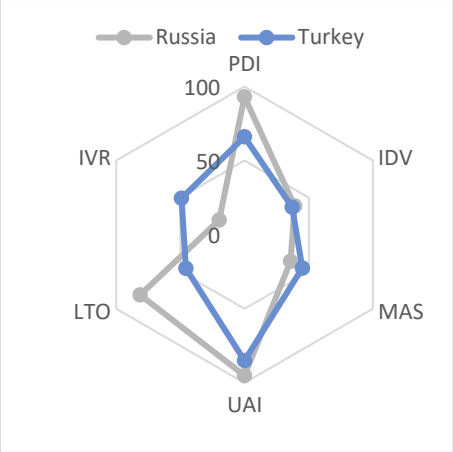


Figure 4: Major deviation factors.

As illustrated in Figure 4, major deviation factors between two countries lay in PDI and LTO scores. Autocratic management character (high PDI) of Russian entities did not constitute a serious problem, as Turkish companies were acting as contractors in service of the prior. Typically Russian sides in contractual negotiations were represented by lower level non-authorized representatives as a higher PDI culture, and this situation created an unbalanced bargaining power to compensate lower negotiation skills arising from higher UAI scores of the Russian side. As both nationalities have similarly low IDV, they were expecting more personal trust rather than organizational level trust. Whenever stronger/individualistic personalities have started to represent Turkish contractors, conflicts started to escalate and almost all the big scale contractors of early 90's had already disappeared from Russian market by early 2000s. This was the consequential effect of higher LTO scores of the Russian side. Turkish companies with short term expectations did not meet the longer term oriented Russian minds; only contracting companies, who adapted themselves to the environment survived.

Case II- Turkey and USA

Especially upon resolution of Soviet Union, US government and companies found lots business opportunities in former CIS countries, like construction of embassy and consulate facilities in the new states employing Turkish contractors. This co-operation progressed strongly in military facilities construction business after Iraq's and Afghanistan's occupation by US forces by early

2000s. Turkish contractors used their competitive advantages of logistics and cultural similarities in the subject countries to take part in the niche market.

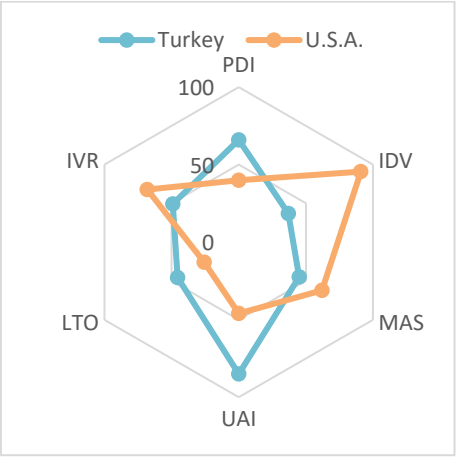


Figure 5. PDI scores.

As illustrated in Figure 5, significant deviations at PDI scores created tension especially in Turkish contractors to adopt themselves to the check and balance mechanisms required by the Americans like QA/QC and document control systems. The second cultural conflict area appeared in very high deviation in IDV scores. While American side preferred to work with well-defined contractual terms and scopes, Turkish side tried to compensate the gap by personal relations, which did not work out well. American side was always looking for systematic organizational relations as a matter of trust. UAI scores can be misleadingly interpreted from Figure 3-3 that US entities were ready to take major part of the risks in conflict zones, however, it was the Turkish entities taking the majority of risks while collaborating with occupation forces in a hostile environment. Uncertainty avoidance is different from risk avoidance as discussed before and in general, these assessed risks were well managed by Turkish construction industry, who were capable of developing interpersonal relations with third parties in those regions, where they had historical strong cultural ties.

Conclusive Remarks

Above two cases based on construction management experience of the author illustrates significant coherence of Hofstede's dimensional varieties when applied to construction management practice. Expectations and experience well match however, needs further survey among construction managers and their everyday faced difficulties while working in multinational environment. Of course, time to time, individual characters might highly deviate from the expected national culture values. However, as it is not possible and practical to carry out personal socio-psychological tests on business counterparts, a broader cultural understanding on the national scale might guide business efficiently.

For centuries, historians to sociologist and anthropologists to psychologists developed numerous theories to describe the origins and parameters, which are making cultures and civilizations so different from each other. Significant number of those studies concentrated or focused on the deviation axis between East and the West; most famous being the Clash of

Civilizations by Samuel P. Huntington in 1996. However, it was not primarily civilizations, but cultures clashing. In this respect Geert Hofstede's cultural dimensions study constitutes an important landmark on understanding human nature, thus understanding international or multinational conflict areas. Its methodology of using only IBM employees might be questioned in regards to reflective sampling, however, the results obtained generally match with worldwide observations and validated by works of others. Increasing the awareness on possible conflict areas is a key factor for a more harmonious world.

Another remarkable issue regarding conducting social survey studies worldwide is the identity and personality of the surveyor. As Hofstede admits, it is hard to relieve facts about *eastern* cultures with surveys prepared by *western* minds; similar to quantum physics, where presence of observers might change the results of observation. However, until a completely new methodology is invented, this is the only valid option in our hands. Lastly, Hofstede's idea that *cultural dimension rankings are isolated from time-wise effects as the change is global*, may not be reflecting the regional radical deviations of the last decades. Still -to some extent- revolutions and counter-revolutions continue; 1979 Iran, 1989 Soviet Union, dissolution of Yugoslavia in 1992, are a few samples of which, cultural differences were the motivating forces of disintegration and for the newly formed states, national behavior patterns are radically changing.

Hofstede's contribution will be continued to be questioned for its deterministic and sometimes reductionist approach for modelling of a very complex subject, but it will definitely keep its benchmark position for further surveys.

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Partnering in Total Quality Management Practices and Quality Culture

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Abstract

The quality offered by the suppliers is a very important factor in total quality management practices in the construction sector, and it is necessary to establish standards regarding product quality, to determine the quality expected from suppliers with specifications, standards etc. and to inform suppliers, to identify problems and to support suppliers in improvement studies in order to provide the product at the desired standards, in good quality, economically and at the best time. It is possible to improve communication, establish trust-based, harmonious, and long-term relationships with suppliers, and ensure their participation in quality practices, by applying the partnering approach, which is a collaborative approach that involves customers, contractors and suppliers dedicating themselves to closer working relationships to increase performance and improve production. It is necessary to ensure the participation of all employees for continuous improvement of the process and to establish a corporate culture for total quality management practices to be successful.

In this study, the partnering approach in total quality management practices in the construction sector, quality culture, the importance of it in terms of the success of the practices will be mentioned.

Keywords: *Corporate culture, partnering, quality culture, total quality management.*

Introduction

Total quality management is an integrated management concept for the continuous improvement of product and service quality with the participation of everyone involved in the organization. It is the continuous improvement of all activities in a company and achieving profitability by satisfying employees, customers and all other project stakeholders with the participation of all employees in the organization. Since various research studies have shown that quality-focused companies achieved success, the expectations from total quality management are generally expressed as better employee participation and relations, improved product and service quality, higher productivity, greater customer satisfaction, increased market share, and improved profitability (Evans & Lindsay, 2019).

The facts that the product has different features than the other sectors, the function, location, size of the project, the scope of the service to be provided, the construction technique, architectural features, the qualifications of the project team, etc. with the uniqueness of

project, the participation of many disciplines in the process, the differentiation of the organization in each project make the implementation of total quality management in the construction sector difficult. It is seen that the implementations are unsuccessful due to reasons such as lack of questioning what to achieve from total quality management, failure of employee participation, lack of motivation, failure of suppliers to be included in quality practices, lack of infrastructure required for change (technical tools etc.), training applied only at the top management level (Güner & Karaçar, 2016).

Ensuring the effective employee participation for continuous improvement of the process in practices is one of the most important factors affecting the success of total quality management. Since the construction sector has sub-systems, it is possible for many different units to work with each other, and everyone in the organization is each other's customer. However, the establishment of temporary organizations at the project level and the constant change of participants in the process due to the uniqueness of the project causes communication and motivation problems and hinders the employee participation. In order to ensure employees participation, in addition to applications such as authorization and teamwork, employees'opinions should be sought regarding applications such as examinations, quality inspections, quality control circles, self-managing teams, etc. and other issues such as communication, top management leadership, education and training, motivation, workplace quality, salary satisfaction, recognitions and rewards, corporate culture, etc. and appropriate motivation tools should be used. It is necessary to ensure the cultural change required for continuous improvement and to create the corporate culture (Güner & Karaçar, 2016).

Corporate culture is a set of habits, behaviors, rules and principles in a company. In order to create a corporate culture in a company, it is necessary to provide cultural change within the framework of a holistic structure (Sommerville & Sulaiman, 1997). Cultural change is a change in personal and organizational behavior. This change requires communication between all employees and top management as well as communication with customers and suppliers. Change must start from top management, and everyone must be involved. Since it is not easy for people to give up the values and habits they have adopted, cultural change takes time and is very difficult. Top management should support and lead this change (Güner & Karaçar, 2016).

The quality offered by the suppliers is a very important factor in total quality management practices in the construction sector, and it is necessary to establish standards regarding product quality, to determine the quality expected from suppliers with specifications, standards etc. and to inform suppliers, to identify problems and to support suppliers in improvement studies in order to provide the product at the desired standards, in good quality, economically and at the best time (Berry, 1991). It is possible to improve communication, establish trust-based, harmonious, and long-term relationships with suppliers, and ensure their participation in quality practices, by applying the partnering approach, which is a collaborative approach that involves customers, contractors and suppliers dedicating themselves to closer working relationships to increase performance and improve production (Barlow, 1996).

Project partnering is a means to apply total quality management to the construction industry through teamswork with various parties (Kanji & Wong, 1998). Partnering is more than a set of goals and procedures; it is a state of mind, a philosophy and it represents a commitment of respect, trust, cooperation, and excellence for all stakeholders. Partnering is a system of conducting business that maximizes the potential for achieving project intent, attaining

specified quality, improving communication and resolving conflicts (Bayramoğlu, 2000). However project partnering, managing the supply chain as a whole and adopting total quality systems and procedures cannot yield best results without the creation of a quality culture for the parties to operate in (Kanji & Wong, 1998). In this respect, the organizations need to shift from their current culture to a total quality management culture that focuses on quality as a key strategy. Changing corporate culture or organizational culture is increasingly recognized as one of the primary conditions for successful implementation of total quality management (Mahmood et al., 2006).

In this study, the partnering approach in total quality management practices in the construction sector, quality culture and the importance of it in terms of the success of the practices will be mentioned.

Partnering in Total Quality Management Practices and Quality Culture

In the construction sector, the client, consultants, contractor, subcontractors, suppliers involved in the project, play a role in delivering a quality project. Here someone's failure affects the success of the project. The quality offered by the suppliers in total quality management practices, is a very important factor. Accordingly, it is necessary to include suppliers in the quality organization established at project or company level and to determine the quality expected from suppliers with specifications and standards, to identify problems, to support suppliers for improvement studies, to establish trust-based, harmonious, and long-term relationships with them and to guide them in total quality management process (Berry, 1991; Güner & Karaçar, 2016). In this respect, applying the partnering approach, which is a collaborative approach that involves customers, contractors and suppliers dedicating themselves to closer working relationships to increase performance and improve production, is required in terms of ensuring the participation of suppliers in quality practices (Barlow, 1996).

The partnering approach is the key that will unlock the techniques and principles of total quality management to provide customer satisfaction in the construction projects. Partnering and total quality management work within a continuous improvement approach by sharing common goals, and are placed in close proximity in this respect (Bayramoğlu, 2000). Partnering is a management approach used to achieve business value and increase the efficiency of the construction industry. Partnering aims to accomplish a positive environment for the project focused on achieving success for all participants by establishing a good relationship and a "*pain and gain sharing*" mentality (Hosseini et al., 2018). By applying project partnering, results such as improved efficiency, cost-effectiveness, reduced cost overruns and delays, lower administration costs, better time control, increased productivity, less conflict and improved conflict resolution strategies, dispute reduction, the opportunity for innovation, sharing risk between parties and financial success because of win-win attitudes are obtained. Moreover, partnering leads to improved work environment and continuous improvement of quality in product and services and earlier completion of the project (Hosseini et al., 2018; Bayramoğlu, 2000).

Successful partnering requires a plan in which partnering approach can be applied in an organization that focuses on quality, an effective project team, a set of tools by which the partnership approach can be structured and applied, implementation of determined standarts and specifications about product and service quality, management's commitment and

leadership, identification of problems and establishment of long-term and trust-based relationships between different parties for continues improvement. Project partnering is an approach used to enable the different parties involved in a project to work cooperatively. Project partnering is a collaborative management effort among contracting and related parties to compete a project in the most efficient, cost-effective method possible, by setting common goals, keeping lines of communication open and solving problems together as they arise (Kanji & Wong, 1998). It requires for cultural changes among the different parties to cooperative relatonships. Much of the literature tends to presume that cultural alignment where organizations share some basic values, attitudes and beliefs, is a prerequisite for partnering (Bresnen & Marshall, 2000). Effective partnership requires a high level of trust and sharing, and achieving it calls for a cultural and behavioral change in values, organizational structure, the way people work together.

Cultural change is a change in personal and organizational behavior (Sommerville & Sulaiman, 1997). Cultural change requires communication between all employees and top management as well as communication with customers and suppliers. Change must start from top management, and everyone must be involved. It is necessary to analyze the main influence factors determining the culture of the organization in order to ensure cultural change in a company and to create a corporate culture. The factors determining the culture of the organizations consist of internal influence factors (routine, ritual and procedures, control and reward system, organization structure, stories, myths and heroes, symbols, power structure) called as the cultural web and external influence factors (societal values and business environment). In order to change these values in the long-term, planning, patience and determination are required together with top management leadership (Figure 1) (Sommerville & Sulaiman, 1997).

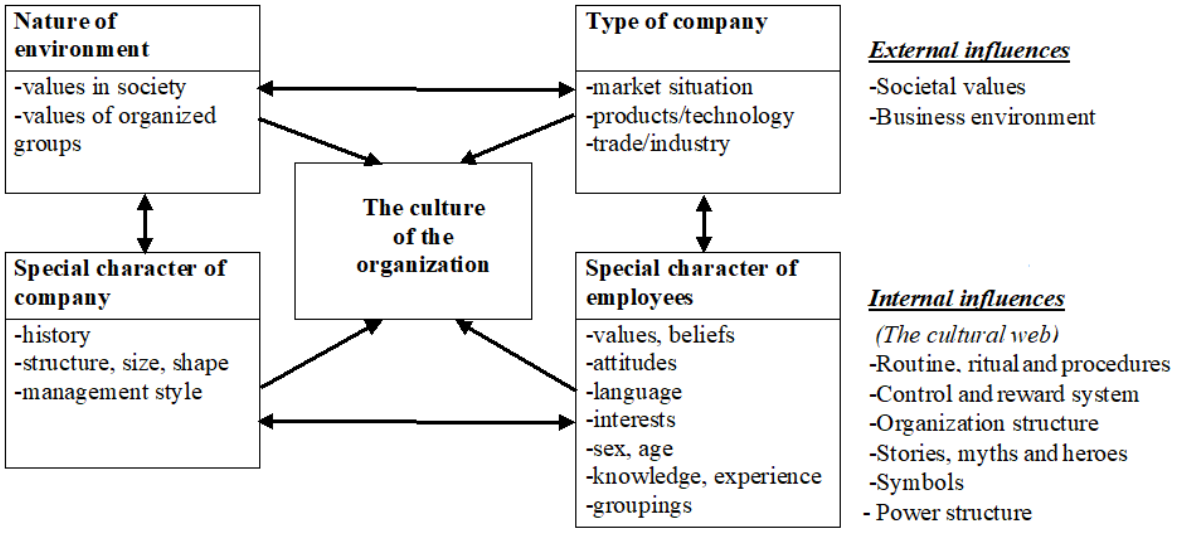


Figure 1: Factors determining the culture of the organization in the construction sector.

Here, it is easy to change the organization structure, control and reward system, routines and procedures which are expressed as hard part of the cultural web but stories, myths and heroes, symbols, power structure (politics that influence decision) which are expressed as soft part of the cultural web are difficult to change. Figure 1 shows the main influence factors affecting

the culture of the organization and the change in any of these elements will affect the culture of the organization (Sommerville & Sulaiman 1997).

In an organization where cultural change is achieved, there is a belief that everyone feels responsible for continuous improvement of work processes and customer satisfaction (Güner & Giritli, 2004). Systems that enable participation such as quality circles, recognition and rewards etc. should be used in changing the corporate culture. Education and training should be widespread in the organization in order to change the attitudes of employees and increase the productivity (Güner & Karaçar, 2016). If the corporate culture obtained after cultural change meets the needs of all stakeholders, including suppliers, in the continuous improvement of the process, this adaptable nature is called quality culture. Quality culture is referred to as an environment reflecting positive commitment to quality outcomes, products, systems, and processes; it stresses upon continuous improvement (Alotaibi, 2014). An organization with quality culture is also defined as an organization with clear values and beliefs that promote total quality behavior (Linkow, 1989).

Partnership approach, which is a tool for applying total quality management to the construction industry through teamwork, is a business execution system that maximizes the potential of improving communication, resolving conflicts, achieving quality determined by the application of total quality systems and procedures in managing the supply chain as a whole. Barriers to partnering are expressed as old style management, top management's failure to understand partnering, lack of commitment, poor planning, communication problems, having different values and failure to achieve culturel change (Bayramoğlu, 2000). In research studies it is seen that these factors also affect total quality management practices. In a study while the factors such as top management's commitment and leadership, communication, corporate culture, training, teamwork, employees' satisfaction and participation, establishment of long-term relationships with subcontractors and suppliers are identified as critical success factors in total quality management practices in the construction sector, factors such as lack of top management's commitment, perception of costly and time-consuming practices, lack of training and communication, lack of employees' participation, challenges in cultural change, and selection of subcontractors with low bids are also identified as barriers to total quality management practices (Shoshan & Çelik, 2018).

Conclusion and Recommendations

In total quality management practices, a plan in which partnering approach can be applied in an organization that focuses on quality, an effective project team, a set of tools by which the partnership approach can be structured and applied, implementation of determined standarts and specifications about product and service quality, management's commitment and leadership, identification of problems and establishment of long-term and trust-based relationships between different parties for continues improvements are required for successful partnering, which is a teamwork approach that involves customer, contractor and suppliers dedicating themselves to closer relationship to increase performance and improve production.
Establishing such trust and cooperative relations requires a cultural change; cultural and behavioral change in the way people work together and participate in quality practices. In total quality management practices, the organization at both project and company level should be established by including suppliers and ensuring that all employees communicate with each other and with top management. Systems that enable participation such as quality circles, recognitions and rewards, etc. should be used in ensuring cultural change. Training should be

widespread in the organization and appropriate motivation tools should be used. Top management should demonstrate commitment and leadership in applying project partnering and support cultural change with clear and visible actions.

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Reinforced Concrete Industrial Chimney Construction Management Site Application

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Abstract

Reinforced concrete industrial chimney is a special type of building in construction sector with using slip form system and continuous concrete casting technic. One of the hardest operations in reinforced concrete industrial chimney is to save the center point on vertical direction. There are limited standards and source about reinforced concrete chimney construction. In this study, the issues have to be paid attention at construction process are approached by following the method which is using in chimney construction site application works in order to ensure available criteria in standards.

Keywords: *reinforced concrete industrial chimney, continuous concrete casting, slip form, project management.*

Introduction

Reinforced concrete industrial chimney is a special type of construction with using sliding form system and continuous concrete casting technic. It is needed to be well planned.

Concrete design, installation of reinforcement, sliding form system setup, handling of construction material while sliding form was rising, continuous concrete casting, saving the center point of chimney on vertical direction are the important subjects for the management of reinforced concrete industrial chimney construction and should be well planned.

There are very limited number of research papers on site practice. In one of these studies, Selmanpakoglu (2011) studied on site application of sliding form system. According to this study; the setup of the sliding form system was done by laser pointers installed on the basement of chimney to check the vertical direction.

Most of the previous studies on reinforced concrete industrial chimneys are about theoretical calculations. Nuhoglu and Sahin (2005) investigated the dynamic behavior of industrial chimneys. Kahyaoglu and Koyluoglu (1972) studied on the calculation method of chimney. Sengun (2010) worked on computer aided design of chimney. Ramesh and Helen (2013) evaluated the feasibility of sliding form system with using building information modelling. Solomin (2016) investigated the tension on the shell of reinforced concrete industrial chimneys.

At this study, the construction method and followed steps of 95 meters height reinforced concrete industrial chimney, which has been constructed in Mersin province, are investigated from beginning to the end.

Material and Method

Reinforced concrete industrial chimney construction; due to the sliding form system and continuous concrete casting technic, it is necessary to decide on concrete design decision, continuous concrete casting, reinforcement installation, sliding form system installation, material handling during the operation, sliding form system setup to save the chimney center point on the vertical direction, and good planning and work follow-up for the management of all these works. Construction management points which are related with these steps shown above are investigated as below:

Concrete Design

Concrete grade, which will be used in reinforced concrete industrial chimney, will be determined by static calculation. Concrete design should be determined according to Turkish Standard TS 802 and there should be specific work bearing in mind that the casting conditions. In order to reduce the workability-setting time of concrete due to the continuous concrete casting and the surface adherence due to the use of sliding form, the design of the concrete should not include sulfate resistant cement, slag or fly ash added cement. The retarder additive to be used in concrete should be decided according to the tests which are performed at site conditions. Crushed sand ratio in the aggregate should be less than general ratio. Washed and separated river sand should be chosen. Concrete mixtures should be prepared according to these general criteria that are given above and cube samples should be prepared, and it should be seen that the 7 days old samples' compressive strength provides the static project value.

Reinforcement

All the rebar to be used for reinforcement must be obtained from the producer who certify that they produced in accordance with Turkish Standard TS 708, and it should be seen that the rebar of all nominal diameters provides tensile strength tests and provide the static project value.

Sliding Form System

After the site application and construction of the basement are completed, sliding form system, which is appropriate to the type and dimensions of chimney, should be installed on the basement. It should be ensured that the deviation distances occurring in the vertical axis from the center of the concrete chimney must be within acceptable limits according to ACI 307-98 standard. In order to track the smoothness in the vertical direction during the upward movement of the sliding form, four fixed points must be prepared on the sliding form system carrier frame. Four target boards should be placed on the chimney basement in the projection of these four points.

Rising Up the Chimney

Moving the sliding form upwards by about 2.5 cm at a time, after each movement of 25cm in total, the deviation of the optical chassis on the target boards should be read and recorded. According to each reading, the sliding form system settings should be intervened, and the sliding form should be moved upwards in the direction closest to the vertical axis of the chimney in accordance with ACI 307-98 standard.

Findings and Discussion

Project Calculation Criteria

As a result of the project work carried out in the reinforced concrete industry chimney, the concrete class to be used is determined as C30/37 and the reinforcement steel rebar class is S420.

Concrete Design

The preliminary design prepared for the concrete in accordance with the requirements of concrete chimney hauling with sliding form, is given in Table 1 following the instruction of experience of project management and the recommendation of the ready-mixed concrete company. In the laboratory environment, concrete was prepared according to Table 1 and it was observed that the concrete prepared by 7 days and 28 days concrete pressure tests fulfilled the calculation criteria (Table 2).

Table 1. The preliminary design of concrete.

Order No	Material	Explanation
1	Concrete Class	C30/37
2	Environmental Impact Class	XC3
3	Consistency Class	S4
4	Chloride Content (Cl) (By weight of cement maximum Cl %0.1)	0.1
5	Density Class	Normal
6	Water/Cement	0.55
7	Water (TS EN 1008)	186 kg/ m^3
8	Mineral Additive Type	No
9	Dmax	22mm
10	0-5mm Crushed Sand (TS 706 EN 12620+A1)	827 kg/ m^3
11	7-15mm Crushed Aggregate	252 kg/ m^3
12	15-22mm crushed Aggregate	741 kg/ m^3
13	Portland Cement CEM I 52.5R / TS EN 197-1:2012	360 kg/ m^3
14	Super Plasticizer (TS EN 934-2:2011+A1:C3.1/C3.2) (By weight of cement %0.8)	2.88 kg/ m^3

Table 2. Concrete compressive strength test results (C30/37).

Sample Age	1.Set (MPa)	2.Set(MPa)	3.Set(MPa)	Average(MPa)
7 days	40.1	39.5	38.8	39.5
28 days	46.6	46.2	43.4	45.4

After achieving the aimed concrete strength in the laboratory, it is necessary to be determine the retarder additive ratio in order to have the desired workability time of the concrete. Since the tests carried out in the laboratory environment can be misleading, this test was performed with the concrete produced directly in the ready mixed concrete plant. By weight of the cement weight 0.2 - 0.3 - 0.4 - 0.5 – 0.6 – 0.7% ratios of the retardant additive (TS EN 934-2 O: 10) (ASTM Type D) prepared with 1 each 100cm * 100cm * 100cm sizes and 6 pieces of 15cm*15cm*15cm sizes cube samples for each ratio were prepared.

After pouring $1m^3$ samples, every two hours after casting and the setting of concrete was observed rodding with rebar (Table 3). Samples with 15cm*15cm*15cm dimensions whose setting conditions are applicable were subjected to 7 days old and 28 days old pressure tests and the observation and test results are given in Table 4. According to the results, the most suitable ratio for the setting retardant additive was evaluated as 0.6% by weight of the cement. Accordingly, the amount of set retardant additive to be used in $1m^3$ concrete (360kg*0.006) was calculated as 2.16 kg.

Table 3. Determination of retarder amount.

Workability	Retarder ratio by weight of cement					
	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%
Slump (cm)	22	21	20	21	21	21
2 hours (cm)	0	0	0	0	0	0
4 hours (cm)	0	0	0	0	0	0
6 hours (cm)	100	100	50	10	0	0
8 hours (cm)	100	100	100	60	75	30
10 hours (cm)	100	100	100	100	100	70
12 hours (cm)	100	100	100	100	100	100

Table 4. Compressive strength of concrete with retarder.

Workability	Retarder ratio by weight of cement					
	0.2%	0.3%	0.4%	0.5%	0.6%	0.7%
7 days old (MPa)	35.5	39.5	39.6	40.3	35.8	36.8
28 days old (MPa)	44.7	45.9	44.9	42.9	44.5	45.7

Reinforcement Steel

It is seen that the rebar of all nominal diameters which come to the construction site provide the project value by performing tensile tests (Table 5).

In the reinforcement installation, all rebar inserts, including the vertical distribution bars left before raft foundation concrete casting, should be installed due to the work area is narrow and the spreading of the workmanship over time due to the continuity of the casting. At the same

time no resistance point is formed in the reinforced concrete structure. In order to make labor possible and to keep the rebar loss at the lowest rate, rebar lengths are taken maximum 6 meters.

Table 5. Rebar tensile test results (S420).

Order No	Nominal diameter (mm)	Yield Strength (N/ mm^2) (min420)	Tensile Strength (N/ mm^2) (min 500)	Tensile Yield Ratio (min 1.15)	Re,act/ Re,nor (max1.3)	Rupture Elongation (%) (min10)	Nominal Weight (kg/m)
1	10	481	588	1.22	1.14	17.90	0.621
2	10	485	590	1.22	1.15	19.80	0.623
3	10	465	569	1.22	1.11	20.40	0.625
4	12	431	522	1.21	1.02	21.20	0.889
5	12	449	567	1.26	1.07	18.50	0.891
6	12	459	576	1.25	1.09	20.70	0.893
7	14	421	559	1.33	1.00	15.70	1.211
8	14	424	557	1.30	1.01	15.70	1.213
9	14	425	558	1.31	1.01	19.60	1.215
10	16	467	572	1.23	1.11	16.10	1.582
11	16	467	578	1.24	1.11	16.70	1.583
12	16	470	580	1.23	1.12	17.40	1.585
13	18	482	599	1.24	1.15	18.40	2.001
14	18	481	597	1.24	1.14	15.90	2.002
15	18	481	598	1.24	1.14	20.90	2.003
16	20	445	578	1.30	1.06	17.80	2.471
17	20	437	575	1.32	1.04	15.90	2.473
18	20	441	580	1.32	1.05	19.70	2.475
19	22	474	659	1.39	1.13	14.90	2.986
20	22	475	658	1.38	1.13	15.20	2.988
21	22	476	660	1.39	1.13	20.10	2.990
22	25	459	588	1.28	1.09	23.00	3.851
23	25	462	586	1.27	1.10	13.60	3.852
24	25	459	584	1.17	1.09	16.50	3.853

Setup of Sliding Form System

After the site application and construction of basement are completed, sliding form system which is appropriate to the type and dimensions of chimney should be installed on the basement. After the sliding form system has been commissioned and the concrete pouring has started, the upward movement of the sliding form, the installation of the reinforcement into its place and the concrete casting works continue uninterruptedly up to the top level where the reinforced concrete construction will be completed. For this reason, continuity of the production and construction of the concrete chimney on the central axis, requires shift work, strict control and coordination.

Lifting system parts of the sliding form are; hydraulic power center, hoses, jacks and climbing rods. After the chimney basement concrete is poured, application and installation of sliding form carrier frames on concrete floor is made. The number of sliding form carrier frames is

selected according to the chimney diameter. On the frames that are bearing the sliding form; depending on the number of frames used, and in at least four of the optical plumbing stands, they are prepared at the same equal distance as possible. Target boards placed at the base upper level are adjusted to show the values to be read in the optical condition depending on the chimney slope and height.

Rising Up the Chimney

From the beginning of the concrete pouring, one immobile concrete pump and one mobile crane are continuously installed in the site and kept ready for service. During the upward movement; after the first 15 meters, the concrete and the reinforcement are transported to the working platform at the upper level by means of the elevator installed in the center hole of the chimney. The concrete, which is carried to the platform by buckets, is casted into the form by hand carts and placed into the form with vibrator. The setting of the concrete is measured by rodding before the 2.5 cm movement of the form again. The chimney reinforced concrete work lasted a total of 27 days and the equivalent cube compressive strength test results of the poured concrete during this period are given below. (Table 6)

Table 6. Chimney concrete compressive test results.

Concrete Casting Day	Compressive Strength of Concrete (MPa)		Concrete Casting Day	Compressive Strength of Concrete (MPa)		Concrete Casting Day	Compressive Strength of Concrete (MPa)	
	7 days	28 days		7 days	28 days		7 days	28 days
1st day	37.8	41.6	10th day	37.8	40.4	19th day	40.1	43.2
2nd day	38.6	43.8	11th day	37.6	39.9	20th day	38.8	44.2
3rd day	37.6	43.0	12th day	36.9	40.4	21th day	39.6	42.9
4th day	39.9	44.6	13th day	40.5	43.8	22th day	38.0	40.5
5th day	38.1	41.7	14th day	38.6	42.0	23th day	38.2	41.7
6th day	38.3	41.1	15th day	37.8	41.3	24th day	39.3	43.6
7th day	40.1	43.2	16th day	39.6	43.2	25th day	37.8	40.4
8th day	37.6	40.3	17th day	39.4	42.4	26th day	41.5	44.3
9th day	42.0	43.0	18th day	38.8	41.1	27th day	39.7	41.7

Adjustment of Sliding Form System

The management of the construction team, timely supply of materials, vertical transport of materials as the chimney rises, the form surface adheres to the concrete during the upward movement of the sliding form are all difficulties in the construction of reinforced concrete chimney, but the most important issue is the adjustment of the sliding form to keep it vertical. As the concrete chimney rises, sliding form adjustments should be made depending on the diameter changes according to the project and the deviation distances occurring in the vertical axis of the chimney center should be maintained within acceptable limits.

The vertical movement of the sliding form is adjusted with a part placed inside the jacks and moves about 2.5cm upward at each step. During the upward movement of the sliding form, the smoothness in the vertical direction is ensured by following the projections of the four points fixed on the form and the four target boards fixed on the floor.

The sliding form is moved upwards approximately 2.5cm at each time, and after each movement of 25cm in total, the deflection of the optical plumb on the target boards is read and recorded and the sliding form settings are interrupted according to the reading at each level and the sliding form goes in the direction closest to the vertical axis of the chimney is provided. Considering that the concrete construction speed of the reinforced concrete industrial chimney is approximately 3.5 meters per day, the sliding form moves upwards on average 350cm / 2.5cm = 140 times per day. After every 25cm advance of the chimney, the target board is read. This means that the sliding plate can be adjusted on average 14 times per day depending on the readings on the target board.

The layout of the optical plumb and target board of the 95 m high reinforced concrete industrial chimney constructed in Mersin is given in Figure 1. Due to the installation height of the 1.5m sliding form, along with scaffold and other parts, optical reading started from the 3rd meter. Optical reading was made up to 93.25m height, which is the bottom level of the 25cm thick floor of the 1.5m parapet at the top of the chimney. The deviation from the vertical axis calculated according to the optical plumb-target board readings made during the construction of the reinforced concrete industrial chimney is given in Table 7.

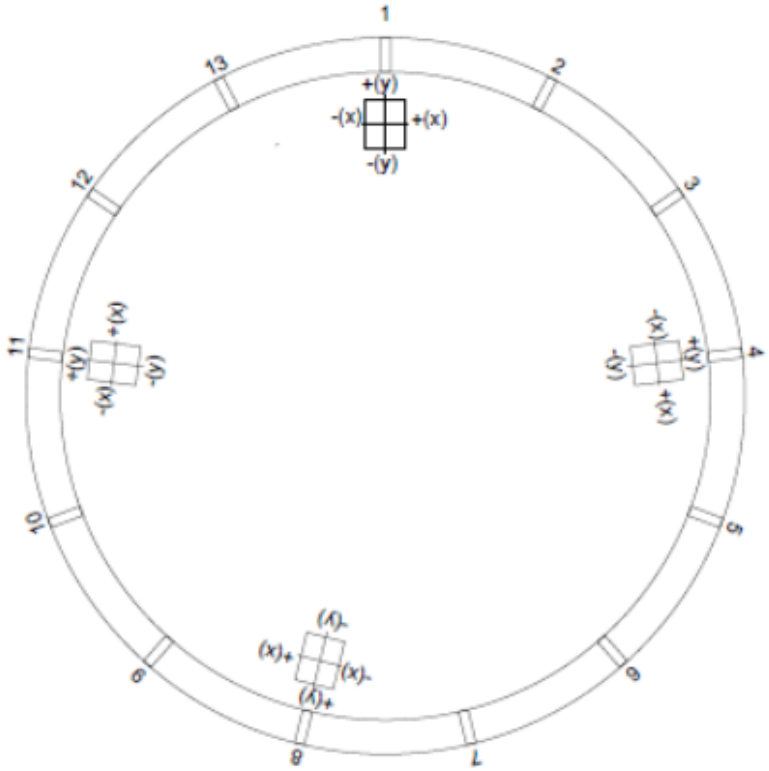


Figure 1: Sliding form feet and placement of target boards.

Table 7. Deviation distance from vertical axis of chimney center.

Optical Readings (mm)									
Order No	h (m)	Optic No:1		Optic No:2		Optic No:3		Optic No:4	
		X	Y	X	Y	X	Y	X	Y
1	3.00	6	-7	-9	2	-10	-8	-2	-5
2	3.25	12	-6	-10	0	-13	-7	2	-17
3	3.50	14	-6	-12	2	-3	-13	2	-17
…	…	…	…	…	…	…	…	…	…
323	83.50	10	-3	-19	5	-17	-19	19	-10
324	83.75	8	0	-15	0	-19	-20	16	-8
325	84.00	8	4	-18	0	-15	-15	19	-10
…	…	…	…	…	…	…	…	…	…
348	89.75	2	-10	5	12	-11	10	3	10
349	90.00	0	0	13	13	-13	10	13	-10
350	90.25	-9	17	-6	15	-13	10	13	8

When the values given in Table 7 are examined, the highest deviation distance from the vertical axis of the chimney center of the industrial chimney; h = 83.75 meters at the optical reading 3, -19mm / -20mm was determined and the deviation distance was calculated as 27.59mm. According to the ACI 307-98 standard, the center point of the shell shall not vary from its vertical axis by more than 0.001 times the height of the shell at the time of measurement, or 25mm, whichever is greater. According to this:

$$95m \times 0.001 = 0.095m = 95mm \quad (1)$$

$$95mm > 25mm \quad (2)$$

The upper limit of the deviation from the vertical axis is calculated as 95mm. The deviation distance from the axis in the highest vertical direction determined according to the optical readings given in Table 1; It is 27.59mm <95mm and conforms to the ACI 307-98 criteria.

Conclusions and Suggestions

The construction of the reinforced concrete industrial chimney is one of the special construction type within the civil engineering sector. Due to the limited number of technical personnel specialized in the site applications of reinforced concrete industrial chimney construction and the theoretical studies addressing issues other than the construction technique of the chimney, there are not enough scientific studies related to the site application of the concrete chimney construction.

In this study, it is expected to contribute to the development of new methods by explaining the main issues to be taken into consideration for the project management of reinforced concrete industrial chimney construction together with their reasons and by giving information about how a site application is performed. In addition, in the construction of reinforced concrete industrial chimneys; management of site teams, determination of concrete class to be used, preparation of concrete design, curing of concrete, working platforms,

vertical transportations and occupational safety is expected to provide benefits in dealing with many issues.

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TS 706 EN 12620+A: Aggregates for Concrete

TS 708: Steel for The Reinforcement of Concrete – Reinforcing Steel

TS 802: Design Concrete Mixes

TS EN 1008: Mixing water for concrete - Specifications for sampling, testing, and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete

TS EN 197-1: Cement-Part 1: Compositions and Conformity Criteria for Common Cements

TS EN 934-2: Admixtures for concrete, mortar, and grout - Part 2: Concrete admixtures - Definitions, requirements, conformity, marking and labelling

Roadmap For Integrated Usage of BIM And Lean Methods Throughout the Lifecycle of Modular Construction Projects

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Abstract

The emerging modular construction sector has attained ample interest given the plethora of benefits compared to conventional construction. However, with incorrect execution and lack of early planning, exorbitant costs are witnessed. This study focuses on portraying the integrated usage of Building Information Modelling (BIM) and lean construction methods throughout the lifecycle of modular construction projects to aid early planning. In this scope, a systematic literature review was executed and validated with experts' interactions for developing a roadmap. The outputs consist of illustrations shedding light on the topic currently. Previous studies depicted projects integrating these concepts at design stage, supply chain, or during module construction. However, this research considers the whole lifecycle, and the methodology integrates hands-on experiences from qualified industry experts. With the roadmap, project teams can get access to early-on guidance to efficiently handle a modular construction project. Hence, mitigating cost overrun and optimizing quality alongside clear communication with all organizational levels.

Keywords: *Building Information Modelling, design stage, guideline, lean construction, off-site construction, prefabrication, prefabricated construction, productivity.*

Introduction

Modular construction has gained much attention throughout the years due to its applaudable benefits when executed correctly. In brief contexts, modules produced in the factory for various project types are transported to the site ready to be installed and used. The time aspect is a remarkable element in this method of construction whereby site preparation is performed simultaneously to the module construction off-site. Similarly, modular construction positively adds on to sustainable built environment while reducing construction and demolition waste production and enhancing recycling possibilities of module at the end of the project's lifecycle (Ji et al., 2020).

With the fruitful outcomes that are derived from this modern method of construction, offsite construction does witness real-time challenges which are being investigated by researchers till date (Barkokebas et al., 2021). The design, transportation, and installation phases of an offsite project come along with constraints not only structurally but also the movement feasibility to the site (Wei al., 2021). Zhang et al. (2020) emphasizes on the need to consider production line and on-site installation of a modular project for process improvement. Current modular

construction projects lack a lean integrated approach, and it is of utmost importance to showcase effectiveness of lean tools and techniques to be used in different production stages (Innella et al., 2019). Hence, this study generates a structured roadmap showcasing the usage of Building Information Modelling (BIM) and lean construction methods throughout the lifecycle of modular construction projects which will aid in mitigating cost overruns and avoiding redundant waste production.

Research Background

Lean Construction Methods

Initially used in the manufacturing industry, lean production methods determine work cultures which aim at waste elimination. With a single waste source, the expected forecast is like a ripple effect and as production is more than required, cost overruns are witnessed with an overall non-value adding situation (Innella et al., 2019). Most commonly compatible lean construction methods for the modular construction sector include but are not limited to the Last Planner System (LPS), Just in Time (JIT), Value Stream Mapping (VSM), and Kanban system. Xing et al. (2021) investigated the implementation of multiple lean construction techniques and deduced that the most adopted one is the LPS with a percentage usage of 77.3%. Another commonly used lean construction method is the Just in Time technique. The arrival of modules as per and when needed to the site enables eradicating inventory waste (Si et al., 2021). Design for Manufacture and Assembly (DfMA) has seen overwhelming application in the prefabrication sector whereby cost is minimized and overall value adding activities are witnessed (Gao et al., 2020). With the urge for continuous improvement, including all organizational levels from the start of a project and having set goals, enables value adding activities throughout the project's lifecycle.

BIM in Modular Construction

BIM deems as a suitable platform to be embedded in a project aiming for clarity and cooperability from start to finish. Till date, a significant awareness rise was witnessed regarding BIM adoption for boosting efficiency of projects. However, managers are reluctant when it comes to making the investment in the platforms for information sharing and collaborating teams due to the short duration of projects being worked on (Barkokebas et al., 2021). BIM has also seen integrations with other platforms for achieving environmental analysis of prefabricated elements (Ji et al., 2020). For sustainability prospects, material passports are being digitalized into BIM to support an environmentally friendly project (Atta et al., 2021) Internet of Things (IoT) and BIM have also witnessed major attention in current research due to the real time database which exactly pictures the demands for logistics purposes (Lee & Lee., 2021). Smart BIM entered the industry with an aim to facilitate the on-site assembly services (Zhou et al., 2021). As for the possible BIM authoring software, Yin et al. (2019) suggests Revit, Bentley, and ArchiCAD. Quality-wise BIM platforms is a rich and reliable option when opted as from the design phase (Li et al., 2020).

Research Methodology

The methodology consisted of a thorough literature review and precise analysis was performed with the case studies from the publications. To further cover all aspects of the research topic, experts in the field were contacted and their valuable judgement were recorded as well as validations to the derived outputs. This addition ensured that hands-on perspectives were also considered which strengthened the findings from the literature review. Figure 1 summarizes the flow of the methodology and depicts how the outputs were derived.

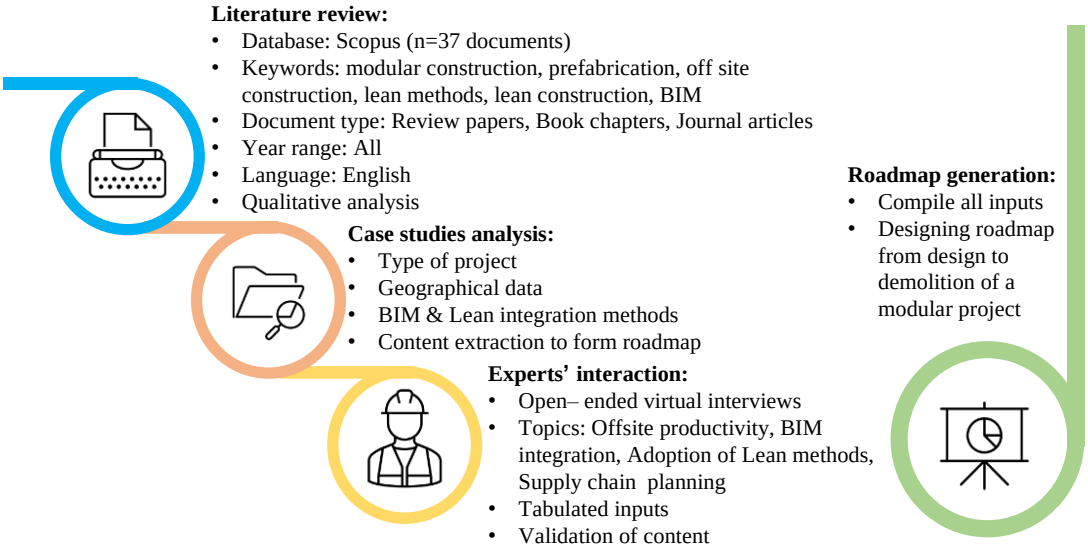


Figure 1: Research methodology.

Database Navigation and Literature Review Process

Throughout the literature search, it was deduced that Scopus deemed as the most reliable and broad database which covered publications holistically. Hence, with some set criteria such as keywords, document type, language, and technical field, the systematic literature review turned out precisely. An example of the database search is as follows: (TITLE-ABS-KEY (modular AND construction)) AND (BIM AND lean) AND (LIMIT-TO (DOCTYPE ,"ar") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE , "ch")) AND (LIMIT-TO (SUBJAREA, "ENGI")) AND (LIMIT-TO (LANGUAGE, "English")). An average of 87 documents were found during the database search. With analysis of titles and abstracts, the duplicates were removed, and the most related document were downloaded. Mendeley was used for navigating through and saving the documents. The finalized set of qualitative content was 37 documents. Full texts were checked, and publications that already performed case studies were then classified for data extraction.

Experts' Interaction

Data acquired from literature review were processed with Microsoft Excel in the form of graphs and tables. In the quest to form a roadmap of BIM and lean construction methods inclusion throughout the lifecycle of a modular project, 3 industry experts were contacted. The interaction

was semi-structured open-ended virtual interviews. Topics such as offsite productivity, BIM integration in construction, supply chain management, and overall current modular construction trends were discussed. This proved to be very enriching while experts incorporated their experiences to provide significant feedback on the subject. Hereafter, the experts were asked to validate the outputs derived in the investigation. Table 1 shows the profile of the experts that were considered for contributing to this study.

Table 1. Experts' profile.

Expert no.	Profession	Qualification	Years of experience in modular construction	Country	Interview duration (Minutes)
1	BIM consultant & founder	Bachelor's in Architecture	5	Ireland	40
2	Project coordinator	Bachelor's Applied technology (Architecture, project & facility management)	2	Canada	30
3	Project manager	Bachelor's Civil Engineering (lean 6 sigma black belt, Project Management Professional)	8	United Arab Emirates	25

Findings

Case Studies Adopting BIM and Lean in Modular Construction

Throughout the literature review, case studies were encountered, and the authors have portrayed productivity increase upon applying frameworks which suggest usage of BIM and lean concepts in modular construction. Table 2 below shows the relevant case studies analysed and the according methods applied with the productivity rise percentage.

Table 2. Case studies analysed in the literature review.

Project ID	Type of project	Geographical location	BIM-based methods	Lean concepts	% rise in productivity	Reference
1	Residential	Canada	-	Value Stream Mapping (VSM), Continuous flow, Balanced line	20	Zhang et al. (2020)
2	Commercial	Brazil	3D model-Revit & Dynamo	VSM	23.3	Barkokebas et al. (2021)
3	Residential	China	Luban BIM	-	-	Ji et al. (2020)
4	Residential	USA	BIM & GIS	Just in Time (JIT)	90 (In terms of decreased idle time of module)	Lee and Lee. (2021)
5	Commercial	Hong Kong	3D model-Solidworks	Kanban	50	Jiang et al. (2022)
6	Industrial	China	BIM & laser scanning	-	-	Li et al. (2020)
7	Residential	Hong Kong	BIM with IoT & Blockchain		50+	Li et al. (2022)
8	Commercial	Egypt	3D model-Revit & Navisworks	-	50	Eldeep et al. (2022)
9	Residential	Iran	-	VSM, JIT,Total Productive Maintenance (TPM)	43	Heravi et al. (2019)

Zhang et al. (2020) formed an elaborate framework which demonstrates usage of Value Stream Mapping at each stage of a production line which was segmented to tackle each stage such as floor framing, panel fabrication, among others. By using BIM and Value Stream Mapping at the premanufacturing phases of offsite construction, Barkokebas et al., 2021 achieved a 23.3 % increase in productivity. In China, Luban BIM collaboration platform is commonly adopted for developing the 3D model, quantity take off, and simulation while adding on to the environmental assessment of modular construction projects (Ji et al., 2020). The crucial start, which is the supply chain and logistics handling, can be efficiently tackled if BIM and Geographic Information System (GIS) integration is performed. With real time information by subscribing to the Internet of Things (IoT) databases, the digital twin can indicate exact demands at the logistics stage (Lee & Lee., 2021). In the highly digitalized sector, robot

involvement for assembling of modules proved to enable 50% productivity rise alongside Kanban principles (Jiang et al., 2022). When it comes to a collaborative platform, Li et al., 2022 applied a blockchain enabled IoT BIM platform that included all stakeholders alongside the project team members. A rarely applied lean construction method known as Total Productive Maintenance (TPM) was depicted by Heravi et al. (2019) in a residential building with improvements seen in the timeline and cost-wise.

Experts' Interaction Outputs

The 3 experts contacted in this study all agree that good project management with BIM and lean construction methods form the stable foundation required to achieve efficiency in a modular project. Furthermore, based on their valuable hands-on experiences, a major point that was outlined is that the new technologies would require further investment, and this is linked to the major pillar which is the client. For example, knowing that investing in sensors to monitor health of the structure, would guarantee a better future for the building and the facilities management, the client has the final verdict in this. Similarly, based on location of the project, while being situated in an urban area, the thought should be given to commute and accommodation of workers at the installation phase. This is also another reason where latest technologies are not being opted for by clients if the latter can be done the traditional way and cheaper. In terms of the demolition stage, since modules can be recycled and reused most of the time, a similar approach to the supply chain management performed with BIM and lean construction tools can be integrated again to relocate or organize the demolition process. This shows how modular construction contributes to the circular economy in the sustainable built environment and adds value to the architecture, engineering, and construction industry.

Roadmap for Integrating BIM and Lean Construction Methods Involvement in a Modular Project Lifecycle

Like a hierarchical representation, the roadmap developed proceeds in a systematic order that accompanies the team members of a project from supply chain to the occupancy phase. The holistic consideration promises mitigation of risks early on and prepares a project to achieve full efficiency with integration of all organizational levels. At the occupancy phase, remarkable efforts have been witnessed whereby integrating sensors to BIM platforms have shown how structural health of components can be monitored in real-time (Olawumi et al., 2021). Overall management of a project efficiently can be achieved via a cloud-based BIM platform (e.g., BIM 360 Field), storing all databases made accessible to project teams (Zhao et al., 2019). Taking into consideration case studies' performances and suggestions from industry experts, the roadmap in Figure 2 paves a clear way for the project team to uplift the work culture and make the utmost of the highly digitalized industry.

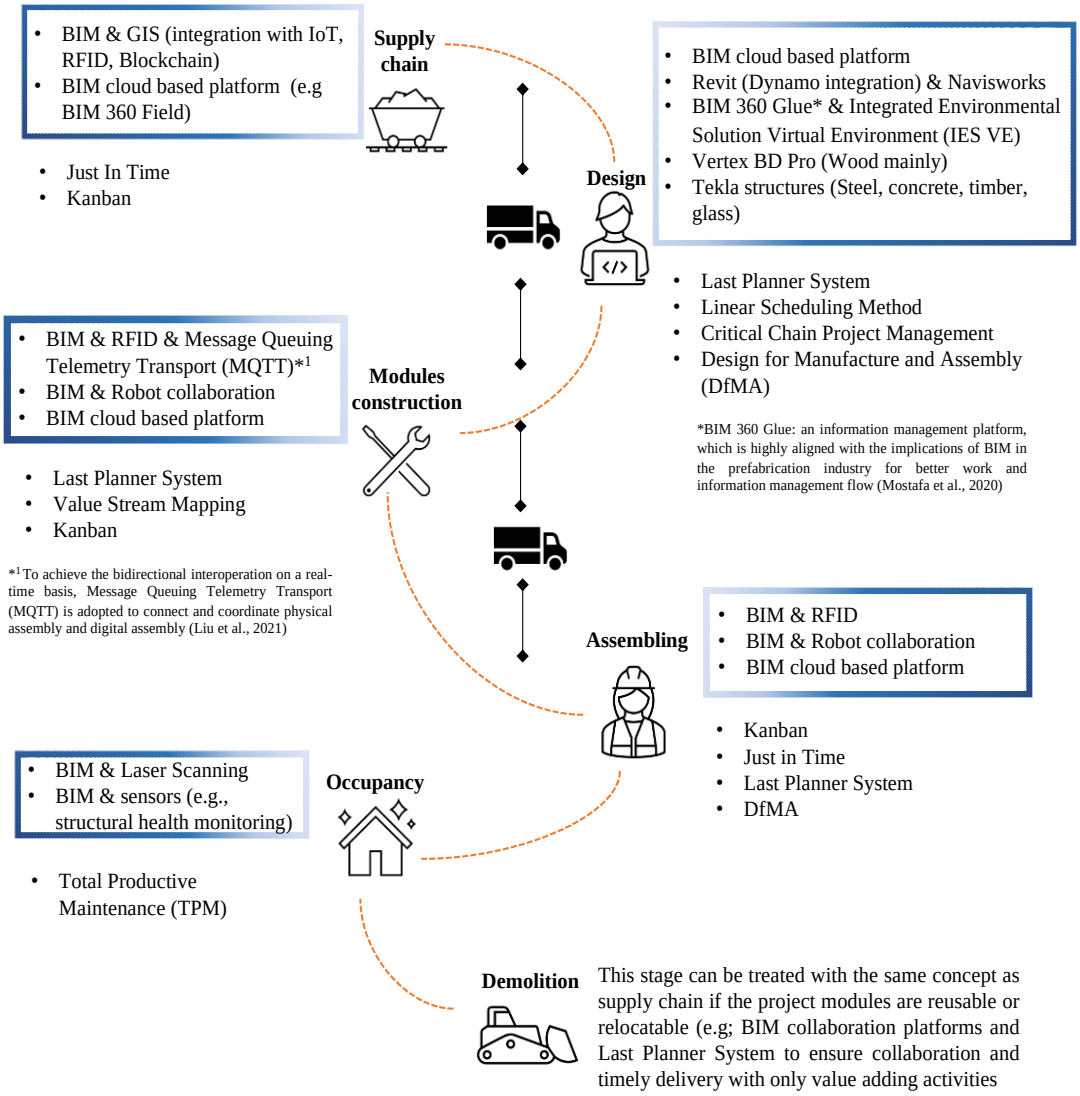


Figure 2: Roadmap for usage of BIM and lean construction methods in the lifecycle of a modular project.

Discussions

With a thorough exploration on BIM platforms and lean concepts used in the prefabrication sector, the most common and major issue withholding projects from making the change is the investment factor. Given the projects' short timeline, project managers are reluctant to invest and are not fully confident in the efficacy range to witness. While investigating the lean construction concepts, Just in Time principles are among the most needed throughout the modular construction lifecycle. However, with the waiting period for supply chain to fully implement the latter, the other parties such as contractor, client, and designers are left with no choice than to witness some barrier between their respective involvement stages (Mossman and Sarhan., 2021). Due to the working style of manufacturing industries, modular projects deem suitable for applying most of the lean concepts and when combined with BIM platforms, the exponentially rising costs could be tackled soon. Moreover, applaudable interest was denoted

in terms of blockchain, laser scanning, RFID, IoT, and Genetic Algorithms usage with BIM platforms. These had as aim to handle the large databases and provide real time updates to all organizational levels; hence, decreasing the cost overruns and scheduling risks of modular construction projects. A remarkable investigation by Li et al. (2018) introduces a concept namely RBL-PHP (RFID/BIM/Lean – Prefabricated House Production) and the latter displays how to decrease uncertainties from the logistics phase with evidence shown in workshops done with academicians and practitioner. Figure 3 shows the identified frequency of the mentioned methods which are applied to modular projects. The frequency appearance was acknowledged from literature review documents and the demolition phase was the sole item depending on experts' statement since there was an absence of literature relating to the latter.

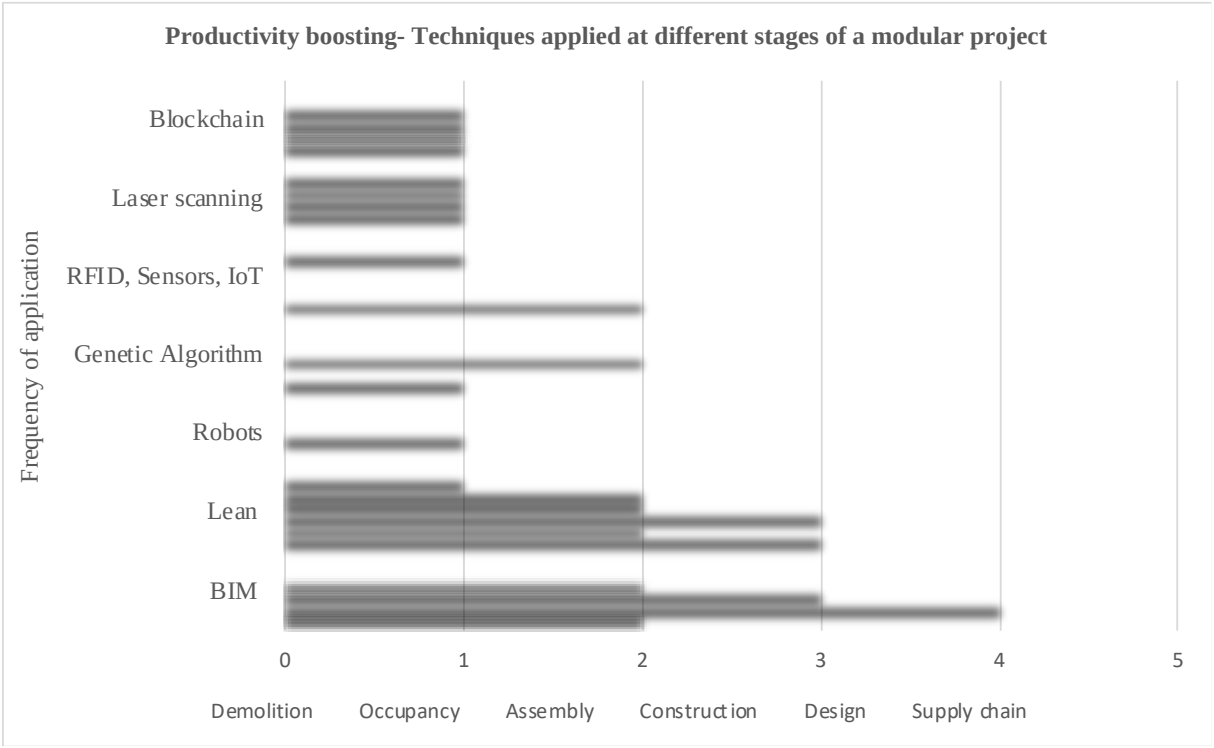


Figure 3: Application frequency of methods for efficient modular construction.

Conclusion

This study specifically indicates how efficiency can be achieved with BIM and lean construction methods usage throughout the lifecycle of a modular project. With the holistic consideration from supply chain to demolition, the roadmap did not leave any loopholes. Referring to the latter can direct team members towards early planning and all-inclusive collaboration, hence mitigating cost overruns and witnessing value adding activities at every phase. BIM platforms have justified their performance in multiple cases as analysed in this study. From the logistics handling to the occupancy stages, with commitment for collaboration and accessibility, the productivity of a modular project is guaranteed. Lean construction methods have depicted the positive integration of all organizational levels while promoting value-adding tasks in the projects. One limitation of this study included the lack of projects or expert's awareness of how the demolition phase could take place efficiently with BIM and lean construction methods. This is mainly due to the lack of BIM and lean adoption in the demolition phase of modular construction projects in the current industry. Future studies could focus on

how to handle the early integration of technologies such as IoT, blockchain, RFID, sensors, and Genetic Algorithms, will lead modular projects towards on budget achievements alongside quality optimization. A precise attention can also be given to the demolition stage of a modular project while bearing in mind the plethora of potential in terms of sustainability achievements.

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Exploring The Critical Success Factors of Offsite Construction Method in Turkey

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Abstract

The offsite construction method consists of well-established techniques, which can enhance the productivity of the construction industry by transferring some portion of onsite work to fabrication shops. Even though it has many advantages, the implementation of offsite construction is still limited in the Turkish construction industry, and several challenges affect the success of its applications. This paper aims to examine the Critical Success Factors (CSFs) for successfully implementing the offsite construction method in Turkey. In this respect, a total of 14 CSFs evaluated under five categories by utilizing Analytical Hierarchy Process (AHP). The results showed that the three most critical factor groups are i) leadership, ii) technical, and iii) resources. The first five most significant CSFs were determined as i) project managers' problem-solving ability, ii) contractors' leadership & experience, iii) effective information sharing, iv) skilled labor availability, and v) the maturity of techniques & technologies used. This research provides insight into the Turkish construction industry for further deployment of offsite construction methods in the market.

Keywords: *Analytical Hierarchy Process, critical success factors, offsite construction.*

Introduction

Offsite construction is one of the oldest construction methods. It refers to the planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support a permanent structure's rapid and efficient construction (Schoenborn, 2012). Previous studies have shown that offsite construction has many advantages over traditional construction methods. Improved quality, lower costs, and lower labor requirements on-site (Goulding et al., 2017) are some advantages of the offsite construction method. Moreover, preproduction in a controlled environment minimizes the risk of delays due to weather conditions (Lu & Liska, 2008). Modular construction, which can be defined as a subcategory of offsite construction, can save around 40% of construction time compared with traditional construction methods. Offsite construction offers possible cost reductions with on-site overhead reduction, design standardization, a high energy efficiency level, and higher installation efficiency. Automated machinery usage in offsite construction facilities can result in higher product quality. (Kamali & Hewage, 2016).

On the other hand, although the offsite construction method is deep-rooted, it is not commonly used as the traditional method of construction. The UK's market share of offsite

construction is around 6-7% (Taylor, 2010). The share of offsite construction methods in the USA is 7% (HAC, 2011). Moreover, Polat and Damcı (2007) point out that while the market share of precast concrete is only 6% in Turkey, it rises to 40% in northern Europe. Even though offsite construction is crucial for developing countries like Turkey, not much research has been conducted on determining critical success factors for offsite construction in Turkey. Thus, this study aims to contribute to the literature by determining essential success factors from the perspective of the Turkish construction market.

Literature Review

Offsite Construction

Most applications of the Architecture, Engineering, and Construction (AEC) industry are not appropriate for mass production, and it causes the sector to be inefficient and unproductive. On the other hand, off-site construction has a great potential to increase productivity by providing automation in the production of building elements (precast or compound materials) in a factory environment (Laubier et al., 2019). As Martinez et al. (2021) state, off-site construction has competitive advantages in the industry because of the adoption of automation and innovative approaches. Therefore, the sector has benefited from manufactured construction for years. Modern Method of Construction (MMC) originated in the United Kingdom by referring to both offsite-based construction technologies and innovative onsite technologies (Goodier & Gibb, 2006). As its definitions suggest, MMC is an innovation-based term rather than consisting only of industrialized or off-site techniques (Burwood & Jess, 2005). Especially after World War II, there has been an increasing demand for new housing in the US and Europe. Trials of applying off-site construction techniques in high-rise buildings led to the emergence of twenty and more story pre-constructed buildings. In addition, modern techniques increased the possible complexity level of using off-site construction. Therefore, the construction industry may benefit from off-site construction to achieve its potential, considering the positive effects of emerging approaches.

Factors, Enablers, and Barriers of Offsite Construction

Critical success factors of off-site construction have been a research topic to understand the concept and determine ways to increase its application. Findings from numerous studies vary due to the market conditions of the countries where the study occurs. Several studies have investigated different subsections of off-site construction, such as modularization, prefabrication, preassembly, and industrial building systems (e.g., Kamar et al., 2010; Li et al., 2018; Yunus & Yang, 2012; Gibb & Isack, 2003). In addition, there is much research on off-site construction and its subsections to determine benefits, weaknesses, and barriers. In this research, to evaluate the factors from a broader perspective, literature with different countries' different subsections of off-site construction is used as a source.

James et al. (2014) conducted a study in the US and investigated critical success factors and enablers for industrial modularization. This study determined 21 critical success factors through a literature review. The research findings showed that 57% of CSFs were related to the owner of the project, 33% were related to the contractor, 7% of critical success factors were related to vendors & technology licensors, while 3% were related to other stakeholders.

In this study, CSFs were also examined according to the project phases to which they were related. It was found that 31% of CSFs were related to the assessment phase, while 23% were associated with the basic design, and 20% were related to the selection. Three other phases of the project, execution, opportunity framing, and startup, were related to 27% of CSFs. According to this research, the three most essential CSFs are module envelope limitations, alignment on drivers, and owner's planning resources & processes.

Similarly, Elnass et al. (2014) searched for the factors and drivers affecting the decision to use off-site manufacturing systems in the house building industry. Thirty interviews were conducted with clients, contractors, consultants, project managers, design managers, and contract/construction managers to understand the OSM from the perspectives of construction professionals. The outcomes of the interviews were cross-checked with 15 case studies. According to the result of this research, time, quality, and cost were selected as critical factors affecting the decision to implement off-site construction. Predictability, productivity, interface issues, environment issues, performance, labor, and lack of space were considered moderately essential factors. Safety, project complexity, and logistics issues were determined to be usually crucial with very low importance impact with 10 to 14 out of 100.

Moreover, Xiahou et al. (2018) researched the driving factors of China's construction industrialization (CI). The authors conducted a systematic literature review, and 14 CIDFs were determined using the grounded theory method (GTM). Furthermore, a questionnaire was conducted with 123 professionals involved, and the identified factors were listed according to their relative importance. Findings of this research showed that; lack of labor, shortage of resources, productivity improvement, serious environmental problems, and quality improvement were forming the most significant five driving factors of CI. On the other hand, in Turkish literature, critical success factor determination for off-site construction was partly done by some studies focusing on specific techniques (Polat & Damcı, 2007). Thus, this study aimed to fill this gap in the literature and present the CSFs in Turkish off-site construction.

Methodology

This study aims to find the critical success factors of off-site construction in Turkey and determine a consistent ranking among them. For this purpose, factors were defined through a detailed literature review then an AHP model was developed to prioritize the selected success factors.

Identification of Critical Success Factors

We conducted a literature review to understand the concept of off-site construction and determine its benefits and use areas. In total, over fifty papers were reviewed related to off-site construction. The literature review considered similar terms such as OSM, OSP, OSF, IBS, Pre-assembly, Prefabrication, and Prefab. A systematic selection of the papers was processed to determine CSFs from the literature. As a result of the literature review, a total of 74 factors were selected. Then, the final list of 14 factors was listed under five categories (regulatory, technical, process, resources, and leadership) after combining similar CSFs. Table 1 shows the factor list with references.

Table 1. Factor list.

Group	No	Factor Name	Reference
Regulatory	1	Government Promotion	(Li, et. al., 2018)
	2	Supporting Policies & Legislations	(Xiahou, et. al., 2018), (Yunus, et. al., 2012)
	3	Revisions to Building Regulations	(Pan, et. al., 2007), (Elnass, et. al., 2014)
Technical	4	Timely Design Completion	(O'Connor, et. al., 2014), (Li, et. al., 2018)
	5	Assembly Planning Method	(Li, et. al., 2018)
	6	Preliminary Module Definition	(O'Connor, et. al., 2014)
	7	Designers' Experience	(Li, et. al., 2018), (Kamar, et. al., 2010)
Process	8	Effective Information Sharing	(Li, et. al., 2018), (Kamar, et. al., 2010)
	9	The Maturity of Techniques & Technologies Used	(Li, et. al., 2018), (Kamar, et. al., 2010)
Resources	10	Integration of the Supply Chain	(Xiahou, et. al., 2018), (Ismail, et. al., 2012)
	11	Sufficiency of Manufacturers and Suppliers of Prefabricated Components	(Li, et. al., 2018)
	12	Skilled Labor Availability	(Li, et. al., 2018), (Blismas, et. al., 2008), (Pan, et. al., 2007), (Gibb, et. al., 2003), (Elnass, et. al., 2014), (Kamar, et. al., 2010), (Xiahou, et. al., 2018), (Yunus, et. al., 2012)
Leadership	13	Contractor Leadership & Experience	(O'Connor, et. al., 2014), (Kamar, et. al., 2010)
	14	Project Managers Ability to Solve Problems	(Li, et. al., 2018), (Kamar, et. al., 2010)

Analytic Hierarchy Process (AHP)

AHP was introduced to literature by Thomas Saaty in 1980. It was designed to compare interchangeable elements efficiently and determine their importance by pairwise comparison. The following attributes of AHP make it suitable for this study (Saaty, 1988): measuring priorities and choosing among alternatives, calculating the consistency of the acquired answers. Sipahi and Timor (2010) showed that AHP is used more frequently than Fuzzy AHP, ANP, and Fuzzy ANP alternatives. Since the dependency between the determined CSFs is absent or negligible, AHP is also applied in this study.

We implemented the AHP method in three steps in this study:

1. We defined the goal and established a hierarchical structure.
2. The priorities of the factors were evaluated through pairwise comparison matrices using the Likert scale.

3. The comparison matrix was formed and normalized.

Data Collection

A focus group was formed to evaluate factors determined from the literature review. Collected factors from the literature investigated the offsite construction from every different point of view, so they were not necessarily meant to be critical success factors for the Turkish construction industry. The focus group consists of four experts in various areas of the construction industry to have a broader perspective (Table 2).

Table 2. Focus group information.

No	Profession	Experience
1	Academician	11 years
2	Business Development	18 years
3	Project Management	10 years
4	Manufacturer	13 years

Table 3 shows the details of the participants for AHP analysis. The questionnaire was distributed by e-mail to 138 professionals from the construction market. Forty-two experts responded to the questionnaire with a response rate of 30,4%. Experts with less than five years of experience formed only 22,5% of the total responders. The majority of experts had experienced between 15 – 20 years.

Table 3. Expert information.

Experience	Number of Experts	Percentage (%)
Technical Office	12	30,0
Company Owner	10	25,0
Field - Operation	9	22,5
Business Development	3	7,5
Procurement	3	7,5
Design	1	2,5
Management	1	2,5
Academic	1	2,5

Findings

Factor groups' weights are presented in Table 4. According to the results, leadership (0.232) was selected to be the most critical CSF group. At the same time, the technical category (0.231) was ranked as the second most important factor group. These categories were followed by the resources (0.199), the regulatory (0.171), and the process categories (0.167),

respectively. Finally, in terms of CSFs, project managers' problem-solving ability (0.125), contractor leadership & experience (0.107), and effective information sharing (0.094) were found as the most important critical success factors for offsite construction.

Table 4. Importance weights of CSFs.

Group	Group Weight (w_g)	Critical Success Factor	Factor Weight Among Group (w_f)	Factor Weight Global (W)
Leadership	0.232	Contractor Leadership & Experience	0.461	0.107
		Project Managers Problem Solving Ability	0.539	0.125
Process	0.167	Effective Information Sharing	0.563	0.094
		The Maturity of Techniques & Technologies	0.437	0.073
Regulatory	0.171	Government Promotion	0.322	0.055
		Supporting Policies & Legislations	0.368	0.063
		Revisions to Building Regulations	0.310	0.053
Resources	0.206	Integration of the Supply Chain	0.321	0.066
		Sufficiency of Manufacturers and Suppliers	0.324	0.067
		Skilled Labor Availability	0.355	0.073
Technical	0.231	Timely Design Completion	0.269	0.062
		Assembly Planning Method	0.230	0.053
		Preliminary Module Definition	0.193	0.045
		Designers' Experience	0.309	0.071

Discussion and Conclusion

Offsite construction has many advantages over the traditional method of construction. However, the offsite construction method obtains a meager market share relative to the traditional method of construction. Thus, this study aimed to define CSFs of offsite construction in Turkey. After determining critical success factors through the literature review, a questionnaire survey was conducted, and the AHP model was developed. The results showed that project managers' problem-solving ability (0.127) and contractor leadership & experience (0.107) were the most important critical success factors for offsite construction. These two factors showed that experience and leadership play the most crucial roles in the success of the offsite construction method. A study conducted in Australia resulted that industry knowledge was the most critical barrier to offsite construction methods (Blismas & Wakefield, 2008). The findings of Blismas and Wakefield (2008) match the

conclusions of this study by looking from another point of view. Project managers' problem-solving ability was rated as the second most important critical success factor in a study conducted in China (Li et al., 2018), similar to the results obtained in this study. Another study conducted in the UK also determined the leadership and management level as the second most crucial CSF, which also validates this study (Kamar et al., 2009).

Moreover, Effective information sharing (0.094) was the third most critical success factor according to the findings of this study. Another study in Malaysia shows that good working collaboration and effective communication channels were considered the four most significant critical factors (Ismail et al., 2012). These factors were subcomponents of the factor of effective information sharing that took place in this study. In another study conducted in Malaysia, effective information sharing was found to be the second most crucial CSF for industrialized building systems (Kamar et al., 2010).

This study contributes to the literature by determining critical success factors from the perspective of the Turkish construction market. Moreover, similar developing countries may benefit from the findings when evaluating offsite construction's success factors for their markets. However, this study has some limitations as well. The data used in the analysis are obtained from experts, and the experts' answers are subjective. Future studies might develop this study by applying different analysis methods.

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A Review on Implementation of Lean Construction Principles into Off-Site Construction Methods

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Abstract

Number of construction projects have increased in the recent decades due to rapid urbanization, globalization, population growth especially at the metropolis cities. Traditional on-site construction methods are not sufficient enough to satisfy demands like performing faster construction, less workmanship on site as well as minimized occupational accidents. On the other hand, off-site construction methods enable to manufacture components of the buildings in a more controlled environment while achieving more efficient construction planning, minimized accidents at site, less workmanship and less disruption to the local people. Project performance of the off-site construction projects can be enhanced by eliminating all unprofitable activities and generating value through the construction project life cycle. The main purpose of this paper is to present possible benefits of implementation of lean construction principles into off-site construction methods. In this regard, a brief information about off-site construction methods and lean construction will be mentioned. Then, a systematic literature review will be carried out regarding the implementation of lean construction principles into off-site construction methods. Finally, possible benefits by implementation of lean principles will be listed based on the results obtained from the systematic literature review.

Keywords: *construction project performance, lean construction, off-site construction, systematic literature review.*

Introduction

Construction projects are unique and non-standardized products (Murphy et al., 2018). The management of the construction projects has become more challenging as the complexity of construction projects increases (Bataglin et al., 2017). As a result, performance of the construction projects ends up with undesirable outcomes such as longer construction time, waste generation and lower efficiency in production (Sutrisna et al., 2022). Off-site construction is a method to manufacture building components in a more controlled environments and it contributes to reduce construction time, defects and unforeseen events (Barkokebas et al., 2021). There are studies demonstrate that off-site construction can be enhanced by integration of lean construction principles. As an illustration, Du et al. (2022) demonstrate to improve production scheduling of prefabricated components by integration of Just-in-time (JIT) and value-based management (VBM). Ahmad et al. (2019) focus on the elimination of non-value added (NVA) activities to enhance production processes in precast

concrete components by JIT, Kanban and layout improvements. In this sense, the main aim of this study to present a systematic literature review to identify possible benefits of implementation of lean construction principles into off-site construction. The structure of the paper is as follows. First, research methodology utilized in this paper will be mentioned. Then, a brief introduction to lean construction and off-site construction will be given. Thereafter, lean construction principles implemented in the off-site construction will be analyzed. Finally, results regarding the previous step will be discussed in detail.

Research Methodology

As a research methodology, systematic literature review has been conducted in order to determine the potential contribution of the lean construction principles though off-site construction. For the selection of the relevant papers regarding the research question, Scopus database has been utilized. Research articles and conference papers that have the key words including both "Lean Construction" and "Off-Site Construction/Prefabricated Construction" in abstract or key word sections are selected. According to initial search results, total number of 75 papers have been listed in the subject area of engineering. Among 75 papers, there are 33 papers encountered explicitly mention "Lean Construction" and "Off-Site Construction" between the years 2002 and 2022, and merely 16 of the papers demonstrated the potential contribution of lean principles via quantitative analysis. As a result, the response for the research question is tried to be drawn among 16 papers.

Lean Construction

Lean production is a management approach that combines principles, tools and techniques in the manufacturing environment which was firstly emerged in the manufacturing sector (Pedo et al., 2021). Lean construction is evolved through the adaptation of lean production systems firstly introduced in car manufacturing sector in 1990s (Koskela et al., 2019). Lean construction aims to reduce waste by eliminating all unprofitable activities and generate value all phases for the construction project (Lalmi et al., 2022). Lean construction principles can be applied to optimize construction management process (Brissi et al., 2022). As an illustration, Sacks et al. (2010) developed a framework in order to analyze the interaction of lean principles on BIM functionality, and they ended up 52 positive and 4 negative synergies between LC and BIM principles based on the previous literature. In that study, contribution of lean principles has been categorized regarding flow process, value generation process, problem solving and developing partners; and contribution of BIM has been categorized regarding design, design and fabrication detailing, preconstruction and construction. Babalola et al. (2019) identified 32 lean practices and associated the benefits with the implementation of lean practices in terms of economic, social and environmental aspects through a systematic literature review. Erol et al. (2017) focused on the positive impacts of implementation of lean construction principles on project duration of the residential buildings. Nowotarski et al. (2016) studied cost saving in the construction projects and revealed that lean management enables ease of cost saving. Fitchett and Rambuwani (2022) proposed lean principles as a strategy to reduce wastes in construction projects.

Off-Site Construction

Off-site construction enables to plan, design, fabricate and assembly of the building components in a more controlled environment rather than the final location of the building components (Marinelli et al., 2022). Off-site fabrication (OSF), off-site manufacturing (OSM), pre-assembly and prefabrication are the alternative terms that commonly used in the literature to mention off-site construction (Sutrisna et al., 2022). Marinelli et al. (2022) underline the biggest advantages of off-site construction as decrease in construction time on site, increase in the quality and elimination of defects. According to Tzourmakliotou (2021), the roots of off-site construction methods can be traced to the Roman time in AD-43 where Romans built same and repeating components of the forts. Britishers also utilized off-site construction method to be able to transport simple modular houses to construct new settlements. In 19th century, United States get benefit of the off-site methods to address the housing needs during the California Gold Rush. In recent decades, usage of off-site construction methods has increased to address problems regarding low efficiency and productivity issues in on-site construction approaches (Ahn et al., 2022). Nowadays, the implementation of off-site construction can be encountered especially in buildings from low-rise to high-rise (Thai et al., 2020). Shibani et al. (2021) mention the predominant building materials used in prefabricated form as wood, concrete and steel. In addition, Ginigaddara et al. (2021) categorize types of off-site construction under non-volumetric (components, panels, foldable structures) and volumetric (pods, modules, complete buildings). Further definitions, examples and features for the off-site construction categorization is presented in Table 1.

Table 1. Types of off-site construction (Adapted from Ginigaddara et al., 2021).

Types of Off-Site Construction					
Non-Volumetric			*Volumetric*		
Components	*Panels*	*Foldable Structure*	*Pods*	*Modules*	*Complete Buildings*
Definition: Non-volumetric elements of any shape or size, excluding flat panels	*Definition:* Flat elements that do not create usable space	*Definition:* A stack of panels interconnected with hinges	*Definition* Enclosed spaces repeatedly made with high level of finishing	*Definition:* Volumetric parts of a whole building	*Definition:* Single unit or single module building
Features: Mass manufacture, high level of pre-design, structural and nonstructural elements	*Features:* Usually rectangular, different subcategories are available	Features: Not common, economically unviable	*Features:* Repetitive, limited mix, high level of finishing	*Features:* Light-weight structures, have potential to become a complete building	*Features:* Large and complex, serves special needs
Examples: Trusses, staircase, columns, beams	*Examples:* Floor, wall, ceiling, roof panels	*Examples:* Residential buildings	*Examples:* Kitchen, bathroom, prison pods	*Examples:* Residential, school, apartment building	*Examples:* Construction site shed, disaster recovery building

Implementation of Lean Construction Principles into Off-Site Construction

Ahmad et al. (2019) highlight that application of the lean approach in off-site construction has several evidence in the improvement of the construction project objectives. In this regard, Meiling et al. (2012) conduct a survey to obtain the most suitable lean management principles applied in timber-framed module prefabrication manufacturing company for ensuring continuous improvement. Fourteen lean principles are divided into 4 categories in terms of long-term philosophy, the right process will produce the right results, add value to the organization by developing your people and partners and continuously solving root problems drives organizational learning. Creation of a continuous process flow to bring the problems, utilization of pull systems to avoid overproduction, stopping the work flow to fix problems in the first time, standardizing tasks for employee empowerment, growing leaders to teach lean philosophy to others, making decisions slowly and implementing decisions quickly, "go and see" to understand work at the exact condition, utilization of reliable technology, respect to other people are listed as the top lean principles used in the lean management based on the survey results. Hermes (2015) argues integration of construction processes with industrial mass production as an innovative approach and points out that continuous improvement can be achieved by utilization of modularization and prefabrication methods. In this sense, two lean approaches namely as Last Planner System (LPS) and Lean Project Delivery System (LPDS) are proposed to structure the manufacturing processes in terms of flow of the information and reduction of wastes. LPS is a scheduling method that requires partnership among project stakeholders. LPS enables to reduce errors and costs as well as catch the project deadlines. In LDPS, different phases of construction project like design, construction and operation are considered simultaneously rather than separately among project participants. LPDS is an efficient method to determine and manufacture standardized prefabricated components by communicating each party in advance. Trevisan et al. (2016) discuss the pull production system in the context of customized prefabricated building elements. The study of Trevisan et al. (2016) reveals that lead times and inventory levels can be decreased by implementation of pull production through customized prefabricated components. Bataglin et al. (2017) mainly focus on the process of planning and controlling the logistics of the Engineer-to-order (ETO) prefabricated buildings. In that study, 4D simulation model was tested for controlling the assembly process of ETO prefabricated buildings. The results demonstrate that visualization ease exchange and update the information among stakeholders and increase the reliability and transparency of the process among different disciplines. Heravi and Firoozi (2017) examine production line of prefabricated steel frames via Value Stream Mapping (VSM). VSM is lean technique that enables to determine non-value activities in the process. Heravi and Firoozi (2017) utilize VSM for identifying wastes and their root causes in the current production line for that purpose. According to remodeling of the production line, lead time of production is reduced by 34% and cost is reduced by 16%. Ahmad et al. (2019) focus on the integration of lean approach into to the reinforcement work process in the component production of industrialized building system precast concrete construction to identify and eliminate non-value added (NVA) activities. NVA activities in the production line are identified as unnecessary inventory, excessive movement and coordination issues; and JIT, Kanban, layout improvement have become the lean principles addressed for the elimination of NVA activities. Murphy et al. (2018) state the problem in prefabricated elements as waste due to waiting and defects during construction. In their study, utilization of Virtual Design and Construction (VDC) methods enable to increase productivity up to 30% during production. In addition, VDC methods address the predictably problem considering the coordination among different trades and provide feedbacks in design phase for the further stages of the production. Xu et al. (2018) propose an integrated cloud-based Internet of Things (IoT) platform to facilitate operation process (production, logistics, on-site assembly) of lean prefabricated

construction. Utilization of IoT technologies enable to enhance automation, real-time data collection, remote control, visibility and traceability of lean prefabricated construction processes. Their study demonstrates that overall paper works have been lessened by 40%; the time for locating a prefab, waiting time for delivery, and order picking time have been reduced by over 20% through real-time information sharing. In addition, on-time delivery rates have been enhanced by 7.3%. Goh and Goh (2019) develop a detailed simulation model to present Prefabricated Prefinished Volumetric Construction (PPVC) operation by Discrete Event Simulation (DES) and VSM. Total Quality Management (TOQ), internet-based Kanban system and construction robotics are the lean principles implemented where those principles enabled to reduce cycle and process times by 81.27%, increase resource utilization rates by 17.91%, decrease work-in-progress levels by 74.30%, enhance process efficiency by 4.58 and labor productivity by 398%. Bataglin et al. (2020) propose a model based on pull production and reduce variability principles for planning and controlling of ETO prefabricated building system in the context of the site installation and logistics. Implementation of the model contributes improvement of the reliability of overall planning process by 95% and productivity up to 39 components per day. Darwish et al. (2020) integrate DES into lean philosophy to analyze various scenarios in multiwall panel production line. In the first scenario, process flow and floor layout modifications were done and according to initial results, idle time was reduced by 40% and total duration is reduced by 30%. In the second scenario, the previous nailing system was replaced, and total duration is reduced by 4% while the idle time increased by 30%. In the final scenario, the approaches used in first and second scenario were combined, and the cycle time and idle time were reduced by 42% and 35% respectively, and the production rate of panels were increase as 8 panels per day. Kanai and Fontanini (2020) study on a method to improve process flow planning of prefabricated concrete panels based on VSM and Visilean® though four scenarios. In the current scenario, real system was taken account to collect factory data. In the future scenario 1, pushed system was used and a little improvement was observed in comparison to the current scenario. In the future scenario 2, time of the current scenario was reduced by 25% with integration of pull system. Finally, process flow time of the current scenario was optimized up to 50% in the ideal scenario by implementing JIT system. Barbokebas et al. (2021) draw on digitalization by BIM-lean approach for enhancement premanufacturing processes during design, procurement, and bidding in off-site construction and a framework was developed in this sense. Lean philosophy was used to measure, identify and implement opportunities for improvements. Data collection and analysis were carried out considering “go and see” and VSM lean principles, planning and improvement for the future processes were done with Kaizen and waste minimization principles. The developed framework via lean-BIM integration ensures 22%-47% of task durations were reduced in pre-award and post-award phases of the project. Ayinla et al. (2022) analyze the wastes in off-site production of wall panel through two case studies. Wastes are identified considering Value Stream Analysis (VSA) and root cause analysis. Their analysis show that 47% NVA time is spent in the production line and overall lead time can be reduced up to 70% in a more organized flow. Du et al. (2022) address the scheduling problem during production of the prefabricated components by applying biogeography-based optimization (BBO) in planning and production stage where JIT and value-based management (VBM) are two core lean principles benefitted for the scheduling optimization in a limited time. Laika et al. (2022) suggest determining wastes in precast concrete production process via root cause analysis and eliminate wastes by 5S (sort, set in order, shine, standardize, sustain) and JIT techniques. According to their analysis results, total production time is reduced by 39%, total production cost is reduced by 33% and total idle time in production is reduced by 90%.

All in all, potential benefits of lean construction principles applied in off-site construction are summarized in Table 2 with their reference studies.

Table 2. Potential benefits of lean construction principles in off-site construction (References: A: Meiling et al. (2012), B: Hermes (2015), C: Trevisan et al. (2016), D: Bataglin et al. (2017), E: Heravi & Firoozi (2017) , F: Ahmad et al. (2019), G: Murphy et al. (2018), H: Xu et al. (2018) , I: Goh & Goh (2019), J: Bataglin et al. (2020), K: Darwish et al. (2020) , L: Kanai & Fontanini (2020) , M: Barbokebas et al. (2021) , N: Ayinla et al. (2022), O: Du et al. (2022), Laika et al. (2022)).

ID	*Lean Construction Principle*	*Potential Contribution in Off-Site Construction*	*Reference Study*
1	5S (sort, set in order, shine, standardize, sustain)	elimination of waste	P
2	Continuous improvement	employee and customer satisfaction, improved product quality	A, B, M
3	Decide slowly, implement fast	consideration of all options and risks in advance	A
4	Go and See	observation of the actual work in progress	A, M
5	Just-in-Time (JIT)	elimination of unnecessary inventory, addressing coordination issues	F, L, O, P
6	Kanban	increasing visualization, enhancement of communication among parties	F, I
7	Last Planner System (LPS)	decreasing errors and cost, following up the project deadlines	B
8	Layout improvement	reduction of idle time	F, K
9	Lean Project Delivery System (LPDS)	investigating which components can be standardized in advance	B
10	Pull production	avoiding over production, optimization of lead times and inventory levels, increasing project schedule reliability, increasing productivity	A, C, J, L
11	Root cause analysis	identifying wastes	A, E, N, P
12	Standardization	employee empowerment, decreasing customized work	A, B
13	Stop the line	obtaining a better quality end product	A
14	Value Based Management (VBA)	creation of value for all parties	O
15	Value Stream Mapping (VSM)	identifying wastes and root causes of the wastes	E, I, L, M, N
16	Visualization	ease of exchanging and updating information among parties, increasing reliability and transparency of the process	D, G, H, L
17	Technology (BIM, IoT etc.)	optimization of task duration, increasing automation of the work, enabling real time data collection, better visualization and traceability	H, I, M
18	Total Quality Management (TOQ)	higher productivity, increasing profitability	I

Discussion and Conclusion

In this study, a systematic literature review has been carried out in order to identify potential contribution of lean construction principles in off-site construction. According to literature review analysis, implementation of lean construction principles mainly addresses to optimize construction project time, reduce errors and waste, increase end-product quality, produce more reliable project schedules, enhance project coordination and communication among different disciplines. Optimization of project duration and enhancement of the communication are the top two construction project objectives analyzed in the previous literature. As an illustration, construction project schedule optimization for off-site construction has been performed through lean techniques including JIT, LPS, layout improvement, pull production, standardization and VSM. Besides, Kanban, LPDS, visualization, technology are utilized in order to enhance communication among several trades in off-site construction process. Even though the lean principles have several benefits in off-site construction sector, the shortcomings of the implementation of lean principles can be listed as follows. First of all, lean philosophy is not common in the construction sector, so adopting it might take some time considering the traditional management approaches in the construction sector. As lean construction is a state-of-art method, integration of it may require high initial investment cost at the beginning.

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Design-Construction Interface Problems in Construction Projects

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Abstract

The success of a construction project highly depends on delivering it on time, within budget, and at the required quality. To achieve project goals, the assessment of the constructability of the design gains prominence, as well as the well-management of the design process. Failure of design professionals to consider how a builder will implement the design can lead to disruptions and conflicts during the construction process. Consequently, many design-construction interface problems may arise and affect the overall project performance. This study focuses on the causes of design-construction interface problems and how to define them clearly. To achieve research objectives, a comprehensive literature review will be conducted, the most common design-construction interface problems will be identified and their root causes will be determined.

Keywords: *construction management, design conflicts, design-construction interface problems, design management.*

Introduction

With the breakthroughs of the public and private sectors, the process of managing large and complex projects has emerged. Recent years have seen a considerable increase in the push to improve design performance or to create high-quality design solutions in shorter timeframes. This is due to the increasing complexity of projects and the fiercer market rivalry (Tzortzopoulos & Cooper, 2011).

A project is an organization of a wide range of members of the project team. Throughout the project life cycle, each member of the project team is essential. According to Sugumaran (2013), the effectiveness of the decision-making and execution process throughout the entire project team is directly related to the information's availability, dependability, and accessibility as well as one's capacity to visualize what other parties convey. The quality of a construction facility is frequently a reflection of the data produced throughout the planning and design phases, and particularly of the level of construction input to the design process, therefore the design-construction interface is particularly crucial (Sugumaran, 2013).

First of all, it is important to define the concept of "interface". "Interface" is defined by Healy (1997) as; "a boundary where an interdependency exists across that boundary and where responsibility for the interdependency changes across that boundary" (Quoted by Yeganeh, 2019). Interfaces are the contact points for every work package and it's related to stakeholders

or stage/phase. Poorly managed interface management leads to poor productivity, poor quality, and increased cost which affects overall project performance negatively. Alarcon (1998) asserts that to successfully complete this step and improve the design-construction interface, it is crucial to distinguish between tasks that contribute "value" and those that generate "waste" throughout the design and building processes.

It is crucial to identify the major causes of errors and discrepancies and either eradicate them or lessen their negative effects to pinpoint problematic areas in the design-construction interface and create proposals for workable solutions. Accordingly, this study concentrates on;

1. analyzing the management of the design phase, errors, and failing points;
2. identifying causes of problems that occur during the design and construction phases;
3. sorting out relationship networks between stakeholders and assessing the potential causes of inconsistencies;
4. and analyzing the impacts of the above on project performance.

Therefore, this paper aims to focus on the causes of design-construction interface problems, search how to define them clearly. With this aim, the most common design-construction interface problems will be identified and their root causes will be determined. To reach these objectives, a comprehensive literature review has been conducted.

Design-Interface Problems

Many problems occurred in the construction projects, especially in interfaces. But there are no universally accepted definitions of Interface Management and its constituent parts. However, often, interfaces are seen as the divisions between autonomous, yet interdependent systems, project phases and scope packs, building materials, and stakeholders (Shokri, 2016). Problems with the design-construction interface vary in how they are categorized. The main attitude should be to trace and control them. For this reason, it is important to be aware of these problems at every phase and to foresee what causes these problems and what consequences these problems will have.

Bogus et al. (2003) stated that any attempts to reduce the overall project delivery time can be thwarted if design and construction are viewed as independent entities, often with little to no cooperation between them. Such a reduction is possible by moving toward an integrated design-construction interface (Quoted by Yeganeh, 2019). However, sometimes the stakeholders, which have their own goals, face different challenges during any phase of the project. Therefore, understanding the causes and their causation, which are connected to all project phases, can aid practitioners in taking them into account and avoiding their unfavorable effects in future projects, improving the interface integration, and making better judgements that may improve project performance (Yeganeh, 2019).

When the literature is examined, it has been seen that these problems are categorized differently according to the reasons for their emergence and the interfaces they occur. For this reason, what this "interface" is and what it consists of has been tried to be explained. Questions such as what is design-oriented interface management (1), what are the problems in the design management process (2), how is the contract management in particular (3), what are the problems for the project stakeholders (4), and the problems in the constructability axis (5) were examined under the headings.

Interface Management

The idea behind project management is interface management, which provides a "bird's eye perspective" and assists in avoiding time overruns, lowering cost overruns, minimizing reworks in construction, and also gaining quantifiable advantages like increased customer satisfaction (Manoj, 2010). To minimize their potential to have a detrimental influence on the project, interface issues inside the project's organization must be properly addressed. Wideman (2002) made two definitions of Interface Management: (1) *"The management of communication, coordination, and responsibility across a common boundary between two organizations, phases, or physical entities which are interdependent"*; and (2) *"managing the problems that often occur among people, departments, and disciplines rather than within the project team itself."* (Quoted by Chen, 2008) As explained here, Interface Management involves every part of the project in the built environment such as the project life cycle process, different phases of the life cycle, resources, schedules, systems, contracts, etc. Therefore, Interface Management cannot be considered separately from project management activities.

In this study, the authors focused on the problems which affected the design and construction phases especially. These two main processes are closely interconnected and the shortcomings in the design directly affect the construction process. Therefore, the problems in the design phase should be identified firstly, then their potential impacts on constructability will be discussed.

Problems Related to Design Management

The gap between design and management has grown as a result of changes in the construction industry, the continued specialization of professions, and the increasing use of alternative procurement methods. The requirement for a design expert with managerial and technological skills has also been emphasized by the researchers. To maintain the concerns with cost management and design development across the many phases, the role of the design manager as an information manager has evolved and gained relevance (Smith, 2004). Sinclair (2011) stated: 'Design management is the discipline of planning, organizing and managing the design process to bring about the successful completion of specific project goals and objectives.' (Quoted by Knotten, 2017)

To reach the project goals on time and within budget, especially the tendering process should go smoothly. There should be a good management plan for successful tendering. Through the involvement of more assured architects and designers in the planning process, the planning was growing better. It demonstrated the value of management assistance for process implementation (Fundli, 2014). If construction professionals cannot make decisions based on assumptions correctly, design changes can appear at later phases. Undurraga (1996) stated that, in Latin American countries, according to estimates, design errors cost between 20 and 25 percent of the overall building time (Quoted by Alarcon, 1998). According to Sun (2006), changes always necessitate rework, which drives up the cost of the project. In addition to rework, editing project documents, changes in schedules, and procedures can be seen as other effects. Also, "poor constructability of design option", "coordination efficiency between design, procurement and construction is low", "communication with consulting engineers is inefficient", "poor management of design variation processes" and "information management of design is not standardized" are identified as design-related interface management problems

(Zhang, 2018). In the study by Picas (2020), *poor coordination, inherent uncertainty in information flows,* and *the lack of timely responses from clients* are found as the main design problems. According to Zhang (2018), insufficient design data causes; *high construction cost of design option* and *uncertainty of projects' specific scope, and unclear parameters of equipment cause deviation in project cost.*

Knotten (2017) studied success factors in building design management. He finds the design phase important to pass the project process successfully. According to the results of the survey, *communication* and *decision-making* are the most important ones. When analyzed by phases, Alarcon (1998) detected some problems during the execution phase of the projects. They are *poor design quality, lack of design standards,* and *lack of constructability*. After the survey, during design phases, the most important problems are *defects of individual specialists and the lack of coordination among specialties, changes introduced by the owner and the designers, inconsistencies among drawings and specifications, designers with little construction knowledge,* and *non technical specifications* (Alarcon,1998). In another study, Tzortzopoulos (2007) revealed a case study and reached that since design and construction are typically developed concurrently, there is a perception that the detailed design process should be separated from the construction planning phase. However, this does not always occur due to ineffective information sharing with external designers. As a result, a lot of design choices are made on the construction site. Because of that statement, the primary concerns include clear roles and responsibilities, the availability of design managers with the necessary skills, and a clear understanding of what the organization wants to accomplish through design management (Tzortzopoulos, 2007). As Mendelson (1997) stated that the design phase is to blame for 75% of the issues that arise on the job site (Quoted by Choudhry, 2017). In the design phase, *data provided to designer are incomplete* and became the most ranked cause. In the construction phase, *owner proposes changes due to financial problems* got the first position. According to Al Mousli (2016), contractor involvement in the design phase of the project enhance constructability and lower the likelihood of design modifications. The problems at this phase are *lack of contractor involvement during the design phase, delay in preparing construction documents, time limitation in the design phase, lack of coordination inside the design firm* and *undefined owner scope.* After the study, *lack of coordination inside the design firm* became the most ranked design-construction related interface problems.

Design-related Contract Management

A key factor in controlling the design deliverables at various phases is design-related contract management (Zhang, 2018). Every construction project starts with the details set in the contract and the form of agreement. Project duration, management type, quality standards, construction method, and responsibilities of every stakeholder are the topics that the contract should include. There are some requirements to ensure that the contracts are not changed in the other phases of the project. The more details there are, the more accurate the project's start can be. Customer requirements, constructive elements, and quality standards are established during the design phase of construction projects. Drawings, technical specifications, and other design documents are the bases for those requirements. During the design phase, the client's requirements are determined, and methods, drawings, and technical specifications are used to specify the constructive elements and quality standards (Sugumaran, 2013). Contracts that were created based on conceptual designs and clients may have ambiguous project definitions. These deficiencies become design changes when the contractor(s) start work because, while project design is evaluated by the architect, the project is also improving and changing. Especially the change orders are the main reason that affects every possible issue on the

project performance. A change order is a request made in writing to the contractor that is provided after the contract has been signed and authorized by the owner to alter the scope of the work, the contract price, or the scheduled completion date. Changes to the designs and contract paperwork typically result in changes to the contract's timeline or price. Contractual conflicts are also more likely to arise as a result of changes (Yeganeh, 2019). Before the contract execution, the bidding process is a challenging and important step. According to Yeganeh (2019), giving the contract to the lowest bidder despite the quality of the services is in the top 10 significant causes of design-construction interface problems. The other problems about contractual problems are *delays in preparing designs by the design team, delays in design approval by the employer, unclear scope of work,* and *change orders*.

Problems from Construction Parties' View

According to Sugumaran (2013), it is quite typical for the construction team to not participate at all in the planning phase but still take on the duty of effectively completing a project once the design is ready for execution. This lack of an integrated strategy frequently results in antagonistic interactions between project participants, raises the risk of mistakes, and frequently overlooks crucial opportunities for improved project performance. As Arain (2016) cited; building project completion success is largely dependent on effective coordination, cooperation, and communication between construction parties. Owners, designers, construction companies, subcontractors, and maintenance companies are included in these construction parties (Wang, 2000). Construction projects frequently involve numerous temporary groups working in unregulated circumstances (Daniels, 2014). Therefore, relationship networks of multiple stakeholders and their roles in the project phases and the design-construction interface have started to be discussed. Because interface issues arise whenever two or more stakeholders interact to fulfill the objectives of a construction project in this fragmented environment (Marzuki, 2019). One problem can be the most important item for a stakeholder but less important for another. For example, as mentioned in Sugumaran's study (2013), the *effect of incomplete plans* is the most important cause of design-construction interface issues according to contractors, while it is the least important origin for design consultants. Al-Hammad (2000) discussed interface problems among the various construction parties. He grouped problems under these categories: financial, inadequate contract and specification, environmental problems, and other common interface problems. *The owner's low budget for construction relative to requirement, delay in progress payment by the owner, insufficient working drawing details, and poor quality of work* are selected through the survey as the most rated problems respectively. Furthermore, Arain (2016) studied potential causes of inconsistencies from contractors' views. He investigated these problems according to project phases and *involvement of designer as a consultant, communication gap between constructor and designer, insufficient working drawing details, lack of human resources in the design firm, lack of designer's knowledge of available materials and equipment* are listed as the most important causes.

According to Chen (2008), finding solutions for Interface Management that are generally applicable and enhancing the project's overall Interface Management performance becomes quite challenging. This study offers a multi-perspective analysis of the built environment related to interfaces to bridge the gap and explore all the root causes of interface difficulties. He made categories and one is about *people/participants*. From his perspective, four major causes are identified, supported by minor factors and sub-factors: *poor communication among parties, poor decision-making, poor coordination among parties, and financial problems.*

Interface problems between stakeholders that affected project performance are studied very often. In the study conducted by Daniels (2014), he focused on describing the project complexity to the project participants and improving project planning. The project management plan model is suggested for effective interface management among project participants. This plan's early formulation allowed for its effective implementation and had a beneficial impact on the creation of scheduling and budgeting activities. Other key benefits included having a dynamic online version available to all stakeholders and providing training for new stakeholders. Also, Huang (2008) discussed the effects of interface problems among construction parties upon project performance. He categorized them into seven groups: *financial problems, inadequate contract and specification, environmental problems, other common interface problems, technological improvement, track characteristics,* and *cultural difference.* The results of the analyses show that coordination and experience factors directly influence the project's performance. Project partnering and configuration management are two solutions he proposed to improve the performance.

Constructability

There is widespread agreement that constructability reviews must happen throughout the design process (Arditi, 2002). It is often late for this issue, which needs to be considered and planned during the concept design phase of the project. This issue, which is generally limited to the experience and knowledge of the designer, becomes a difficult situation to prevent and when the contractor is selected and the construction activities are about to begin, the problems begin to increase. This naturally results in extra time and extra cost and thus negatively affecting the project performance. According to Arditi (2002), constructability input has been hampered by the designer's incomplete comprehension of construction necessities, divergent objectives between design and construction specialists, and the owners' opposition to formal constructability approaches due to the projects' very visible additional costs. Also stated by Arditi (2002), incorporating construction expertise into design procedures significantly increases the likelihood of completing a project with higher quality standards, safely, on schedule, and for the lowest possible cost. In the study conducted by Arditi (2002), the factors that enhance and constrain constructability are studied. Project complexity, design practices and philosophy by designer, and project delivery system are rated as the most significant factors that enhance constructability. Faulty working drawings, incomplete specs, and lack of communication are estimated as constraints on this issue. As concluded in the study, the application of proven constructability studies to projects, particularly those that are vast and complicated, as early as the conceptual planning phase to save both cost and time (Arditi, 2002).

To summarize, these findings showed that the great majority of the design-construction interface problems are related to the viewpoint of project management. With the inclusion of interface management at project phases, project management will become more comprehensive and open to management. It will make the interface problems easier to control and lessen them. As shown in Table 1, problems are categorized through interface points related to management areas from the literature review findings. Considering that most of the problems affecting the construction activities are caused by the design process and design professionals, with a communication gap in those phases. Insufficient design data causes incorrect assumptions and it brings failure in tendering stage. Subsequently, the contractor who receives the job will have undertaken a job for which the scope is inaccurate, as s/he has received the job as a result of the bidding process with missing documents as a base. As a result, design changes begin to occur, and factors affecting project performance emerge.

Table 1. Design-construction interface problem categories and causes.

Problem Categories	Causes
Problems Related to Design Management **(**Zhang, 2018; Picas, 2020)	▪ Design professional with no management and technological skills ▪ Design changes (rework, editing in project documents, changes in schedules and procedures) ▪ Incorrect assumptions during the tendering stage ▪ Inherent uncertainty in information flows ▪ Insufficient design data (high construction cost of design option, uncertainty of projects' specific scope)
Problems Related to Construction Parties **(**Chen, 2008; Al-Hammad, 2000; Daniels, 2014; Arain, 2016)	▪ Temporary groups ▪ Owner's low budget ▪ Delay in progress payment by the owner ▪ Poor quality of work ▪ Involvement of designer as a consultant ▪ Communication gap between constructor and designer ▪ Lack of human resources in the design firm ▪ Poor decision-making ▪ Poor coordination among parties
Problems Related to Design Contracts **(**Huang, 2008; Yeganeh, 2019)	▪ Change orders (contractual conflicts) ▪ Delays in preparing designs by the design team ▪ Delays in design approval by the employer ▪ Unclear scope of work ▪ Inadequate contract and specification
Problems Related to Constructability **(**Arditi, 2002)	▪ Designer's incomplete comprehension of construction necessities ▪ Divergent objectives between design and construction specialists ▪ Faulty working drawings, incomplete specs

Conclusion

The most important criteria to call a project successful is that it is completed on time, within the planned budget, and with the right quality. The way to a successful project goes through a healthy project management process. Proper communication, effective leadership, timely and accurate schedules, a design-oriented budget and process planning are some of the items in this process. The integration of all components and their smooth operation in the project process can be achieved with interface management. As the use of efficient interface management methodologies spreads, project teams become more collaborative, which boosts profitability, lowers costs, improves time management and strengthens customer/client relationships (Manoj, 2010).

Problems may arise during long project processes. Design, procurement, and construction activities can be intersected coincidently in some project delivery systems that cannot be

tolerated. These “interfaces” are the real break points for the projects and should be solved properly with the right tools. The important thing is to identify these design-construction interface problems at the right time, define and address them to the appropriate location. This research aims to investigate, define and determine the root causes of interface problems in the construction industry with an expanded literature review. The literature has been grouped based on different sub-headings related to the design process especially and it has been tried to go down to the root causes.

In the upcoming thesis project, this study will be extended with real data from the construction industry to successfully combine practice and theory through the effort the of authors.

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Comparative Evaluation of the Interior Design Processes of Rentable Stores in Shopping Malls in Turkey

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Abstract

Having a critical importance for the retail sector in Turkey and increasing in number every day, shopping malls have a dynamic structure due to their character. In order to ensure the sustainability of their functionality, those who manage these buildings, which are constantly updated / renewed and exposed to tenant / user circulation, need to regulate the spatial organization processes in order to keep the said dynamism under control. In this sense, the most effective and valid instrument is the decoration specifications.

There is a need for a well-structured specification for the rentable areas within the structure of shopping malls, each of which has a different corporate identity, to carry the design line of the shopping malls and to reflect the brand concept of the tenants. The specification covers not only architectural but also electrical and mechanical projects where all stores are fed from a common infrastructure. In this study, a comparative evaluation of the specifications regulating the decoration processes of the shopping malls, which have become the locomotive of retail merchandising in big cities, is presented in the context of architectural, electrical, and mechanical headings. Within the scope of the study, different scaled shopping malls, which are in Istanbul, which has the highest number of shopping malls in Turkey, and which were determined to operate the decoration processes systematically with expert opinions were handled.

Keywords: *shopping malls, design specifications, design management, retail areas.*

Introduction

Hornbeck (1962) defined the concept of shopping as “the combination of the place where actions such as looking at a commercial product, learning the price, examining and purchasing are done through the exchange method” (Parlakdağ, 2019). Based this traditional definition today it is a bit different because of shopping malls are thought as an important public area. Shopping malls, where the one of the most visited public areas in the world, makes the product, customer and seller come together for not only purchasing, selling the goods and services but also socialization. Today, shopping mall users prefer to spend most of their times in the

shopping malls for shopping, entertainment, food and beverage, socialization, education activities etc. (Dikmen & Bozdemir, 2021). As a result of this, it is needed to design and organize the spaces in an effective way to ensure the needs of shopping mall users (Dikmen & Bozdemir, 2021).

As of Q1 2022, the existing shopping mall supply in Turkey was recorded as 14 million m² in 453 shopping malls. There are approximately 895 thousand m² of leasable area in 30 shopping malls under construction and the total supply in Turkey is expected to reach 14.9 million m² by the end of 2024 (GYODER, 2022).

Because of being many shopping malls, leasable area in these malls and many different sizes and features of shops in the shopping malls, it is important to regulate and manage the design and implementation process in the quickest way for the proper operation process of the shopping malls.

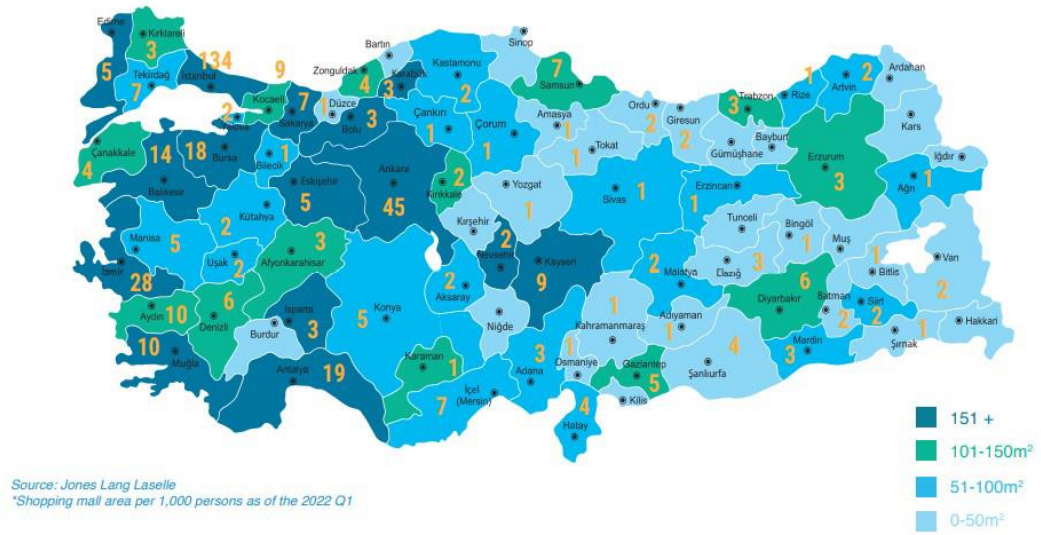


Figure 1: GLA* Volume and number of shopping malls according to cities.

In Türkiye, İstanbul has the most shopping malls as it is seen in Figure 1. So, this study aims to compare the evaluation of the specifications regulating the decoration processes of the three important shopping malls, in Istanbul, considering the highest share of shopping volume and number of shopping malls in Türkiye, to explore the need of detailed specifications to manage the shopping mall shop design and implementation process. So, in this study in the the current technical specifications of these three shopping malls has been evaluated in the context of architectural, electrical, and mechanical headings.

Decoration Specifications of Shopping Malls

In general, there are three aspects of the design for shopping malls. The first of these is the design approach of the shopping mall. This approach also dates a standard for the stores it contains. The second of the three aspects mentioned comes into play here: Leasable areas. It is of great importance that the leasable areas have their own design approach and that they could meet the standardization of the shopping mall. The third aspect could be shown as the corporate identities of the brands in the leasable areas. Each brand has a design approach that defines

itself. In fact, to put it with a metaphor; The corporate identity of brands and the design approach of shopping malls are two different clusters and there are leasable areas at the intersection of these two clusters.

In particular, brands with chain stores have to carry out architectural works in which they could reflect their corporate identities in shopping malls designed with different concepts. The most important tool to capture this intersection is the decoration specifications. For the solution of this problem, each shopping mall has its own decoration specification. Every shopping mall has to define certain limits to the design freedom of its tenants with a specification that could protect its design approach at the maximum level. Brands can also know their own limits thanks to these specifications.

Although the responsibility of the stores may seem like signage and display standards at first glance, it is actually much more than that. Both directly related and independent works such as the level of the floor in the store, the cables to be used in the electrical installation, the capacities of the ventilation grilles must meet the expectations of the shopping mall. Because the units in the mall could be rented. In other words, the continuity of the brands settled in these units is not certain. Therefore, variable users must meet these standards.

The level of detail of a decoration specification should be fine-tuned. Decoration specifications that are not too detailed may create gaps in the design and this may cause conflicts between the owner and the user. Specifications that contain too many details may overwhelm the user and may be the reason why they do not prefer that mall. Therefore, the level of detail needs to be adjusted very well.

In this study, which aims to understand this process with many delicate balances and to determine its open points, if any, the project sets that are included in the decoration specifications of three important shopping malls located on Büyükdere Street, which can be defined as the important commercial axis of Istanbul, and expected from the users, have been evaluated comparatively. Malls whose names are hidden due to data privacy are defined as SM01, SM02 and SM03 (Table 2, Table 3, & Table 4). In the selection of shopping malls, the views of the managers of the architectural offices, who are especially involved in the design and implementation processes of the chain stores, were utilized. Ten different architectural offices, whose opinions were taken, were asked about the shopping malls that they found the decoration specifications to be successful in the projects they carried out, and by evaluating the quantity of the answers, the first three shopping malls at the top of the list were progressed.

Data Collection & Findings

The study consists of two parts: Comparison of the project sets in the decoration specifications and evaluation of expert opinions. The comparative evaluation of the project sets was shared in the paper.

The study was started by taking the opinions of the managers of the companies that mainly make store decorations in shopping malls. First of all, the managers were asked about the content of architectural, electrical and mechanical project sets that are generally required in each project in the interior application works they carry out in shopping malls. The responses received are compiled in Figure 1.

Table 1. Expert value summary of project sets of decoration specifications of shopping malls.

Architectural Project Set	**Electricial Project Set**	**Mechanical Project Set**
Furnished floor plan	Lighting layout	Fire extinguishing installation plan (upright, sprinkler, fire cabinet, etc.)
Suspended ceiling plan (superposition of architectural, electrical and mechanical projects)	Lighting installation plan	Plumbing plan
Wall plan	Socket and switch installation plan	Heating and cooling system plan
Floor plan	Cable tray plan	Ventilation installation plan
Sections	Single line scheme	Natural gas installation plan
Facade views (two and three dimensional)	Clipboard details (dimension, image, etc.)	Account reports
Three-dimensional images of the store	Clipboard loading ruler	Details of the equipment to be used (brand, certificate, warranty certificate, etc.)
Signage design (Plan – section – view)	Total power calculation	
Details of the materials to be used (brand, certificate, color, etc.)	Heat control calculation	
	Details of the material to be used (brand, certificate, warranty certificate, etc.)	

Then, the architectural, electrical, and mechanical project sets included in the decoration specifications of three different shopping malls evaluated within the scope of the study are listed in Table 2, Table 3, and Table 4 in comparison.

Table 2. Architectural project set outline of shopping malls (SM01, SM02. SM03).

SM01	**SM02**	**SM03**
Construction drawings (furnished plan) s:1/100 ~1/50	Floor Plan S: 1/50	Demolition plan for stores that have already been designed and implemented S:1/50
Wall plan s:1/100~1/50	Floor Plan S: 1/50	Architectural construction plan / walls, columns, etc. S:1/50
Floor covering plan S:1/100~1/50	Longitudinal and Transverse Sections S: 1/50	Furnished layout showing movable and fixed furniture S:1/50
Suspended ceiling plan (with ceiling elevation and sections) S:1/100~1/50	Inside Views S: 1/50	Material definitions are specified and dimensioned construction plan S:1/50

Table 2. Architectural project set outline of shopping malls (SM01, SM02. SM03) (continuation of table).

SM01	SM02	SM03
Architectural / mechanical / electrical ceiling coordination plan s:1/100~ partial 1/50 if necessary (lighting, sprinkler heads, hatches, vents, voice alarm loudspeakers, emergency exit fixtures, detectors, music speakers in one plan should be displayed)	Material lists and (if requested) technical specifications of all finishing materials to be used	Material definitions, color separations are specified and dimensioned; Floor plan containing the manufacturer's name and product code numbers of the material S:1/50
Sections S:1/100~1/50 (min. 2 pieces) (may increase according to the size of the area)	Plans, sections and views including the design of the sign,	Ceiling plan and sections containing all ceiling materials, codes, maintenance covers, cat ladder (maintenance platform), locations of all lighting and installation elements, manufacturer's name and product code numbers of the material, technical application details S:1/20
Front View As 2d And 3d Renders S:1/100~1/50	Suspended Ceiling Plan S: 1/50 (Plans showing the superposed state of lighting fixtures, equipment on the ceiling of all disciplines, intervention hatches, fire detection and sprinkler system)	Preliminary electrical plan / lighting, socket locations, switches, thermostat, telephone etc. S:1/50
Sign design (plan section and details) :1/50~1/20~1/5	Fire and Emergency Escape Sign Information	Minimum 2 cross-sections and views specified and dimensioned with material colors and definitions S:1/50
Static project and calculation (required in stairs and mezzanine floor plan)	After the construction is completed, the delivery of the “as-built” projects	Colored store front and signage plan, view and sections S:1/50~1/20
Elevator (if necessary)	3D Modeled showcase image	Colored perspective drawings or pictures and photographs of similar store decorations
Facade static calculation for lifestle park tenants (open space)		Samples of used coating materials

Table 2. Architectural project set outline of shopping malls (SM01, SM02. SM03) (continuation of table).

SM01	SM02	SM03
Drawing of the screen and the visual to be covered with the screen		Site list, details and work schedule
Bill of materials and fire certificates (samples on request)		Projects of facade/showcase design should be presented with 3D visuals and 3D drawings showing their relations with neighboring stores. (in 3ds or skp format)
		Lighting project for lighting design (ceiling, floor, wall plans + luminaire specs)

Table 3. Electrical project set outline of shopping malls (SM01, SM02. SM03).

SM01	SM02	SM03
Electrical projects delivery list	Lighting installation plan S: 1/50	Galvanized cable tray plan
Galvanized cable tray plan	Socket and switch installation plan s: 1/50	Socket and power plan
Socket and Power Plan	Weak current installation plans (fire detection, telephone, data, music broadcast, announcement, securit etc.) S:1/50	Lighting Plan
Lighting plan	Cable tray installation plan S: 1/50	Weak current plan (fire detection, telephone, voice alarm and voice over, security (panic) button and cctv, data, tv)
Lighting installation plan, (S: 1/50) (Lighting on Duty, Kit luminaire and Emergency direction (EXIT) line plans should be on a separate sheet.)	Board loading ruler	Single Line and Control Diagrams (in the form of terminal numbers and cable sections)
Weak Current Plan (Fire Detection, Telephone, Voice Alarm and Voice Over, Security and cctv, data, tv)	Panel single line diagram	Board view, manufacturing details (inside and outside)
Single Line and Control Diagrams (indicating terminal numbers and cable sections)	Panel dimensions and appearances	Voltage Drop Calculation
Board view, manufacturing details (inside and outside)	Voltage drop and heating calculations in cables	Heat Control Calculation

Table 3. Electrical project set outline of shopping malls (SM01, SM02. SM03) (continuation of table).

SM01	SM02	SM03
Voltage drop calculation	Material brands and certificates, warranty documents, material presentation forms to be used during the application	Lighting calculation (sqm / watt calculation should be made to indicate that the lighting power specified in the specification is not exceeded)
Temperature control account	After the implementation is completed, “delivery of as-built projects”	Total Power Calculation (sqm / Watt calculation should be made to indicate that the total power specified in the Specification is not exceeded)
Total Power Calculation (indicating that the total power specified in the Specification is not exceeded) Watt / sqm calculation should be made and its suitability should be stated)		
Board loading ruler		
Panel dimensions and images and panel 3 line diagram (After Project and Single line approval, during Project delivery)		
Legend		
Material presentation files of the materials to be used		

Table 4. Mechanical project set outline of shopping malls (SM01, SM02. SM03).

SM01	SM02	SM03
Fire extinguishing system plans(with upright&pendent sprinklers, if any fire cabinet projects)	Electrical - Mechanical data sheet	Mechanical - Electrical data sheet
WSHP (water source heat pump) Heating-cooling piping system plans	Implementation projects including changes to be made in existing air conditioning-ventilation ducts and vents (Channel elevations must be submitted as written on the plans and together with the sections.) S: 1/50	Plumbing plan (includes grease trap connection for Food-Court, hypermarket, restaurant and cafe Tenants)

Table 4. Mechanical project set outline of shopping malls (SM01, SM02. SM03) (continuation of table).

SM01	SM02	SM03
HVAC (heating, ventilation and air-conditioning) Duct system plans	Clean water installation application projects including the changes to be made in the existing water installation, (Should be submitted with the lower levels written.) (Scale :1/50)	Air conditioning and ventilation plan (with pressure loss calculations in shops allowed by the Management Plan)
Plumbing (clean water and waste water, drainage) system plans	Implementation projects including the changes to be made in the existing sewage and utility water installations S :1/50	Fire installation (sprinkler and fire cabinet) plan
Natural gas installation plans (if any)	Implementation projects including the changes to be made in the existing heating-cooling installation S :1/50	Hood Fire Extinguishing System project for stores with hoods
Section, view plans for critical suspended ceiling areas	Implementation projects including the changes to be made in the existing automation installation S :1/50	Heating-cooling installation project
Wet area 1/20 plan, details and views	Fire detection and warning system projects, water fire extinguishing projects (with installation sub-codes written), emergency lighting and guidance projects, smoke evacuation projects will be submitted for approval. S :1/50	Natural gas project approved by IGDAS (local authority for mechanical issues)
Equipment list (indicates equipment specifications) and Equipment installation procedures	After the implementation is completed, the delivery of the “as-built” projects related to the changes mentioned above S :1/50	Suspended ceiling plan (shows suspended ceiling elevation, sprinkler plans)
Catalogs and certificates indicating the model-brand and technical features of the Equipment to be used,	A list of brands and models of all materials and equipment (battery, etc.) To be used should be given and processed on the projects.	Descriptions
Equipment Election outputs		
Account reports of all projects		
Seismic System projects		

Results

When the project sets obtained from the expert validations are compared with the project sets included in the decoration specifications of the shopping malls covered in the study, it is seen that there is a great similarity in fact. All the projects set details included in the expert opinions are requested in every shopping mall. Expert opinions on the subject are given below:

- Looking at the tables, it can be mentioned that the detail expectation level of each shopping mall is different. For example, it could be said that the electrical project set of SM01, the mechanical project set of SM02, and the architectural project set of SM03 are more detailed than other projects. Experts' interpretation of this situation is in the form of the approach of the architect / engineer who writes the relevant sections in each decoration specification. The experts, whose opinions were taken, stated that they made more than one store application in three different shopping malls selected as samples.

- The experts stated that the project sets included in the decoration specification do not differ significantly in terms of themselves, and that the expectations of each shopping mall are basically the same.

- Experts stated that even though the design concept of shopping malls is different from each other, it is important for brands with tenants to display their corporate identities everywhere, so they must achieve a standard that suits different identities. They especially underlined that the standards regarding leasable areas must be largely similar, since shopping malls are commercial enterprises and brands play an important role in the value they will create.

- The standards in the decoration specifications are considered as the usual project items for professional architectural offices. Thanks to the accumulated know-how developed by working in different shopping malls, he gains confidence in every completed project and is ready for the next project. However, for an architectural office that has just entered the sector, the decoration specifications in question can be considered as a factor that requires long hours. They stated that the level of difficulty decreases inversely with experience.

- In the interviews, it was stated that the determining factor of an interior project carried out in any shopping mall is directly related to the approach of the management of that shopping mall. The experts, who said that besides the decoration specifications being the determining factor, bilateral communication is at least as important as it, said that the negativities encountered during the process are mostly resolved through communication. Experts shared that the difficulty they experience while working on a project is directly related to the character of the technical personnel in the shopping mall management, rather than the complexity of the decoration specification.

Conclusion

In the light of the data obtained in this study, it could be said that the decoration specifications of the shopping malls are basically prepared to reflect the same expectation. It is seen that a systematic approach and setup are needed to accurately reflect the design approach of different brands in different shopping malls for the quick and well design and implementation process. This study is a prelude to the preparation of the said infrastructure.

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Analysis of Parameters Affecting Decision Making to Retrofit of Existing School Buildings Using Ensemble Machine Learning Methods

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Abstract

To protect the occupants' lives, it is important to ensure the structural safety of the existing building stocks. For this reason, the issue of retrofitting existing buildings is a frequently encountered situation today. However, decision-making about building retrofitting or complete demolishment is a cost- and time-consuming challenge. Therefore, this study aims to identify and measure parameters that influence the decision-making process about retrofitting a building. To address this issue, first Pearson correlation was used for establishing the relationship amongst the retrofitting feature, then three ensemble machine learning models (MLs), named Random Forest (RF), Gradient Boosting (GB), and Adaboosting (AB), employed for determining the building health condition. To establish the model's effectiveness, this research collected health monitoring reports obtained from 111 school buildings within eight cities in Turkey. The important building features were used to classify the health condition of the building. Based on the results the AB outperformed both RF and GB considering accuracy, F1 score, precision, and recall metrics (79%, 79%, 80%, and 79%). Also, feature selection using Pearson correlation could improve the performance of RF and GB by up to 3%.

Keywords: *building retrofitting, classification, correlation, retrofitting parameters.*

Introduction

Building structures are designed to safely withstand various loads such as dead, live, wind, earthquakes, and dynamic vibration throughout their lifecycle. Under these loads, building components can be damaged at varying rates and degrees depending on the design, materials, construction methods, quality of workmanship, environmental conditions, and the use of the building. Ensuring the structural safety of the existing building stocks is essential for protecting the life and property of the occupants. In this respect, the decision to retrofit or demolish aged buildings is a frequently encountered task for construction professionals. The decision about the health status of the aged building is a complex, cost- and time-consuming

challenge due to its dependency on several influential parameters. In addition, it is important to determine and evaluate the performance of the building in terms of mitigating financial losses (Perez et al., 2019).

Two ways are followed to increase the declining building performance to acceptable levels as a result of the evaluation. The first of these is the applications aimed at increasing the structural performance of the structure such as retrofitting, renovation, maintenance, and repair. The second is the complete demolition of the structure and the construction of a new structure that can provide the desired performance (Kusar et al., 2013). However, in general, it is seen that applications such as retrofitting or renovation are preferable compared to demolishing and rebuilding the building due to reasons such as causing less environmental pollution (Dong et al., 2005), mostly more economical (Egbelakin et al., 2014) and demolition is not possible in the especially historical buildings (Bruce et al., 2015). On the other hand, it may be preferred to demolish and reconstruct the building for reasons such as life cycle costs of the building, cheaper energy use and meeting the expectations of the building owner (Yılmaz et al., 2018).

Retrofitting has been defined by The Federal Emergency Management Agency (FEMA) as a tool to modify existing structures and reduce disaster risk to mitigate the effects of natural hazards (Witucki et al, 2021). In the Turkish Building Earthquake Code (TBEC), on the other hand, retrofitting applications are defined as increasing the strength and deformation capacity of the building's structural system, adding new elements to the building, strengthening the junction areas and reducing the mass of the building to reduce the effects of earthquakes (TBEC, 2018). With retrofitting applications, the loss of life and property that will occur due to the collapse of the structure under the loads can be prevented. In addition, the durability of the structure can be increased with structural additions. Retrofits require less time and cost than demolishing and rebuilding the structure (Perez et al., 2019; Ghosh Mondal et al.; 2019). Furthermore, retrofitting the structure is a more ecological option when the damage to the environment is compared (Yılmaz et al., 2018).

The building cost ratio (retrofitting cost/ (demolition + rebuild cost)) is usually considered when deciding whether to demolish and rebuild or retrofit a structure. It is generally recommended that the retrofit cost not exceed 40% of the rebuild cost. While calculating the building cost ratio to decide on retrofit or demolition and reconstruction, parameters such as existing concrete strength, existing reinforcement strength and class, number of floors, the age of the building, earthquake zone, foundation type, ground class, and whether there is a shear wall or not are also important along with the retrofit method (Uluöz, 2010). Therefore, the determination of these parameters and relations between the parameters are effective in taking the retrofit or demolish decision.

Although there are many studies on retrofitting methods and varying costs according to these methods in the literature, there are few studies on retrofitting parameters. Jafarzadeh et al. (2014) analyzed the retrofitting projects of 158 schools in Iran and used multiple regression analysis to calculate the cost of retrofitting. It was found that the total area of the building was the variable most associated with the retrofit cost. In another study, a survey was conducted with 385 civil engineers in Turkey and when the answers obtained were examined, it was seen that the earthquake damage level, building statics, and earthquake class were the most effective parameters for the retrofitting cost (Yılmaz et al., 2018).

Recently machine learning (ML) approaches are widely adopted due to their ability to utilize the record for aiding human decision-making within different fields (Bodendorf et al., 2021; Meharie et al., 2021). The successful implementation of ML in different fields encouraged the research on different ML approaches within the construction management field. Consequently, Artificial Neural Networks (ANNs) (Jiang, 2019), Support Vector Machines (SVMs) (Peško et al., 2017), K-nearest Neighbors (KNN) (Farid et al., 2018), Naive Bayes (NB) (Zhu et al., 2021) and Decision Trees (DTs) (Kwon et al., 2015; Mistikoglu et al., 2015) are widely used for classification tasks within construction management literature. To aggregate the benefit from these single ML approaches, ensemble ML predictors are introduced. The ensemble models achieved enhanced robustness and stability (Saqlain et al., 2019) by training single ML approaches to benefit from the best prediction of each contributing ML predictor. To this end, tree-based ensemble predictors, such as Random Forest (RF) (Farid et al., 2019; Zhu et al., 2018), AdaBoosting (AB) (Neloy et al. 2019), and Gradient Boosting (GB) (Ding et al., 2016; Farid et al. 2019) have proven to be successful within different construction management studies. These tree-based methods are using different approaches to combine single DTs for improving the prediction performance of a single DT.

In the light of the above observations, this study aims to develop a machine learning model to identify the parameters affecting the decision-making process regarding the retrofitting of a building, measure the relationships between these parameters, and predict the retrofit or demolition decision. For this purpose, structural health monitoring reports were obtained from schools in different provinces of Turkey. Pearson correlation was used to establish the relationship between retrofitting parameters extracted from the reports, and then three ensemble ML models called RF, GB, and AB were used to evaluate the health of the building. Finally, the results of the three predictor models were evaluated using accuracy, precision, recall and F1 score metrics.

Methodology

The outline of the present study is depicted in Figure 1. This study was conducted in three stages: Data acquisition and pre-processing, feature engineering, and modeling of the ensemble retrofitting predictors. The briefed procedure in this study is coded using Python programming language and associated libraries.

Data Acquisition and Pre-Processing

For this study, 111 structural health monitoring reports were collected from eight cities within Turkey. The health monitoring reports were obtained from school buildings. The parameters associated with the retrofitting decision were extracted from the report using expert judgment. Besides, the decision about the retrofitting or complete demolition was used as labels for every single record. Accordingly, the extracted dataset contained 111 records with 20 feature columns.

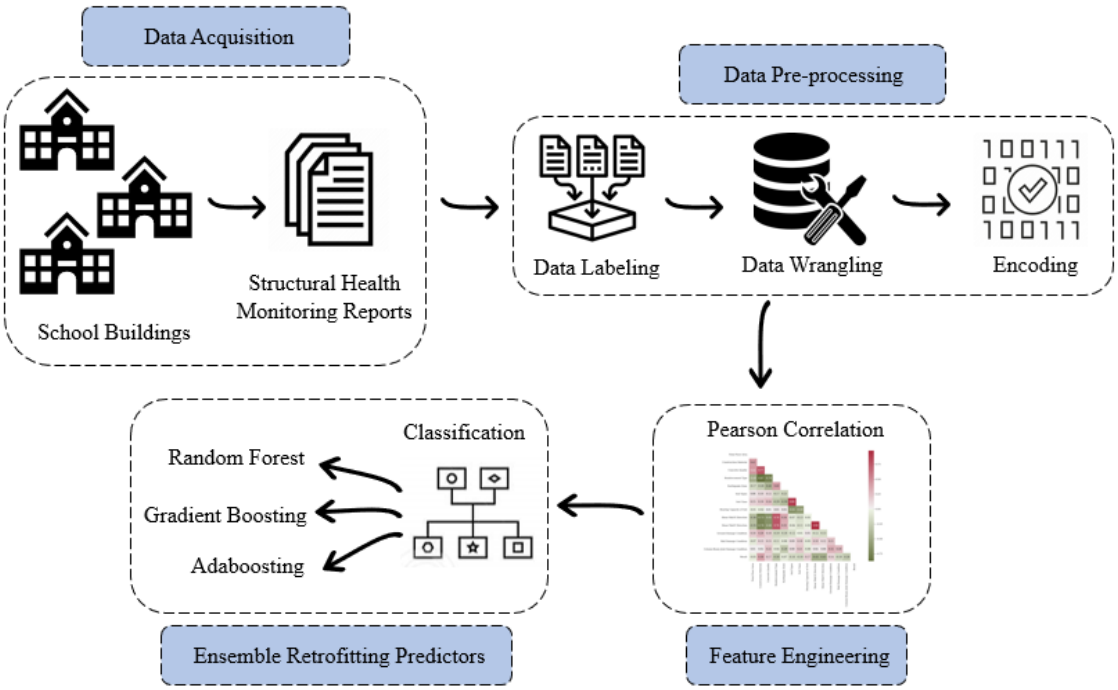


Figure 1: Flowchart of the study.

Following, during the pre-processing stage, the parameters with missing values (retrofitting cost and building cost ratio) were removed. In addition, the redundant retrofitting parameter (floor area) was also erased. Besides, a record with more than half missing values was also removed. This resulted in a dataset of 110 records that were explained through 17 feature columns. To increase the prediction accuracy of the adopted ensemble models, the numerical variables were divided into intervals. Therefore, the 83 collected building age attributes (SP2), ranging between nine to 78 years old, were divided into four intervals, as shown in Table 1. The construction material feature (SP5) comprised reinforced concrete and brick materials. Here, the brick attributes represent the clay brick, hollow brick, and masonry wall materials. The quality of the reinforcement concrete is influential in the structural health status of the building and thus the quality of concrete and reinforcement types are also extracted in separate feature columns. So, the 63 records of concrete quality (SP6), ranging between 0.79 and 23.45, are also divided into four classes. The missing values in the concrete quality feature (SP6) that are associated with the brick materials are replaced with the brick category (Table 1). Likewise, the missing values of the reinforcement type feature (SP7) are also replaced with the brick. Moreover, missing values of the soil type (SP9) and soil class (SP10) features that are described within four classes, are replaced with the mode soil type and soil class of that city. The missing values associated with soil bearing capacity (SP11) are replaced with the average bearing capacity of soil within each of the eight cities. Furthermore, the missing values of the shear wall-X direction (SP12) and shear wall-Y direction (SP13) features are replaced with 0, suggesting the possibility of no shear wall existence in the collected school records. However, for the column-beam joint damage condition feature (SP16) the missing values are flagged with “not defined”.

The displayed variables in Table 1 were evaluated for selecting the influential features and then encoded using label encoding.

Table 1. School buildings parameters (SP) description.

Identifier	Feature	Type	Attribute	Frequency
SP1	City	Categorical	Amasya	8
			Bayburt	3
			Giresun	11
			Gümüşhane	4
			Ordu	24
			Sivas	35
			Tokat	21
			Trabzon	4
SP2	Building Age	Numerical	Class 1 [9, 23)	19
			Class 2 [23, 30)	19
			Class 3 [30, 40)	50
			Class 4 [40, 78]	22
SP3	Number of Floors	Numerical	1	12
			1.5	9
			2	31
			3	31
			4	19
			5	7
			7	1
SP4*	Total Floor Area	Numerical	[52.56, 4987.86]	106
SP5	Construction Material	Categorical	Clay Brick	14
			Hollow Brick	16
			Masonry Wall	4
			Reinforced Concrete	76
SP6	Concrete Quality	Numerical	Class 1 [0.79, 7.13)	16
			Class 2 [7.13, 9.03)	15
			Class 3 [9.03, 11.78)	29
			Class 4 [11.78, 23.45]	16
			Brick	34
SP7	Reinforcement Type	Categorical	S 220	63
			S 420	12
			Brick	35
SP8	Earthquake Zone	Categorical	Zone I	59
			Zone II	12
			Zone III	35
			Zone IV	4
SP9	Soil Types	Categorical	I	5
			II	33
			III	69
			IV	3
SP10	Soil Class	Categorical	Z I	5
			Z II	44
			Z III	58
			Z IV	3
SP11*	Bearing Capacity of Soil	Numerical	[9.9, 70.3]	76
SP12*	Shear Wall-X Direction	Numerical	[0.0, 24.17]	53
SP13*	Shear Wall-Y Direction	Numerical	[0.0, 20.19]	53
SP14	Ground Damage Condition	Categorical	Minor	9
			No Damage	101
SP15	Wall Damage Condition	Categorical	Minor	90
			Moderate	8
			Heavy	11
			No Damage	1
SP16	Column-Beam Joint Damage Condition	Categorical	Minor	2
			Moderate	83
			Heavy	20
			Not Defined	5
SP17	Decision	Categorical	Demolish	59
			Retrofit	51

* Since they contain a large number of different attribute data, it is stated how many different data were obtained from 110 records together with the minimum and maximum values in attribute and frequency columns.

Feature Engineering

In this study, the Pearson correlation was used for establishing the relationship among the retrofitting features (Figure 2). Based on Figure 2, four feature columns were displaying high correlations with the other retrofitting features. To improve the prediction accuracy, the features with intercorrelation higher than 0.20 are removed. Therefore, shear wall-X direction (0.45), shear wall-Y direction (0.45), construction material (0.38) reinforcement type (0.30) are removed.

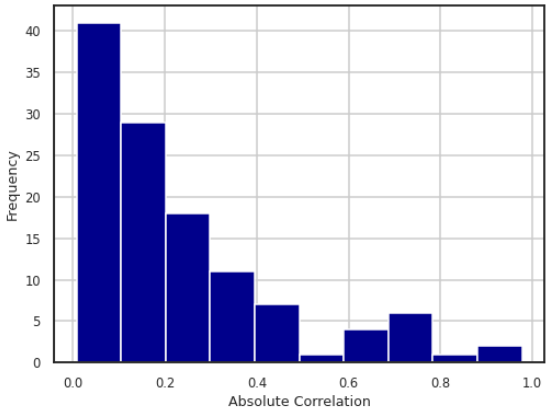


Figure 2: Pearson correlation amongst retrofitting features.

The Pearson correlation of the retrofitting features with the decision column was also evaluated (Fig. 3). The observations from the feature correlations with the output decision variables determine the influential parameters for predicting the demolishing or retrofitting decisions. In this respect, the retrofitting feature with no correlation with the output decision variable was removed. So, the total floor area feature with 0 correlation is removed.

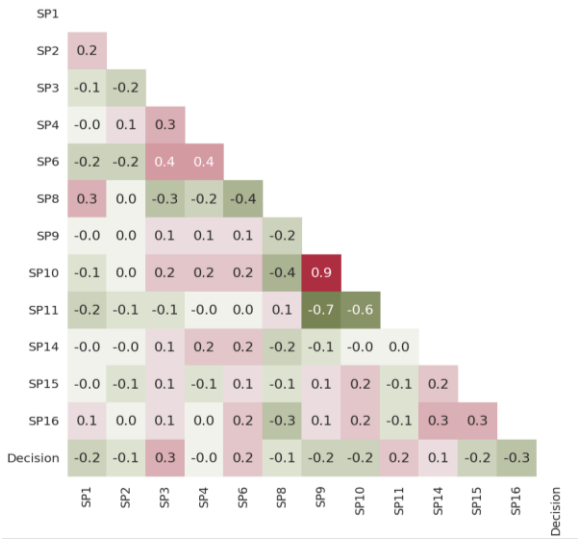


Figure 3: Correlation of feature columns with retrofit/demolish decision output.

The general statistical description is given in Table 2. The processed dataset (Table 2) was used for training the ensemble predictors in this study.

Table 2. Feature statistical description.

	mean	std	min	25%	50%	75%	max
SP1	4.20	1.80	0.0	4.0	5.0	5.0	7.0
SP2	1.68	0.99	0.0	1.0	2.0	3.0	3.0
SP3	2.55	1.39	0.0	2.0	3.0	3.0	6.0
SP6	1.79	1.48	0.0	0.0	2.0	3.0	4.0
SP8	0.85	0.99	0.0	0.0	0.0	2.0	3.0
SP9	1.64	0.62	0.0	1.0	2.0	2.0	3.0
SP10	1.54	0.63	0.0	1.0	2.0	2.0	3.0
SP11	21.71	9.47	9.9	15.34	19.7	24.38	70.3
SP14	0.92	0.28	0.0	1.0	1.0	1.0	1.0
SP15	0.99	0.46	0.0	1.0	1.0	1.0	3.0
SP16	1.66	0.83	0.0	2.0	2.0	2.0	3.0
Decision	0.46	0.50	0.0	0.0	0.0	1.0	1.0

Ensemble Retrofitting Predictors

In this research, three tree-based ensemble approaches were used for decision-making about the retrofitting or demolishing of the studied school buildings. A DT is an ML approach that uses a tree-like structure comprising nodes and branches for predicting different class outputs. Though a single DT often results in a good prediction output, it is prone to overfitting: a predictor that works over a specific dataset only and cannot results in an equally good prediction over a different dataset. To address the overfitting issue of DT and increase its generalization ability, different tree-based ensemble predictors were introduced. These tree-based ensemble predictors are using different methods to train a predefined number of DTs to predict the classes with higher accuracy than the contributing single DTs. In this study, three tree-based ensemble approaches such as RF, AB, and GB have been utilized to predict the retrofitting requirement of the school buildings. The tree-based ensemble approaches (RF, AB, and GB) were fine-tuned by iterating through a different number of trees to find the one that results in the most accurate prediction. The iterations are performed using a grid search procedure obtained from Scikit-Learn (Buitinck et al., 2013; Pedregosa et al., 2012) library. Accordingly, RF is trained with 20 to 200 DTs at 10 intervals (Figure 4).

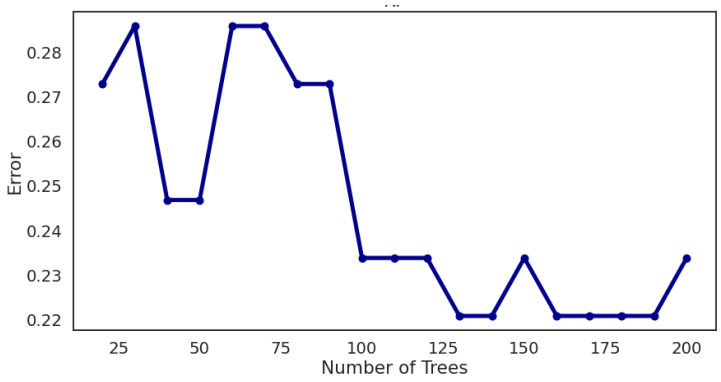


Figure 4: RF iterations for different numbers of DTs.

As is displayed in Figure 4, the RF with 130 DTs resulted in the least error and therefore the RF predictor is trained with 130 DTs. Likewise, the accuracy of AB was iterated with 100, 150, and 200 DTs estimators while using 0.01 and 0.001 learning rates. Finally, the performance of GB is investigated with 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, and 100 DTs, while experimenting with each case with learning rates of 0.1, 0.01, and 0.001, as well as 1 and 0.5 subsamples (Figure 5). As suggested in Fig. 5, the GB obtained the best prediction accuracy with 10 DTs. Besides, 0.1 was found to be the optimum learning rate.

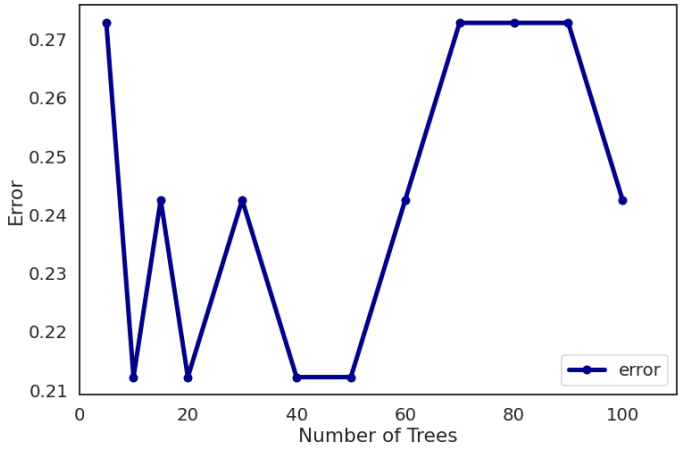


Figure 5: GB iterations for different numbers of DTs.

Evaluation Metrics

To evaluate the model performance, four widely used classification evaluation metrics as accuracy, F1 scores, precision, and recall (Zhou & El-Gohary, 2016) are used. The prediction accuracy of the ensemble retrofitting predictors (RF, AB, and GB) is to be evaluated using the accuracy metric as presented in Eq. 1.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (1)$$

The accurate prediction of the retrofit and demolish classes are called True Positive (TP) and True Negative (TN), respectively. Thus, the wrong prediction of each decision class is

regarded as False Positive (FP) and False Negative (FN). So, the accuracy of each ensemble predictor was evaluated by adding the number of TP and TN predictions as displayed in Eq. 1. While, accuracy provides insight into the overall performance of all classes, to evaluate the accuracy of each class, the F1 score is used (Eq. 2), using precision (Eq. 3) and recall metrics (Eq. 4).

$$F1\ score = \frac{2\ \times (Precision\ \times Recall)}{Precision + Recall} \tag{2}$$

$$Precision = \frac{TP}{TP + FP} \tag{3}$$

$$Recall = \frac{TP}{TP + FN} \tag{4}$$

The three described ensemble predictors are to be trained using 70% of the school building records for classification between retrofit and demolish decisions. Also, 30% of the school dataset is to be used for evaluating the RF, AB, and GB prediction performances.

Results and Discussions

This section represents the performance evaluation of the ensemble retrofitting predictors using the described methodology. In this respect, Figure 6 presents the accuracy of the three adopted ensemble predictors.

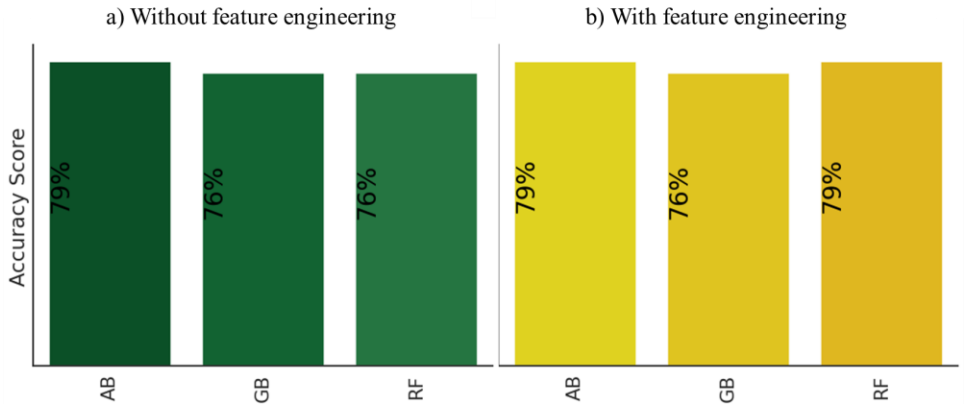


Figure 6: Accuracy performance of ensemble retrofitting predictors.

As shown in Figure 6a, AB outperformed RF and GB in terms of accuracy. Also, Figure 6b indicates that feature engineering using Pearson correlation could improve RF performance by up to 3%. In addition, the precision, recall, and F1 score metrics are also evaluated (Figure 7).

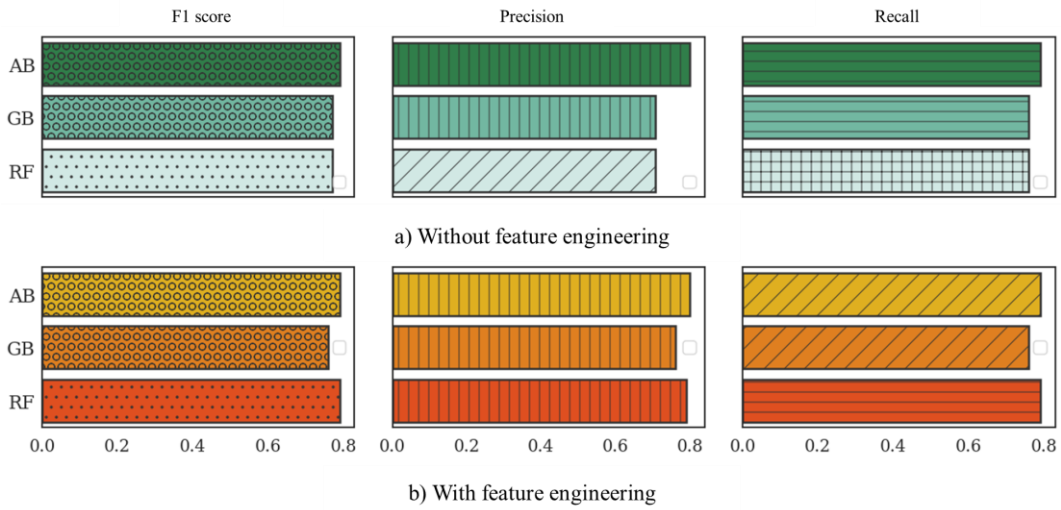


Figure 7: Precision, recall, and F1 score metrics of ensemble predictors.

As it is observed from Figure 7a, both AB and RF show high prediction performance considering the F1 score and recall metrics. However, for precision, the AB displayed superior performance compared with RF and GB. Also, selecting the influential features using Pearson correlation could improve the precision of RF and GB predictors and also enhance the recall metric in the RF model. The observations from Figure 6 and Figure 7 show the effect the feature engineering using Pearson correlation in improving the prediction accuracy of the RF and GB ensemble approaches. However, AB has not shown any improvement in selecting the input feature variables.

In addition, to evaluate the prediction performance within each demolish and retrofit class, the confusion matrix of each ensemble predictor is assessed (Figure 8). Even though, both RF and GB could outperform the prediction associated with the demolish decision, their prediction accuracy for the retrofit decision is less accurate than that of AB. In contrast, AB could achieve equally good prediction accuracy for both retrofit and demolish classes.

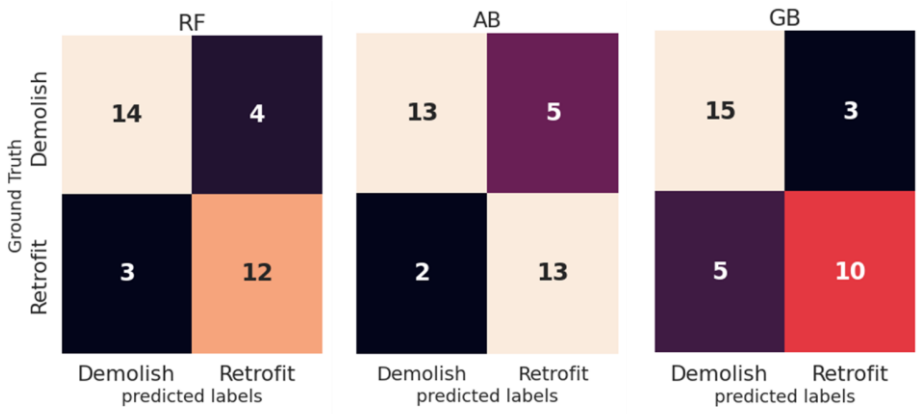


Figure 8: Ensemble retrofitting predictor accuracy for retrofit and demolish classes.

Furthermore, the computational cost of three ensemble retrofitting predictors is compared, considering the training time. In this regard, RF, AB, and GB consumed 0.16s, 04.69s, and 2.05s, respectively. AB was observed to be the most expensive predictor consuming 4.69s of

GPU time to train 100 records. Hence, for decision-making with high accuracy and low computational cost, the RF showed to be a better predictor compared with AB and GB.

Conclusion

The retrofitting or demolition decision regarding the health status of the building is an important decision that has a huge impact on the safety of the existing building and occupants' lives. Though ML approaches proved to be successful for data-oriented decision-making, their prediction accuracy is largely dependent on the abundance of data and choice of ML. As a result, this study proposes an ML-based methodology that allows predicting the retrofit status of the school buildings using very limited records while achieving high prediction accuracy.

This study evaluated the structural health status of the school buildings with a framework consisting of data collection and pre-processing, feature engineering, and modeling of three ensemble predictors. Here, the Pearson correlation was used for selecting the retrofitting features that have low intercorrelation along with a high correlation with decision output. The selected features are used to train and test RF, AB, and GB ensemble predictors. The results demonstrated improved prediction by combining the Pearson correlation and ensemble predictors. Besides, the AB and RF displayed superior prediction considering both accuracy (79%) and F1 score (79%) metrics. Considering precision metric, AB (80%) outperformed both RF (79%) and GB (76%). The observations suggested that utilizing AB over selected influential features can achieve high retrofitting prediction. However, AB is considerably more computationally expensive than RF. Therefore, for decision-making based on both accuracy and computational efficiency criterion, RF results in a better performance.

Even though this research was conducted using a small dataset of 110 records, combining feature engineering with ensemble predictors allows for achieving high prediction accuracy. The data collection is an expensive and lengthy procedure; therefore, the outcome of this study allows professionals to benefit from ML-based prediction using limited available records. This, in turn, facilitates integrating expert judgment with machines to enhance the decision-making quality while reducing human error. Moreover, this study is performed over the balanced dataset and thus the proposed methodology remains to be experimented with over the imbalanced structural health monitoring dataset. This can extend the practicality of the proposed approach for construction professionals.

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Design Strategies for Reducing Embodied Water of Buildings: Material Selection

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Abstract

Water scarcity is seen as one of the most serious disasters that humanity have started to face. As construction is one of the leading sectors contributing to the water footprint, effective actions are needed to be taken to reduce embodied water of buildings. Water-related matters in the construction industry are generally addressed to reduce consumption at the operational stage. Green building assessment and certification systems which aim to improve water, energy efficiency and indoor air quality are mainly focused on water consumption at building operation stage. Construction materials have a significant impact on embodied water of buildings. For this reason, at the early stages of design (conceptual design and/or initial phases) definition and application of alternative materials, techniques and/or systems can help to reduce embodied water of buildings significantly. Based on literature review, this study aims to examine and develop design strategies for reducing embodied water of buildings at the design stage which can be used both at the regional and global scales.

Keywords: *design, design management, embodied water, green buildings, water footprint.*

Introduction

Water is one of the primary and non-replaceable sources for all living beings. There is a substantial strain on the availability of freshwater supplies (Arosio et al., 2019) due to rapid growth in world population, industrialization, waste generation, contamination of water resources and rapid depletion of resources without commensurate increases. The water shortage which is one of the most challenging problems humanities face nowadays is anticipated to result in much greater problems in the future (Ercin & Hoekstra, 2013). These problems are projected will not to be only economic but also social (Chai et al., 2021). According to the World Economic Forum, due to its effects on health and livelihoods, water scarcity is a primary factor of migration (The Global Risks Report, 2022).

The construction industry has a substantial environmental impact with its production process and outputs (Sertyeşilışık & Sertyeşilışık, 2017). In addition, it consumes lots of supplies including materials, land, energy and water (Bardhan, 2011). In order to produce building

materials, more than 3 billion tons of raw materials which corresponds 40-50% of global resource use are consumed every year around the world (Abd El-Hameed et al., 2017). Even the water demand of the construction sector is very high (Rivero-Camacho & Marrero, 2022; Tian et al., 2019; Mannan & Al-Ghamdi, 2020), the impact of buildings on freshwater is still unclear (Pomponi & Stephan, 2021; Stephan & Crawford, 2014).

Based on the literature review, most of the studies regarding the water use in buildings focus only on the operational phase (Stephan & Crawford, 2014). Green building assessment and certification systems which are the driving forces for energy and water efficiency of buildings and indoor air quality improvement in buildings and current building regulations focus solely on the operational phase too (Al-Qawasmi et al., 2019). In Leadership in Energy and Environmental Design (LEED), only water consumption of indoor water fixtures, irrigation and mechanical processes are assessed (USGBC, 2021). Building Research Establishment Environmental Assessment Methodology (BREEAM) mainly focuses on water use in indoor water fixtures; but it also has a criterion about monitoring water consumption of construction plant, equipment, and site accommodation (BRE, 2021). Water and energy nexus is generally neglected in green building systems and current regulations (Pinto et al., 2017).

In spite of rising of environmental concerns, current methods only include adapting environmental criteria to existing projects and procedures to meet legal and business objectives (Morini et al., 2019). All these drives humanity to understand and take an action regarding the water crisis. Life cycle practices is becoming more prominent in construction sector (Chan et al., 2022). As a matter of fact, comprehensive evaluation methodologies that can be employed globally are needed (British Standard, 2016). To serve this purpose, the concept of water footprint (WF) and embodied water emerged (British Standard, 2016).

Design process influences 80% of the products' environmental effect (Thackara, 2016, as cited in Morini et al., 2019). Therefore, it is crucial to specify construction materials with low embodied water at early design stage (Sertyeşilışık & Sertyeşilışık, 2017). In order to solve sustainable challenges with respect to the environmental or social implications of the materials used, current approaches, which are created for the financial advantage of the corporations utilizing them, are insufficient (Kruzner, 2012). In green building systems, using the Environmental Product Declarations (EPD) certified products is encouraged in terms of life cycle of materials, there is no requirement regarding embodied water (USGBC, 2021; BRE, 2021).

This study aims to evaluate the current design strategies and methods as support for the low embodied water buildings. Through evaluation of literature, it is intended to support building designers and stakeholders on how to reduce the overall WF of buildings during the early design stages by material selection.

Embodied Water of Buildings

While water is needed to produce raw materials and finished goods, it is also required for main energy sources like electricity (Mousavi et al., 2015). Therefore, in order to analysis total water consumption, these invisible variables should also be accounted for in the calculations. WF is index of freshwater consumption covering direct as well as indirect water use, and it is comprised of blue, green and grey components (Hoekstra et al., 2011). Blue WF means surface and groundwater which is a measure of freshwater consumption to produce

something or service; green WF refers the rainwater meaning the rainwater retained in the soil, and grey WF refers pollution, and it means measure of freshwater consumption to remove contaminants (Čuček et al., 2015).

Embodied water, also referred as virtual water, is the total water volume consumed in manufacture and transport a product during all production process and it consisted of both direct and indirect water demands (Abd El-Hameed et al., 2017). Hoekstra et al. (2011) indicated that while the embodied water is referred to as volume of the water embedded in the product, WF is assessing type of water and as time and location of the water use. Since these two terms (embodied water and WF) are accepted to mean the same in the literature, they are assumed to be interchangeable in this paper.

Both direct and indirect water usage are taken into consideration while calculating the embodied water (Hoekstra et al., 2011; Abd El-Hameed et al., 2017). Although it depends on the scope of the studies carried out, direct water consumption covers water demand of production process (Abd El-Hameed et al., 2017), and indirect water consumption include required volume of water for the amount of energy used during the production process and mining of raw materials (Mousavi et al., 2015). In some studies (e.g., Ding et al., 2021) water consumptions of facilities are also included in direct water consumption while meals served to staff are included to indirect water consumption.

Even while the current emphasis is on water usage in construction operations, looking from the life cycle perspective is becoming more popular (Chan et al., 2022). Studies show that embodied water of materials is much higher than the consumption of water in operational phase. Stephan and Crawford (2014) calculated water used by residential building during its entire lifespan (the study includes pre-construction, construction, use, maintenance, and repair phases; excludes demolition phase) as 35,881 kL. Embodied water presents the most significant contribution with 13,673 kL which corresponds the 38.20% of the whole building water consumption while the water consumption of operational phase is 11,856 kL (Stephan & Crawford, 2014). Another study analyses the WF of the residential building covers the urbanization, construction (includes embodied water of materials), renovation (for 20, 40, 70 years) and demolition phases shows that construction phase has the biggest rate in terms of water consumption (Rivero-Camacho & Marrero, 2022). According to Gimeno-Frontera et al. (2018), water demand of production, construction, use, and end of life stages of food retails store is 1.73E+02 l/m^2 year, 7.21E+00 l/m^2 year, 1.61E+04 l/m^2 year, and 1.29E+01 l/m^2 year, respectively. Therefore, it is crucial to select low embodied water materials during the design stage (Sertyeşilışık & Sertyeşilışık, 2017) and adding the requirements to construction specification to guide the other decision makers and contractor.

Research Method

This paper investigates design strategies based on material selection for reducing embodied water of buildings. A comprehensive literature review which consisted of the peer- reviewed articles published in academic journals till the end of 2021 have been conducted. Articles were retrieved from the following databases: Science Direct, Scopus and Web of Science. Following an in-depth literature review, relevant articles that focus only the construction materials are analyzed, and design strategies have been gathered.

Findings

Most of the studies (e.g., Bardhan & Choudhuri, 2016; Gerbens-Leenes, 2018; Nezamoleslami & Hosseinian, 2020) are conducted on embodied water of agricultural or animal products since these are the most contributing materials. Majority of literature and references in Table 1 and 2 calculates the embodied water of building materials includes materials and/or manufacturing processes of these materials that are used in structural system (Figure 1). Structural materials are the bulkiest and heaviest components of a building, these materials consume high amount of water (Tian et al., 2019). Furthermore, manufacturing process has a determining impact on water pollution (Mousavi et al., 2015). Selection of building materials with low embodied water has a major impact to reduce embodied water of buildings (e.g., Stephan & Crawford, 2014). As all references in Table 1 and 2 have different results even the same product is assessed the embodied water indicators (location, type of water and time), calculation methodologies and databases are different. The purpose of this current study is not comparing the results of the examined literature and references in Table 1 and 2, the focus of this study is evaluating different outcomes and factors that affect the embodied water within the same study.

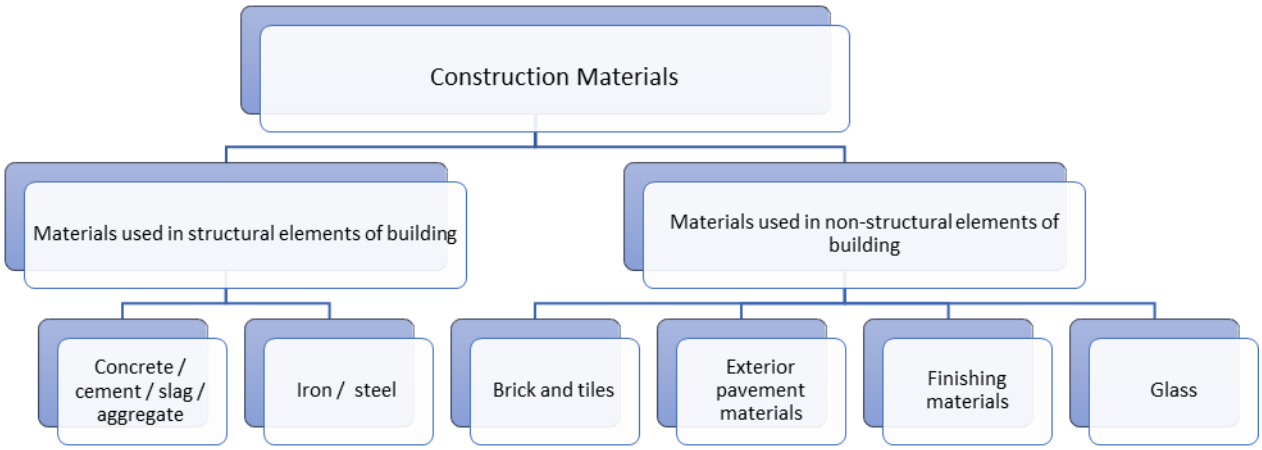


Figure 1: Types of building materials studied in literature.

In recent years, studies on embodied water of concrete and/or its raw materials (cement and slag) have been increased. This is mostly due to the fact that a substantial quantity of water is used in manufacturing process of concrete (Meyer, 2009; Ding et al., 2021). Ding et al. (2021) indicated that the most contributing items to embodied water of concrete are coarse aggregate. Using aggregates gathered from marine instead of land aggregates and using seawater in locations which suffer from the water-stress instead of freshwater will help to decrease the embodied water, but travel distance should be taken into consideration (Arosio et al., 2019). Portland cement has a huge impact on embodied water of the product (Wang and Chang, 2021). According to Gerbens-Leenes et al. (2018) and Batuecas et al. (2021), embodied water of the cement can be decreased with using alternative raw materials mentioned in Table 1 to Portland cement. Based on the WF of concrete analyses conducted in different locations, Ding et al. (2021) stated that the reason of higher embodied water could be result of undeveloped economy, and inadequate transportation systems in that region.

Table 1. Examples for studies on embodied water of concrete/cement/slag.

Study	Material	Blue WF	Grey WF
Gerbens-Leenes et al. (2018)	Portland cement (CEM I)	2.2 l/kg	210 l/kg
	Portland and composite cement (CEM II/B)	1.8 l/kg	210 l/kg
Hosseinian and Nezamoleslami (2018)	Cement plant	3,614,035 m^3/year	
Arosio et al. (2019)	Concrete with land aggregates (freshwater used in process) - Baseline	1.65-5.48 m^3/m^3	
	Concrete with land aggregates (seawater is used in process)	2%-9% reduction from baseline	
	Concrete with marine aggregates (seawater is used in process)	36%-80% reduction from baseline	
Vergara and John (2019)	Concrete (30 MPa, d: 2362.5 kg/m^3)	0.547-2.634 m^3/m^3	
Batuecas et al. (2021)	Ordinary Portland cement	116.96 m^3/m^3	
	Alkaline activated slag	114.56 m^3/m^3	
	Hybrid from slag	97.46 m^3/m^3	
	Hybrid from fly ash	96.85 m^3/m^3	
Ding et al. (2021)	Concrete	2,115.79 L/m^3 - 2,407.48 L/m^3	

According to study conducted by Gerbens-Leenes et al. (2018), grey WF of the steel and iron production is much higher than the blue WF. The reason is that significant risks relating to water are raised by steel and iron industry (Gu et al., 2015). It is important to improve sewage treatment efficiency and monitor the leakage through the water network so that grey WF can be reduced (Nezamoleslami & Hosseinian, 2020). According to Octavia et al. (2017), wastewater treatment system should be integrated to decrease water pollution and reduce gray water footprint. The ingredient of the material has also a determining impact as the production process and generated waste are different (Gerbens-Leenes et al., 2018; Wang & Chang, 2021). Since the equipment used for the manufacturing consume considerable quantity of both direct and indirect water, installing and/or replacing energy efficient equipment and fittings help to reduce WF (Nezamoleslami & Hosseinian, 2020). Using renewable energy systems which can produce the required energy for the production process helps not only reducing the water footprint but also carbon footprint (e.g., Ding et al., 2021).

Table 2. Examples for studies on embodied water of steel and iron.

Study	Material	Blue WF	Grey WF
Gu et al. (2015)	Iron and steel enterprise	2.44×10^7 (m^3/year)	6.5×10^8 (m^3/year)

Gerbens-Leenes et al. (2018)	chromium-nickel unalloyed steel	76.9 l/kg	1500 l/kg
	unalloyed steel	11.8 l/kg	2270 l/kg
Ma et al. (2018)	Crude steel	7.19 m^3/ton	12.04 m^3/ ton
Nezamoleslami and Hosseinian (2020)	Steel plant	56.868 million m^3/year	

In addition to structural materials, finishing materials also have considerable impact on embodied water (Abd El-Hameed et al., 2017). Ingredients and different processes during manufacturing alter the WF of the material and marble tiles and natural stones for flooring; silicate paints for internal coating and silicone acrylic paint for external coating can be selected to reduce embodied water based on study conducted by Abd El-Hameed et al. (2017). While the Solvay process has determining impact on blue and grey water of the glass (Gerbens-Leenes et al., 2018); additional processes such as laminating and strengthening also increase the embodied water of the glass (Abd El-Hameed et al., 2017).

Discussion

This study provides a framework for understanding the significance of material selection in reducing the embodied water of buildings. From the water efficiency point of view, important spots to be considered during the material selection and preparing specifications are summarized in this study. Designers and other decision makers can use the outputs of this study in the design stage.

It is crucial to lower the WF of construction materials to reduce the embodied water of the buildings (Stephan & Crawford, 2014; Rivero-Camacho & Marrero, 2022; Gimeno-Frontera et al., 2018). Type of the raw materials affects overall WF of the construction materials as shown in literature and references Table 1 and Table 2. Selecting raw material that meets the performance requirements, lower embodied water of the whole product (Gerbens-Leenes et al., 2018; Arosio et al., 2019; Batuecas et al.,2021). Alternative raw materials for concrete, cement and aggregate listed in Table 1 can be suggested to designers while selecting building materials. Ordinary Portland cement has a large carbon footprint owing to the quantity of cement clinker it contains (Qu et al., 2021) which also has a greater WF related to carbon footprint. Using composite cement with Portland cement, alkali-activated and hybrid cement mortars may reduce embodied water by about 20%, 4%, and 17% respectively as shown on Table 1. Different materials and/or processes might have opposing effects on blue and gray water footprints; as shown in Table 2, Gerbens-Leenes et al. (2018) found that although the blue WF of chromium-nickel unalloyed steel is greater than that of unalloyed steel, its grey WF is lower. Furthermore, while examining alternative raw materials with low embodied water, it is critical to assess their long-term performance (Arosio et al., 2019). Using seawater and marine aggregates in concrete as alternative to fresh water and land aggregates which is suggested by Arosio et al. (2019), may raise additional concerns regarding the long-term performance of the structural system. Marine aggregates, which are available in the sea naturally or dredged from the seabed, are widely utilized in the United Kingdom, several European nations, Japan, and China due to the worldwide scarcity of land aggregates (Liu et al., 2018). Due to chloride and sulphate content, marine aggregates have detrimental effect on concrete such as sulphate attack and steel corrosion (Liu et al., 2018) which are the same durability implications of utilizing seawater in concrete (Qu et al., 2021 and Tang et al., 2015). While protection measures against steel corrosion can be listed as coating reinforcing

steel with epoxy, using stainless steel and/or galvanized steel, application of fibrous composites as an alternative to steel, and using corrosion inhibitors; strategies against the sulphate attack could be using mineral admixtures for instance ground granulated blast furnace slag, increasing the depth of burial coating, blending mortar with ground glass powder, addition of magnesium oxide, superplasticizer and barium carbonate (Tang et al., 2015). All these strategies can be evaluated according to economic and durability concerns during the design stage (Sertyeşilışık & Sertyeşilışık, 2017) and any clauses may be added to construction specifications. Since the extraction of marine aggregates has negative impact on sea topography and sea ecosystem (Desprez, 2000), further investigation is needed before encouraging the use of marine aggregates (Arosio et al., 2019). Construction materials are exposed to different processes during the manufacturing stage to meet different performance needs (Gerbens-Leenes et al., 2018; Abd El-Hameed et al., 2017).

Water and energy nexus is often neglected (Pinto et al., 2017). Indirect water consumption as a consequence of the energy consumption is higher than the direct water consumption (Hosseinian & Nezamoleslami, 2018). Therefore, efficiency of equipment used in the production line is critical (Nezamoleslami & Hosseinian, 2020). It may be advised to repair and maintain the process equipment on a regular basis and to replace it with more efficient models after it reaches the end of its useful life (Nezamoleslami & Hosseinian, 2020). Based on these explanations it might be recommended to designers to add these requirements to construction specifications and identify the manufacturers that meet these criteria.

Water consumption of meal of personnel working in final assembly also has a significant effect on embodied water of construction material (e.g., Ding et al., 2021). Hosseinian and Nezamoleslami (2018) calculated the WF of a cement plant which is located in Iran. Ding et al. (2021)'s study revealed that average WF of concrete production of Northwest China is 2,159 L/m^3 and WF of personnel meal accounts for 35.20% of the overall WF. Nezamoleslami and Hosseinian (2020) determined the WF of steel plant in Iran to be $56.868*10^6$ m^3 whereas staff meal is 36.14% of the total WF. For this reason, it is crucial the management of human resources (Nezamoleslami & Hosseinian, 2020) and automatization of manufacturing processes (Ding et al., 2021) are.

As indicated by Mousavi et al. (2015), manufacturing process generates large amount of waste that releases to water. It can be suggested to consider manufacturers who provide waste treatment systems and leakage monitoring systems (Nezamoleslami & Hosseinian, 2020). For this reason, these requirements can be added to construction specifications.

The findings presented in this study are limited to literature review consisted of the peer-reviewed articles published in academic journals till the end of 2021. Blue WF is calculated in most of the studies (e.g., Vergara & John, 2019). Although the grey WF of manufacturing process is higher than blue WF as indicated in all references in Table 1 and Table 2, there are relatively few research (e.g., Ma et al., 2018) that include grey WF into the calculations. Further studies need to be conducted for different types of construction materials in different locations. Moreover, since embodied water depends on the type of water used and time, these parameters should be taken into account in future studies.

Conclusion

This research aims to examine existing literature on embodied water of buildings and gather the design techniques and approaches to reduce whole water demand of the buildings. It is important to giving the right decisions that reduce the environmental effects of the building at the design stage (Sertyeşilışık & Sertyeşilışık, 2017). Therefore, it is crucial to select low embodied water materials during the design stage and adding the requirements to construction specifications to guide the contractor, other decision makers and manufacturers. Even the embodied water depends on the location, time (for example rainy season or drought season) and type of water used (Hoekstra et al., 2011); based on the literature and references in Table and 2, there are several measures that can be used both regionally and globally to reduce embodied water of the construction materials. If the alternative raw material which requires less water (e.g., Gerbens-Leenes et al., 2018) meets the performance requirements, it could be substituted with traditional material. Until recently, virtual water was neglected while assessing the water consumption of building and/or building material (Al-Qawasmi et al., 2019; Stephan & Crawford, 2014). Studies (e.g., Ding et al., 2021) show that virtual water which is an indicator of water consumption of energy usage, raw material extraction, and staff meals have a greater impact than direct water consumption. Energy demand of the equipment can be reduced with replacing them with the efficient ones (Nezamoleslami & Hosseinian, 2020). Furthermore, using renewable energy systems will help to reduce fossil fuel consumption, carbon footprint as well as water footprint (Ding et al., 2021; Hosseinian & Nezamoleslami, 2018; Nezamoleslami & Hosseinian, 2020). Since the manufacturing process releases large amount of waste to water (Mousavi et al., 2015), to reduce grey water footprint sewage and waste treatment systems should be installed or improved and leakage monitoring system to intervene when there is a leak should be installed (Nezamoleslami & Hosseinian, 2020). Water consumption due to personnel meals also has a determining effect on total WF which highlights the industrial processes' reliance on people and the importance of human resourcing (Ding et al., 2021; Hosseinian & Nezamoleslami, 2018; Nezamoleslami & Hosseinian, 2020). Moreover, based on literature review it can be recommended that in material selection phase designers may ask embodied water calculations from the manufacturers or check this information from the EPD or other relevant documents if available.

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Construction in Uncertain Economic Conditions

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Abstract

According to the reports of the Central Bank of Turkey for 2020, construction companies constitute 14.76% and the number of employees working in sector constitutes 9.91% of Turkey in general. The construction sector has an active role in the Turkish economy. The Turkish construction sector has been adversely affected by epidemics, the wars in the region, the migrant crisis, inflation, and exchange rate increases. Turkish Contractors Association reported, grew in the first half of 2021, albeit quite limitedly; contracted again and sharply in the third quarter. Uncertain economic conditions leave investors undecided between build or not to build. This research aims to find data in construction sector in uncertain economic conditions. Google Academic is used as the search engine in this research. "Foreign exchange rate", "risk", "building", "inflation", "construction industry", "construction sector" are selected as keywords to conduct research for this study. The search was carried out between March and April 2022, and 168 results were listed. According to their relevance to the topic, nineteen articles are selected. From the selected articles, it is observed that there are researches in the literature about affordable housing, cost estimation, late payment, challenges, international construction markets and risk factors and the critical success factors of construction companies. These articles show that there is a significant connection between the construction sector and economic situation of the countries and there are some precautions to prevent economic loss for the companies. As a result of this study, it has been thought that the production of solutions for these uncertain conditions of the Turkish construction sector will be supported by examining the studies conducted in the literature.

Keywords: *construction, economic conditions, exchange rate, inflation, risk.*

Introduction

Construction sector effects both domestic and global economy of the world. This powerful sector also influenced by the change in the economies of the countries and world. Bid or no bid decision (Li et al., 2020), and to build or not to build decisions (Adabre et al., 2022) identify by the uncertain economic conditions.

Along with the pandemic, a serious economic crisis has emerged in the whole world and in Turkey. With the material and labor prices changing and increasing day by day, and increasing, serious cost differences have emerged between the start and end of the project in the construction sector, and it has become difficult for the sector to cope with such conditions Considering that there have been uncertainties in the economy in the past, this study aims to

reach studies that examine the attitudes and solutions of the construction sector in such crises and uncertain economies. For this reason, in this study, literature sources were examined using the "Google Academic" database and the problems encountered in economic uncertainties in terms of the construction sector and the approaches taken against them were summarized. Thus, it is thought that this study will be a roadmap for the current economic situation.

Methodology

Construction under uncertain economic conditions is a problem with broad implications. In this study a literature review is conducted to address effects of the uncertain economic conditions to construction sector. Systematic literature review technique is a method for reaching knowledge with a systematic way. A traceable and repeatable research method is important for future research (Jesson et al., 2011). Jesson et al. (2011) defined six methodology stages to define systematic literature review. These are, define the research question, design the plan, search for literature, apply exclusion and inclusion criteria, apply quality assessment and synthesis. In this study, the literature review was shaped around with two simple research questions. These questions can be summarized as below;

- What are the effects of uncertain economic conditions to the construction sector?
- Are there any studies that offer solutions to the problems of the construction sector in uncertain economic conditions?

Google Academic search engine was used to reach relevant studies to the research questions. Keywords were selected to identify economic condition and construction sector. Selected keywords were “foreign exchange rate", “risk,” “building”, “inflation”, "construction industry" and "construction sector". The search was carried out between March and April 2022, and 168 results were listed. Nineteen studies were selected by reading abstracts of the studies and determination of their relevance to the questions.

Findings

As a result of the literature review, it has been shown that researchers have started to be made on the effect of uncertain economic conditions on the construction sector in recent years. Selected studies for this research are summarized in Table 1. When the nineteen selected studies were examined, it was seen that the studies could be classified within the framework of five main topics. These topics can be summarized as affordable housing, cost estimation, late payment and nonpayment, challenges associated with international construction markets and risk factors and critical success factors. Selected studies will be summarized under these topics in the following sections of this study.

Affordable Housing

It has been seen that one of the nineteen selected studies can be examined under the title of affordable housing. This study can be summarized as below;

Adabre et al. (2022) emphasized in their study that the gap between income groups in developing countries has increased. Housing needs of people from middle- and low-income groups is a problem.

Table 1. Studies about uncertain economic conditions.

	Journal / Conference	
Gunduz et al. (2022)	Housing Policy Debate	Buying Citizenship: A Boon to District-Level House Prices in Istanbul.
Adabre et al. (2022)	Cities	To Build or Not to Build, That Is the Uncertainty: Fuzzy Synthetic Evaluation Of Risks For Sustainable Housing In Developing Economies.
Bovkun et al. (2021)	Proceedings - 2021 3rd International Conference on Control Systems, Mathematical Modelling, Automation and Energy Efficiency, SUMMA	Methodical Approach to Minimizing Risks in Road Construction.
Chattapadhyay et al. (2021)	Buildings	Risk Identification, Assessments, and Prediction for Mega Construction Projects: A Risk Prediction Paradigm Based on Cross Analytical-Machine Learning Model.
Tam et al. (2021)	Proceedings of the 24th International Symposium on Advancement of Construction Management and Real Estate	Assessment for the Correlation Between Stakeholder Motivation and Company Profitability in Construction Industry Based on a Human Motivation Theory.
Yap & Cheah (2020)	Journal of Engineering, Design and Technology	Key Challenges Faced by Chinese Contractors in Malaysian Construction Industry: Empirical Study.
Omotayo et al. (2020)	International Journal of Productivity and Performance Management	Systems Thinking and CMM For Continuous Improvement in The Construction Industry
Li et al. (2020)	Journal of Construction Engineering and Management	Empirical Bid or No Bid Decision Process in International Construction Projects: Structural Equation Modelling Framework.
Moreno-Cabezali & Fernandez-Crehuet (2020)	Computers & Industrial Engineering	Application of A Fuzzy Logic-Based Model for Risk Assessment in Additive Manufacturing R&D Projects.
Moraghen et al. (2020)	International Journal of Finance & Economics	The Impact of Exchange Rate and Exchange Rate Volatility on Mauritius Foreign Direct Investment: A Sector-Wise Analysis.

Table 1 (Continue). Studies about uncertain economic conditions.

	Journal / Conference	
Nguyen & le Hoang Thuy To Nguyen (2020)	The Journal of Asian Finance, Economics and Business	Critical Factors Affecting Construction Price Index: An Integrated Fuzzy Logic and Analytical Hierarchy Process.
Oteng-Abayie & Dramani (2019)	Construction Management and Economics	Time-Frequency Domain Causality of Prime Building Cost and Macroeconomic Indicators in Ghana: Implications for Project Selection.
Odediran & Windapo (2018)	Built Environment Project and Asset Management	Risk-Based Entry Decision into African Construction Markets: A Proposed Integrated Model.
Omotayo et al. (2018)	International Journal of Productivity and Performance Management	Critical Success Factors for Kaizen Implementation in The Nigerian Construction Industry.
Ujene & Idoro (2015)	Journal of Building Performance	Direct Costs Prediction of Structural Elements of Small and Medium Rise Buildings.
Abdul-Rahman et al. (2013)	Journal of Professional Issues in Engineering Education and Practice	Late Payment and Non-payment Encountered by Contracting Firms in a Fast-Developing Economy.
Olatunji (2010)	Construction Management and Economics	The Impact of Oil Price Regimes on Construction Cost in Nigeria.
Gonzalez et al. (2006)	SSRN Electronic Journal	Linear and Nonlinear Interest Rate Exposure of Spanish Firms.
Chua et al. (2003)	Journal of Construction Engineering and Management	Impacts of Obstacles in East Asian Cross-Border Construction.

The residential buildings with high-rise buildings, which the government has brought as a solution for low- and middle-income groups, are not preferred by people, they turn into uncontrolled areas and as a result, ghost housing areas are formed. For this reason, states are torn between whether to build housing for low- and middle-income groups. The increase in the construction costs and the increase in the land prices increase the housing prices. In the solution proposals for people to produce their own houses, this time the demand for the land increases and speculative prices emerge. Housing structures for high-income groups are being built. A hybrid model is required here. Housing structures built by the private sector under the coordination of the state. It is expected that the decisions to be taken will be economically, socially and environmentally sustainable. Housing prices and rental prices should be accessible (affordable), environmentally friendly designs should be made, access to clean water, energy and sewerage systems, work, shopping areas, education and health services should be accessible. Housing production is in direct relation with the political and economic situation of the country. In their study, delays in payments by/clients are at the forefront of the risks that prevent the development of sustainable housing needs in the country. In the second place is fluctuation in exchange rate. Third place is fluctuating cost of finance (interest rates). In the fourth place, inflation rate volatility was determined. The fact that the first four risks are related to financing shows that the construction sector and accordingly the housing need are directly

affected by the economy. Together with the studies summarized above, it is seen that the issue of affordable housing is especially important for the construction sector.

Cost Estimation

It has been seen that three of the nineteen selected studies can be examined under the title of cost estimation. These studies can be summarized as below;

Oteng-Abayie and Dramani, (2019), emphasized in their study that investors are curious about the current costs associated with construction, as well as how costs will rise during construction. Firms use consumer price index and exchange rate in order to make cost estimations of construction projects in an inflationary environment. In this study, they aimed to test the accuracy of this method. The study was conducted in Ghana. They found that the prime building cost index and the non-food consumer price index go together. To make short-term project investments for investors in regions with high inflation. They emphasized that domestic materials should be preferred due to the increase in exchange rates in materials supplied from abroad.

In the other study, Ujene and Idoro, (2015), developed cost estimation models of the structural elements of low and medium height structures. In three of the models they developed, they also added inflation data to the model. It is thought that the participation of inflation data in direct cost calculation models is important for economies where inflation is effective.

Another research is conducted by Olatunji (2010) that investigated the effect of oil price regimes on construction costs in Nigeria. As a result of the study, a significant relationship was found between oil prices and inflation, between cement prices and oil and inflation, and between these and construction costs. This research is important as it is a study that proves the effect between oil prices and construction costs.

Together with the studies summarized above, it is seen that the issue of cost estimation is especially important for the construction sector. Suggested solutions and models can help project stakeholders in cost estimation, enabling them to finish the project process with less damage in uncertain economic conditions.

Late Payment and Nonpayment

It has been seen that two of the nineteen selected studies can be examined under the title of late and nonpayment. These studies can be summarized as below;

Abdul-Rahman et al. (2013) emphasized in their study about late payment and nonpayment situation in the construction sector. In the construction sector, which is a labor-based sector, late payments to contractors make workers' payments difficult. Although the approach of the employers to make the payments as late as possible seems to be advantageous for the employer but the late payments of the subcontractors cause a series of late payments and cause the non-financially strong contractors to increase their borrowing-by-borrowing. Timely payment is an important factor for companies to make a profit. Among the reasons for late payment, it is stated that the employer's deficiencies in management, insufficient financing for the project, and the contractor's use of late payment for his own advantage. Uncertainties in the market also cause

late payments. In the other study, Odediran and Windapo (2018) conducted research about delays in payment and shortage in payment are among the financial risks for companies that will do business in the international construction sector. It is seen that the problems related to payment are frequently mentioned in the literature and are a general problem.

Together with the studies summarized above, it is seen that the issue of late payment and nonpayment especially important for the construction sector.

Challenges Associated with International Construction Markets and Risk Factors

It has been seen that eleven of the nineteen selected studies can be examined under the title of challenges associated with international construction markets and risk factors. These studies can be summarized as below;

Gunduz et al. (2022) investigaed in their study, the short-run impact of relatively wealthy foreigners on the residential property prices in Istanbul investing to buy a Turkish passport. It was found that the Turkish CBI (Citizen by Investment) program positively impacts house prices by 2% in the districts, which are likely to be favored most by immigrant investors.

In other studies, Bovkun et al. (2021) proposed a methodological approach to minimizing risks in road construction in their study. In this study, the researchers identified the risk factors of the road construction and according to those data, key risk indicators were developed. At the end of the study, the researchers predicted and assessed the likelihood of risk materialization during road construction. Chattapadhyay et al. (2021), developed a risk prediction system based on a cross analytical-machine learning model for construction megaprojects. With this model, the researchers aimed to help stakeholders in achieving project success.

Another study that can be evaluated under this topic is done by Tam et al. (2021) and the researchers aimed in their study to express the correlation between stakeholder motivation and profitability in relation to the inflation in these macro-economic conditions and come up with a human motivation theory. On the other hand, Li et al. (2020) proposed a model for Chinese international contractors to make a bid or no bid decision. Researchers have identified some factors for the decision to participate in the tenders of international construction projects. In the proposed model, foreign exchange rate fluctuation of currency and inflation rate fluctuation risk in host country factors are included under the country risks category.

Yap and Cheah (2020) emphasized in their study that exchange rate fluctuations in developing countries pose a financial risk for international contractors. Inflation is an important risk that affects material, labor and transportation costs. In the research, it was seen that exchange rate and inflation are among the main problems of Chinese contractor companies doing business in Malaysia. In the other study, Odediran and Windapo (2018) have identified the risks of the international construction market and make recommendations on how they can reduce the risks so that South African companies can enter the international construction sector. In this study, volatility in foreign exchange rates, fluctuation in inflation rate/rising inflation and volatility in interest rate were found among economic and financial risks.

Moraghen et al. (2020) analyzed the structure of foreign direct investment inflow in different sectors of the Mauritian economy. In that study, the researchers emphasized that the construction sector has shown continuous growth during the past decade, even in the last years,

the trend of the growth of the construction sector is began to go downtrend. In other study, Nguyen and le Hoang Thuy To Nguyen (2020) searched for a decision-making approach for calculating critical factors that affect the construction price index in their study in Vietnam. The research results showed that the top five critical factors affecting the construction price index in Vietnam are consumer price index, gross domestic product, basic interest rate, foreign exchange rate, and total export and import.

Gonzalez et al. (2006) investigated the effect of interest rates on sectors in Spain. In the study examining the data between 1993 and 2001, it was determined that the increase in interest rates affected the construction sector the most. The reason for this finding was defined as the construction sector is being a capital-intensive sector and the construction sector is being the active sector in the growth of the Spanish economy. Chua et al. (2003) examined the factors of cost growth in East Asian countries, China and Singapore in their study. It has been determined that the construction costs in China are higher than in Singapore. Among the reasons why costs are generally higher are losses due to fluctuation of foreign exchange rate, and losses due to fluctuation of labor and material prices.

Together with the studies summarized above, it is seen that the issue of challenges associated with international construction markets and risk factors is especially important for the construction sector. Suggested solutions and models can help project stakeholders enabling them to finish the project process with less damage in uncertain economic conditions.

Critical Success Factors

It has been seen that three of the nineteen selected studies can be examined under the title of critical success factors. These studies can be summarized as below;

Omotayo et al. (2018, 2020) suggested the Kaizen method to improve the processes of Nigerian construction companies. Financial risk management is among the critical success factors so that they could apply the kaizen method to their companies. It has been mentioned that inflation and late payments create financial risks and affect the improvement of processes. It is thought that the construction sector is necessary for growth in developing countries, and therefore, it is thought that it will be beneficial for both companies and the country's economy if construction companies review and improve their processes. In the other study, Moreno Cabezali and Fernandez-Crehuet (2020), studied risks associated with Additive Manufacturing (AM) Research and Development (R&D) Project Management. The results of this study showed that the risks “Defects occurring during the manufacturing process”, “Defective design”, “Poor communication in the project team” and “Insufficient financing” are determined as the most critical success factors in AM R&D Project Management.

Together with the studies summarized above, it is seen that the issue of critical success factors is especially important for the construction sector. Suggested solutions and models can help project stakeholders enabling them to finish the project process with less damage in uncertain economic conditions.

Conclusion

In this research study, answers to two questions were sought from the literature. These questions were (i) What are the effects of uncertain economic conditions to the construction sector? and (ii) Are there any studies that offer solutions to the problems of the construction sector in uncertain economic conditions? When the studies in the literature are examined, it is seen that the studies are shaped around the topics of affordable housing, cost estimation, late payment and nonpayment, challenges associated with international construction markets and risk factors and the critical success factors. In the examined nineteen studies, some models were developed, and some solutions were presented in order to cope with the uncertain economic conditions in the construction sector. When the studies' common view is summarized, it is clearly seen that the construction sector is directly affected by the uncertain economic conditions. Because, it has been seen in some of the examined studies that even though growth in many sectors stops and the growth rate in the construction sector decreases during economic crises, the sector must continue working and progress in order to fulfill the needs such as housing and infrastructure etc.

In this study, it is seen that there is a strategic relationship between the construction sector and the economy in terms of countries. Therefore, it should be investigated how the construction sector can function and how the production in the sector can continue with minimum damage during economic fluctuations and solutions should be produced in this direction. It is thought that such preventions can be taken together with the academical studies, and the solutions produced in the sector.

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The Effect of Economic Factors on the Bidding Decision of Contractor Construction Firms: The Case of Antalya Province

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Abstract

Public construction projects are mostly awarded to contractors by tender method. The survival of contractor construction companies in a competitive environment depends on taking on new projects that will offer them the highest return and market share. The decision to bid or not to bid on new projects has always been an important issue for contractor construction companies. It is very difficult to make a decision to bid, because it is affected by many factors and because of the complexity and uncertainty it contains. For this reason, many academic studies have been conducted on the determination of the factors affecting the decision to bid and on decision support methods for bidding. When the literature is examined, it is seen that the biggest factor in bidding is economic factors. In this study, the effect of current economic factors in Turkey on the decision of the contractor construction companies to bid was investigated. In the case study, public construction tenders held in the province of Antalya were examined.

Keywords: *construction, decision to bid, factor, project management, tenders.*

Introduction

The construction industry is one of the most important industries in any economy because the annual value of construction put in place is very large, the industry employs a very large number of workers as it is very labor-intensive, and it affects the activities of many side industries such as materials, manufacturing, chemicals, etc. All private and public investments are directly or indirectly related to the construction industry (Sümer et al., 2020). Globally, the construction industry has continued to play a critical role in economies of both developed and developing nations (Zhao et al., 2014). The developing countries' construction contracting firms are on the rise and are becoming important global players (Low et al., 2020). Developing countries' construction contracting firms are playing an important role in the worldwide economy, and are nowadays open to different challenges as they need to operate in risky political conditions and markets (Korkmaz & Messner, 2008).

Finding a project to bid on is essential for construction engineering contractors to survive market competition (Yan et al., 2018). To survive in a competitive construction industry, it is extremely imperative for a firm to secure tenders and produce a profit (Egemen & Mohamed, 2007). While the construction market offers contractors considerable opportunities to bid, it requires contractors to carefully select construction projects that are most suitable to them

(Wang et al., 2020). Any invitation to tender is potentially a business opportunity. A decision is needed to either explore it (so use time and resources to prepare a bid) or decline it in search for better options. This implies that a variety of decisions are taken at different management levels to minimize cost and increase revenue (Biruk et al., 2017). The decision is not only related to win or lose the chance of the tender, but it is also about the ability to finish the project as planned with expected profit (Egemen & Mohamed, 2007).

The bidding process involves the bid/no-bid decision which is crucial and associated with risks and uncertainties due to various factors that influence it (Enshassi et al., 2010). The influencing factors might relate to the contractor himself, to the client, or to the project conditions and the general environment. Bidding decision problems are highly unstructured. Typically, contractors make their decisions based on their common sense or the rule of thumb which may lead to suboptimal decisions. This is why many researchers have been involved in the development of bidding strategy models (Mahamid, 2022). The aim of this study is to investigate the effect of current economic factors on the bidding decisions of contractor construction companies in Antalya. For this purpose, a literature review will provide a summary of the previous studies conducted to identify the related factors, then the effect of the current economic situation on the bidding decision will be revealed.

Literature Review

Over the years, the bid/no bid decision has attracted the attention of many researchers. A relatively large number of studies have focused on identifying the factors affecting the decision, but few studies have investigated and developed relevant bidding strategy models (Enshassi et al., 2010). Some of the studies conducted for this purpose are presented below under two main headings which are “Studies Focused on Factors” and “Studies Focused on Bidding Strategy Models”.

Studies Focused on Factors

One main problem of bidding strategy models is the inability to illustrate how a bidding decision was made. Ahmad and Minkarah (1988) argued that one way to minimize such an issue is only through uncovering potential underlying factors affecting the decision. Based on a questionnaire survey conducted among the top construction contractors in the United States (USA), Ahmad and Minkarah (1988) identified 31 factors affecting bid/no bid and markup decisions. Since then, their opinion is echoed by many kinds of researches focusing on the determination of factors affecting bid/no bid decision (Li et al., 2021). Bageis and Fortune (2009) concluded that the critical factors affecting the bidding decision in Saudi Arabia to be client financial capacity, prompt payments, project payment system, clarity of the work and specifications, and project cash flow. Alsaedi et al. (2019) conducted a study to identify the factors affecting the contractors’ bidding decisions in Saudi Arabia-based construction projects, and found 6 critical factors. the top six critical factors were “size of the job”, “type of the job”, “company’s strength in the industry”, “designer/design quality”, “rate of return”, and “project cash flow”. In Nigeria, Oyeyipo et al. (2016) conducted a study to identify the main factors influencing contractors’ bidding decisions in construction projects. Based on the findings of the study, the most significant factors affecting the bid/no-bid decision were “financial capability of clients”, “availability of capital”, and “availability of material”.

Shokri-Ghasabeh and Chileshe (2016) conducted a study to investigate and rank the critical factors influencing the bid/no-bid decision criteria and their importance in the Australian construction industry. They identified the 26 most common decision-making criteria and they accordingly grouped them into 5 categories, namely project, market, contractor, client, and contract. Li et al. (2019) investigated the factors affecting bid/no-bid decisions of international projects in Chinese construction projects. A total of 41 factors were identified through a literature review as having an impact on the bid decision. Ultimately, 9 main factors were identified as influencing the bidding decision, with contractor's capability and country risk of the host country, being the most important. Chileshe et al. (2020) investigated and ranked the critical factors influencing the bid or no-bid decision and their importance for the indigenous small building contractors within the Tanzanian construction industry. The 7 most highly ranked factors (among the 30 considered) are: availability of capital, financial condition of the client, project size, expected profit, project type, need of work, and current workload. Oke et al. (2020) indicated that the decision to bid is a complex activity that requires the consideration of several factors. These factors can be related to capability, time requirement, and cost implication. They performed a study to evaluate the factors related to time and cost performance to test their effect on the bidding decision. Structured questionnaires were used to gather data from construction professionals in both consulting and contracting firms. The study reported the reputation of the client as the most critical factor related to time performance that influences bidding decisions, while location and condition of the site were identified as the key factors related to cost performance. Thus, the reputation of the client, the location, and the condition of the site should be given the most priority by a contractor at the time of bidding.

Studies Focused on Bidding Strategy Models

A great number of research studies have been done to develop bid/no-bid models; and thereby aid the contractors to make the best decision during the bidding process (Biruk et al., 2017; Chisala, 2017; Egemen & Mohamed, 2007, 2008; El-Mashaleh, 2010, 2013; Lesniak & Plebankiewicz, 2015; Lin & Chen, 2004; Lowe & Parvar, 2004; Ratekar et al., 2016; Shi et al., 2016; Wanous et al., 2000, 2003). Lesniak and Plebankiewicz (2015) designed a bid/no-bid decision model based on fuzzy theory, the authors distributed surveys to operating contractors in Southern Poland in order to make a list of the most influential factors in a bidding decision. The fuzzy set theory was incorporated into the evaluation of overall factors to find a convenient solution to the problem. Shi et al. (2016) introduced a novel model by using a rough set (RS), and general regression neural network (GRNN), based on niche particle swarm optimization (NPSO) algorithm for bid/no-bid decision-making. Biruk et al. (2017) developed a parametric approach, which was a combination of the Analytic Hierarchy Process (AHP) and linear programming model for the purpose of making a decision about whether to bid or not based on a calculation of the total price of the bid. The authors drew a relationship between the bid price and project attractiveness. Chisala (2017) developed a quantitative model to support the decision-makers during the bidding stage. the proposed model was based on a simple additive weighted scoring (SAWS) to produce importance weights of the critical bidding factors and to generate importance scores based on external and internal factors. The decision tree algorithms are used in several real-world applications. It is used in businesses in the visualization of probabilistic business models; in intrusion detection for generating algorithms to design rules for an automatic intrusion detection system; in energy modelling for building; in medicine for diagnosis of various diseases; in the industry for production quality control (Patel & Rana, 2014). The decision tree algorithm has been

effectively used in modelling systems for capturing and extracting the knowledge from datasets. The primary task implemented in these systems is using algorithms to determine the best classification of data according to the decision tree rules (Magesh et al., 2013). Gündüz and Al-Ajji (2021) developed bid/no-bid models for design-bid-build projects for contractors by using Chi-square Automatic Interaction Detector (CHAID) and Classification and Regression (CRT) decision tree algorithms.

In conclusion, as seen from previous literature studies, the most important factors affecting bidding are economic factors.

Current Economic Factors in Turkey

In a year passed after the whole world faced an epidemic of a prevalence that has not been experienced for a long time; the human burden has increased, millions of people have been unemployed, and the social and economic difficulties have become more acute. However, despite the ongoing uncertainties regarding the epidemic, the way out of this eco-health crisis has become more visible as a result of the rapid progress in vaccination efforts. After a turbulent 2020, the global economy is finally starting to emerge from the worst phases of the Covid-19 pandemic. Rapid worldwide policy responses to the post-pandemic economic and health crisis have prevented potential worsening consequences. In addition, consumer behavior that changed with the epidemic led to an increase in demand in some sectors, while disruptions in supply chains led to an increase in the costs of imported intermediate goods. Inflation risks arising from high input costs, shortage of supply and relatively high demand on a sectoral basis maintain their importance in the global economy. In the last quarter of 2021, global economic activity increased more slowly than expected due to concerns about the Omicron variant in the Covid-19 outbreak, the chip crisis, problems in global supply chains, rising inflation on a global scale, and related interest rate hikes (SBB, 2021).

The Russia-Ukraine war increases global risks at a time when the impact of the Covid-19 epidemic is decreasing. The global effects of the war were felt through many channels. Rising commodity and food prices, supply cuts and food security problems stood out as the most obvious consequences of the war. War causes global financial fluctuations and political uncertainties. In addition, the planned and planned sanctions against Russia and the reactions to these sanctions cause uncertainties in terms of global economic activity. On the other hand, the global recovery tends to slow down as the extraordinary government incentives implemented during the epidemic period are reduced to a minimum (SBB, 2022).

Due to the global economic crisis, problems such as high inflation and slowdown in growth rates have emerged in all countries of the world. On the other hand, Turkey is one of the countries experiencing the problem of high inflation at the highest level in the world. According to the latest issue of the World Bank's Turkey Economy Monitor report published on February 25, 2022, the Turkish economy, which recorded a strong growth beyond expectations in 2021, is expected to grow at a much slower pace in 2022, with increasing domestic macroeconomic and financial difficulties slowing growth. Frequent changes in monetary policy settings and a series of interest rate cuts since last September caused the Turkish Lira to fall to historical lows and inflation to record highs (World Bank, 2022).

As a result of the above mentioned economic difficulties; the construction industry in Turkey has also faced serious cost increases. According to the data of the Turkish Statistical Institute

(TUİK) which is shown in Table 1, the Domestic Producer Price Index reached its highest level in the last 20 years (TUİK, 2022a). Similarly; annual construction cost change rate which is shown in Figure 1 have reached 106.87% (TUİK, 2022b). As can be seen in Figure 2, the market prices of rebar and concrete, which are among the basic cost items in the construction sector, have increased significantly in the last year. The main reason behind all these price increases is the depreciation of the Turkish Lira against the US Dollar. Average exchange rates are shown below in Table 2.

Table 1. Domestic producer price index (D-PPI).

Year	D-PPI (%)
2001	88.6
2002	30.8
2003	13.9
2004	13.8
2005	4.54
2006	11.58
2007	5.94
2008	8.11
2009	5.93
2010	8.87
2011	13.33
2012	2.45
2013	6.97
2014	6.36
2015	5.71
2016	9.94
2017	15.47
2018	33.64
2019	7.36
2020	25.15
2021	79.89
2022	144.61

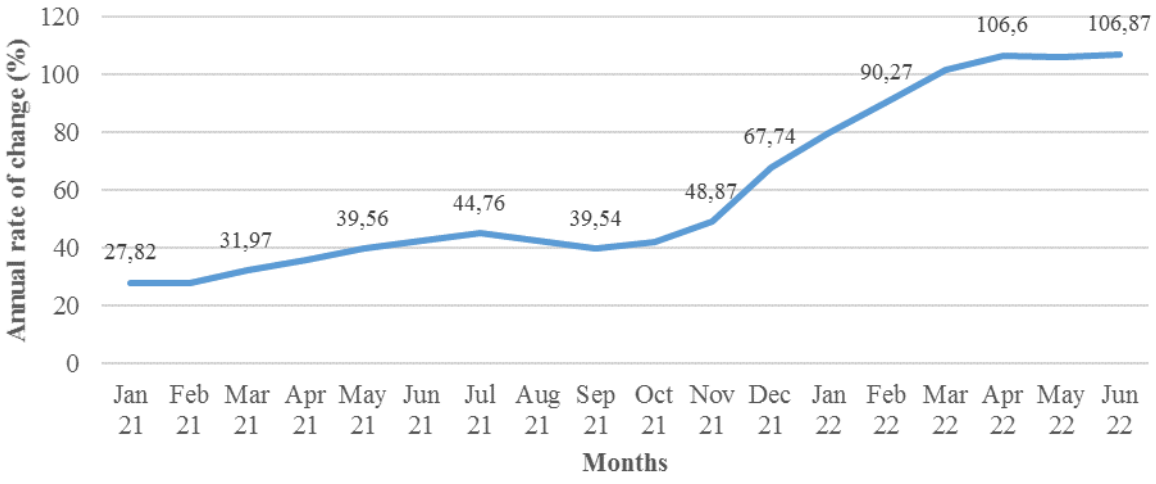


Figure 1: Annual construction cost change rate.

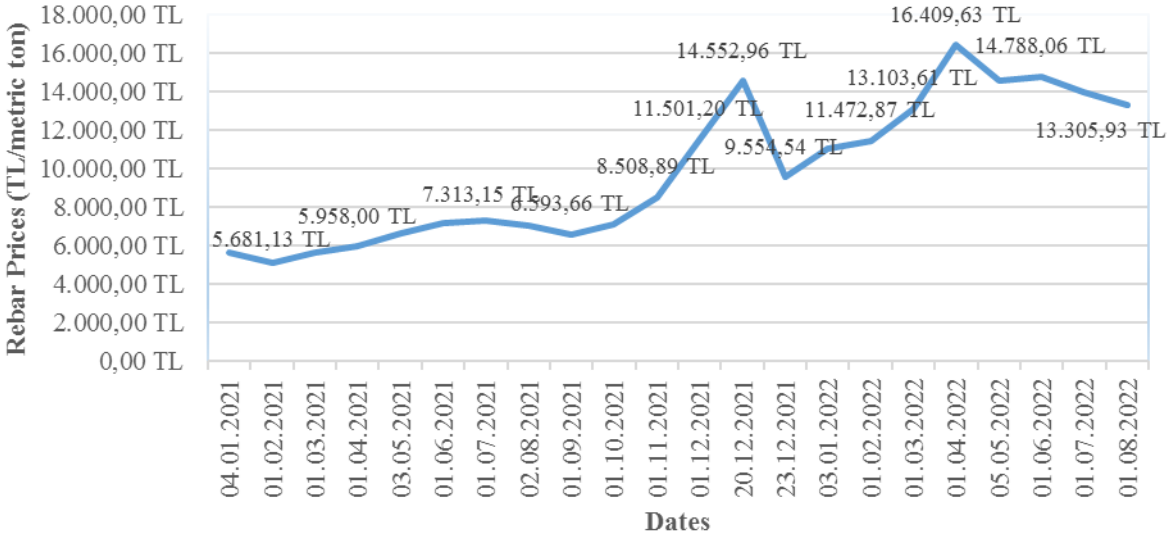


Figure 2: Rebar market prices (https://www.demirfiyatlari.com/#demirfiyatendeksi).

Table 2. Average exchange rates (USD $) (https://www.doviz724.com/yillara-gore-ortalama-amerikan-dolari-kuru.html).

Year	Turkish Liras	Rate of Change Compared to the Previous Year
2001	1.234	
2002	1.514	22.69%
2003	1.499	-0.99%
2004	1.429	-4.67%
2005	1.347	-5.74%
2006	1.439	6.83%
2007	1.308	-9.10%
2008	1.299	-0.69%
2009	1.555	19.71%
2010	1.508	-3.02%
2011	1.679	11.34%
2012	1.801	7.27%
2013	1.906	5.83%
2014	2.192	15.01%
2015	2.726	24.36%
2016	3.028	11.08%
2017	3.656	20.74%
2018	4.824	31.95%
2019	5.683	17.81%
2020	7.023	23.58%

2021	8.927	27.11%
2022	15.347	71.92%

Bidding Decision of Contractor Construction Firms: The Case of Antalya Province

Within the scope of this study, the proposals of the contractor construction companies that bid for the tenders of the public institutions in the province of Antalya were examined. Considering the date of September 15, 2021, when the dollar exchange rate started to rise in Turkey, the effect of firms on their decision to bid or not have been examined. For this purpose, the necessary data has been obtained from the Electronic Public Procurement Platform (EKAP), where the tender statistics are published by the Public Procurement Authority (KİK). The tenders for which the results of the tenders have been published since 2018 have been taken into account, and it has been examined whether the ratio of the tenders for which no bids have been given among the canceled tenders has increased in the period when the economic situation deteriorated. Demolition tenders, which were among the canceled tenders, were not taken into account.

As can be seen in Table 3 below, a total of 454 construction tenders were made in 2018, with the result announcement published. 96 of these tenders were canceled for various reasons. Among the canceled tenders, the number of those for whom no bids were made is 14. Its ratio to the total number of tenders is 14.58%.

A total of 230 construction tenders were made in 2019, with the result announcement published. 38 of these tenders were canceled for various reasons. Among the canceled tenders, the number of those for whom no bids were made is 6. Its ratio to the total number of tenders is 15.79%.

A total of 305 construction tenders were made in 2020, with the result announcement published. 53 of these tenders were canceled for various reasons. Among the canceled tenders, the number of those for whom no bids were made is 2. Its ratio to the total number of tenders is 0.04%.

Between 01 January 2021 and 15 September 2021, a total of 292 construction tenders were made. 54 of these tenders were canceled for various reasons. Among the canceled tenders, the number of those for whom no bids were made is 10. Its ratio to the total number of tenders is 18.51%.

Between 15 September 2021 and 31 December 2021, a total of 133 construction tenders were made. 62 of these tenders were canceled for various reasons. Among the canceled tenders, the number of those for whom no bids were made is 25. Its ratio to the total number of tenders is 40.32%.

Between 01 January 2022 and 01 June 2022, a total of 203 construction tenders were made. 89 of these tenders were canceled for various reasons. Among the canceled tenders, the number of those for whom no bids were made is 27. Its ratio to the total number of tenders is 30.33%.

Table 3. Total rate of no-bids.

Period	Total Tenders	Total Canceled Bids	Total No-bids	Ratio
01 January 2018-31 December 2018	454	96	14	14.58%
01 January 2019-31 December 2019	230	38	6	15.79%
01 January 2020-31 December 2020	305	53	2	0.04%
01 January 2021-15 September 2021	292	54	10	18.51%
15 September 2021-31 December 2021	133	62	25	40.32%
01 January 2022-01 June 2022	203	89	27	30.33%

Conclusion

This study contributes to the body of knowledge in bid/no-bid decision-making in construction projects. The economic factors seen in the literature review are among the most important factors affecting the bidding decisions of construction contractor companies.

In this study, it has been tried to determine whether the economic environment in our country has an effect on the decision of the contractors to bid. According to the results of the tenders held in Antalya, obtained from the Public Procurement Authority, it has been observed that there has been a decrease in the bid submission decisions of the contractor construction companies since mid-September, when the exchange rate increased rapidly in Turkey. This allowed the strong influence of the economic factors mentioned in previous studies on the decision to bid in a real economic uncertainty situation to be observed.

The limitation of this study is that it was carried out only in a narrow scope, such as the tenders of public institutions in the province of Antalya. In future studies, it is thought that expanding the scope of the study across the country will be more beneficial in academic terms.

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Causal Relationships between Construction Cost Index and Macroeconomics in Turkey

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Abstract

Construction cost fluctuations are crucial for project performance and it is very difficult to predict future cost fluctuations in developing and volatile economies. The construction cost index (CCI) is a statistical indicator that is an aggregate of material and labor costs produced and published by the Turkish Statistical Institute every month. CCI is widely used for future cost prediction by practitioners. This study aims to determine causal relationships between construction costs and major macroeconomic indicators such as; the consumer price index, producer price index, exchange rate, construction turnover index, etc. Autoregressive Distributed Lag (ARDL) Model and Granger Causality Test are employed to determine the cointegration and causality between the construction cost index and other macroeconomic indicators. This study provides important findings for improving future construction cost estimates. It also provides important candidate variables that can be used in cost estimation algorithms in the future.

Keywords: *construction cost index, cost estimation, Granger causality test, time-series analysis, Turkish construction industry.*

Introduction

Construction projects are complex due to long-term activities and several inputs such as material, equipment, labor and management. Such projects should be managed properly to ensure project success. Cost fluctuations caused by economic developments are one of the major problems affecting construction project performance (Enshassi et al., 2009, 2010). Fluctuations in both material and labor prices should be predicted accurately for proper budget allocation. For this purpose, practitioners should determine leading indicators and predict future construction costs using several forecasting models, especially in developing countries.

In recent years, forecasting models, developed using time-series data, have been implemented by many researchers. The determination of the independent variables used in these models is also of key importance for the success of the model. Many factors from supply-demand indicators to general economic conditions may affect future construction costs. Thus, determining potential leading indicators of construction costs is very crucial to forecast accurate future costs. Considering the macro-level, it can be claimed that macro cost indices such as consumer price index (CPI) (Shane et al., 2009) and producer price index (PPI) may

help to determine construction costs. Besides, there may be mutual effects between industrial indicators such as construction turnover, housing starts, etc… and construction costs. Finally, the exchange rate ($/TL) can be seen as potential factors affecting construction cost movements.

In this context, this paper aims to investigate potential leading indicators to forecast construction costs in Turkey. For this purpose, major potential indicators were determined using literature studies and causal relationships between these indicators and construction cost index (CCI) were investigated using Autoregressive Distributed Lag (ARDL) Model and Granger Causality Test.

Literature Review

Many studies have investigated leading indicators and their effects on CCI. While some studies have focused on accurate CCI forecasting, some have focused on determining leading indicators.

Shane et al. (2009) studied internal and external factors affecting construction cost escalations. The authors emphasized that market conditions and inflation are significant factors causing project cost escalations and they should be taken into account in cost forecasting. With the determination of the effects of economic indicators on construction costs, there has recently been an increase in the use of time series methods. From the earliest studies, Hwang (2011) developed a forecasting model to predict CCI using CPI as the independent variable. The author compared the vector autoregression (VAR) model as a multivariate time series model and the autoregressive integrated moving average (ARIMA) model as a univariate model. As a result, it has been observed that the VAR model with CPI made more accurate long-term predictions. Ashuri et al. (2012) have identified leading macroeconomic indicators affecting CCI movements. To that end, the authors employed Johansen cointegration and granger causality tests. The results showed that CPI, PPI, GDP and money supply are the major leading indicators affecting CCI. Xu and Moon (2013) constructed a VAR model using CPI to forecast CCI and the results showed that multivariate models can provide more accurate predictions. Yorucu (2013) used two time-series methods, ARDL and granger causality test, to investigate the relationships between construction industry indicators and macroeconomics in North Cyprus. The author has determined the causal effects of macroeconomics on gross domestic product and construction value-added. Shahandashti and Ashuri (2016) forecasted Highway CCI using the vector error correction model (VECM). Independent variables used in the model are determined using granger causality and Johansen cointegration tests. The authors determined crude oil prices and average hourly earnings as major indicators for the prediction model. Moon and Shin (2018) which is the latest literature study, predicted CCI using the google search query. A VECM model has been constructed and the query of ‘project management salary’ has been determined as the independent variable. The results show that the VECM model produces more accurate predictions than univariate models.

Literature studies mostly focused on United States of America data and there is no evidence on model applicability in developing countries. This study investigates causal relationships between CCI and certain macroeconomic indicators in Turkey which is one of the developing countries.

Methodology

This paper employed ARDL model and granger causality test to determine the relationships between major price indexes and CCI. Potential price indexes are determined as CPI, PPI, exchange rate (ER) and construction turnover index (CTI) between 2015-2020 using literature findings and data were collected using several institutes provide official data such as Turkish Statistical Institute (TURKSTAT), The Organization for Economic Co-operation and Development (OECD), and The Central Bank of the Republic of Turkey (CBT) (Table 1). Owing to structural breaks in economies during the COVID-19 epidemic, collected data is limited to 2020.

Table 1. Time-series variables and data sources.

Variable	Source
Building Construction Cost Index (CCI)	TURKSTAT
Consumer Price Index (CPI)	OECD
Producer Price Index (PPI)	OECD
Exchange Rate ($/TL) (ER)	CBT
Construction Turnover Index (CTI)	TURKSTAT

Augmented Dickey-Fuller Unit Root Test

The nature of the time-series data is an important factor to employ an appropriate model. Most time-series models are required stationary data. Augmented Dickey-Fuller Test (ADF) (Dickey & Fuller, 1979) is a widely used technique which determines lag lengths using Akaike Information Criterion (AIC) (Akaike, 1974) and whether the data is stationary or not. ADF test is a kind of hypothesis test that tests the null hypothesis is that time-series data is not stationary. If the test results indicate that data is not stationary, data should be differenced using Eq. 1. Differencing should be repeated till ADF test results show that data is stationary.

$$\nabla X_t = X_t - X_{t-1} \tag{1}$$

where: ∇X_t : Differenced X_t

X_t : X value at t time

X_{t-1} : X value at t-1 time

Autoregressive Distributed Lag (ARDL) Model

Autoregressive Distributed Lag (ARDL) Model proposed by Pesaran et al. (2001) is a type of cointegration test implemented to time-series data. If two time-series are cointegrated, it means that one influences the other's direction. ARDL model can determine both short-run and long-run cointegration and main advantage of model is that it can be implemented both stationary and non-stationary time-series. The most important assumption in the model is that the dependent variable should be stationary in the first difference (I(1)). The ARDL model representation is given in Eq. 2 and 3;

$$\Delta CCI_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta CCI_{t-i} + \sum_{i=0}^{n} \alpha_{2i} \Delta CPI_{t-i} + \sum_{i=0}^{n} \alpha_{3i} \Delta PPI_{t-i} + \sum_{i=0}^{n} \alpha_{4i} \Delta ER_{t-i} + e_t \quad (2)$$

$$\Delta CTI_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta CTI_{t-i} + \sum_{i=0}^{n} \alpha_{2i} \Delta CCI_{t-i} + e_t \quad (3)$$

which represents dependent variables CCI and CTI in t time and independent variables, their lagged values and error term. Long-run and short-run cointegration between variables is tested using Eq. 2 and 3. ARDL model is fitted using Bayesian information criterion (BIC) which is an indicator denotes model fit introduced by Schwarz (1978). ARDL model uses the bounds testing procedure which is based on F statistics. If the computed F statistics is higher than reference values, this indicates a significant cointegration between variables.

Granger Causality Test

Granger causality test proposed by Granger (1969) is a hypothesis test that determines whether a time-series data is useful for short-term forecasting of another. Granger causality test depends on Wald statistics and if the significance value of the Wald statistic is lower than 0.05, it means that X independent variable and its lagged values Granger cause Y dependent variable. In other words, the null hypothesis of the Granger causality test is that X does not cause Y. In this study, the Granger causality test was used to determine the causality direction of the variables that integrated each other.

Results and Discussion

ADF Test Results

As mentioned before, it is crucial to determine whether the time-series data are stationary or non-stationary. ADF test results of the time-series included to analysis are presented in Table 2. The null hypothesis of tests is that data has a unit root and it is non-stationary. As is seen, all time-series are stationary at their first differenced data.

Table 2. ADF test results.

Variable	Original data		1st differenced data	
	ADF Test Stat.	p-value	ADF Test Stat.	p-value
CCI	0.4614	0.9839	-6.1125	0.0000
CPI	1.9407	0.9998	-3.7181	0.0064
PPI	0.31122	0.9769	-3.6718	0.0072
ER	-0.4296	0.8964	-4.2670	0.0013
CTI	-1.4451	0.5536	-6.7591	0.0000

The ARDL model and Granger causality test, two main methods employed, require different types of data in terms of stationary. ARDL model requires data stationary at most first difference (I(0) or I(1)) (Nkoro & Uko, 2016). Contrary to ARDL model, Granger causality

test requires stationary data (I(0)) (Granger, 1980). Therefore, raw data were used for the ARDL model and first differenced data were used for the Granger causality test.

ARDL Model Results

This paper examined two different cointegration models. First model (Model 1) employed CCI as dependent variable and CPI, PPI and ER were decided to be independent variables. Second model (Model 2) employed only two variables that are CCI and CPI. The bounds test model diagnosis results of the models are presented in Table 3. As a result of the preliminary analysis, it was observed that the CPI did not cause a significant change and was excluded from Model 1. The bounds test is a hypothesis test in which the null hypothesis is that there is no cointegration relationship.

Table 3. Bounds test results and model diagnostic of ARDL models.

Model	Calculated F-statistic	Significance level	Critical bound		Model Diagnostic (Prob.)		
			I(0)	I(1)	Breusch-Godfrey LM Test	Heter. Test (ARCH)	Ramsey RESET Test
Model 1	5.51	10%	3.28	4.27	0.4849	0.8287	0.1141
		5%	3.98	5.09			
	BIC	Adj. R^2	Specification				
	40.4022	0.9973	ARDL(1,4,1)				
Model 2	3.72	10%	4.15	4.92	-	-	-
		5%	5.12	6.04			
	BIC	Adj. R^2	Specification				
	-	-	-				

As shown in Table 3, F-statistic of Model 1 is higher than all critical bounds (I(0) & I(1)) which means that a significant long-term cointegration between variables was detected in Model 1. On the other hand, F-statistic of Model 2 is lower than all reference bounds which means that there is no level relationship in Model 2. Analysis results confirm that PPI and ER are cointegrated with CCI.

After a statistically significant model has been established, model diagnosis should be examined. Model diagnosis consists of a set of tests; lack of serial correlation and lack of heteroscedasticity of residuals, specification errors, and stability of the model. For a fit model, the null hypothesis of model diagnosis tests should be accepted. Besides, CUSUM and CUSUM of squares should remain within the reference range (Figure 1). It is seen in model diagnosis results, Model 1 is fitted and statistically significant (Table 3 and Figure 1).

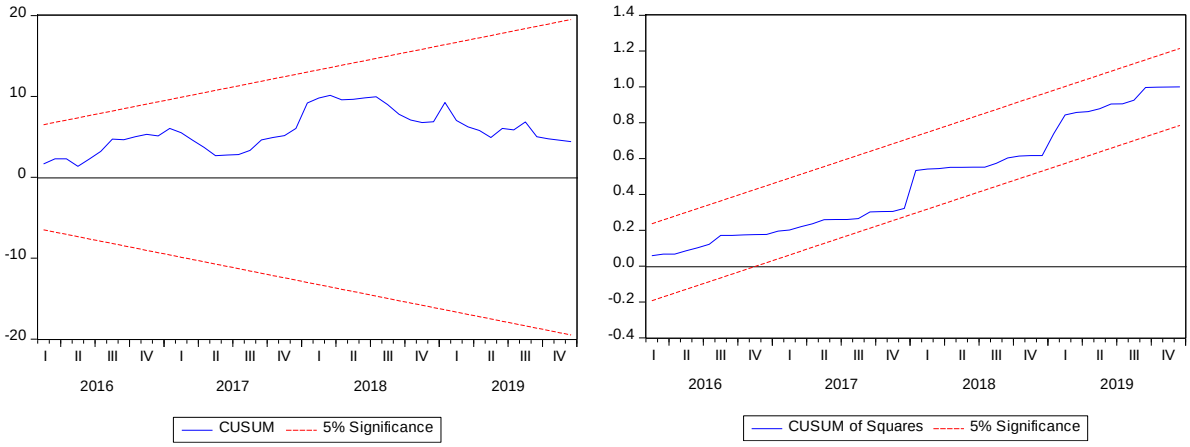


Figure 1: CUSUM and CUSUM of squares.

Following testing model diagnostics, long- and short-run regression coefficients can be discussed. Regression coefficients of Model 1 are given in Table 4 and 5.

Table 4. Long-run coefficients of ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ER	4.5667	7.4435	0.6135	0.5425
PPI	0.8711	0.2623	3.3205	0.0017

Table 5. Short-run coefficients of ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.8372	0.4043	4.5437	0.0000
ER	-4.5466	2.7958	-1.6262	0.1106
ER^{-1}	-6.5143	2.2421	-2.9053	0.0056
ER^{-2}	-1.0569	1.4826	-0.7128	0.4795
ER^{-3}	-5.4179	1.4158	-3.82674	0.0004
PPI	1.3742	0.2615	5.2544	0.0000
CointEq	-0.3049	0.0734	-4.1529	0.0001

As seen in Table 4, while PPI long-run regression coefficient is statistically significant, ER has no statistically significant long-run effects on CCI. The short-term regression coefficients given in Table 5 reveal a different situation. First and third lagged values of ER have statistically significant effects on short-run cointegration relationship. Literature studies mostly pointed to a cointegration relationship between CPI and CCI and shaped the prediction models using this variable (Hwang, 2011; Xu & Moon, 2013). These studies were conducted on the USA, which is a developed country and has a reserve currency. This study shows that PPI also should be considered as a leading indicator of CCI. Besides, it is clearly seen that ER is another leading indicator of CCI in developing countries.

Granger Causality Test Results

ARDL model reveals long-run relationships between variables and cointegration results are not directional. Thus, in order to identify unidirectional causality, the Granger causality test

was applied. As mentioned in the methodology section, the Granger causality test determines causal relationships and its null hypothesis is that "lagged X values do not explain the variation in Y". Granger causality test results for CCI, PPI and ER are given in Table 6.

Table 6. Granger causality test results.

Causal Relationship	Chi-Sq	df	Prob.	LM Test	Heter. Test
ΔER Granger Cause ΔCCI*	18.6295	4	0.0009	0.4071	0.5140
ΔCCI Granger Cause ΔER	5.5393	4	0.2363	-	-
ΔPPI Granger Cause ΔCCI*	19.6932	4	0.0006	0.5429	0.7002
ΔCCI Granger Cause ΔPPI	2.9248	4	0.5705	-	-

Granger causality test results show that ER and PPI granger cause CCI. Thus, both variables in the cointegration model also cause the variation in CCI. Considering that the literature findings mostly on country with reserve currency, it is understood that ER should be considered as an important leading indicator of CCI in developing country economies. Especially in countries with high import rate, this effect may increase. On the other hand, another variable a causal relationship determined is PPI which is the major indicator of costs in the manufacturing industry. The manufacturing industry is the major industry that supplies materials for the construction industry. Cost increases in the manufacturing industry are directly reflected on the product, therefore the input costs of the construction industry also increase.

Conclusion

This study determined the leading indicators affecting CCI using time-series analysis techniques ARDL Model and Granger causality test. The variables included in the analysis were determined as CPI, PPI, ER and CTI based on the literature. The cointegration test between the variables was performed using the ARDL model, and cointegration was detected between the PPI, ER and CCI. However, it is observed that CPI and CTI have not any cointegration with CCI. After the cointegration analysis, the direction of the causality relationship between the variables and CCI was determined using Granger causality analysis. As a result of the analysis, it was seen that both variables had effects on CCI. This study revealed that price index of manufacturing industry is the one of the major factors affecting construction costs. In addition, ER is crucial for costs especially due to its effects on imported materials and energy costs. The study is considered to be one of the pioneering studies, especially in developing economies. In the future, it will be possible to produce more successful cost estimations with forecasting models developed using these variables.

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Overview of Financed-Based Scheduling in Construction Management Research

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Abstract

Finance-based scheduling (FBS) has been a focus of debate over the last two decades and is of considerable interest to professionals and researchers. In the early studies, researchers have developed models that deal with cash flow constraints and scheduling problems. On the other hand, recent studies consider resource and finance constraints simultaneously. Some of these recent studies have also considered different financial alternatives and project valuation methods. Even though researchers have generated quite a volume of academic work on FBS, there has been no attempt to offer a comprehensive review to summarize and critique the existing literature on FBS and to provide ideas for future work. A comprehensive and thorough review of previous studies in the area of FBS would be of great value to researchers who want to explore future research opportunities in FBS. The objective of this study is to provide enough insight to the state of the research in the existing literature, hence drawing the attention of researchers to new directions in FBS. This systematic review of FBS-related studies identifies the research gaps and highlights virgin areas for further research. The new directions presented in this study can motivate researchers to undertake FBS-related research, which in turn may help schedulers to develop and implement reliable financially sound work schedules in their construction projects.

Keywords: *cash flow, finance-based scheduling, scheduling.*

Introduction

One of the most important factors in the success of construction projects is the efficient use of resources. Procuring required resources when needed is essential to accomplish the project goals. Failing to provide the necessary resources on time may lead to another failure in completing the project on time and within the allocated budget. Besides, having the required

cash readily available to supply these resources is another critical factor in accomplishing the project goals. Hence, financing the required cash is considered to be one of the challenging tasks of contractors in the construction industry (Elazouni, 2009). For example, cash deductions in progress payments for collateral purposes and delay in progress payments by employers are claimed to be the main reasons for financing problems of contractors (Alavipour & Arditi, 2018a). These factors may destabilize contractors' cash flows, which brings the need of additional cash to prevent imbalances in the cash flows. This additional cash can be obtained from financial institutions in return of a fee paid by the contractors (Ali & Elazouni, 2009). It should be noted that this fee is a cost for the contractor which is also known as the finance cost. It directly affects a contractor's cash flow. Therefore, it is crucial to consider the need of additional cash to prevent imbalances in the cash flows and its finance cost while establishing schedules. However, it is commonly claimed that the financing cost has been ignored in establishing schedules by schedulers. Elazouni (2009)'s contention is that schedulers usually consider scheduling and project financing as two different and independent processes. The need for an approach considering these two processes simultaneously has led researchers to develop the Finance-Based Scheduling (FBS) approach. The FBS approach includes financial constraints in the scheduling process. In this study, a systematic and detailed literature review was conducted to investigate and clarify the research gap in the existing FBS literature. Within the scope of this study, it was aimed to determine which factors, methods, constraints, and objective functions are concerned in the existing studies. In addition, methodologies and techniques used to solve FBS problems in existing studies are identified in this study. Finally, the research gap in the existing FBS literature is discussed.

Methodology of Systematic Literature Review

In this study, the existing FBS literature has been reviewed to highlight the future research trends. A systematic literature review is conducted by following the steps defined in Amer et al. (2021)'s study. The steps of the systematic literature review can be seen in Figure 1. In this study, Scopus has been selected as the database to review the literature. The following search query is used in this study: {"finance-based" AND "scheduling"} OR {"financing cost" AND "scheduling"} OR {"finance cost" AND "optimization"}. The research with these keywords returned a total of 367 publications. They were screened by looking at the titles, and those that were not relevant were excluded. This step led to selection of 60 publications for abstract-based screening. When their abstracts are examined, 6 publications were excluded due not being able to access to full text of them. In addition, 8 publications were excluded due to their irrelevance to FBS. Then, the full textes of the selected publications were screened. After the full text screening step, 39 publications were considered to be relevant. Then, the references of each publication were examined which led to addition of extra 15 publications to the existing list. Next, author knowledge-based screening was performed. It was observed that 4 more publications can be added to the existing group. All previous steps were repeated until there were no other relevant publications that could be added to the existing group. Finally, the findings of the systematic literature review were presented and discussed.

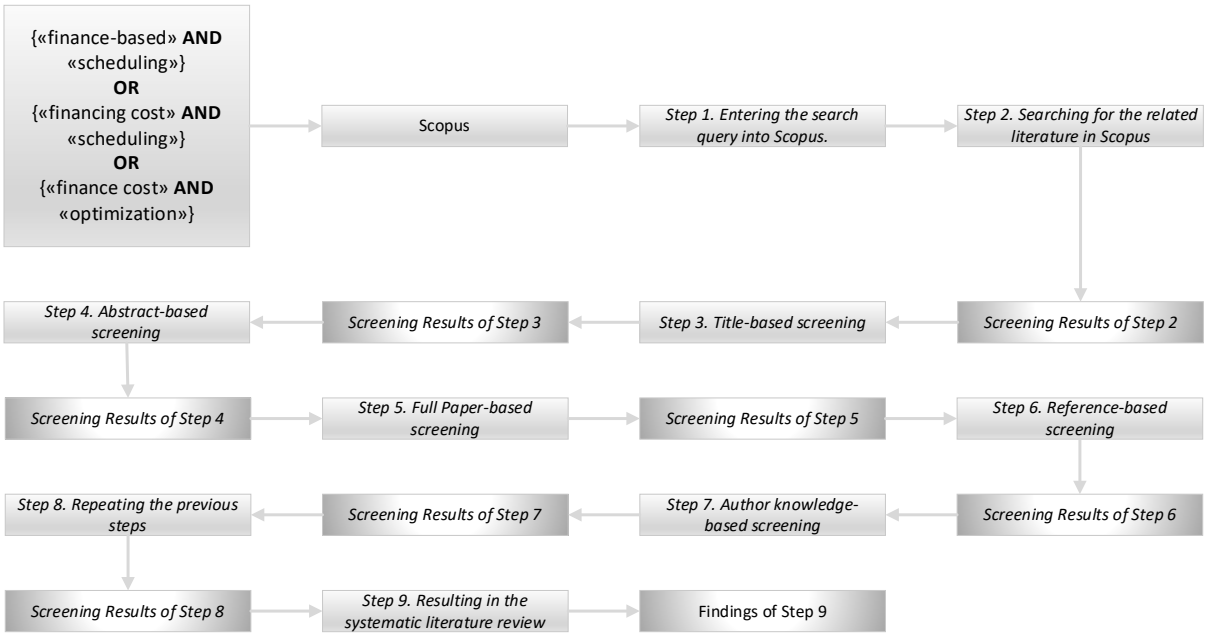


Figure 1: Flow diagram of the systematic literature review.

Findings of the Systematic Literature Review

After the systematic literature review, 47 publications were found to be related to FBS. These publications are categorized according to the publication type. The majority of the publications (i.e., 35 of 47 publications) are journal papers. The rest of the publications consists of 3 conference papers, 1 discussion article, 1 closure article, and 1 technical note. Nevertheless, the full text of the six publications could not be accessed. The discussion paper, closure paper, and the six inaccessible publications were excluded from further investigations. Figure 2 shows the names of the journals and conferences and the number of corresponding publications.

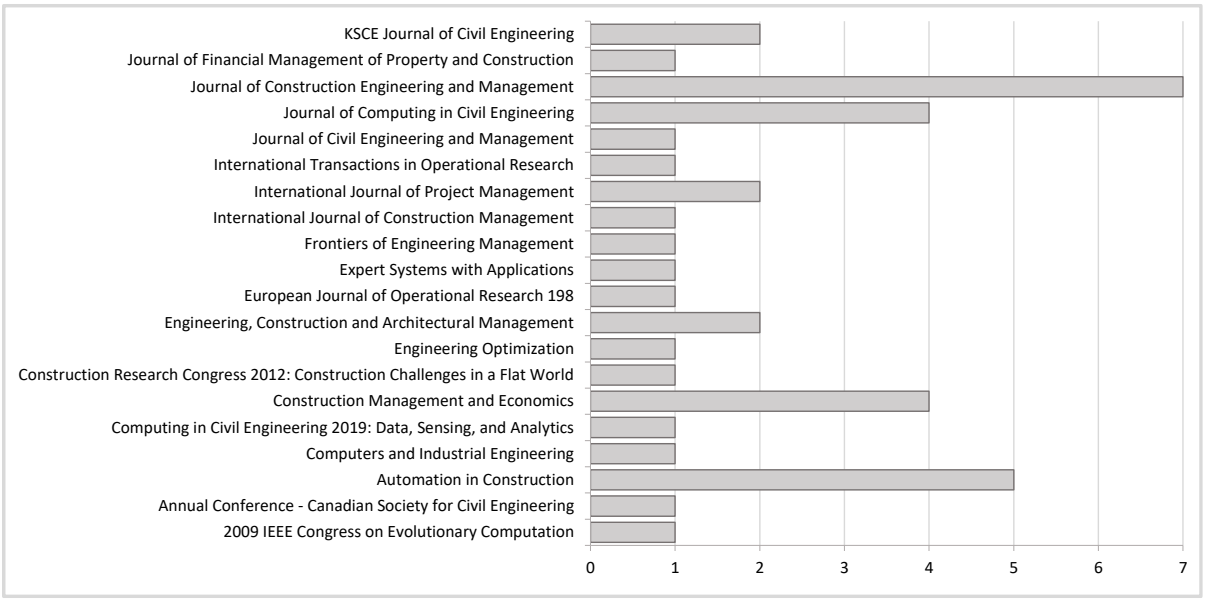


Figure 2: Distribution of the published literature around FBS.

When the algorithms used in the developed models are considered, mathematical algorithms (e.g., Linear Programming, Integer Programming) were used in 10 publications, heuristic algorithms were used in 3 publications, meta-heuristic algorithms (e.g., Shuffled Frog-Leaping Algorithm, Max-Min Ant System) were used in 22 publications, and hybrid algorithms (e.g., Linear Programming/Genetic Algorithm, Mixed-Integer Linear Programming/Heuristic) were used in 3 publications. Additionally, Pareto Optimality Efficiency Network were used in 1 publication (Figure 3). This finding reveals that the researchers frequently prefer meta-heuristic algorithms that can provide near-optimal solutions in a short time due to the need of longer time to solve FBS problems by mathematical algorithms.

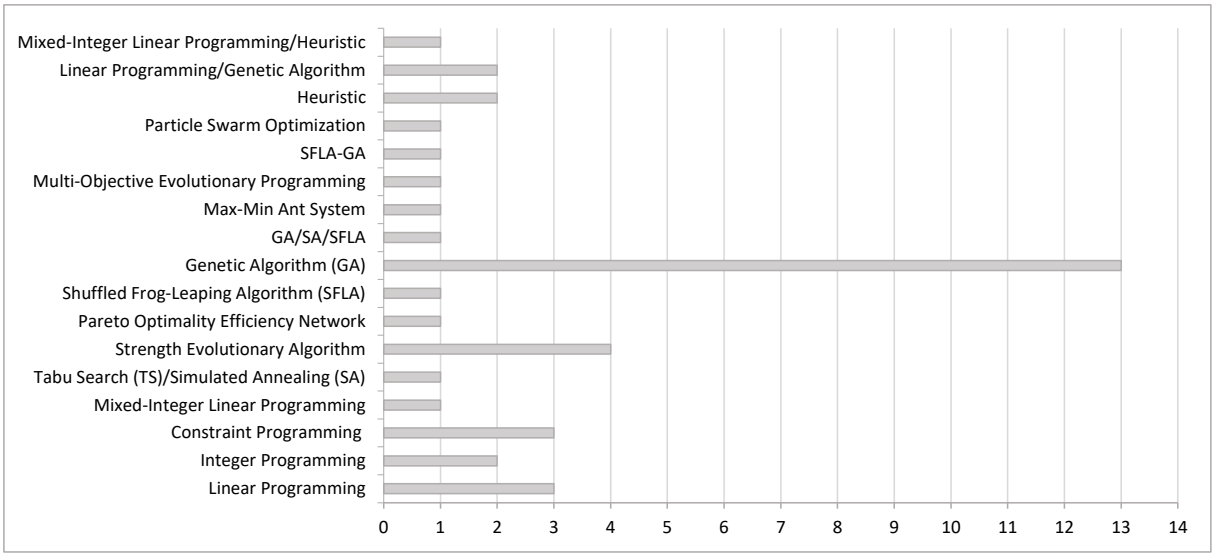


Figure 3: Types of algorithms used in the developed models.

It was observed that different factors are taken into account in development of FBS models (Table 1). While most studies consider portfolios containing a single project, the literature review reveals a limited number of studies that consider portfolios containing more than one project. In addition, there are studies that allows changing the original project duration because there is a need of extending the project duration due to the financial constraints. On the other hand, studies exist proposing models that keep the project duration fixed. In addition, some researchers have modified these FBS models by adding time-cost trade-off or crashing features to allow changing the durations of activities. However, it should be also noted that the original project duration and duration of activities remain unchanged in the FBS models that consider resource leveling. Besides, the FBS models that consider non-cash resource management (e.g., including resource leveling into the model) allow considering only one resource type or multiple resource types.

The literature employs different objective functions (Table 2) to achieve the optimization goals. The objective functions considered in the literature are categorized into four main groups, namely, (1) time, (2) cost and profit, (3) cash, and (4) resources other than cash. It was observed that a significant number of FBS models aim to minimize the increase in the original project duration caused by the finance gap. The FBS models focused on minimizing cost rather than the increase in the original project duration use the minimization of the amount of borrowed credit and the finance cost.

Table 1. The methodologies and methods, portfolio types, project duration, activity duration, and resource type factors in the FBS-related literature.

Author Name / Publication Date	Methodologies/Methods	Project Type on Portfolio		Project Duration		Activity Duration		Resource Type	
		Single Project	Multiple Projects	Fixed	Variable	Fixed	Variable	Single Resource	Multiple Resource
Elazouni and Gab-Allah (2004)	Mathematical / Integer Programming	✓			✓	✓			
Elazouni and Metwally (2005)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Elazouni and Metwally (2007)	Meta-Heuristic / Genetic Algorithm	✓			✓		✓	✓	
Liu and Wang (2008)	Mathematical / Constraint Programming	✓			✓		✓		✓
Ali and Elazouni (2009)	Meta-Heuristic / Genetic Algorithm	✓			✓		✓	✓	
Afshar and Fathi (2009)	Meta-Heuristic / Genetic Algorithm		✓		✓	✓			
Elazouni (2009)	Heuristic Algorithm		✓		✓	✓			
Liu and Wang (2009)	Mathematical / Constraint Programming	✓			✓		✓	✓	
Senouci and Rayes (2009)	Meta-Heuristic / Genetic Algorithm	✓			✓		✓	✓	
Abido and Elazouni (2009)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Liu and Wang (2010)	Mathematical / Constraint Programming		✓	✓		✓			
Fathi and Afshar (2010)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Elazouni and Abido (2011)	Meta-Heuristic / Strength Evolutionary Algorithm		✓		✓		✓		
Abido and Elazouni (2011)	Meta-Heuristic / Strength Evolutionary Algorithm		✓		✓		✓		
Jiang et al. (2011)	Mathematical/Pareto Optimality Efficiency Network	✓		✓		✓			
EL-Abbasy et al. (2012)	Meta-Heuristic / Genetic Algorithm		✓		✓		✓		
Alghazi et al. (2012)	Meta-Heuristic/Shuffled Frog-Leaping Alg. (SFLA)	✓		✓	✓	✓			
Alghazi et al. (2013)	Meta-Heuristic / Genetic Algorithm	✓			✓	✓			
Elazouni and Abido (2014)	Meta-Heuristic / Strength Evolutionary Algorithm	✓			✓		✓		✓
Elazouni et al. (2015)	Meta-Heuris./Genetic Algr.-Sim. Annealing and SFLA	✓			✓	✓			
Gajpal and Elazouni (2015)	Heuristic Algorithm		✓		✓	✓			
Tabyang and Benjaoran (2016)	Mathematical / Linear Programming	✓		✓		✓			
El-Abbasy et al. (2016)	Meta-Heuristic / MOSCOPEA	✓			✓		✓		✓
Elbeltagi et al. (2016)	Meta-Heuristic / Particle Swarm Optimization	✓			✓		✓		✓
Al-Shihabi and AlDurgam (2017)	Heuristic Algorithm / Max. Min. Ant Syst.	✓			✓	✓			
El-Abbasy et al. (2017)	Meta-Heuristic / Genetic Algorithm		✓		✓		✓		✓
Alavipour and Arditi (2018a)	Mathematical / Linear Programming	✓		✓		✓			
Alavipour and Arditi (2018b)	Mathematical / Linear Programming	✓		✓		✓			
Alavipour and Arditi (2019a)	Mathematical/Meta-Heuristic	✓			✓		✓		
Alavipour and Arditi (2019b)	Mat.-Meta-Heuristic / Linear Prog. - Genetic Alg.	✓			✓		✓		
Shiha and Hosny (2019a)	Meta-Heuristic / Genetic Algorithm	✓		✓		✓			
Shiha and Hosny (2019b)	Meta-Heuristic / Genetic Algorithm		✓	✓		✓			
Tavakolan and Nikoukar (2019)	Meta-Heuristic / SFLA ve Genetic Algorithm	✓			✓		✓		
El-Abbasy et al. (2020)	Meta-Heuristic / Genetic Algorithm		✓	✓			✓		
Al-Shihabi and AlDurgam (2020a)	Mathematical / Mixed-Integer Linear Programming	✓			✓		✓		
Al-Shihabi and AlDurgam (2020b)	Mat.-Heuristic/Mixed-Integer Linear Progr.-Heuris.		✓		✓		✓		
Liu et al. (2021)	Mathematical / Integer Programming	✓			✓		✓	✓	
Abido and Elazouni (2021)	Math. - Meta-Heuristic / Multi-Obj. Evolu. Progr.	✓			✓		✓	✓	
He et al. (2021)	Meta-Heuristic/Tabu Search and Simulated Ann.		✓	✓		✓		✓	

Table 2. Objective functions considered in the FBS models.

Author Name / Publication Date	Objective Function										
	Duration		Cost and Profit				Cash			Resources other than cash	
	Minimization of Total Project Duration	Minimization of Extended Duration	Minimization of Finance Cost	Minimization of Total Project Cost	Minimization of Required Credit	Maximization of Profit	Minimization of Max. Overdraft	Minimization of Cash Fluctuations	Maximization of Net Present Value	Minimization of Resource Fluctuations	Minimization of Peak Resource Demand
Elazouni and Gab-Allah (2004)	✓	✓									
Elazouni and Metwally (2005)	✓					✓					
Elazouni and Metwally (2007)				✓		✓					
Liu and Wang (2008)						✓					
Ali and Elazouni (2009)						✓					
Afshar and Fathi (2009)	✓	✓	✓		✓						
Elazouni (2009)	✓	✓									
Liu and Wang (2009)						✓					
Senouci and Rayes (2009)	✓					✓					
Abido and Elazouni (2009)			✓			✓					
Liu and Wang (2010)						✓					
Fathi and Afshar (2010)	✓	✓	✓		✓						
Elazouni and Abido (2011)	✓		✓		✓	✓					
Abido and Elazouni (2011)	✓		✓		✓	✓					
Jiang et al. (2011)			✓			✓					
EL-Abbasy et al. (2012)	✓		✓				✓				
Alghazi et al. (2012)						✓					
Alghazi et al. (2013)						✓					
Elazouni and Abido (2014)			✓			✓				✓	
Elazouni et al. (2015)	✓					✓					
Gajpal and Elazouni (2015)	✓	✓									
Tabyang and Benjaoran (2016)							✓				
El-Abbasy et al. (2016)	✓		✓	✓	✓	✓				✓	✓
Elbeltagi et al. (2016)	✓		✓	✓				✓			
Al-Shihabi and AlDurgam (2017)	✓	✓									
El-Abbasy et al. (2017)	✓	✓	✓	✓	✓	✓				✓	✓
Alavipour and Arditi (2018a)			✓								
Alavipour and Arditi (2018b)			✓								
Alavipour and Arditi (2019a)	✓	✓	✓			✓					
Alavipour and Arditi (2019b)			✓			✓					
Shiha and Hosny (2019a)			✓			✓					
Shiha and Hosny (2019b)						✓	✓				
Tavakolan and Nikoukar (2019)	✓		✓			✓			✓		
El-Abbasy et al. (2020)	✓	✓	✓		✓	✓					
Al-Shihabi and AlDurgam (2020a)	✓		✓		✓	✓					
Al-Shihabi and AlDurgam (2020b)	✓	✓									
Liu et al. (2021)						✓					
Abido and Elazouni (2021)						✓	✓	✓			
He et al. (2021)							✓				

Moreover, the literature review reveals that maximizing the project profit and net present value objectives have been used in a limited number of FBS models. Despite the fact that most of the FBS-related studies have ignored the optimization of resources other than cash, it should be noted that a number of studies have considered objectives (e.g., minimization of resource fluctuations, maximum resource demand) to include management of resources other than cash in FBS models (Table 2).

Table 3. The parameters considered in the FBS models.

Author Name / Publication Date	Resource Leveling / Resource Allocation					Financing Alternatives and Usages		Float Usage
	Release and Re-Hire	Resource Idle Days	Moment	Resource Un-levelling Penalty	Max. Resource Demand	Evaluation of Different Financing Alternatives	Charges on Unused Portion of Credit	
Elazouni and Gab-Allah (2004)								✓
Elazouni and Metwally (2005)							✓	✓
Elazouni and Metwally (2007)			✓	✓				✓
Liu and Wang (2008)					✓			
Ali and Elazouni (2009)					✓			✓
Afshar and Fathi (2009)								✓
Elazouni (2009)								
Liu and Wang (2009)								
Senouci and Rayes (2009)								
Abido and Elazouni (2009)								✓
Liu and Wang (2010)								✓
Fathi and Afshar (2010)								✓
Elazouni and Abido (2011)								✓
Abido and Elazouni (2011)								✓
Jiang, Issa and Malek (2011)						✓		
EL-Abbasy et al. (2012)								✓
Alghazi et al. (2012)								✍
Alghazi et al. (2013)								✓
Elazouni and Abido (2014)	✓	✓			✓			✓
Elazouni et al. (2015)								✓
Gajpal and Elazouni (2015)								✓
Tabyang and Benjaoran (2016)						✓		
El-Abbasy et al. (2016)	✓	✓			✓			✓
Elbeltagi et al. (2016)			✓					✓
Al-Shihabi and AlDurgam (2017)								✓
El-Abbasy et al. (2017)	✓	✓			✓			✓
Alavipour and Arditi (2018a)						✓		
Alavipour and Arditi (2018b)						✓		✓
Alavipour and Arditi (2019a)						✓		✓
Alavipour and Arditi (2019b)						✓		
Shiha and Hosny (2019a)						✓		✓
Shiha and Hosny (2019b)						✓		✓
Tavakolan and Nikoukar (2019)						✓		
El-Abbasy et al. (2020)								✓
Al-Shihabi and AlDurgam (2020a)								
Al-Shihabi and AlDurgam (2020b)								✓
Liu et al. (2021)					✓			✓
Abido and Elazouni (2021)		✓						
He et al. (2021)								✓

Parameters and factors considered in the FBS models are presented in Table 3. It was observed that the most frequently used methods in resource management (i.e., resource leveling and resource allocation) are also used in some of the FBS models. For example, "release and re-hire" and "resource idle days" are the optimization parameters considered by

some FBS models for the efficient usage of resources other than cash. Minimizing these two parameters provides a smoother resource usage profile and reduces the maximum resource demand. As far as the financing alternatives are concerned, most of the studies focused on FBS have only used credit line as a financing tool. However, it should be also noted that a limited number of FBS models have considered short-term and long-term credits as financing alternatives.

Conclusion

Finance-based scheduling has been a focus of debate over the last two decades and is of considerable interest to professionals and researchers. Even though researchers have presented quite a volume of academic work on FBS, there has been no attempt to offer a comprehensive review to summarize and critique the existing literature on FBS and to provide suggestions for further research. A systematic literature review has been conducted in this study to identify the research gaps and possible areas for further research. Indeed, the existing models have some shortcomings. For example, many developed models considered the credit line the only financing tool. However, there are many other options to finance a construction project, such as short-term loans (Alavipour & Arditi, 2018a), long-term loans (Alavipour & Arditi, 2018a), balloon payments (Halpin & Senior, 2009), trade financing (Peterson, 2013), and subcontracting (Tabyang and Benjaoran, 2016). In addition, a limited number of FBS models in the literature consider multiple projects simultaneously. The findings of this study also show that researchers ignored using different objective functions when they included resource leveling feature in their FBS model. Moreover, the impact of using different objectives (e.g., net present value) for FBS should be explored to improve existing models. Research on the impacts of using different financing alternatives, objectives, and multiple projects is underway. Until the time this research is completed, it would be prudent for schedulers to keep in mind that these factors may have an impact on their schedules developed via FBS.

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The Turkish Construction Sector from a Macroeconomic Perspective

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Abstract

In this paper construction sector is discussed from a macroeconomic perspective to gain insight into the interaction of the sector with the economy. Hence, it has strong linkages with the other sectors, the responsive characteristics to the macroeconomic conditions, and the potential to absorb an unskilled labor force, it is important to understand the interactions to apply a proper economic policy that serves to reach desired economic development. A set of macroeconomic data i.e., cost of inputs, production and turnover, aggregate output, investments, and monetary tools is analyzed to reveal the effects of the sector on the economy. The results have shown that excessive allocation of resources to the sector and providing support in a way that is incompatible with macroeconomic realities have devastating effects on the economy in the long run.

Keywords: *construction economics, economic growth, GDP, macroeconomics, Turkey.*

Introduction

The construction sector has been considered a prominent catalyst for economic growth and development. Therefore, the relationship between the construction sector and the economy has been the subject of debate for a long time from various perspectives such as economic growth (Yiu et al., 2004; Wilhelmsson & Wigren, 2011; Qabaja & Tenekeci, 2022), capital formation (Esfahani & Ramirez, 2003; Lakshmanan, 2011; Ansar et al. 2016; Ertugrul & Pirgaip, 2021), employment (Wells & Wall, 2003; Chiang et al., 2015; Gulluk-Senesen et al., 2018), sectoral output (Ilhan & Yaman, 2011; Gregori & Pietroforte, 2015; Ali et al., 2019). In these researches, different results have been observed for different countries, time frames, and circumstances yet no consensus has been settled up. These results also prove that the relationship between the construction sector and the economy is more complicated than anticipated.

Infrastructure and housing are the two main outputs of the sector that have a huge impact on economic and social development. Moreover, its strong linkages with other sectors and potential to absorb an unskilled labor force give it political appeal. Consequently,

policymakers use the sector as an economic speculation tool during periods when unemployment and economic stagnation raise.

From another viewpoint, there are discussions about the macroeconomic, spatial, social, and environmental effects of unplanned growth in the sector beyond the economic capacity. These discussions also focus to ensure not postponing real and sustainable economic growth by preventing the excessive transfer of economically scarce resources to the construction sector.

However, it is still not clear how construction-oriented economies can achieve sustainable economic growth and desired development in the long run. This research aims to reveal if a construction-oriented economy provides the expected outcomes to achieve sustainable economic growth or not. Moreover, it indicates how both the excessive incentives provided by the government to the sector and the labor and capital absorbed from other sectors lead to a complete deformation of the economy and misuse of the scarce resources when the expansion of the construction sector exceeds the limits within which efficient production can be achieved. It is assumed that approaching construction as a sub-branch of economics and investigating its interactions with the economy enables us to reveal its effect on sustainable economic growth and desired economic development in the long run, especially in developing countries. Thus, the economic decisions and regulations related to the construction sector can be developed more properly while preventing the misallocation of scarce resources and the establishment of an idle capacity. The evaluation of the construction sector in the Turkish economy between 2000 and 2020 is investigated by examining macroeconomic data from different perspectives to improve our understanding of the interaction between the construction sector and the economy.

The various variables are collected to discuss the relationship between the construction industry and the economy from a multidimensional perspective. The production and turnover, aggregate output, labour force, and investments are selected variables to examine this issue very deeply. The data used in analyses are obtained from the Turkish Statistical Institute (TurkStat).

The time series and scatter diagrams with regression analysis are mainly used to investigate the relationship between selected macroeconomic variables. Then, the outcomes of these analyses are interpreted logically, and the results are presented in the upcoming sections. If the data is published in current prices, it is adjusted to constant prices using a proper deflator to show the real effect, not the nominal. The data obtained from national sources expressed in Turkish Lira, except where indicated otherwise.

Literature Review

Bon (1992, 2000) observed that the share of construction in Gross National Product (GNP) follows an inverted U-shape as a country's economic development level increases. The pathway followed by the construction sector linked with the economic development level of a country is true in relative terms, but not in absolute terms. As a country develops, the construction sector's output still grows, but at a slower rate than the overall economy (Ruddock & Lopes, 2006; Lopes, 2009). From these observations, we may conclude that infrastructure and housing needs in a developing economy lead to a dramatic increase in construction activities relative to the economic scale, but in more mature development stages, the growth rate of the sector slows down, and the sector focuses more on maintenance and

repair activities. This process also indicates a structural change in the sector. However, these results in the literature are not consistent across all developing countries due to different economic structures and capacities of the economies.

Another debate rises from the direction of the causality between construction and the Gross Domestic Product (GDP). Tse and Ganesan (1997) observed that increase in the GDP has a causal effect on construction activity in Hong Kong. On the other hand, Chan (2001) for Singapore and Zheng and Liu (2004) for China observed a bi-directional causal relationship between construction activities and GDP. Lewis (2009) found this relationship ran from GDP to construction during an economic upturn and from construction to GDP during an economic downturn. Moreover, Alaloul et al. (2021) revealed that the output of the agriculture and service sectors influences the construction output level.

Construction can be defined as an assembly activity in that inputs comprise unskilled labour-intensive domestic resources mainly produced by fundamental industries, such as cement and steel manufacturing (World Bank, 1984). This nature of construction activity provides strong backward linkages to itself and thus an expansion of the construction industry increases the demand for the products and services of the other supply industries (Bon et al., 1999).

Pietroforte and Gregori (2003) highlighted the increasing importance of the maintenance and repair sub-sector. More recently, Zhu et al. (2020) discovered the effect of the construction sector becoming weaker to promote economic growth. Moreover, there is still little known about how the adaptive capacities of the other sectors affect the supply of the construction sector (Giang & Peng, 2011).

The construction industry has significant potential to absorb unemployment (Turin, 1978) because it is more labour-intensive and requires a less qualified workforce than many other industries (Hildebrandt, 2000). Therefore, the industry is used as a key tool for employment generation policies in various countries through labour-intensive public works projects, especially when demand diminishes, and unemployment rises (Gruneberg, 1997; Hillebrandt, 2000). The most recent example of the application of this policy was experienced during the 2008 economic crisis. Many governments which hold different economic development levels announced financial packages, including infrastructure projects, to stimulate economic activity and generate employment (Donnges, 2009). However, using the industry as an effortless way to generate employment for the unskilled labour force through unplanned public works could damage both the development of the industry and the entire economy (Turin, 1978). These risks should be managed together with fiscal policy by adjusting the number of public expenditures, and monetary policy by changing the interest rates of loans financing these public works projects (Hildebrandt, 2000).

However, on the other side, increasing construction activity does not necessarily always result in economic growth. Excessive supply of scarce resources to the construction industry and over-estimation of demand for infrastructure relative to economic scale may cause the establishment of idle capacity for both housing and infrastructure (Drewer, 1980; Flyvbjerg, 2008; Balaban, 2012). Economic recessions experienced in Singapore and Trinidad and Tobago in 1985 and Southeast Asia in 1997 are unpleasant examples of this phenomenon (Lewis, 1984; Ganesan, 2000). The irrational growth in the construction industry and housing sector caused high inflation, a decrease in housing purchasing power for low-income groups, and capital outflow from productive sectors in East Asia (Aveline & Li, 2004). It has also been observed that the supply surplus of housing leads to the depreciation of residential

buildings, the situation results in the bankruptcy of companies, as in Taiwan (Hsieh, 2005), or may collapse the mortgage loans and initiate an economic crisis such as experienced in the USA in 2008. Orhangazi and Yeldan (2021) highlighted the negative effects of construction-oriented growth in the Turkish economy. Political factors in decision-making may worsen the situation (Devarajan et al., 1993). The construction industry is commonly used by governments, especially in developing countries, to construct publicly visible projects that help them consolidate their political power while raising the rent through sufficient construction projects and transferring it to ideologically supported equity-owners.

The Economy of Turkey

The evolution of Turkey's construction-based, fragile, and developing economy between 2000 and 2020 is observed to examine the arguments of the two opposing views. Turkey transformed its economic system into an open market economy in the early 1980s. The construction sector then moved full speed ahead and experienced two huge expansion periods between 1982-1988 and 2005-2013. The domestic economic crisis in 1994 and 2001, the global financial crisis in 2008, the Turkish currency and debt crisis in 2018, and more recently the economic impacts of the Covid-19 pandemic suspended these processes, and the sector was the first to suffer. Still, the sector has been perceived as a locomotive sector of the Turkish economy by the government. The government used the construction sector as a key tool to overcome economic stagnation and absorb unemployment after the 2001 and 2008 economic crises. The earthquake hazard mitigation process is subject to rent and environmental debates. Many other "megaprojects" such as the 3rd Bosporus Bridge and the Istanbul Airport were realized within this period. Currently, the Channel Istanbul Project planning to open an artifactual crossing from the Black Sea to the Marmara Sea is at the centre of debates just after the currency crisis in 2018 and 2021.

Turkey has been classified as an "Upper Middle Income" country by the World Bank with its GDP per capita increasing from $4.337 to $8.536, the unemployment rate increasing from 6.5% to 13.11%, and the inflation rate decelerating from 54.91% to 12.28% between 2000 and 2020 (World Bank, 2020). In addition, structural change in the Turkish economy between 1970 and 2020 can be traced to the change in the share of sectors in the GDP. In this process, the share of the agricultural sector dropped dramatically from 37.3% to 6.6%, while the industrial share increased from 17.2% to 22.4% and followed a fluctuating course close to horizontal, and the share of services increased from 37.9% to 54.9% with massive acceleration. Although the share of the construction sector, which is 5.8%, has fallen to 5.1% because of the effects of the pandemic, it has approached the levels of 10% in the 2000s. The transformation of the economy from agriculture to a service economy can be defined as "premature deindustrialization" in which economies of developing countries are turning into service economies without experiencing a proper industrialization process (Rodrik, 2016).

Findings

The Production and Turnover

The production index is generated by multiplying hours worked obtained from construction firms with productivity coefficients obtained from fixed prices sector GDP. It aims to observe the changes in production for a specific period. The dataset is available for the construction sector from 2005-2016 with the base year 2010. TurkStat announced that after completing requiring updates, the dataset is going to be continued to be published in 2018. However, the new dataset has not been published yet. Similarly, the turnover index focuses on revenues generated from operating income. It does not consider non-operating income, VAT, revenues from foreign services, etc. Unlike the production index, it is announced at nominal prices by TurkStat. The dataset is available for the construction sector for 2005-2017 with the base year 2010 and 2009-2020 with the base year 2015. However, these two datasets have different calculation rules, so it is impossible to link them to each other. Moreover, the data represented in these two turnover indices surprisingly follow dissimilar trend lines in real prices.

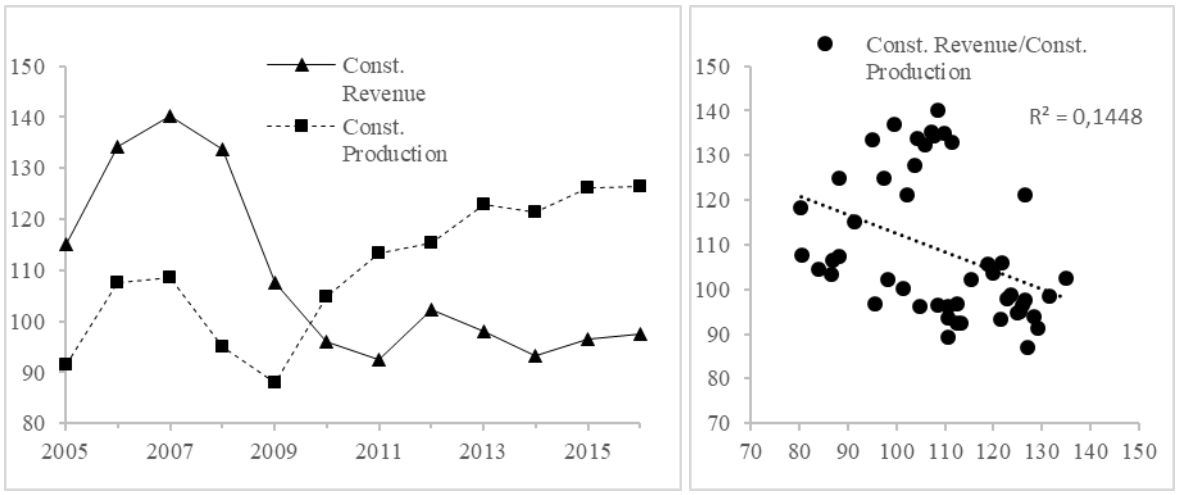


Figure 1a-b: Time series and scatter diagram of the construction revenue and production, respectively.

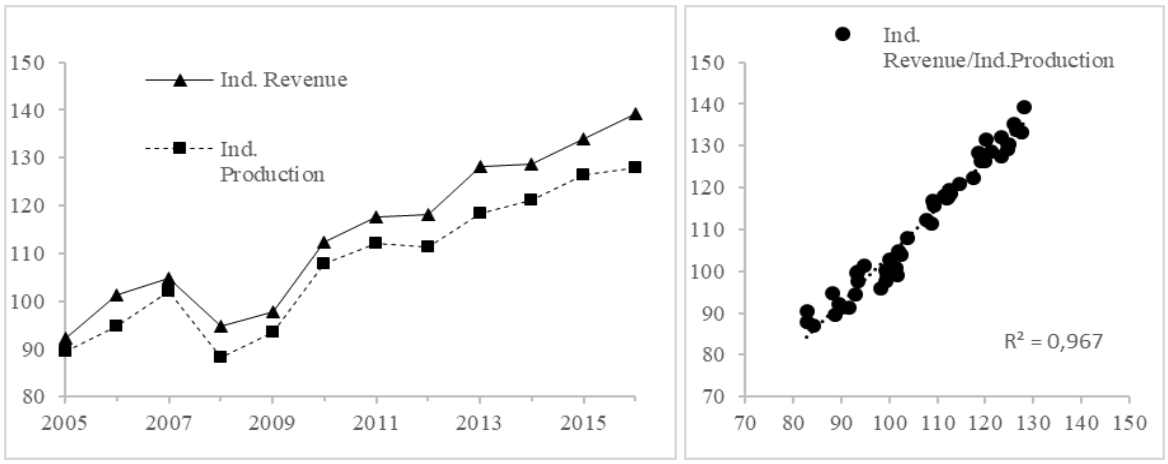


Figure 2a-b: Time series and scatter diagram of the industry revenue and production, respectively.

The negative effects of the 2008 global financial crisis in terms of production and turnover can be tracked for the construction sector in Figure 1a. Both revenues and production reach their peaks in 2007. The construction production index reaches its low in 2009 after two years-long sharp decreases caused by the 2008 crisis, then starts to recover in 2010, and

follows a decreasingly growing pattern until 2016. When the construction turnover index is compared with the construction production index, it reaches its low with two years lag in 2011, thereafter it follows a sideways trend, and it has not given any recovery signal with real prices yet. Figure 1b shows no significant relationship between production and turnover using a simple linear regression model. Moreover, it can be observed that the more the production of construction increases, the total revenue decreases. It means the marginal revenue of the construction output is negative and the average revenue is decreasing. In the short run, an entrepreneur can bear the loss in revenue, but in the long run, producing with negative marginal revenue in a market cannot be maintained without government incentives. Meanwhile, negative marginal revenue expresses the inelastic demand for the construction outputs such as housing and infrastructure. The results show that transferring more factors of production from other sectors to the construction sector or excessive allocation of scarce resources to the sector does not maintain the desired turnover in real terms.

Figure 2a exhibits the industry production and turnover index, both indices reach their peaks in 2007, and after a one-year decrease in 2008, they show steady recovery and follow an almost linear up-trend. This situation implies the industry recovers faster and more proper way when compared with the construction industry. Moreover, a significant relationship between production and turnover can be observed in Figure 2b using a simple linear regression method. This result shows that the marginal revenue of industry outputs is positive in that the increase in industrial production positively affects total revenue.

The Gross Domestic Product and the Share of Construction

The construction sector in Turkey shows rapid growth starting in 2002, just after the 2001 national economic crisis until 2018. The share of the construction output in the GDP increased by 93% and increase from 3.91% in 2002 to 7.53% in 2017 as represented in Figure 5. The global economic crisis in 2008 disturb this process but the sector accomplishes recovery stronger. On the other hand, Figure 3 shows that the share of the industry (excluding the construction sector) remains decidedly fluctuating in a narrow band between 17.69% and 20.04%. The government policies that put the construction sector at the centre of economic growth and development support this situation. The sector is perceived as a “locomotive of the economy” between 2002 and 2018.

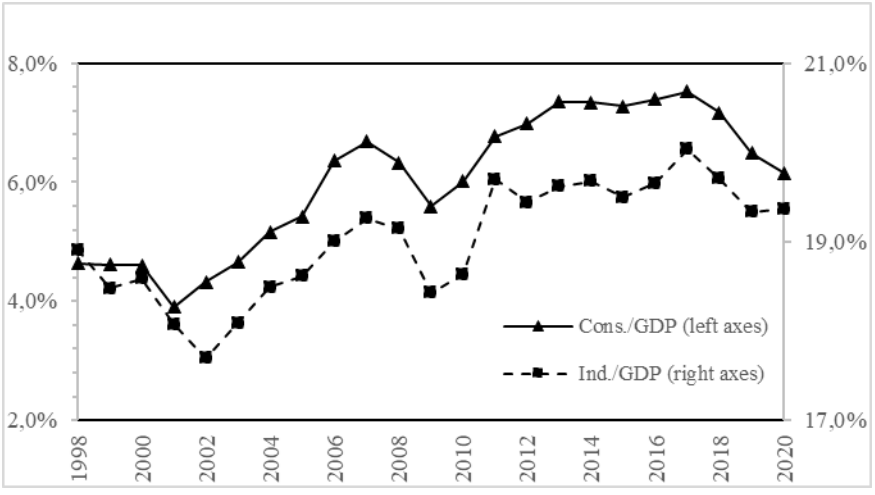


Figure 3: The share of the construction and industry output in the GDP.

Figure 4 exhibits the time-series graph of the GDP (divided by ten to establish scale) and the construction output with seasonally and calendar adjusted 2009 constant prices in Turkish Lira. The GDP and the construction output follow approximately the same pattern until 2018. The devastating effects that began with the Turkish currency and debt crisis in 2018 and continued with the Covid-19 pandemic still affect the sector very deeply. The level of sectoral production began to separate from the economy more significantly than in the economic crisis of 2001 and 2008.

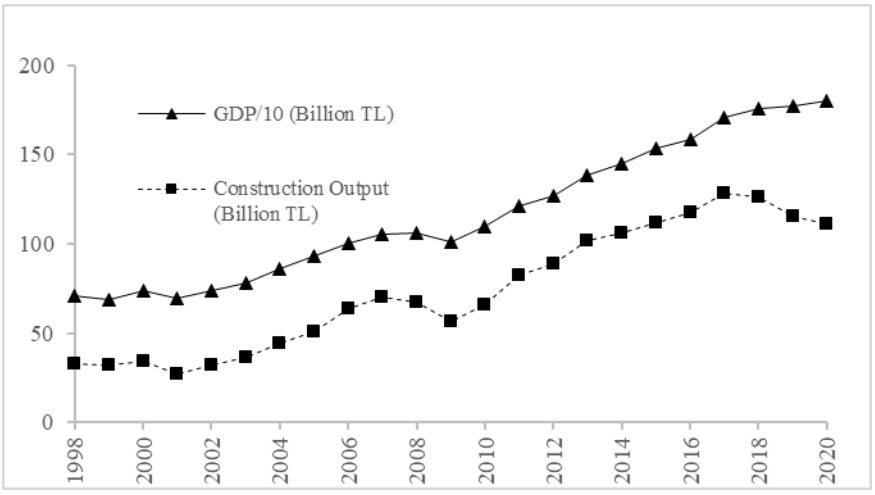


Figure 4: The construction output and the GDP in the Turkish Lira.

However, as can be seen in Figure 5a, the percentage of changes in construction output tends to exaggerate, compared to the GDP, during the booms and slumps accordant with Lewis (2004). On the other hand, Figure 5b represents the percentage of changes in the industrial output that almost follows the GDP. Moreover, no significant lag between the GDP and the construction output is observed yearly. It should be underlined that Birgonul and Ozdogan (1999) observe a nine-month lag in the responsiveness of the construction output in Turkey. That means the construction sector responds rapidly to changes in the economy.

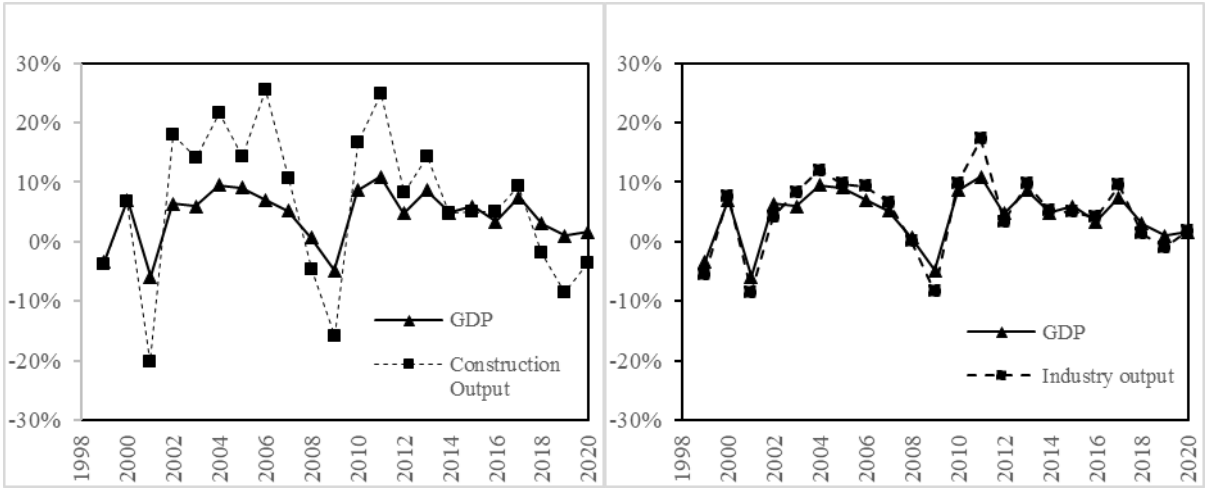


Figure 5a-b: The share of construction and industry in GDP, respectively.

The first reason behind this may be the impact of the public sector's increasing demand for infrastructure projects right after the economic recessions. However, following an economic recession, it may not be easy to find a source of funding for capital-intensive infrastructure projects. In order to overcome this financing problem, governments frequently use the Public-Private Partnership (PPP) as a procurement method. Thus, it transfers financing responsibility to the private sector and supports concessionaires by providing various kinds of guarantees that can be a heavy burden on the public budget. Governments also utilize the output of these projects to consolidate their political position. However, the combined effects of the 2018 crisis and the Covid-19 pandemic on macroeconomic conditions, capacity issues, and previously provided guarantees subject to debates prevent the Turkish government to realize controversial, new infrastructure projects such as the Channel Istanbul Project, so the contribution of the public procurement to the construction demand remains limited.

The second catalyst may be the government intervention in monetary policy through the adjustment of interest rates. The Turkish government tried to keep the demand for housing alive by suppressing the interest rates in the last two quarters of 2020 regardless of the inflation rate and market dynamics. They succeed to create excessive but temporary demand for housing, however, this intervention resulted in heavy damage to the national economy in terms of the exchange rate and inflation. Moreover, increasing demand for mortgage loans with low-interest rates, not by economic conditions, may raise the non-performing loan ratio of the banking system and may cause trouble to the accessibility of financing sources in the future. Consequently, the government had to change all its economic administration and started the raise interest rates dramatically to stabilize macroeconomic conditions.

It should be noted that uncomprehendingly recipes to recover the economy through the construction sector started to become invalid. The breakdown in the construction output level in 2018 differently from the whole economy reveals the need for structural change in the Turkish economy. The “locomotive of the economy” starts to lose its repulsive effect on the economy. The infrastructure investments beyond the economic capacity, limited import opportunities, and low value-added arise from the nature of the construction output, excessive sensitivity to demand conditions, and government interventions to macroeconomic conditions to create demand for the sector begin to cause damage to the economy.

The Construction Labor Force and the Employment

The unemployment and growth rate are the two important indicators that are frequently tracked to monitor the economic outlook of a country. A successful economic policy should focus on both growth potential and employment generation capacity.

The unemployment rate of Turkey follows an increasing trend since the annual average rate of 8.5% was achieved in 2012. This increasing trend also breaks upward in 2019 and reached 13.6% due to the effects of the Turkish currency and debt crisis in 2018 and remains approximately at the same level as the devastating effects of the Covid-19 pandemic on the economy. Figure 6 shows the changes in the unemployment rate, construction employment rate, and industry employment rate (second axes) between 2005 and 2020. Turkstat announced that due to revisions on both population calculations in 2008 and household labour surveys in 2014, it might be deceptive to compare data before and after 2004 (Turkstat, 2020). More notably, the new calculation method has been established at the beginning of 2021, the adjusted series has only been available since 2014, and even worse no guidelines have been

published on how to connect the old and the new series. It is a matter of public debate that these frequent changes made by the TurkStat are a move of manipulation of political power, and the lack of baptism of the institution is questioned.

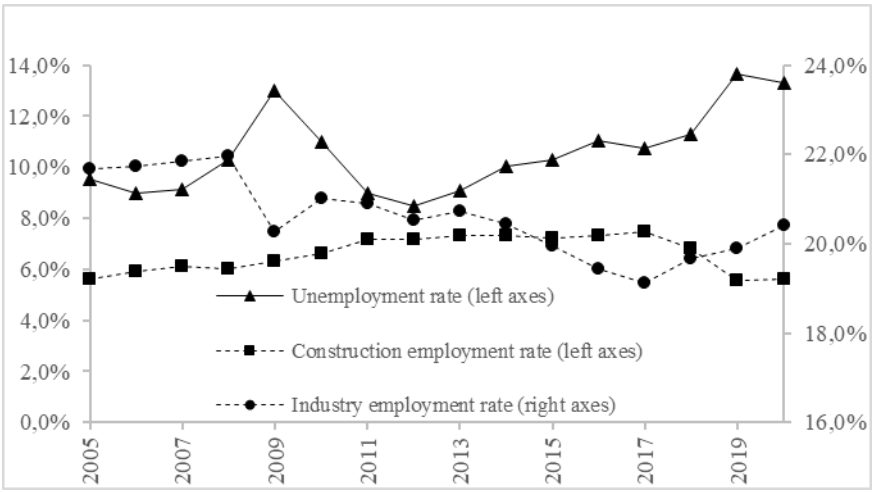


Figure 6: The unemployment rate, the construction, and the industry employment rate.

The construction employment rate increased from a 5.6% annual average rate in 2005 to 7.2% in 2011 and preserve its level until 2017, however it decreases sharply to 5.6% with the effects of the Turkish currency crisis and the Covid-19 pandemic. In the same period, the industry employment rate fluctuates between 19% to 21% annual average rate but shows a regular increase when the construction employment rate decreases significantly between 2018 and 2020.

Figure 7 represents the time-series graph of the construction output and construction employment rate between 2005 and 2020. The construction employment rate and the construction output increased with the same pattern from 2005 to 2011 only disturbed in 2009 by the effects of the global financial crisis in 2008. However, after 2011, the construction employment rate fluctuated around 7.3% although the construction output continued to increase. Since 2018, there has been a regular decline in construction output, while construction employment has fallen by almost 25%. The dataset reveals the differences in the 2008 global financial crisis, the breakdown in the construction sector starting with the Turkish currency crisis and continuing with the Covid-19 pandemic caused more disruptive processes in the construction labour market.



Figure 7: The construction output and the employment rate.

Although the major central banks have resorted to similar expansionary monetary policy tools which were implemented to overcome the 2008 global financial crisis, the depreciation of the Turkish Lira that started in 2018 combined with pandemic restrictions, the resulting increase in the inflation rate, and the insistence behaviour of the CBRT to hold interest rates low could not provide an appreciate environment for the construction sector to support economic growth and to generate employment. Moreover, the temporary, and part-time nature of the construction labour force worsens this situation in terms of unemployment. However, the economic policies established to keep the construction demand alive have some negative consequences if they are not matched with the facts that the economy face. Worse still is that wrong and populist decisions also have an extremely negative impact on the rest of the economy. Moreover, these decisions result in higher inflation, higher interest rates, and a long economic recession.

The Gross Fixed Capital Formation and the Construction Output

Gross fixed capital formation (GFCF) includes all expenditures on fixed capital goods by the public and private sectors. GFCF has two main components: construction, machinery, and equipment. There is a common opinion that emphasizes the strong relationship between economic development and investment level and many studies observed that in developing countries, nearly half of the investments in GFCF comes from construction (Gruneberg, 1997; Hillebrandt, 2000). For that reason, it is necessary to examine the share of construction in GFCF. Figure 8 shows the share of the GFCF in the GDP and the level of GDP.

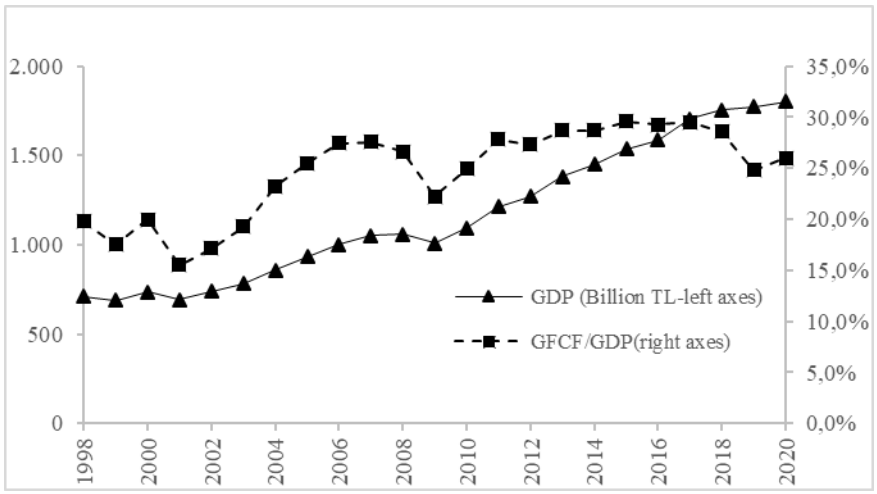


Figure 8: The GDP and the share of the GFCF in the GDP.

The share of the GFCF in the GDP is influenced negatively by the economic crisis in 2001, 2008, and 2018 and bottomed in 2001, 2009, and 2019, respectively. The deteriorating environment of economic trust, rising interest rates, and negative future expectations can be counted as the main reasons. However, the level of investments responds immediately after these breakdowns. During the years that the economy grows, the share of the GFCF in the GDP revolves around 28%. However, these temporary but sharp decreases in the share of GFCF do not have a significant effect on the GDP for that year since the outputs of the investments emerge in the upcoming years. The share of construction in the GFCF between 2009 and 2020 can be observed in Figure 9. The level of construction investments in the GCFC fluctuates around 50%-55% level similar to previously addressed studies for developing countries.

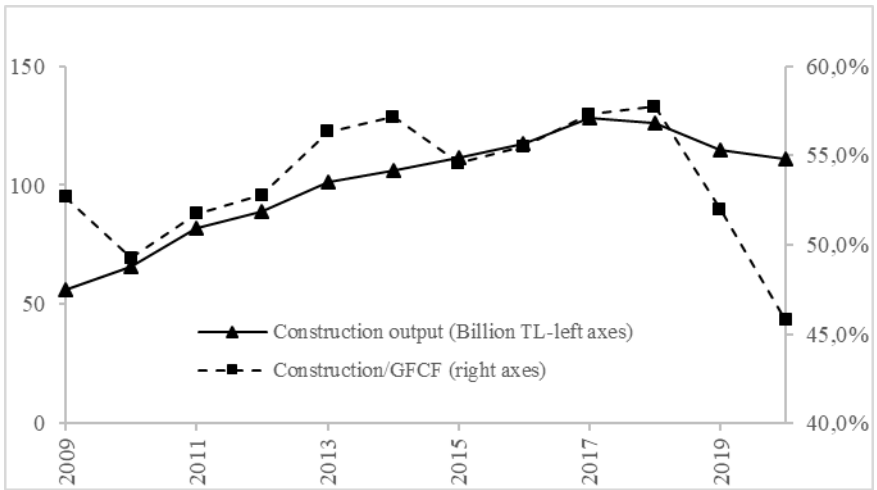


Figure 9: The construction output and the share of construction investments in GFCF.

The negative effects of the 2008 global financial crisis on investments last longer and it bottomed in 2010 with a one-year lag compared with the share of the GFCF in the GDP. A similar scenario is happening after 2018. The GCFC bottomed in 2019 and gives a signal to recover from the bottom despite the ongoing effects of the Covid-19 pandemic on the economy. On the other hand, the construction investments in the GFCF decrease to a lower level in 2020. These observations address that construction investments still suffered after the

2018 currency crisis and decreased by approximately 45% level. It shows that the capital flow to the sector through investments does not provide the expected GDP growth.

Discussion

The evaluation of the Turkish construction industry and its interactions with the Turkish economy during the 2000s are analysed using statistical data published by TurkStat. Economic and social developments and their global impacts make the 2000s an attractive period to investigate the pros and cons of neoliberalism. The global financial crisis in 2008 and the Covid-19 pandemic in 2019 affected the global economic environment as well as the Turkish economy very deeply. Moreover, the national economic crisis in 2001 and the Turkish currency and debt crisis in 2018 increased the burden on the economy. Households and companies have faced rising interest rates, exchange rates, and inflation. In addition, economic stability has deteriorated, confidence in the economy has shrunk, and the country has entered a period of difficulty attracting foreign investors.

The construction sector, whose share in the GDP decelerated to 3.91% in 2002 due to the effects of the national economic crisis in 2001, grew between 14% and 25% annually in the period up to the 2008 global recession and increased its share to 6.68%. There are two main contributors to this fact. First, the high growth rates that Turkey caught after the national economic crisis in 2001 with a steady and relatively low inflation rate caused a decrease in interest rates and an increase in housing demand. The young population of Turkey had a catalyst effect on this process. Second, various kinds of infrastructure projects that were held or excessively supported by the government helped the construction sector to reach extreme growth rates. Although the 2008 global recession briefly interrupted this process, the construction industry has been widely used as a tool to overcome economic recessions due to its strong linkages with other sectors and potential to absorb unemployment. This attitude has been adopted to boost markets after the 2001 national economic crisis and the 2008 global recession by the Turkish government. Moreover, the government has utilized the visible output of the construction sector to strengthen its political position. The governments put into action required legal regulations, provided incentives to the private sector, demanded infrastructure investments, and adjusted interest rates to raise household demand for the housing sector. As a result, the construction sector was mentioned as a “locomotive sector” of the Turkish economy between 2003 and 2017.

However, the excessive support to the sector in terms of the interest rate adjustments and the government demand for infrastructure projects, and the excrescent resource allocation in terms of factors of production such as the capital flow to the sector through investments and the effort of entrepreneurs to enter the sector have not provided expected macroeconomic stability and have accompanied much social and environmental debate. Interest policies that do not coincide with inflation dynamics to encourage construction investments and keep household housing demand alive combined with political and social disputes resulted in an enormous increase in inflation and exchange rate after 2018. Besides that, shifting the leading role in the economy from the production sector to the construction sector, sudden changes in economic management, inconsistent foreign policy actions, and discussions about law and democracy in domestic policy led to a departure from the economic development after 2012.

As a result, in 2018, the construction sector “the locomotive of the Turkish economy” crashed to the exchange rate, inflation, and interest rate spiral. The repayments of private companies

in their foreign exchange debts, the demand for foreign exchange from the household with increasing inflation, controversial issues in foreign policy, and poor economic management turned into a currency and debt crisis. The Turkish Lira lost its value by approximately 130% against the U.S. dollar from the beginning of 2018 to the end of 2020 (CBRT, 2020). This dramatic increase in foreign currency has been affecting traumatically the economy in terms of inflation and interest rates. The upside attacks on the level of exchange rates trigger inflation since the degree of exchange rate pass-through to inflation is relatively high in the Turkish economy. An increasing trend in inflation rate enhances interest rates and the demand for mortgage loans by household decreases significantly. Moreover, instability in the exchange rate and interest rates shakes the trust in the macroeconomic environment and causes a decrease in the level of foreign investments and finance, especially in long-term and complex infrastructure investments. Even worse, the government's persistent opinion of blaming the cause of rising inflation as high-interest rates and its move to further interest rate cuts caused a much bigger exchange rate shock than in 2018. The Turkish lira has lost around 95% of its value against the dollar in just 3 months (CBRT, 2021). Consequently, the government, economic administration, and business world highly debated shifting the direction of the economy from construction to sectors producing value-added products, yet no concrete step has been taken.

The negative and weak correlation between construction revenues and construction production in 2005-2016 signals inefficient production in the sector. Simultaneously, manufacturing revenues and production show a positive and extraordinarily strong correlation. However, construction production rises from approximately 50 billion U.S. dollars to 120 billion U.S dollars. Unfortunately, although the construction sector contributes to the GDP growth during this time, there is no mention of sustainable economic development and continued macroeconomic stability due to the inversely proportional income-production function.

Another important finding that needs to be highlighted is that the construction industry shows a cyclical characteristic. In other words, the sector is impressionable to macroeconomic conditions. During the recessions of 2001, 2009, and 2018, the sector output showed a faster decline than the economy overall. Although the sector recovered its output very quickly after the economic recession in 2001 and 2009, it has not shown any recovery signal in terms of production and labour force in the period starting with the 2018 exchange rate and debt crisis and continuing with the Covid-19 pandemic and the 2021 exchange rate shock. One of the reasons behind this is that despite the economic growth that has been achieved, the relationship between inflation, the exchange rate, and the interest rate has been destroyed by inconsistent monetary policy actions. These policies i.e., decreasing the interest rates incompatible with inflation dynamics were followed to raise household demand in the housing sector and attract investments, however, they cost a heavy bill to the entire economy. Moreover, the need for external financing sources of the sector to finance “megaprojects” in a volatile exchange rate environment and the redundant guarantees that have been provided to these projects by the National Treasury cause a heavy burden on the public budget. Even worse, the allocation of scarce resources in terms of factors of production immoderately to the construction sector may postpone real economic growth.

From the labour market side, it can be observed that the increase in the construction output generates employment until 2011. However, the construction employment rate, which reached a certain level in 2011, has not been able to respond to the increase in the construction output between 2011 and 2018. From 2018 to the present, with the effects of the 2018 Turkish

currency and debt crisis, the Covid-19 pandemic, and the 2021 exchange rate shock, the construction employment rate crashed by around 23% while the construction output loses 13%. The production sector employment rate showed a 7% percent increase in the same period. The different behaviour of the changes in the construction and the production sectors' employment rate reveals the cyclical character of the construction sector once again.

Consequently, the monetary policies have been adjusted to support the sector, and the contingent liabilities to be undertaken raise debates about how sustainable growth can be achieved in an economy where the construction sector is a "locomotive". Moreover, the employment generation in the construction sector is a fact but not unlimited and it is highly sensitive to macroeconomic conditions. Unfortunately, many companies operating in other sectors also shifted their activities to the construction sector to benefit from the government incentives and the high "rent" revenues offered by the construction market. Given this situation and the excessive capital flow through the infrastructure investments to the construction sector has not been realized the expected economic growth and the real economic growth has been offset. In addition, the economy struggles to catch a sustainable growth rate and remains very fragile.

Conclusion

In this study, the relationship between the construction sector and the economy was examined through the case of Turkey between 2000 and 2020 within the framework of two main concepts in the construction economics literature. The first one highlights the construction sector as the driving force of the economy, the sector's backward linkages with the economy, and its potential to absorb unemployment. The second and opposing one focuses on issues in the sector's relationship with the economy, such as its sensitivity to macroeconomic conditions, the problem of idle capacity, and excessive resource allocation.

Classical economic theories emphasize that the main goal of economic development is the achievement of economic growth. Although economic growth is necessary for development, it is not enough on its own (Todaro & Smith, 2015). It is a question mark whether an economic model that focuses on the construction sector is sufficient to achieve this sustainable economic growth. In order to eliminate this question mark, various macroeconomic variables have been selected, analysed, and interpreted logically.

The results show that especially in periods when the construction production-turnover ratio is negative, that is, there is an inefficient production in the sector, transferring more resources to the sector does not provide the desired sustainable and real economic growth. In addition, monetary policies that do not coincide with economic realities to keep demand for the sector alive make the economy fragile and cause currency shocks in countries with high current account deficits, such as Turkey. The high inflation caused by these exchange rate shocks reduces the purchasing power of households and restricts their access to goods and services. This, in turn, decisively affects the quality of life, which is one of the goals of economic development.

In order to prevent all of this, the visible outputs of the sector should not be used as a tool for populist policies. In addition, rent-oriented investments and capital transfer should be prevented and sector outputs should be produced in accordance with the needs of the economy. Although the high financing required by infrastructure projects is transferred from

the public to the private sector through procurement methods such as PPP, the guarantees provided to these projects should be limited in a way that eliminates both the risks on the public budget and the exchange rate risk carried by the private sector.

The data used in this research is mainly obtained from the TurkStat since the TurkStat share limited and not detailed raw data with other data providers such as the OECD, the Eurostat, and the World Bank. The sudden changes in the calculations or the data collection methods and limited or no information about how to link the previous data with the new ones raise some questions and undermine the credibility of the institution. For these reasons, further studies should be conducted with more continuous data for a longer period. Last but not least, the relationship between these indicators should be analysed more deeply from the perspective of causality to validate these findings.

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Factors Determining the Value of Property: Comparison of Real World and Metaverse

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Abstract

Metaverse is a sort of virtual world that creates an atmosphere for people to interact, participate in games, and collaborate. Beyond the unconstrained atmosphere of Metaverse, the function of "make money" has great financial potential for both investors and users. One of the uses of this financial potential is to own the land like a real estate in the "Metaverse" universe and to make profit by designing those plots. For this reason, the factors that determine the land and real estate prices in Metaverse also become crucial issue. This study focuses on the determining factors of land and real estate value on both physical life and Metaverse. This study explains the land and real estate value concept with its factors with traditional approach of physical world. Predictions on real world draw the potentially related factors determining land and real estate value in Metaverse. Collected data using the comparative research method primarily by observation and literature review, and the main goal is to determine similarities and differences between real-world and Metaverse. The significance is understanding for investment values and logic of applications that allow "land-based" crypto trading in the Metaverse, which is seen as the technology of the future.

Keywords: *blockchain technology, land value, metaverse, real estate value*.

Introduction

The metaverse is a computer-based virtual environment where all physical objects, services, families, buildings, world maps, and the universe are located (Brody, 2022). One of the main promises of virtual plots and other purchased virtual assets in the Metaverse is to make money. In addition, since these platforms allow their users to work together and interact, the economic benefits mentioned have potential for various sectors or investors. There have been many studies on concerts, training, and shopping events that are held and have the potential to be realized on Metaverse platforms, but there is very little content about the plots that provide the basis for these sales and create the atmosphere of the productions. In this study, the factors

[1] This paper is based on the author's Master of Architecture thesis.

that determine the financial value of the land on Metaverse are compared with the factors in physical life and evaluated on the examples of three Metaverse platforms.

According to the result obtained from this study, the land and real estate valuation logic in the physical world is similar to the virtual world, but it does not work the same as there are disadvantages such as distance, cost, construction costs, and geographical limitations arising from physical life in the virtual world. On the other hand, there are critical risks such as the volatility of the value of Cryptocoins and the sudden depreciation of the land and real estate owned, despite the possibility of gaining popularity of new platforms to be produced in the future, as Metaverse technology has not yet impacted all our lives and has not been adopted.

The first hypothesis of the study is that the economic values in the physical and virtual worlds will be determined by the value of the currency valid in that world, which is cryptocurrencies in the Metaverse example. At this point, it should be noted that the price of cryptocurrencies is not as stable as the currencies used in physical life. The second hypothesis is that while locational values are important for land valuation, proximity to "central" or "popular" areas that add value to land in the physical world by removing geographic restrictions should not add financial value to land. The idea that physically accessible land is more expensive doesn't make enough sense. Because in the virtual world, users have a feature such as "teleport". For this reason, it can be assumed that physical distances will no longer be an issue. Third, the size of both land in physical life and the Metaverse universe will have a positive impact on land prices. Finally, how "rare" a piece of land is not a comparable issue for the two land types, virtual and physical.

Theoretical Background of the Study

Blockchain technology has evolved since the report on Bitcoin published by Satoshi Nakamoto in 2008 (Nakamoto, 2009). Bitcoin is a digital currency in a decentralized system of networks. It is not real money or commodity value but is somewhere in between, independent of any government or other economic authorities (Baur et al., 2018). Nakamoto (2008) describes Bitcoin as an electronic cash system. According to this definition, Bitcoin can also act as a currency. However, on the other hand, it can be defined as an "asset" as it is an alternative currency. It is not just a currency, but a medium of exchange, a unit of account, and a store of value. In this case, it differs from the concept of "currency" as we know it (Baur et al., 2018).

The economic opportunities offered by blockchain ecosystems are expected to exceed a trillion-dollar market (Bunshnell, 2022). With the correct implementation of the blockchain system, stakeholders can optimize their own activities in line with their own interests and improve service quality (Pazaitis et al., 2017). In that case, it can be said that one of the most important business items of a properly implemented blockchain technology is the establishment of a system-related pricing logic (Lee et al., 2021). Demands for blockchain are evolving and increasing as it creates new business sectors. The scalability logic of blockchain makes it a new ecosystem while improving existing systems (Lee et al., 2021). In this way, new and more reliable business models are proposed.

With the development of technology and Bitcoin, the use of Metaverse has become a growing possibility (Lim et al., 2022). Metaverse refers to a universe powered by the blockchain (Zhao et al., 2022). It is a three-dimensional world that refers to humans and the virtual world they

live in. Thanks to these features, it expands the field of activity of people/users by solving the constraints related to time and resources by getting rid of the problems caused by nature (Momtaz, 2022). With the accessories and other digital assets that users purchase for their avatars, which they use to express their own characters, online virtual asset trading has already begun to change (Fernandez & Hui, 2022). One of these commercial products is land and real estate that allow avatars to spend time

Non-fundable tokens, such as NFTs used within Decentraland, are important not only for online commerce but also for the "Internet of value", where the perception of "value" is reshaped (Goanta, 2020). The Metaverse is closely associated with cryptocurrencies. For example, in The Sandbox, the cryptocoin SAND and in Decentraland, the cryptocoin MANA are important values for purchasing (Vidal-Tomás, 2022).

This study, while determining the pricing determinants of the "lands" traded on Metaverse, makes a comparison with the physical land value determinants known from daily life. It is aimed to determine the tendency of investors and company owners towards the mentioned product by researching the pieces of land sold as Non-Fungible Tokens (NFT) and their market conditions. A framework is presented to understand the relationship between the summary of the determinants that determine the value of physical plots in the literature and the pricing determinants used in the Metaverse. This study is important for investors and potential investors to understand the financial activities that take place on the blockchain. Moreover, due to the size of the NFT asset market and the growth rate it has experienced in recent years, it is important to investigate this topic.

Methodology

With the innovation of Metaverse technology, this study adopts an exploratory research approach, as there are very few studies on the values of the land here. With this methodology, topics that have not been studied before are examined. The steps of the study are to reveal the factors that determine the financial value of the land in Metaverse by comparing it with the physical life through literature review and examples, respectively.

The steps of this approach are as follows. First, blockchain technology, Metaverse, and NFTs will be defined. Based on these definitions, a literature review on Metaverse plots, which are seen as a source of financial income and a review of the three most popular platforms, has been conducted. Meanwhile, the factors that determine land prices in physical life have been determined with the help of the literature, and the physical and virtual land price determinants have been compared. The factors determining the land value in Metaverse were obtained by using a qualitative and exploratory approach (a comprehensive literature review) since the subject in question is new, the application examples are not common, and it promises to be a popular research area. In this way, it aims to establish relations between the land and real estate valuation criteria in the Metaverse platforms, which are the subject of the research, and the criteria in the physical world. The aim of this study is to reveal similar or different land value determinants in Metaverse and physical world lands by comparing them with data in physical life to explain the concept of NFT and the existence of virtual lands and their trading processes. The second is to shed light on Metaverse investors and potential investors by informing them about the details of the issue. The methodology of the research is visualized in Figure 1.

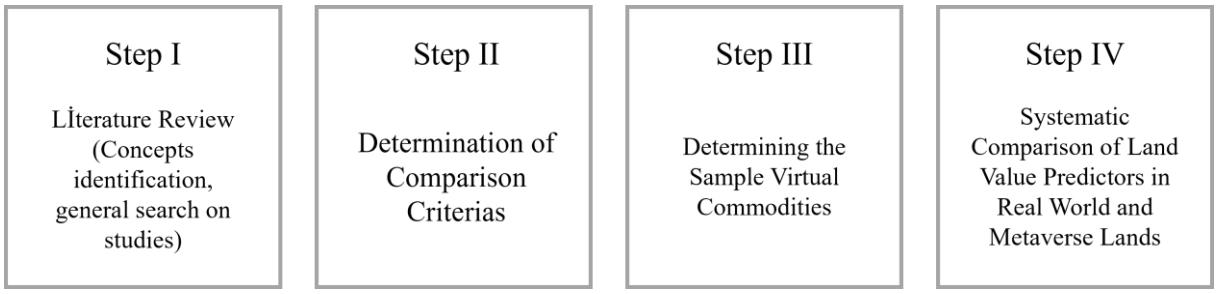


Figure 1: Research methodology.

Lands as Non-Virtual Commodity

In this study, land will be considered a non-virtual commodity and will be associated with the factors that determine the value of land in virtual worlds. For this reason, first, "values" in the physical world gain importance.

Considering that houses consist of reproducible concrete structures and non-reproducible pieces of land, it can be said that the main issue that determines the value of the house is the location of the house, namely the land, and this land capitalizes the market value of the house. In this case, it can be stated that the economic benefits to be produced by the consumption objects built on that land are an important input to understanding land values in the physical world. On the other hand, Davis and Heatcote state that even if the land and the structure on the land are bought and sold together in the housing market, the pricing of the structures and the land will give different reactions to the market conditions (Davis & Heatcote, 2007). According to the study of Yalpır and Bünyan Ünel (2016), the factors that determine the value of land in the physical world are examined under four headings. Legal factors: zoning status and locational factors are expressed as whether the parcel is on the corner or not, whether it is an intermediate parcel, the length and number of facades, the geometric form of the parcel, technical infrastructure, access to roads, and the slope of the surface where the parcel is located. Spatial characteristics are proximity to health, education, security, and other facilities, proximity to public transport facilities, and proximity to waste collection areas. Finally, when local factors are considered, first, population, neighborhood relations, construction density, the development potential of the region, rent, geological characteristics of the region, climate, and pollution rate are expressed. Based on the literature review, the factors that determine the value of the land in the physical world are determined as follows: Zoning and restrictions considered as legal factors. On the other hand, corner parcel, facade length, geometric shape, and technical infrastructure (roads and slope) are the physical factors. Distance to health, education, public institutions, and safety; distance to shopping malls, cultural centers, entertainment centers and green areas; distance to public transport points; distance to waste areas are locational factors. And lastly, population, migration, neighborhood relationships, build-up density, development potential, rent, money making potential, geological features, climate, pollution, considered as local factors.

Virtual Lands as an NFT

Three-dimensional spherical universes have gained popularity in recent years. Virtual worlds have become advantageous, especially by overcoming the limitations created by the

geographical problems of physical life, such as the need to commute. While these environments provide the user with various possibilities, such as elaborately designed graphics, animations, and voice communication facilities, they also have their own virtual economies and currencies (Partala, 2011). Most of the research on NFTs (Ko et al., 2022; Pinto-Guti'errez et al., 2022; Karim et al., 2022; Dowling, 2022) investigated their economic values and characteristics, while a few articles (Goldberg et al., 2021; Dowling, 2022; Nakavachara & Saengchote, 2022) conducted studies on real estate and land on these platforms. Kampakis et al.'s (2022) study examined NFTs as alternative investment instruments. Based on the period in which the research obtained its data, it was concluded that NFTs are an investment instrument that provides financial gain and has its own risk profile.

Designers in virtual worlds take the physical world as their inspiration. Objects, environments, and even all objects in physical life are modeled, and adapted versions of them are created in the virtual world. These designs are simply a three-dimensional re-creation of the physical world in the virtual world. In this case, it can be stated that the similarity of virtual and physical worlds is highly influenced by each other because of their parallelism (Berger et al., 2016). In this case, it can be said that most of the issues that can be discussed and interpreted for the Metaverse platform have their roots in the physical world and the basic logic of these two worlds affect each other. Dowling et al. discovered in their study that the virtual land they examined has the equivalent of a living physical world in the real estate market (Dowling, 2022). In order to determine the land value in the Metaverse, first of all, the factors that determine the value of the NFTs, which are the equivalent of those values, should be known. NFTs earning commercial profits on the Metaverse through programs between applications is a token of value for the market (Momtaz, 2022). According to some academic studies, there are many factors that determine the value of NFTs. One of them is the "scarcity" value, which will contribute to the social status of the owner of the NFT (Lee et al., 2021). On the other hand, being close to the city center, plazas, or business centers for Decentraland parcels is one of the features that increases the value of NFT (Goldberg et al., 2021).

The Sandbox is a universe built on Ethereum blockchain technology. NFT, which represents the ownership of virtual land here, is LAND (Nakavachara & Saengchote, 2022). Here, users can buy LAND. LANDs are the unique digital plots here. These plots come together to form the Metaverse map (VISUAL). All plots here are tradable values (Nakavachara & Saengchote, 2022). There are two main reasons that push users to buy land in Sandbox, OVERLAND, and Decentraland. First, it is aimed at generating income from visitors by establishing various interactions on LANDs; secondly, purchased NFTs can be resold at higher prices in secondary markets (Nakavachara & Saengchote, 2022).

Comparison of Land Value Determinants on Real World and Metaverse

In the Metaverse, the potential income of the land represents the utility of the land and expresses the land value (Huber, 2022). In studies conducted on some platforms in Metaverse, the factors determining the land and real estate values have been explored by many studies (Dowling, 2022; Guven & Ercan, 2022; Goldberg et al, 2022; Nakavachara & Saengchote, 2022; Schonbaum, 2022). The factors identified according to these studies are as follows: cryptocoin's value, location, size of the parcel, popularity, scarcity, memorability.

***Cryptocoin's value*.** The study of Nakavachara & Saengchote (2022) emphasized that the currency used in Metaverse can have an impact on users' buying and selling transactions. For

example, when SAND gains in value significantly compared to other cryptocurrencies, SAND holders will feel richer and will be more willing to buy this cryptocurrency. On the other hand, according to Bunshnell's (2022) research, blockchain systems cannot be protected from global economic forces as they are not resistant to traditional macroeconomic leverage as in global capital markets.

Location. According to Goldberg et al., parcels close to popular buildings, districts, and streets may be affected by the spillover effect of the activities there, and in this way, they may be flooded with visitors (Goldberg et al., 2022). On the other hand, there is no spatially natural reason why one piece of land should be more valuable than another. Because avatars can be teleported in virtual worlds (Morris, 2022). While location is seen as an important factor for virtual lands, it's about being "close" to a place. However, on a platform where users don't walk or travel, "proximity" may not mean anything. In this case, it should be considered that the position change that the teleportable users can perform in one second is not directly related to the distance. On the other hand, the "location" issue starts to gain importance as an activity carried out on a parcel close to or adjacent to a parcel of land will attract users to interact with that area. Hissong stated that plots near the land owned by American rapper Snoop Dogg were selling for much higher prices than expected (Hissong, 2021). Moreover, if you are a fashion entrepreneur, you can benefit from being involved in the digital space where Gucci is located. Moreover, if you want to compete with this brand, you want your land to be as close to that plot as possible (Krion, 2022). This distance will benefit you. Contrary to this view, according to Morris, the idea that geographic space in the virtual world will gain value in the same way as land in the real world is erroneous. Land values in the physical world increase depending on location and utility. Distances are important. Opportunities to overcome those distances are important. It is important in what conditions and when you go to a place in the physical world. These are geographic facts, but in the Metaverse, all distances are faked (Morris, 2022).

Size of parcel. In all three platforms, sales are made in accordance with the determined parcels. The plots used maps are divided into squares. The sales of the parcels are made as 1x1, 3x3, 6x6, 12x12 and 24x24 units. Pricing for each unit is different.

Popularity. Land and real estate in the physical world can be driven by opportunities and constraints. These values become more expensive with their proximity to utilities, communities, and industrial centers, and investors build taller structures to offset the rising density of these regions, which in turn offsets rising land costs (Brody, 2022). Users and investors tend to prefer plots where people are more likely to randomly encounter each other. For this reason, plots close to popular structures are preferred (Goldberg et al., 2021). As the number of people in a region increases, the economy revives, more jobs are created, more people are attracted, and the liquidity of the market increases (Huber, 2022). On the other hand, there is always a risk that new platforms will emerge in the Metaverse supply, but these new platforms cannot be valuable simply by offering more land. These lands are worthless if there is no liquidity, reputation, or utility (Huber, 2022). In this case, it can be stated that the use values and popularity of the owned lands are also important.

Scarcity. Scarcity has a positive correlation with the selling price and a negative correlation with the number of sales (Mekacher et al., 2022). Rare land parcels produced in the metaverse have different prices than rare parcels in real life. While the prices of rare assets in physical life are determined by a market mechanism, prices for artificial rare assets may be limited because, when necessary, an infinite supply of "scarce" assets can be offered (Brody, 2022).

Memorability. According to Goldberg et al., "rememberability" is also a value specifier for virtual lands (Goldberg et al., 2022). This title is about the memorable names of the plots and other memorable factors that can make the plots popular.

Considering these data, the summary table of the factors determining the land value in physical life and in the Metaverse, depending on the main purpose of the study, is summarized in Table 1.

Table 1. Comparison of land valuation factors.

Land Valuation Factors		**Physical World**	**Metaverse**	**Reference**
Legal Factors	zoning and restrictions	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016; Goldberg et al., 2022; Morris, 2022; Hissong, 2021; Krion, 2022
Physical Factors	corner parcel	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016; Goldberg et al., 2022; Morris, 2022
	facade length	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016; Sandbox, 2022; Ovrland, 2022; Decentraland, 2022
	geometric shape	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016; Sandbox, 2022; Ovrland, 2022; Decentraland, 2022
	technical infrastructure (roads and slope)	Very Important	Less Important	Yalpır & Bünyan Ünel, 2016
Locational Factors	distance to public services	Very Important	Less Important	Yalpır & Bünyan Ünel, 2016; Brody, 2022; Goldberg et al. 2021; Huber, 2022
	distance to popular areas	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016; Brody, 2022; Goldberg et al. 2021; Huber, 2022
	distance to public transport points	Very Important	Cannot Evaluate	Yalpır & Bünyan Ünel, 2016;
	distance to waste areas	Very Important	Cannot Evaluate	Yalpır & Bünyan Ünel, 2016;
Local Factors	population	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016; Brody, 2022; Goldberg et al. 2021; Huber, 2022
	migration	Very Important	Cannot Evaluate	Yalpır & Bünyan Ünel, 2016
	neighbourhood relationships	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016
	build-up density	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016
	development potential	Very Important	Very Important	Yalpır & Bünyan Ünel, 2016
	rent, money	Very	Very	Yalpır & Bünyan Ünel, 2016; Brody,

	making potential	Important	Important	2022; Goldberg et al. 2021; Huber, 2022
	geological features	Very Important	Cannot Evaluate	Yalpır & Bünyan Ünel, 2016; Morris, 2022
	climate	Very Important	Cannot Evaluate	Yalpır & Bünyan Ünel, 2016
	pollution	Very Important	Cannot Evaluate	Yalpır & Bünyan Ünel, 2016
Blockchain Based Factors	cryptocoin's value	Cannot Evaluate	Very Important	Nakavachara & Saengchote, 2022; Bunshnell, 2022
	scarcity of NFT	Cannot Evaluate	Very Important	Mekacher et al., 2022; Brody, 2022
	memorability	Cannot Evaluate	Very Important	Goldberg et al., 2022

Discussion

The concept that determines the value of land in the Metaverse depends on its potential income (Huber, 2022). This study determined the similarities and differences between the factors that determine the economic value of the lands in the physical world and the factors that determine the economic value of the lands in the Metaverse. Lands in physical life have practical benefits. For example, land can be used for farming or for underground resources. However, there are no natural resources in the Metaverse (Morris, 2022). When we look at the real-life and virtual-life value indicators of land prices, many "problems" are solved by themselves, as there are no obstacles such as geographical restrictions, ecological conditions, space constraints that exist in physical life but do not exist in Metaverse, and the perception of financial value in virtual lands has completely differentiated from that in physical life.

In this case, it is not appropriate for Metaverse to consider legal factors, which are among the factors that determine land value in the physical world, in the context of "zoning and restrictions." In the Metaverse, plots are segregated as platforms see fit, and these NFTs' own legal safeguards are protected by blockchain-based smart contracts. Considering the locational factors, locational advantages such as being in a corner plot have a positive effect only if they increase the popularity of the plot in question, that is, the density of users. Because there are no technical infrastructure needs such as roads and slopes, technical infrastructure remains unimportant in the cyber world. When locational factors are examined, proximity to popular areas is an important factor for both physical and cyber lands. However, since avatars are not affected by environmental pollution, the risks posed by environmental problems do not exist in the Metaverse. In addition, since the transportation of avatars is provided by teleportation, public transportation opportunities are also insignificant. Considering the local factors, the popularity of the area and its money-generating potential are important for both plots. Climate, pollution, and geological conditions are unimportant in cyber worlds.

Our hypothesis that popular lands are valuable but advantages in terms of proximity are effective in the financial value of the lands has been proven through the literature. However, on the other hand, it is equally difficult for the characters with teleportation power to reach popular or unpopular spots. For this reason, physical distances become insignificant. Finally, it has been proven by the work of Mekacher et al. (2022) that the "scarcity" feature increases

the value of plots, although the "rarity" feature is not a comparable phenomenon for physical worlds and cyber worlds as stated in our hypothesis.

It is true that the economic values in the physical worlds and the Metaverse universes vary depending on the currencies prevailing in the universes in question, but this is not exactly proportional to the value of the "plot". While the ability to freely create ancillary transactions outside the control of the ecosystem in any cryptocurrency created by blockchain technology facilitates "digital dollarization," according to Stiligz (2000), this financial liberalization is likely to raise concerns such as creating economic instability. The systems of Metaverse platforms have virtual economies that must be managed very carefully, and the developers of these universes must design by considering the economic balance and constantly closely controlling the system (Nakavachara & Saengchote, 2022).

Conclusion and Future Work

The universe generated in the Metaverse points to a world beyond the physical universe. For this reason, the metaverse will create a great change in every aspect of human beings. People who could rebuild the world are accustomed to reconstructing the city and its values with the new practices they develop. For example, land has now become a symbol that expresses power and material possibilities rather than physical life.

This study investigates the mechanism of the economic value of the plots on the Decentraland, Sandbox, and OVRLAND platforms on the Metaverse by comparing them with the land valuation factors in physical life. This comparative analysis provides insight into the potential of virtual lands. However, it should be noted that the research findings are highly variable as Metaverse technology is a technology that is constantly renewed and open to development. In the Metaverse, land providers can increase the number of products they offer, destroying the "rarity" feature, which is known to increase the value of the land and, in this way, cause the value of the plots to decrease. It can capture users by offering more than their experiences by establishing a platform other than the platforms discussed. The dynamics determined through today's research, the factors that make the parcels "value" economically, may become completely different with a feature to be developed in the next period. These top three platforms, which we have discussed due to the number of users and market volume, may lose their value over time, or even be closed. Therefore, the fields of study in the Metaverse and the possibilities it offers are endless. New studies to be carried out should examine the factors that determine the price balance of these lands in more detail to be able to manage the risks by considering the aforementioned lands as a financial resource.

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The Importance of Feasibility Study in Real Estate Investment Projects: Example of a Residential Land

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Abstract

Construction is one of the sectors that require large amounts of capital. The construction sector includes very large-scale sub-units such as residential, commercial, road, and bridges. One of the most important factors in all construction projects is the risks that can occur in the project. Failure to make the right decisions at the beginning of the project leads to negativity in the process, causing project failure at any time, in the range of planned costs, and insufficient quality. Inefficient projects cause companies to fail at the end of the process, and even investors face unintended consequences, such as bankruptcy. The cost analysis of land selection must be done correctly, and the benefit of the project must be determined with all the details in mind. The feasibility study of the land compares the cost required for the investment to be made and the benefit of the project. The criteria for Net Present Value (NPV), Internal Rate of Return (IRR), and benefit/cost analysis must be checked to determine the suitability of the investment to be made. This study covers the feasibility study for a residential project in Antalya province. The study aims to calculate NPV, IRR, and benefit/cost analysis. According to the results obtained, the district with the best Benefit/Cost ratio, NPV, and IRR results was calculated as the Muratpaşa district.

Keywords: *benefits of cost analysis, criteria, decision, housing project, feasibility, IRR, NPV, project, residential land.*

Introduction

Shelter has always been one of the most basic human necessities throughout history. Overcrowding of the population led to the creation of new development areas and the extension of construction outwards from the places designated as settlement centers as the historical process continued. As the population density rose as a result of this circumstance, new zoning areas were determined.

In a rapidly developing world, the basic need for housing and shelter is increasing day by day. This basic need is only for shelter for low-income groups. In addition to shelter, featured and certified dwelling structures are preferred for higher-income groups. The diversification of the housing sector for different income groups and the fact that this need has never diminished and even gradually increased in any period keep the interest of investors in this sector at a high level. Over time, the increase of investors in the housing sector, as well as the expansion

of investment projects in each new project, has prompted other investors from other sectors to gravitate to this sector.

Decision-making process is one of the most critical factors in every sector. Making the appropriate decisions can have a positive or negative impact on every process from start to finish. To reduce uncertainties and ensure the successful completion of the project, it is necessary to think carefully and in detail about the decisions to be made on time, to consider all elements thoroughly, and to examine the options in detail. Every stage in the entire process, from the initial idea of the project to the completion of the project and bringing it to the sector, should be considered thoroughly, and all alternatives should be discussed in all detail in the decisions to be taken.

As in every sector, before investing in the housing sector, the investor considers his/her own capital and thinks thoroughly about which region and with which features he/she will invest in a housing project and decides accordingly. In the decisions taken, many factors such as the development of the district and neighborhood, especially the city where the project will be built, the income levels of the people who prefer the region, housing features such as the preferred indoor space, number of rooms, quality of materials used, etc. play an important role.

If the right decisions are not taken at the beginning or during the project, it is likely that the investor will not make the desired profit, incur losses, or even have undesirable consequences such as bankruptcy. All of the aforementioned negativities are not only project-based but may appear as failures in other investment processes of the investor, and gaining the trust of participants and customers in other projects may negatively affect the investor. The decision-making process should be carried out meticulously to avoid these negativities. Land selection is one of the most important stages of the decision-making process.

During land selection, the cost analysis should be done correctly, and the benefit to be obtained from the project should be determined by considering all the details. The feasibility study of the land enables a comparison of the cost required for the investment to be made and the benefits to be obtained from the project. Net Present Value (NPV), Internal Rate of Return (IRR), and cost/benefit analysis criteria should be checked to determine the suitability of the investment.

In this study, Net Present Value (NPV), Internal Rate of Return (IRR), and cost/benefit criteria were calculated for residential lands in 4 different districts in Antalya province. The lands in question are located in the districts of Mollayusuf Mahallesi- Konyaaltı, Sütçüler Mahallesi- Kepez, Çağlayan Mahallesi- Muratpaşa and Altınkale Mahallesi- Döşemealtı.

Feasibility Study

Capital investment is required for the implementation of a construction project in any region. When the characteristics of the construction sector are analyzed, there is a high level of uncertainty. Therefore, a feasibility study is required before starting any project (Mask & Gaikwad, 2021).

In the study prepared for the preparation and evaluation of investment projects, the issues related to investment and preparation of investment projects were examined in detail, and

investment proposals based on the net present value and internal rate of return methods were discussed (Gedik et al. , 2005).

In the studies, Net Present Value (NPV), Internal Rate of Return (IRR), and cost/benefit analysis were used as commonly used criteria to check the suitability of the project in the feasibility study of a housing project in the Pimpri Chinchwad area in India. The aim of this study was to determine whether the project is feasible or not (Mask & Gaikwad, 2021).

In the study conducted in Malaysia, another country located in Asia, a feasibility study and economic evaluation research was conducted on Green Building projects to help the client decide whether the project is feasible and worth continuing (Halil et al., 2016). In the study conducted in Hanoi, Vietnam, the potential for Construction and Demolition Waste (CDW) recycling facilities was evaluated by estimating the potential supply and demand and assessing the probable costs and benefits. NPV and IRR methods were also utilized in this evaluation (Hoang et al., 2021).

In addition to housing projects, green building projects, and recycling facilities, feasibility studies were also carried out for investment projects such as irrigation canal construction projects and railway construction projects. In one of these studies, a feasibility study was carried out in the research to determine the suitability of the irrigation canal construction project in order to increase the yield in the fields in Indonesia (Zakia et al., 2021). Furthermore, in Tanjung Perak Port, Indonesia, a feasibility study was conducted as an intermediate model for the railway construction project, and the railway construction project was categorized as much as possible by determining the NPV, IRR, and benefit/cost ratios (Arga et al., 2020).

In order to emphasize the importance of feasibility study in the construction sector, due to the delay, cost, and other issues that directly and negatively affect the construction sector in Iraq, as well as other issues that affect the quality of construction projects, a study was conducted to assess the level of awareness of feasibility study in construction projects and to identify the effects of feasibility study in the construction sector, and to identify the causes of feasibility study violations in the construction sector (Mohammed et al., 2019).

If we examine the studies carried out in Turkey country, a thermal hotel project to be developed in Afyonkarahisar region was taken into consideration and SWOT analysis was used in the strategic evaluation of the project and, discounted cash flow method was used in the cost analysis. Net Present Value, Internal Rate of Return were calculated in the study (Taktak et al., 2010). The thesis study was carried out in different regions of the province of Istanbul, and the study was completed with a Financial Analysis study by making Residence, Home - Office, and Hotel Project Development in Kartal-Soğanlık Region and Residence, Office, Shopping Center, and Congress Hotel Project Development in Pendik Region (Çalışkan, 2011).

Studies have been carried out in other sectors apart from the construction sector, and it aimed to produce kaolin from the Balıkesir - Sındırgı field to meet the needs of the ceramic enterprises in the region. It was recommended, that the selection between alternative investment projects should be made according to the NPV criterion (Demirbugan, 2008).

Moreover, research conducted to provide information on economic internal profitability, which is a measure of how much the investment project will contribute to the national

economy, was tested with methods using discounted cash flows, and calculations were made according to the internal profitability ratio, net present value, benefit/cost ratio and net benefit/cost ratio method (Mandacı, 1992). In another study, revenue and expenditure forecasts in investment projects were mentioned. The study, by mentioning that the expenditures made in investment projects were often not completed within a year and that expenditures occur at different times during the project, and that the revenues to be obtained from the project cannot be collected at the same time; it was emphasized that revenues and expenditures were not at the same values. Noting that these value differences should be analyzed over similar time periods, it was explained that some of the valuation methods used in the calculations based on the estimates were Net Present Value (NPV), Internal Rate of Return (IRR), and Benefit/Cost Ratio (Gedik et al., 2005). In a different study, the methods of evaluating the economic efficiency of investment projects for the construction of industrial facilities of industrial organizations under uncertainty and risk were examined. In the study, NPV, and IRR examinations were studied for scenarios (Gayfullina et al., 2021).

The purpose of feasibility study can be listed as follows.

1. Determine the benefit/cost ratio for the project
2. To determine the Net Present Value (NPV) and Internal Rate of Return (IRR) for the project.
3. Analyze the parameters to determine if the proposed project is appropriate.

Net Present Value (NPV)

The Net Present Value (NPV) method is a method of calculating the net value (net) at the present time. The present assumption is to explain that the initial time of the calculation coincides with the time the evaluation is carried out or in the 0 year period in the calculation of investment cash flow (Zakia et al., 2021).

In order for a project to be accepted by this method, it must be equal to or greater than 1. Among alternative projects, the project, which has the largest ratio, is prioritized, with greater than 1. As with the NPV method, the selection and magnitude of the discount ratio to be used in this method affect the analysis results very much. The purpose of the method is to prioritize the project, which has the largest benefit/cost ratio in investments to be made, thus maximizing the investor's B/C ratio. The formula used to calculate the NPV value is:

NPV=PWB – PWC

$$\text{PWB} = \sum_{t-0}^{n} CBt(FEB)t$$
$$\text{PWC} = \sum_{t-0}^{n} CCt(FEB)t$$

PWB = Present Worth of Benefit;
PWC = Present Worth of Cost;
Cb = Cash flow benefit;
Cc = Cash flow cost;
FBP = Present Interest Factor;
n = Investment period;
t = Time period;

If the difference is positive, the project is accepted (NPV > 0). In the case of multiple projects, the project with the NPV high should be preferred. If NPV = 0, it is clear that annual acquisition flows barely cover operating costs and annual investment costs (Gedik et al., 2005).

Internal Rate of Return (IRR)

Internal Rate of Return (IRR) is an interest rate (not bank interest) that describes the level of profit from a project or investment in percentage when the NPV value is equal to zero. IRR is the interest rate that illustrates that the benefits presented are equal to zero (Zakia et al., 2021). The formula used to calculate the IRR is;

$$\text{IRR} = iNPV0 + \frac{NPV0}{(NPV0 + NPV1)} \ (iNPV0 - iNPV1)$$

iNPV0 = interest rate net present value at i0;
iNPV1 = interest rate net present value at I;
NPV0 = net present value at i0;
NPV = net present value at i.

In order for a project to be accepted, the calculated IRR investor must be greater than the minimum discount rate accepted. In a selection between alternative projects, the IRR largest project is prioritized. If the IRR has more than one option higher than the discount rate, the IRR higher investment project will take priority.

Benefit Cost Analysis

Benefit/Cost Ratio is calculated in two different ways. According to the first method, also called the most used profitability index, the Benefit/Cost Ratio is the ratio of the sum of the current values of the benefits (cash inflows) that a project will provide during its economic life, the sum of the costs (investment expenditures and other cash outputs) to the sum of the current values. The second method, called the benefit/cost ratio of investment, is calculated by dividing the total of net reduced cash flows into the reduced investment total.

$$BCR = \frac{PWB}{PWC}$$

PWB = Present Worth of Benefit;
PWC = Present Worth of Cost.

In order for a project to be accepted by this method, it must be equal to or greater than 1. Among alternative projects, the project, which has the largest ratio, is prioritized, with greater than 1. As with the NPV method, the selection and magnitude of the discount ratio to be used in this method affect the analysis results very much. The purpose of the method is to prioritize the project, which has the largest benefit/cost ratio in investments to be made, thus maximizing the investor's B/C ratio (Bostancı, 2008).

Purpose of the Study

One of the most important stages at the beginning of all investment projects in the construction sector is the selection of the land. The benefit to be obtained from the project to be developed on the selected land is one of the most important items in terms of the evaluation of the project by the investor. Therefore, every detail, criterion, and all option must be evaluated in order to make the right decision in land selection. This is the same for housing projects as in other construction branches. In this study, the data required for the feasibility study were determined by literature research and expert opinions, NPV, IRR, and Benefit/Cost ratios were calculated, and the final ranking was made.

Within the scope of the study, 4 parcels where the housing project can be realized were selected. In the selection process, attention was paid to the fact that the lands were parcels designated as residential zoned and that they were located in areas with high housing density and preferred by buyers. For this study, surveys were conducted in the fields and regions, and expert opinions were obtained from previous articles, theses, and studies. With the identified data, NPV, IRR, and Benefit/Cost ratios were calculated on the lands, and the final ranking was aimed.

Location of the Case Study

According to TurkSTAT data published on February 4, 2022, Antalya province is the 5th largest city in Turkey with a population of 2,612,834 people and its surface area is approximately 20,177 km². According to TurkSTAT data published on February 4, 2022, there are 19 districts and districts including Akseki, Aksu, Alanya, Demre, Döşemealtı, Elmalı, Finike, Gazipaşa, Gündoğmuş, İbradı, Kaş, Kemer, Kepez, Konyaaltı, Korkuteli, Kumluca, Manavgat, Muratpaşa, Serik, and a total of 914 neighborhoods in these distributions.

As in Turkey in general, the demand for shelter is increasing day by day due to the growing population in Antalya. Due to important factors such as tourism, local and foreign settlers prefer Antalya province. An analysis of TurkSTAT data shows that the number of residential building permits issued by the issuance in 2021 in the districts where the study was carried out among 19 districts constitutes approximately 34% of the province in general and 45% of the occupancy permit.

Density maps according to the sales made on the basis of independent sections on a district basis for 2021 are given below. A part of the Konyaaltı district is shown in Figure 1, a part of the Döşemealtı district in Figure 2, a part of the Kepez district in Figure 3, and a part of the Muratpaşa district in Figure 4.

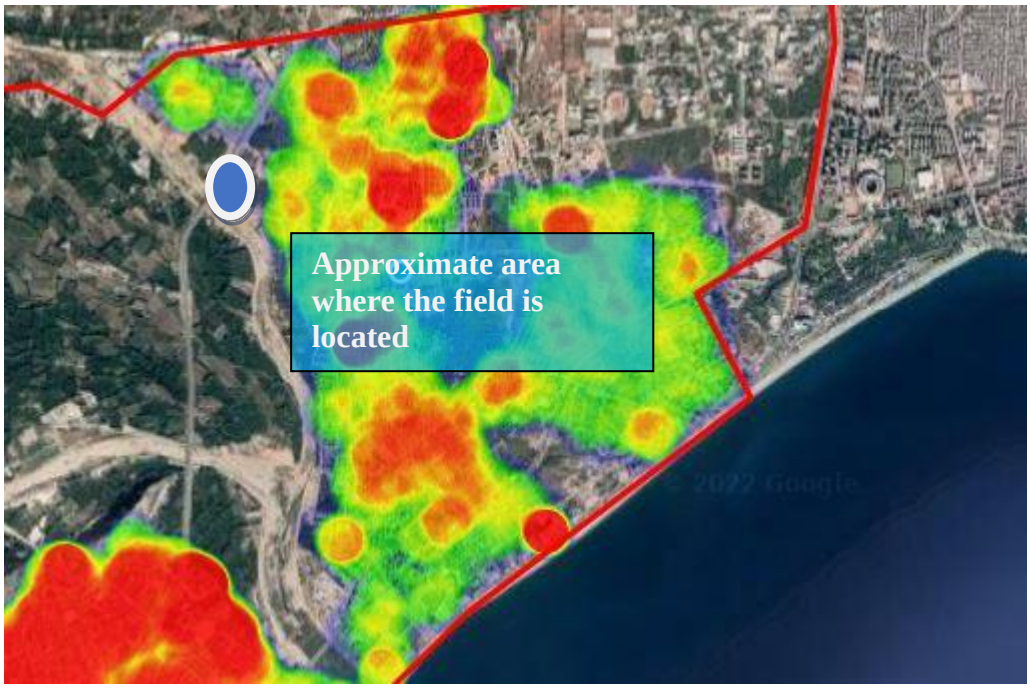


Figure 1: Konyaaltı district independent division density map for 2021 (Reference: parselsorgu.tkgm.gov.tr).

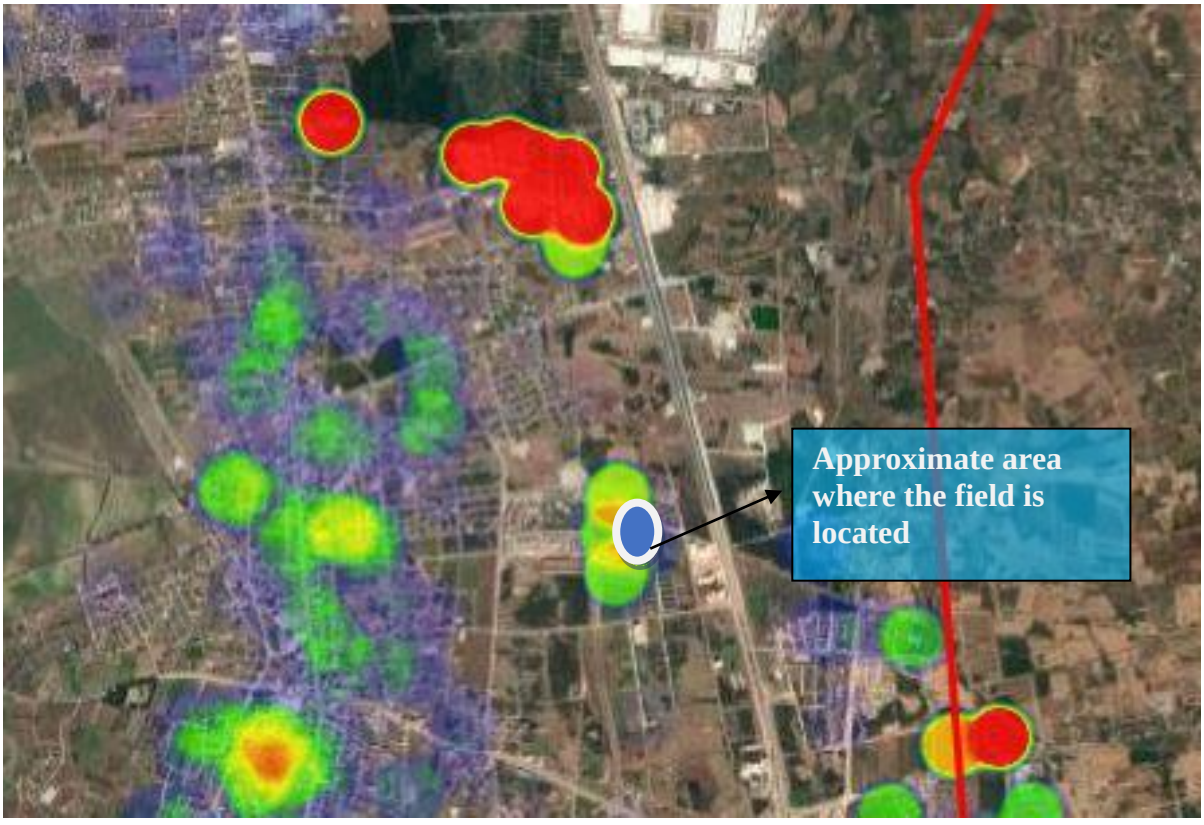


Figure 2: Döşemealtı district independent division density map for 2021 (Reference: parselsorgu.tkgm.gov.tr).

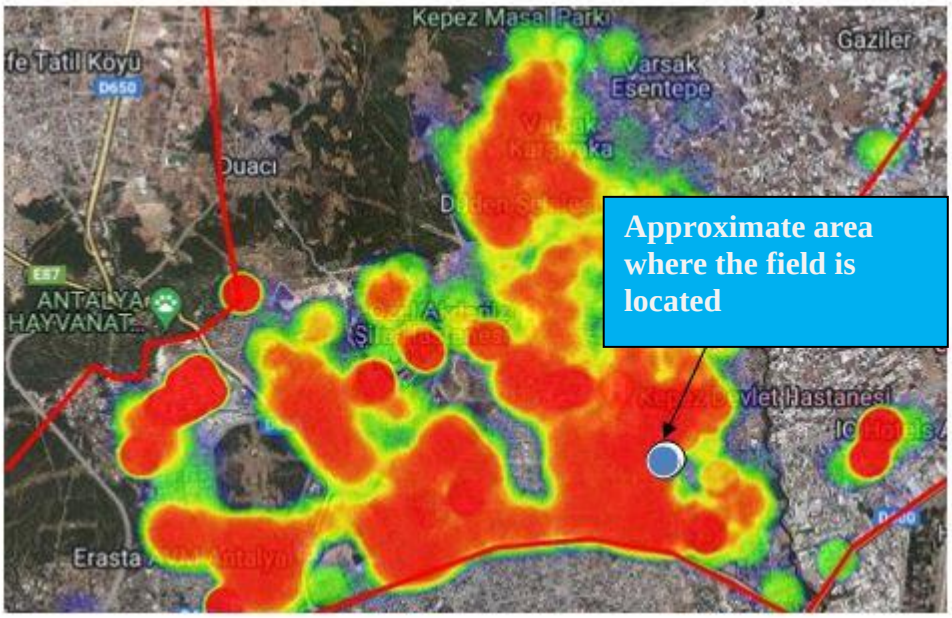


Figure 3: Kepez district independent division density map for 2021 (Reference: parselsorgu.tkgm.gov.tr).

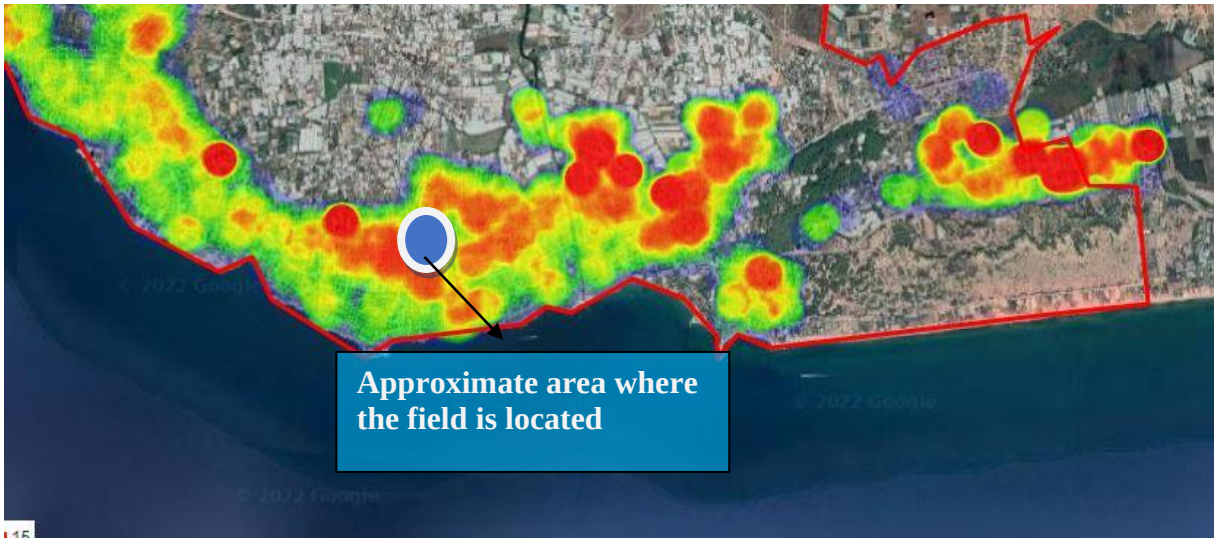


Figure 4. Muratpaşa district independent division density map for 2021 (Reference: parselsorgu.tkgm.gov.tr).

Comparative Feasibility Assessment of the Predicted Housing Zones

NPV, IRR, and Benefit/Cost ratios were studied for the four parcels specified in the study area. The acceptances and assumptions made in the studies are as follows;

-In the determination of the Construction Area, the precedent rights determined for the lands and 30% of the area excluding the precedent were taken into consideration.

-For the Saleable Area, 20% of the construction area was deducted from the approximate construction area with the assumption that the common areas will be more

because the immovables in Konyaaltı and Muratpaşa are qualified, 10% because the immovable in Döşemealtı is a villa, and 10% with the assumption that the common area of the immovable in Kepez district will be lower.

-For the cost item that constitutes the expense item, considering that the buildings to be built in Konyaaltı, Muratpaşa and Döşemealtı will be of higher quality, the 4-C construction class was taken, and the average of the 3-A and 3-B construction class was taken for the construction in Kepez district. Due to the inflation after February 18, 2022, when the unit prices were published, the unit^{m2} price was increased by approximately 35-40%.

-In the sales figures that make up the income, zero housing price averages were taken, taking into account the research made in the region. 23,000 TL/m^2 for Muratpaşa, 8,500 TL/m^2 for Kepez, 20,000 TL/m^2 for Konyaalti, and 17,000 TL/m^2 for Döşemealtı were foreseen.

- The percentage of contractors in the regions is 40% for Muratpasa, 50% for Kepez, 44% for Konyaaltı, 45% for Dosemealti.

-The reduction rate for NPV is taken as 10%.

The results of the work carried out are as follows.

Table 1. Results obtained.

	MURATPAŞA	KEPEZ	KONYAALTI	DÖŞEMEALTI
BENEFIT/COST	36%	11%	30%	27%
NPV (USD)	777.509 USD	12.038 USD	682.278 USD	558.283 USD
NPV (TL)	12.051.391 ₺	186.601 ₺	10.575.315 ₺	8.653.395 ₺
IRR	28%	11%	22%	22%

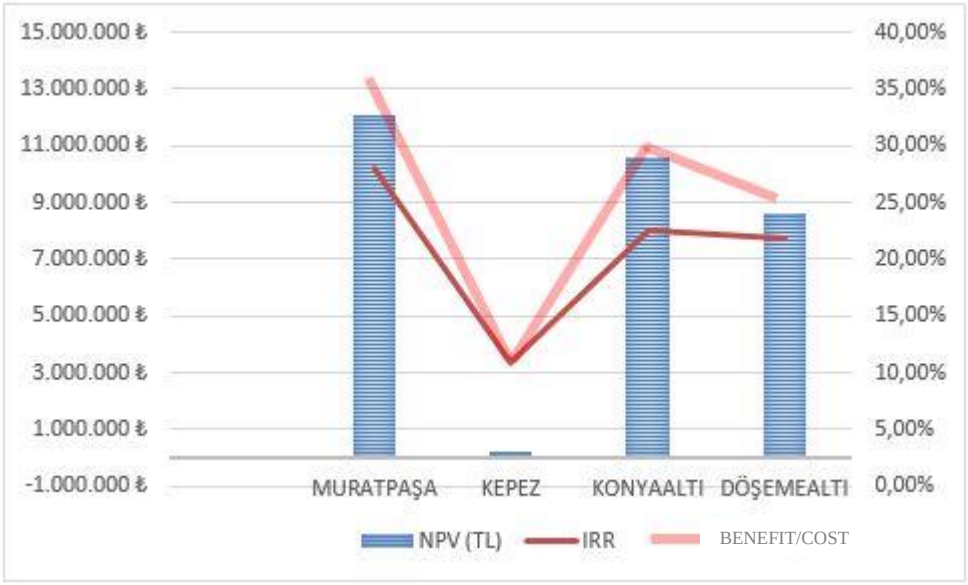


Figure 4: Graphical display of results.

Table 1 shows the data obtained as a result of the study. Figure-4 is the graphical representation of the results obtained.

As can be seen from the results obtained, the district with the best Benefit/Cost ratio, NPV, and IRR results was calculated as Muratpaşa district.

Results

Within the scope of the research aiming at the selection of residential land, first of all, all the criteria that should be considered in the selection of an investment land were identified through other articles, research, theses, publications and interviews with experts.

Considering that housing projects were developed for all lands, NPV, IRR, and Benefit/Cost Ratios were determined by taking into account the income to be obtained from the lands in case of completion of the projects and the costs to be spent and ranking was made among the regions. As a result of the feasibility study, it was seen that the best alternative could be the land in Muratpaşa district.

Research and studies have shown that the proximity of the land to the center, the completion of the infrastructure and especially the high turnover to be obtained from the sale of housing, which constitutes the income item of the project, can be important items in the selection of the land.

When the NPV, IRR and Benefit/Cost Ratios are analyzed; it is contemplated that the investment can be considered for the land in Konyaaltı and Döşemealtı districts in addition to the land in Muratpaşa district. Due to the development of the Döşemealtı district, the increase in interest recently, and the expansion of detached housing throughout the country, it is thought that better results may be obtained in new studies to be conducted in the coming period.

In this study, the criteria are considered in terms of deciding on land selection at the beginning of a project have been shown with sample applications. The criteria, calculations, and acceptances in the study have been taken into account by considering the four selected lands, and do not cover the districts in general. All the details in the study are specific to the field and the process in which the research was conducted.

Finally, in all studies, including the decision-making to be carried out in these districts, land-specific criteria should be determined, research should be carried out, and a project-specific decision should be considered. In addition, the study was conducted on the data identified during the research process, and therefore, future research is recommended even for the same lands, during the investment decision-making process for the process outside the research.

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Consumer Based Perceived Quality in Real Estate 4.0

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Abstract

It is important to perceive the quality and evaluate the service outputs in the competitive environment in the real estate sector. Since the quality perceived by the consumer has a subjective conceptual structure, it is very difficult to define and measure. In consumer-oriented perceived quality, which is characterized as the relationship between expectations and alternatives, pre-purchase expectations, service process experiences, and after-sales services are considered as a whole. Perceived quality creates a reason to buy for customers and provides value to customers by differentiating the existing branded product from its competitors. In this context, various methods are used in the measurement of perceived quality with a consumer approach. In the study, the perceived quality principles of the "Consumer (behavior) Based Brand Equivalence" model, which is used frequently among the measurement methods of consumer-based perceived quality, can be evaluated within the scope of Real Estate 4.0, developed by David A. Aker in 1991, and in addition to the principles of Real Estate 4.0 has been integrated. Determined perceived quality principles were questioned by a survey of 204 people, specifically for the XX brand, which is one of the leading companies in branded housing projects in the real estate sector. With the analysis of the answers to the questions created as a result of the analysis of the concepts and approaches corresponding to the perceived quality components of the XX brand, it was determined which criteria were primarily perceived by the consumer, and the results were discussed.

Keywords: *brand value, consumer based brand equality, perceived quality, real estate, real estate 4.0.*

Introduction

As change accelerates and intensifies with globalization, the importance of information technologies is gradually increasing. The level of information technologies is defined by the concept of Industry 4.0 with the integration of the internet into the industrial value chain (Kartal & Şentürk, 2020). This concept, which is the new paradigm of production, covers many fileds as finance/investment, business management, law, construction, marketing, etc. (Yıldırım, 2020). These transformations also affected lifestyles, demands, tastes, and habits. Worldwide communication opportunities, increasing consumer expectations, and a large number of actors in the construction market increase competition. The competitive environment of the real estate sector has led to the emergence of branded real estate projects (Yetkin & Coşkun, 2021). Functional, innovative, and technological approaches, which put

user profiles at the forefront and which are realized for changing needs, gained value (https://blog.kpmg.lu/four-tech-upgrades-featured-in-real-estate-4-0/). High demand for the real estate projects, has been a driving force for being recognized, to be chosen, and brought mix use projects and other typologies have brought quality within the competitive environment. The reflections of industrial revolutions in the real estate sector are evaluated under the concept of Real Estate 4.0, which has just started to be mentioned (https://yapidergisi.com/mimarlik-ve-endustri-4-0-eslesmesi/). In this context, it is become important for companies to understand the "consumer trends" both on a global scale and local scale, and to make their investment-related analysis and planning in the light of these data (Öztürk, 2016). For this purpose, companies make investments more than before for their corporate and project-based brands in order to maintain their position and increase their market shares. It is of great importance that the marketing studies start from the planning and programming phases within the scope of feasibility studies during the initiative phase, the correct determination of the project scope, and the creation of brand value (Kotler et al., 2017). For the companies developing real estate projects; classification of the customers according to geographical, demographic, psychographic, and behavioral features is seen as one of the most important factors affecting project sales and consumer approaches. In recent years the majority of the investments consist of housing projects, and competition is increasing especially under the "Branded Housing" projects for the middle and middle-upper user group (Çınar & Çako, 2012).

The new marketing strategies that emerged with Industry 4.0 require focusing directly on consumer needs and putting forward innovative solutions for these needs (Yaprak, 2021). In the case of Real Estate 4.0, it has gained importance to have the advantage of consumer/user satisfaction, brand assurance, sales, and after-sales services, and national/international brand competition. Especially in the housing sector, the fact that quality has special importance brings to the fore the housing brands that are compatible with modern technology, have earthquake safety, will protect/increase their economic value, and are presented as investment tools. In this direction, being in the mind of the consumer/user has become a great necessity for companies (Dönmez, 2008). Branding and brand management, which is a professional field of work, should be applied consciously to real estate companies and projects by analyzing market conditions, consumer behavior/demands, positioning in the market, and by creating studies that will provide individual and social benefits (Öztürk, 2016). In this context, the concept of perceived quality has gained importance in the emergence of different concepts with the effects of brands on consumers' minds. Companies achieve quality when they can offer reliable, robust products/services that meet consumer expectations. By this way, trust, utility, function, and value are provided to the consumer (Marcouse et al., 2016).

Quality is an identifiable and measurable variable. Quality management is primarily based on the creation of a system that responds to consumer expectations (Nelson, 2006). By using the conceptual models in the literature, the effect of the brand and brand value on the quality perceived by the consumer can be measured in the real estate sector as well. In 1991, David A. Aaker's "Consumer (behavior) based brand equity model" gained importance in this dimension as one of the important factors in transforming the consumer's choice in favor of the company. However, although there are many scientific studies carried out on brand value in companies in different sectors, sufficient studies have not been found in the real estate sector yet. In this context, the study aims to reveal the factors affecting the 'perceived quality', which is one of the dimensions of brand value, and to reveal the evaluations of the consumers on the subject by exemplifying the counterparts of the factors through an exemplary real estate firm and the projects it produces.

Branding in Real Estate 4.0

In the real estate sector, companies trying to manage their marketing and brand management processes by considering issues such as competition, quality, perception management, retention, and association (Gül & Acar, 2014). The brand concept, which consumers are familiar with in all areas of life, entered the construction industry later. The opportunities offered by Industry 4.0 for strategic marketing have triggered a significant transformation in Real Estate 4.0 in the competitive environment in the sector (Önder, 2021). Among the reasons why product and service-oriented branding works enter the construction sector much later than other industrial production sectors and different service sectors, various problems caused by the internal dynamics of the construction sector arising from project-type production, multi-stakeholder, and multi-stage fragmented structure, and the control of the service and production process are among the reasons. Challenges related to the building are the high demand for the building and the large number of small-scale and non-institutionalized contractors in the market (Karabağ, 2021). However, the rise in user expectations and the efforts to exist in the competitive conditions in the global market has been the driving force for brand studies in the construction industry. The willingness to lead, to leave the competition behind, and to give the best to employees and customers are cited as the most important reasons for companies to benefit from branding (Wheer, 2013).

Nowadays, due to the increase in user expectations and competition conditions in the market, real estate projects, developed for the middle, upper-middle, and upper- income groups, need to be nourishing with some abstract values beyond traditional expectations in order to prominent in the market and meet with the right consumers. At this point, the major values are directing the consumer perception, memorability, and building trust. These values also constitute components of the concept of "brand" (Kocatürk, 2017). In this context, it is necessary to plan marketing and sales strategies based on branding in real estate projects that are prominent with their investment value today. While it is known that traditional management approaches bring traditional results, creative, developing and innovative solutions are expected from brands, avoiding prejudging with more instinctive behavior, believing in the spirit of the brand with corporate employees, working with empathy, and being intertwined with the brand.

Real estate investments strive to establish a long-term trust relationship with the user by prioritizing the benefit/value and satisfaction of the consumer/user, who has gained brand value or is advancing rapidly towards branding. Depending on changing lifestyles and evolving needs, conversions take place on the axis of the consumer/user (Ertuğrul & Deniz, 2018). Quality construction for the consumer is related with meeting expectations such as performance, functionality, reliability, durability, utility, aesthetic requirements in physical dimension (Sümer et al., 2015); also includes abstract values such as socio-cultural environment, status, image, reputation, value and psychological factors in the perceived quality dimension.

Brand Value and Consumer Based Brand Equity

Brand value is a remarkable marketing concept for practitioners and researchers, as it offers companies the advantage of differentiation with high sales and profit margins, and provides the opportunity to develop products/services and protect the brand from competitors (Taşçı & Baş, 2018; Keller, 2003). After the concept of financial valuation, which first came to the fore during company acquisitions or mergers, the increase, and protection of brand assets, etc. are measured for different reasons (Çelik, 2006). Thus, brand consumers; create a value proposition centered on functional, emotional, and personal benefits. The brand value increases brand preference and plays an active role in making the product/service affordable in consumers' minds. Brand equity is also considered an important marketing strategy that companies focus on, with the brand loyalty provided by ensuring trust in the brand, perceiving the products and services as high quality, and reducing all the perceived risks associated with it (Koçoğlu, 2017).

The dictionary definition of “Brand equity” is; In addition to the physical features purchased by the consumer, it is expressed as a brand that is built with an emotional connection, personality, and a satisfying mixture (Aktuğlu, 2011). In terms of brand value measurement, a common measurement model has not been developed yet, since it has a complex structure that combines abstract and tangible elements. The concept of "brand value", which is one of the most critical areas of marketing management, is measured through financial, consumer (behavior) based, and mixed methods. Financially based brand equity means the financial returns of the brand. Consumer-based brand equity, on the other hand, includes abstract components that cover what the consumer learns, hears, sees, and thinks about the brand in the process (Atıgan, 2017; Tosun, 2017). Brand value is the ultimate goal that is desired to be achieved as a result of branding studies. Many factors create brand value. These factors are listed as; brand loyalty, brand awareness, perceived quality, brand associations, owner assets, and competitive advantages (Aktuğlu, 2011). The main source of brand value is consumers. At this point, the brand value taken into consideration is evaluated based on individual consumers (Avcılar, 2008).

Evaluations from the consumer's point of view form a basis for the qualitative assessment of brand equity (Uyar et al., 2018). In the literature, the consumer (behavior) based brand equity model put forward by D. A. Aaker (1991); consists of four components: brand awareness, brand association, perceived quality, and brand loyalty (Figure 1).

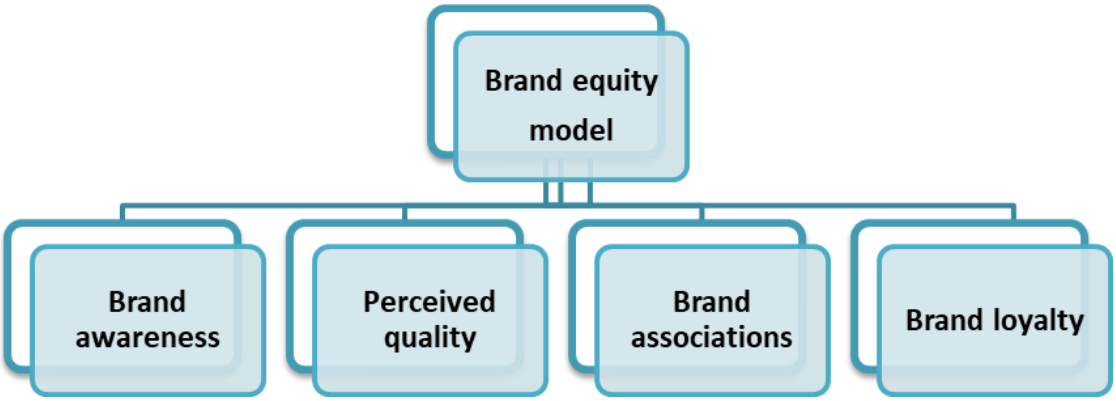


Figure 1: Aaker’s (1991) consumer based brand equity model.

Brand awareness, perceived quality, brand associations, and brand loyalty that are located in the minds of consumers are all combinations of positive and negative thoughts and feelings.

(Biyan, 2019). Today, one of the foundations of the success of companies with high brand value is that the products or services of the brand are perceived as high quality by consumers. The increase in perceived quality, which expresses the quality perception of the consumers, increases the brand value of the companies, as well as the increase in the purchase intention of the consumers, the market share, and profitability of the companies shows the perceived quality importance (Kocatürk, 2017). In this context, the study is examined in terms of perceived quality and dimensions.

Perceived Quality in Consumer Based Brand Equity Model

The perceived quality phenomenon, which is characterized as the relationship between expectations and alternatives, can be defined as the general quality perception of the consumer (Aaker, 1991). The concept of quality is a subject of interest these days, and also concerns all companies. However, quality and perceived quality are different concepts from each other. While quality is objective or product-based, perceived quality is subjective and customer-based. This situation has led companies to intangible benefits that create value and include cognitive and emotional leading associations rather than concrete benefits in providing a competitive advantage (Toksarı & İnal, 2012). It is quite difficult to determine and measure the quality, the reason of subjective concept, and differentiation according to perceptions. Therefore, it is seen that companies attach importance to consumer-focused quality (Atıgan, 2017). Perceived quality is also expressed as a concept that is suitable for the wishes and requirements of the target audience and meets their expectations (Sağlam, 2014).

For many brands, perceived quality defines the competitive environment and their position in it (Aaker, 1996). Consisting of the total perception, quality includes judgments about what is substantial to the customer. Perceived quality is different than attitude. Many low-quality products can generate a positive attitude, as they are not expensive. Therefore, perceptions of quality are subjective (Erdil and Uzun, 2010). In the measurements of perceived quality which are answered by consumers; the use of the X brand is comfortable/easy/hassle-free, the X brand is reliable and durable/robust, and the X brand is of high quality, the maintenance service of the X brand is very good, the answers to the questions are taken and the measurements take place.

Perceived quality creates a reason to buy for customers and provides value to customers by differentiating the existing brand from its rivals (Sağlam, 2014). For the reason perceived quality cannot be determined objectively, it includes consumer judgments about what is important and what is not (Aaker, 1991). For brands, perceived quality defines the competitive environment and their position in this area Aaker (1991); five key factors increase the value of perceived quality (Figure 2).

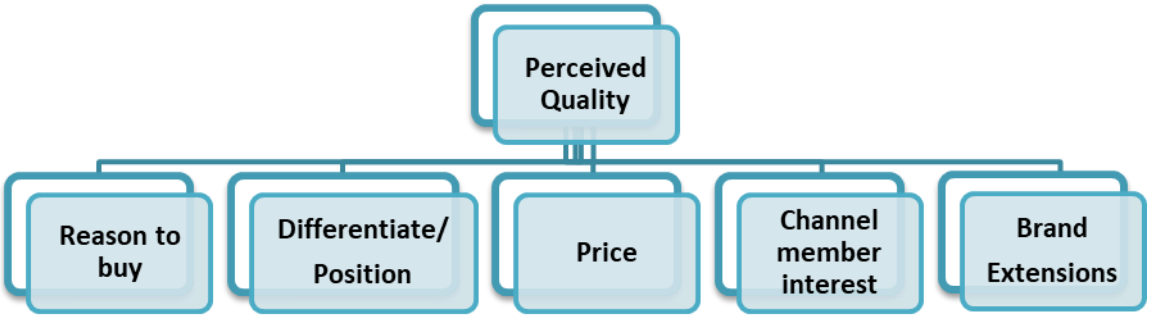


Figure 2: Perceived quality in consumer based brand equity model.

Reason to Buy

Perceived quality is directly related to purchasing decisions. Perceived quality becomes the center of the consumer when consumers do not have knowledge about the product/service or do not have the source and ability to obtain the information (Aaker, 1991). In this case, the perceived quality of the brand, rather than the actual quality of the brand, can be transformed into purchasing behavior by the consumer. The perceived quality of the brand significantly affects the purchasing decisions of consumers. When consumers make their final decisions, they choose the option that offers the highest benefit and acts in this direction. As long as this choice can afford consumer expectations, it affects customer satisfaction and the probability of the customer's repurchase (Kotler & Keller, 2018).

Differentiate/Position

The fundamental positioning feature of a brand is its position in the perceived quality dimension, regardless of the product/service definition (Aaker, 1991). Thus, the brand differentiates itself from its opponents and is positioned in a distinct place in the minds of consumers. Functionally brand positioning targets to create the desired perception in the consumer's minds. It is the work of creating a positive effect, feeling, and story in the mind of the potential customer regarding the product/service. It is hard to create a positive effect on consumers' perceived quality with the not perceived differentiation and looks similar to others. In this context, in a heavily communicative society, positioning can be defined as, a set of ideas that take communication problems seriously (Reis & Trout, 2019). Brands are expected to look different from others, and to position based on difference.

Price

Perceived quality presents advantageous pricing and options to sell the product. This price difference increases profits, and they can be used in research development activities. This resource provided also strengthens perceived quality (Aaker, 1991). Due to the high perceived quality of the brand, selling the product at a high price creates a price difference from its competitors (Sağlam, 2014). The perception of high quality provided to the consumers justifies the price of the product/service and also ensures prestige and social status. Particularly in housing projects, the concepts of status, image, and value are important

concepts in the perception of the brand. With different project concepts, the perception that the price is due to the difference in the project can be an important basis for price comparisons among consumers. At the same time, working with well-known designers/architects creates the impression on the consumer's side that the price is deserved.

Chanel Member Interest

Perceived quality creates importance for retailers, distributors, and other companies. Thus, channel members help distribution channels to win (Aaker, 1991). Channel members also prefer existing brands that were requested by the consumers. In this direction, it contributes to acquiring a distribution advantage for the company. In the real estate sector; real estate advisors, real estate sales sites on the internet, print media, TV shows, social media project promotions, etc. fields can be defined as the channels of the sector. Channel members prefer to have the brand that consumers want. Thus, in new project promotions, the quality perception of the brand can take place in different channels. Thus, in new project promotions, the quality perception of the brand can take place in different channels.

Brand Extension

Brands that have strong in terms of perceived quality can achieve a higher chance of success by expanding further (Aaker, 1991). By using the brand name with high perceived quality in other product/service groups, it takes advantage of the existing brand name and saves the cost of new brand promotion (Erdil & Uzun, 2010). Companies can create value by using the perceived quality of their brand in different products and services. At the point of responding to rival moves, brands, hold a place in the minds of potential customers with a “single-location” strategy rather than a multi-brand strategy (Reis & Trout, 2019). In this way, they can use the same quality perception in other products/services by taking advantage of the existing brand name.

Search Methods

The brand value obtained as a result of branding, in the real estate construction sector significantly affects consumer’s purchasing decisions. The general quality perception of the consumers/users can be evaluated as the superiority of the product/service compared to its alternatives and its suitability for usage expectations (Keller, 2019). Brand value of the real estate projects are interrelated with the brand value of the construction company by which they are developed. In order to analyze the factors affecting brand value, perceived by the consumers for the real estate projects, a survey is prepared. The survey is designed to gather information according to a particular real estate company, considering its projects at all. For this reason, a real estate company with the brand XX is selected because of its branding approach and success both in corporate level and project level, at home and abroad. Survey questions were formed on the dimensions of "Perceived Quality" developed by Aaker for the XX brand in the consumer (behavior) based brand equity model.

Consumer Based Brand Equity Analysis of Brand XX

The determination of brand value and its degree could be determined by the values which existed formed in the mind of the consumer. In this context, survey questions regarding the XX brand were asked within the framework of the components of Aaker's consumer-based perceived quality model, for people who have heard/seen the XX brand at least once. The surveys have been reached via e-mail and a short message (SMS) from the business environment, the close circle, and social media. In the survey, a total of 253 people accessed and 204 participants answered the questions. XX brand, which included Aaker's consumer (behavior) based brand equity measurement model components with the; Perceived quality, the reason for purchase, positioning, price difference, channel member interest, and brand extension have been analyzed on a company-specific basis.

In the first part of the survey, questions have asked to determine the demographic characteristics of the participants, and in the second part, to reveal the consumer-based perceived quality value. Questions oriented to consumer-based brand equity components were asked with a 5-point Likert scale, and while calculating the weighted averages, the option I strongly disagree with was multiplied by 0 and not included in the mean. It is weighted by 'Disagree' 1, 'Partially agree' 2, 'Agree' 3, and 'Strongly Agree' 4 points. Analysis of the results has shown with weighted average tables and graphics. Tables that contain weighted means, for easy reading of the positively and negatively weighted scores, the highest score has shown with a color code starting from dark blue and the lowest score being white.

In the survey study, primarily the findings related to the demographic characteristics of the participants were evaluated. The findings related to gender, age, education level, and occupations have given in Table 1. 51% (130 people) of the participants are mostly men. In the age group part, 32% of the participants (68 people) are in the 46-55 age range. The participants' average age has been detected as 46. Regarding the education status question, participants; 58.02% (123 people) university graduates and 50.47% (107 people) stated as doctors/engineers/architects.

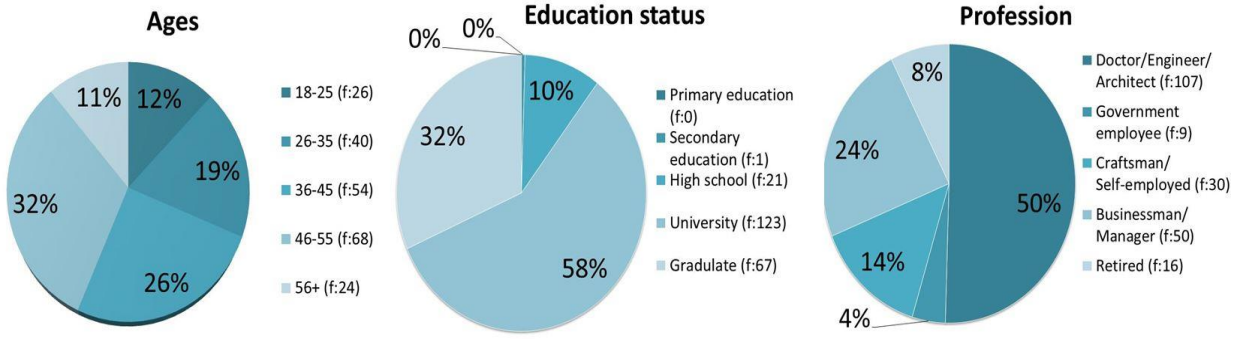


Figure 3. Demographic characteristics of survey participants.

Primarily, when 204 participants were asked to indicate the first three words that came to their minds about the XX brand; the word "brand" took first place with a rate of 65% (127 people). While "High price" was in second place with a rate of 42% (81 People), "Different architectural design" was in third place with a rate of 38% (74 People), (Table 1). In this context, since the additional price that consumers are willing to pay in return for the product and service is an evaluation of perceived quality, XX brand, provides the perception of quality with the values in "brand" and "high price" concepts. Another approach to perceived quality is the judgment of consumers that the quality of a high-priced product will also be high. At this point, the company takes the first place with its brand concept and high price proportions. The

concept of different architectural designs and luxury also supports the perceived quality of the company. There is a direct relationship between the companies that produce luxury goods and services and the perceived quality of the brand (Atıgan, 2017). On the other hand, it has been seen that the patent designs and foundation works, which the company prioritizes in its promotions, lag in creating perception/awareness on the consumer side.

Table 1. Evaluations of the first three concepts that come to mind with XX brand.

WHAT'S ON YOUR MIND ABOUT BRAND XX WİTH THE FIRST THREE WORDS	FREQUENCY	PERCENT
Brand	113	68,48
High price	70	42,42
Different Architectural Design	64	38,79
Luxury	45	27,27
Investment/Value	43	26,06
Social Environment Facilities	29	17,58
Patented design concepts	20	12,12
Reliability	16	9,70
XX Foundation	10	6,06
Status	9	5,45
Spokes person	9	5,45
Advantageous Price	7	4,24
Social Responsibility Projects	4	2,42
XX Production Workshops for women	0	0,00

The average weight evaluations of the questions regarding the brand position in the minds of consumers and the perceived quality model adapted to the sector are given in Table 3, 4, 5, 6, 7. Evaluation that constitutes the reason to the buy of XX brand, "XX brand uses quality building materials" scored 59.92 points above the average (Table 2).

Table 2. Reason to purchase in consumer based perceived quality in XX brand.

Reason to buy								
	The number of responden ts	Strongly disagree %(0)	Disagre e %(1)	Partially agree %(2)	Agree %(3)	Strongly agree %(4)	Weighted average of responses (out of 4)	Weighted average of responses (out of 100)
XX brand uses quality building materials	179	1,68	8,94	44,69	37,43	7,26	2,40	59,92
When I evaluate XX, the concept of quality is in the top 3.	177	3,39	14,69	37,85	34,46	9,60	2,32	58,05
XX brand produces projects with famous architect and designer groups	175	2,86	13,71	44,57	30,86	8,00	2,27	56,86
						AVERAGE		**58,27**

The average positioning value of the XX brand is 61.02 points. “The images of the projects presented by the XX brand are of high-quality” expression received the highest weighted average value with 67.12 points (Table 3).

Table 3. Positioning in consumer based perceived quality in XX brand.

Positioning								
	The number of respondents	Strongly disagree %(0)	Disagree %(1)	Partially agree %(2)	Agree %(3)	Strongly agree %(4)	Weighted average of responses (out of 4)	Weighted average of responses (out of 100)
XX is a high-quality brand	179	2,23	10,61	46,37	34,08	6,70	2,32	58,10
XX brand produces projects in accordance to consumer demands	169	2,37	7,69	52,07	31,95	5,92	2,31	57,84
Project images provided by XX are of high quality	165	1,82	8,48	29,70	39,39	20,61	2,68	67,12
						AVERAGE		**61,02**

In the ranking of the first three words that come to mind about the XX brand, brand and quality are seen as the priority value, while the rate of participation in the statement "I accept to pay a higher price than other projects in order to have a project with XX brand quality" received a score below the average with 41.52 (Table 4). As a result, it has been observed that while consumers perceive XX Company as high quality with its brand value, they do not accept to pay high prices for the brand in particular.

Table 4. Price in consumer based perceived quality in XX brand.

Price								
	The number of respondents	Strongly disagree %(0)	Disagree %(1)	Partially agree %(2)	Agree %(3)	Strongly agree %(4)	Weighted average of responses (out of 4)	Weighted average of responses (out of 100)
I agree to pay a higher price than other projects in order to have a project in the XX brand	168	13,69	31,55	34,52	15,48	4,76	1,66	41,52
						AVERAGE		**41,52**

Channel member interest in consumer-based perceived quality has got a 58.21 average value. The statement "XX brand advertisements and promotions create a high quality connotation" received 64.27 points, and it was concluded that it strengthens the perception of quality with advertisements and promotions (Table 5).

Table 5. Channel member interest in consumer based perceived quality in XX brand.

Channel member interest

	The number of respondents	Strongly disagree %(0)	Disagree %(1)	Partially agree %(2)	Agree %(3)	Strongly agree %(4)	Weighted average of responses (out of 4)	Weighted average of responses (out of 100)
XX creates a high quality connotation in advertisements and promotions.	177	3,95	9,60	25,99	46,33	14,12	2,57	64,27
Brand XX advertises too often	179	2,79	16,20	31,84	38,55	10,61	2,38	59,50
The fact that XX is involved in different real estate and promotion channels helps me think that it is a quality company.	171	7,02	25,73	30,99	29,24	7,02	2,04	50,88
						AVERAGE		**58,21**

XX brand extension in consumer-based perceived quality has got a 53,7 average value. The statement "XX brand advertisements and promotions create a high quality connotation" received 64.27 points, and it was concluded that it strengthens the perception of quality with advertisements and promotions (Table 6).

Table 6. Brand extension in consumer based perceived quality in XX brand.

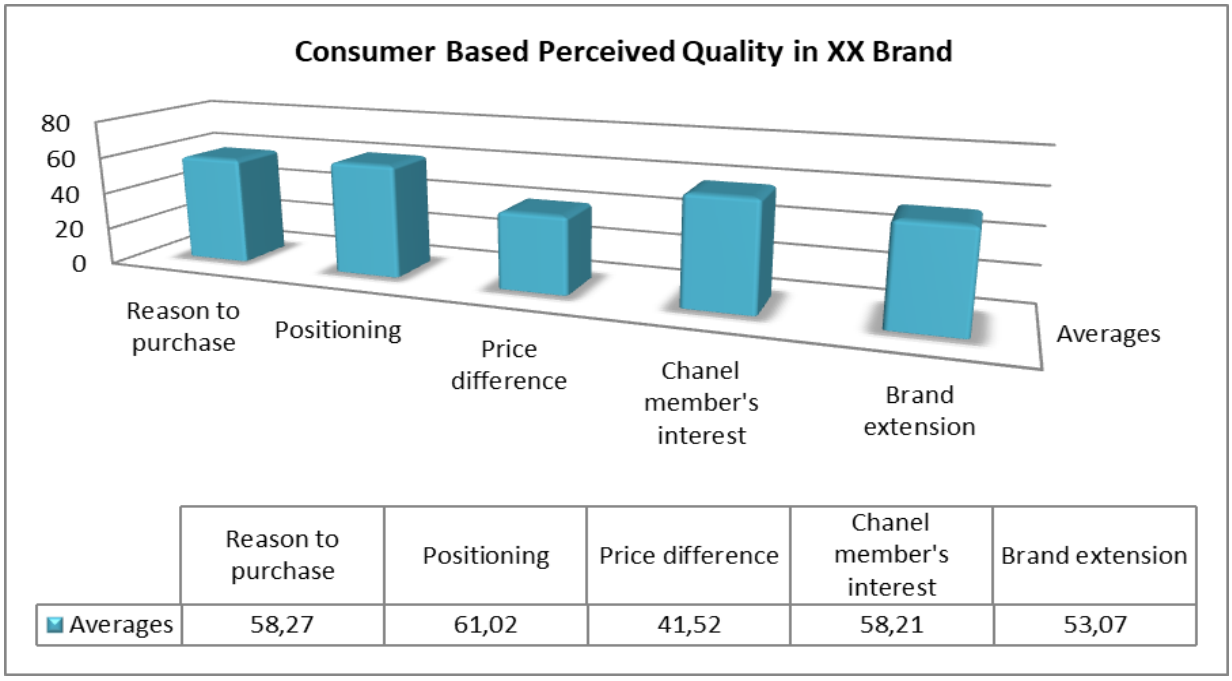
Brand extension								
	The number of respondents	Strongly disagree %(0)	Disagree %(1)	Partially agree %(2)	Agree %(3)	Strongly agree %(4)	Weighted average of responses (out of 4)	Weighted average of responses (out of 100)
Patented products offered by XX create a perception of high quality	169	2,96	15,38	43,20	32,54	5,92	2,23	55,77
Developing projects in different regions makes XX think that the company is of high quality.	169	5,92	23,67	37,28	24,26	8,88	2,07	51,63
						AVERAGE		**53,7**

In the study, the perceived quality dimensions and their equivalents were determined as a result of the evaluations of people who have heard/seen the XX brand at least once;

- ***Reason to buy.*** Among the factors affecting the quality perception of the brand, the comment that the brand uses high quality building materials has the highest score with 59.92 points. The consumer/user gave an average of 58.27 points to their reason for purchasing (Table 2).
- ***Positioning.*** Among the perceived quality factors of the XX brand, quality positioning got the highest value with an average of 61.02. The quality of the project images presented by the brand provided the highest value for consumers with 67.12 points (Table 3).

- ***Price.*** While various project awards such as the highest quality and most prestigious housing awards received by the XX brand contribute to the perception of quality, they also play a role in increasing the profit margin in project sales prices. Among all the factors affecting the perception of quality, the price-based assessment which was directed to the consumer, with 41.52 points took the lowest value (Table 4).
- ***Channel member interest.*** It is seen that, the promotions carried out by the brand through social media and different real estate channels have created a high-quality perception among consumers, with a high score of 64.27. It can be said that the brand's frequent advertising and presence in different real estate channels create a high-quality perception with an average of 58.21 points (Table 5).
- ***Brand extension.*** It is seen that, the brand is aiming for high market share with different project segments, non-governmental organizations, and social projects under its corporate structure. While the brand extension factor, which affects the perceived quality of the brand, scored with an average of 53.7 points, may be interpreted as patented design products created a higher quality perception, and that project developments in different regions had a slightly lower effect on quality perception (Table 6).

Table7. Consumer based perceived quality in XX brand.



	Reason to purchase	Positioning	Price difference	Chanel member's interest	Brand extension
Averages	58,27	61,02	41,52	58,21	53,07

As a result, the perceived quality average is 54.41 in return for the marketing strategies developed by XX firm within the scope of Real Estate 4.0 (Table 7). Approaches that are effective in the formation of consumer/user-based perceived quality; The use of quality building materials, the quality of project visuals, advertisements and promotions, projects which are located in the real estate channels, and patented products, can create a quality connotation for the brand by contributing to the perception of the brand as high quality in consumers/users.

Results

The "Perceived quality" dimension, which is under the title of consumer (behavior)-based brand value, has gained a significant value today. Consumer-based brand equity is seen as one of the important factors in transforming the consumer's choice in favor of the firm. The concept of "Perceived quality", which is defined as the general quality perception of consumers / users, is a subject that attracts intense attention by all companies today.

For this purpose in this study, the "Consumer (behavior) based brand equity" model was integrated with real estate 4.0. The factors that play an important role in consumers' purchasing decisions and affect "Perceived Quality" are determined through a real estate firm and the perception of the consumers'/users on this issue has been trying to be measured. Like the general perception of branded products, branded housing is perceived as high quality by the consumers and the persistence of this perception affect the brand value positively. Within the scope of the evaluated XX real estate company's branded housing projects, it is seen that producing and presenting projects that meet the needs/demands of the consumer/user, especially with the dimension of "positioning", can make significant contributions to the perceived quality. However, as a result of the research, although the brands create high connotations, real estate consumers are within the dilemma of quality and price, and it has been concluded that the price difference is strong enough to change the brand orientation. In this respect, the fact that real estate development companies should offer price positioning strategies and project promotions as equivalents within the dimensions of quality perception can provide important contributions to the company.

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Examination of Projects of Privately-Owned Residential Buildings

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Abstract

Generally, residential projects are planned (scheduled) according to construction companies' institutional data and standard man-hours data provided by governmental agencies. And the construction duration appeared from these schedules. And in the contract phase, the determined construction duration is an obligatory variable. These projects are carried out in accordance with the schedule. However, some residential projects are also carried out by the building owners or their partners. Even if the project starts within planning, some deviations between as-built and as-planned situations can occur, and it can be difficult to predict how the project will progress due to reasons such as resource problems, economic situations of contractors, or environmental factors. In this study, some residential projects made by contractors, the building owners or their partners are categorized and discussed. Project information such as start/end dates, license date, building inspection information, construction area, and construction cost are examined.

Keywords: *estimating, planning, residential projects.*

Introduction

Before starting the construction projects, cost, quality, and time planning are made. However, since each construction project has its unique structure, deviations may occur in these plans. It is expected to occur more in private construction projects. Because situations such as slow resource transfer or excessive time are seen more frequently. Although there are no such problems with resource transfer or planning in public buildings, the construction process may not go as planned due to special situations that will be encountered in practice. Seasonal factors, the economic situation of the country, the situation of the contractor performing the work, a situation related to the legislation, or another external factor can be shown as the reason for this. Success factors are inputs that directly or indirectly affect the success or outcome of the project (Duy Nguyen et al., 2004; Masrom et al., 2015). The success of a

project also depends on factors such as project complexity, technical expertise, organizational competence, and risk management (Doloi et al., 2011).

Residential projects are at the forefront of private construction projects. The construction process of residential projects is completed by either the contractors or the landowner. There are building inspection firms that follow the process of residential projects in Turkey. These firms are assigned to residential projects by a government agency (Provincial Directorate of Environmental, Urbanism and Climate Change), and this building inspection firm is obliged to conduct interest inspections throughout the construction process. These building inspection firms receive money from the relevant government agency according to the completion percentage of the construction in return for this service. This fee is calculated according to the total cost of the construction. Money flows to the state institution by the owner of the building. Then, the building inspection firm receives this money for certain periods according to the completion percentage of the construction. The sample progress payment related to the completion percentage of the construction prepared by the Provincial Directorate of Environment, Urbanization and Climate Change is shown in Table 1 below.

Table 1. Sample progress payment report for the inspection service fee.

Sample Progress Payment Report for the Inspection Service Fee		
Relevant Administration	XXXXX	
Building Owner	XXX XXX	
Building License Date and Number	06.04.2022 2022/12	
Address of the Building	XXX XXX XXX	
Layout/Island/Parcel No	KXXDXXAXC/XXX/XX	
Building Construction Area (m2) and Type	1223.0 Frame Concrete Frame	
Title / Permit of Building Inspection Agency	XXX Building Audit Co.Ltd /XXX	
Address of Building Inspection Agency	XXXXX	
Job Description (Structure Department)	Installment Rate %	Realization Rate %
a) Project Inspection Fee to be Paid at the Stage of License Obtaining	10	10
b) Excavation and Foundation Up to the Upper Level	10	10
c) Structural System	40	40
d) Part of the Building Prepared for Plastering, Including Roof Cover, Fill Wall, Door and Window Frames, Installation Infrastructure	20	20
e) Mechanical and Electrical Installation and Remaining Structure Section	15	15
f) Approval of the Work Completion Report by the Related Administration	5	5
Toplam		100
1-…….. Total Realization Rate as of Date		100
2- Total Realization Rate in the Previous Progress Report		100
3- Total Ratio in this Progress Payment		5
3-a) The rate based on this progress payment		4.7
3-b) Share of Ministry and Related Administration in this progress payment		0.3

4-The approximate unit cost of the building in the year of implementation	1,305
5-Building Construction area	1,223
6-Construction cost	1,596,015
7- This progress payment is based on the audit service fee.	0
8-Audit service fee rate (additional service fee rate if necessary)	1.5
9-Inspection service fee accrued in this progress payment	0
10-Amount of audit service fee to be paid (including VAT)	0
11-Additions and Deductions (including VAT)	-193.91
12-Amount to be Allocated for Completion (VAT Included)	0
13-VAT	215.46
14-a) Amount to be paid to the building inspection company (Including VAT, Ministry and Related Administration Share VAT, Unit Price Update Difference)	1.146.74
14-b) Ministry Share (Excluding VAT)	35.91
14-c) Ministry Share (VAT)	6.46
14-d) Relevant Administration Share (Excluding VAT)	35.91
14-e) Relevant Administration Share (VAT)	6.46
14-f) Unit Price Update Difference (VAT Included)	0
Organizers	
Building Inspection Authority Officer	Relevant Administrative Officer
	Approver

Table 1 contains general information about the sample project. There are details such as the owner of the building, the license date of the building, the detailed address of the building, the building inspection information, the construction area and the cost of the building. As seen in Table 1, a certain amount of construction must be completed for the building inspection firm to receive progress payment. These; a) Project Inspection Fee to be Paid at the Stage of License Obtaining (10%), b) Excavation and Foundation Up to the Upper Level (10%), c) Structural System (40%), d) Part of the Building Prepared for Plastering, Including Roof Cover, Fill Wall, Door and Window Frames, Installation Infrastructure (20%), e) Mechanical and Electrical Installation and the Remaining Structure Section (15%), and f) Approval of the Work Completion Report by the Relevant Administration (5%). The building inspection firm may request the progress payment of more than one completed stage from the relevant directorate at the end of each stage or cumulatively. The relevant directorate, on the other hand, approves the progress payment after examining it and makes the payment to the building inspection firm. This payment to be made is called level progress payment.

Within the scope of this study, a progress payment report of 249 inspection service fees by Bitlis Provincial Directorate of Environment, Urbanization and Climate Change is examined. In the next stages of the study, more emphasis will be placed on estimation. Within the scope of this study, however, is limited to the classification of these reports only. We also thank the employees of the relevant directorate for allowing this data to be shared for an academic study.

Results

Various classifications have been made for 249 different residential projects. These classifications are related to the building construction area, construction cost, the month in which the construction began and project duration of the building. The input variables are listed as below.

- Building construction area: the area of total project that includes all stories of buildings.
- Construction cost: The total declared cost of the buildings.
- The month of the project's beginning: The month and the season supposed to affect the project progress so that this variable is considered as input of the model.

Building Construction Area

Building construction areas are included in the related database. The construction areas range between 186 m^2 and 11440 m^2.
Figure **1** shows the distribution of construction areas.

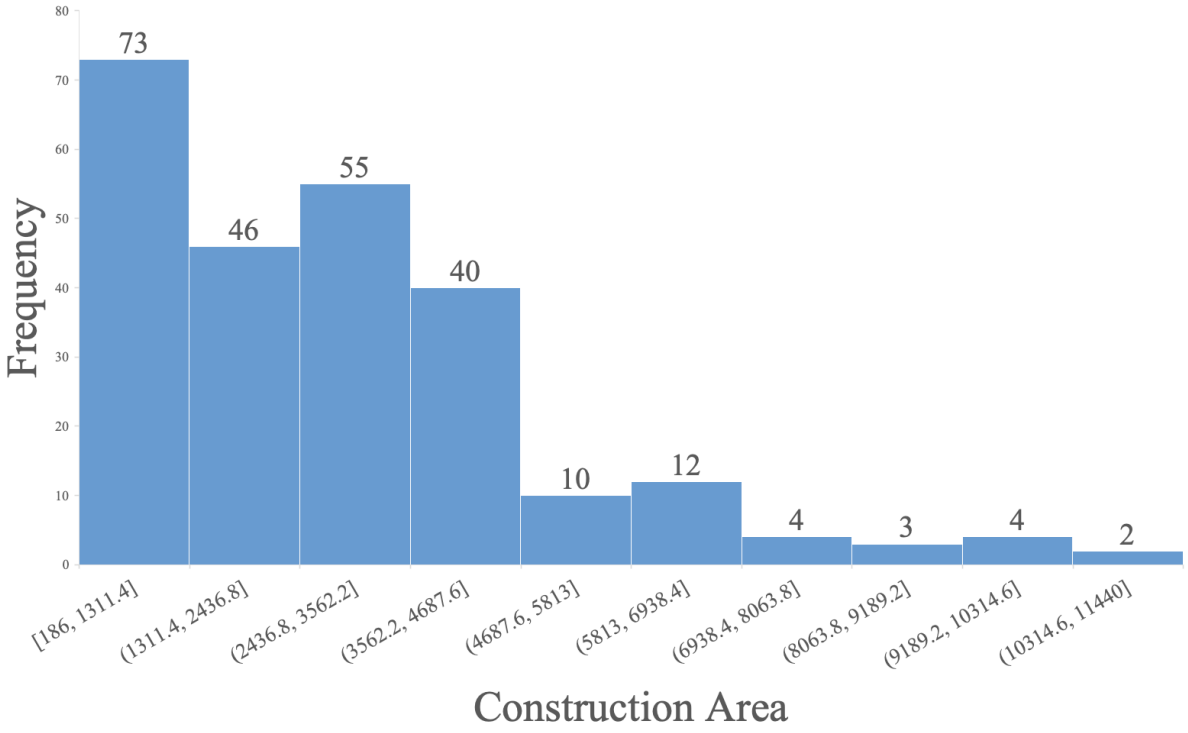


Figure 1: Distribution of construction areas.

Construction Cost

The construction costs are included for each construction project. These cost values are declared costs to the governmental agencies. The range of the costs distributed between ৳206,963.00 and ৳ 37,054,160.00. Figure 2 shows the distribution of the construction costs in the related location. From the graph, it can be asserted that from both Figures 1 and 2, the distributions are skewed to left.

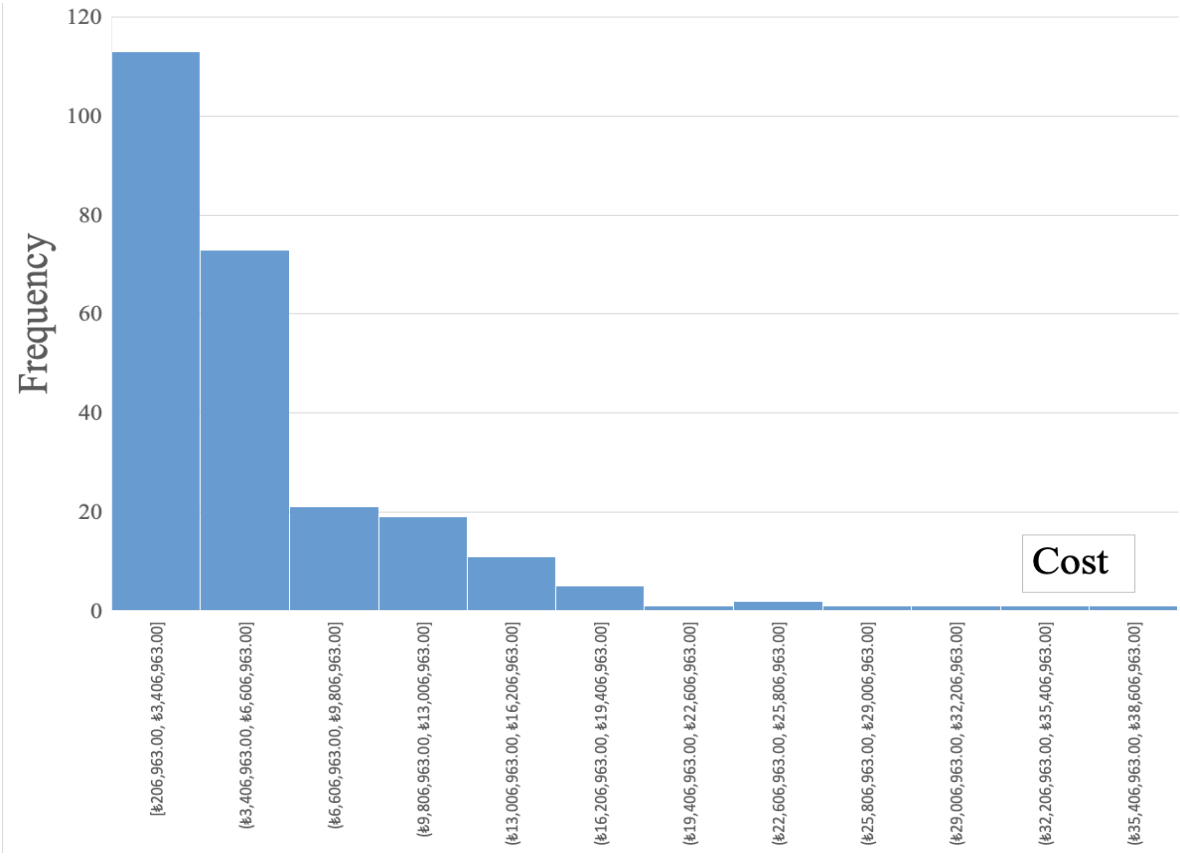


Figure 2: The distribution of construction costs.

The Month in which the Construction Began

For these 249 projects, the start month is collected to see the distribution of the starting season. The variable stored as a discrete variable, figure 3 shows the distribution of starting month of these 249 projects.

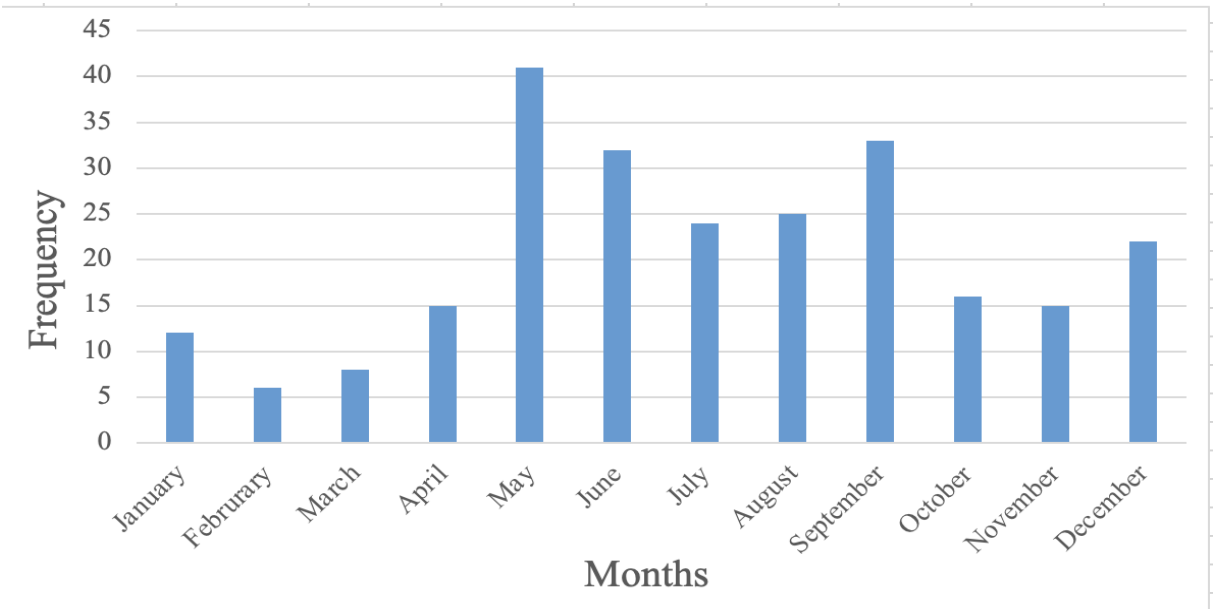


Figure 3: The distribution of starting months of constructions.

Correlation between Project Duration and Costs

In this study, the relationship between the construction costs and project durations is searched. Figure **4** gives the relationship between costs and durations. In the figure, there is no rational correlation appears. However, there are a few partial linear relationships appear.

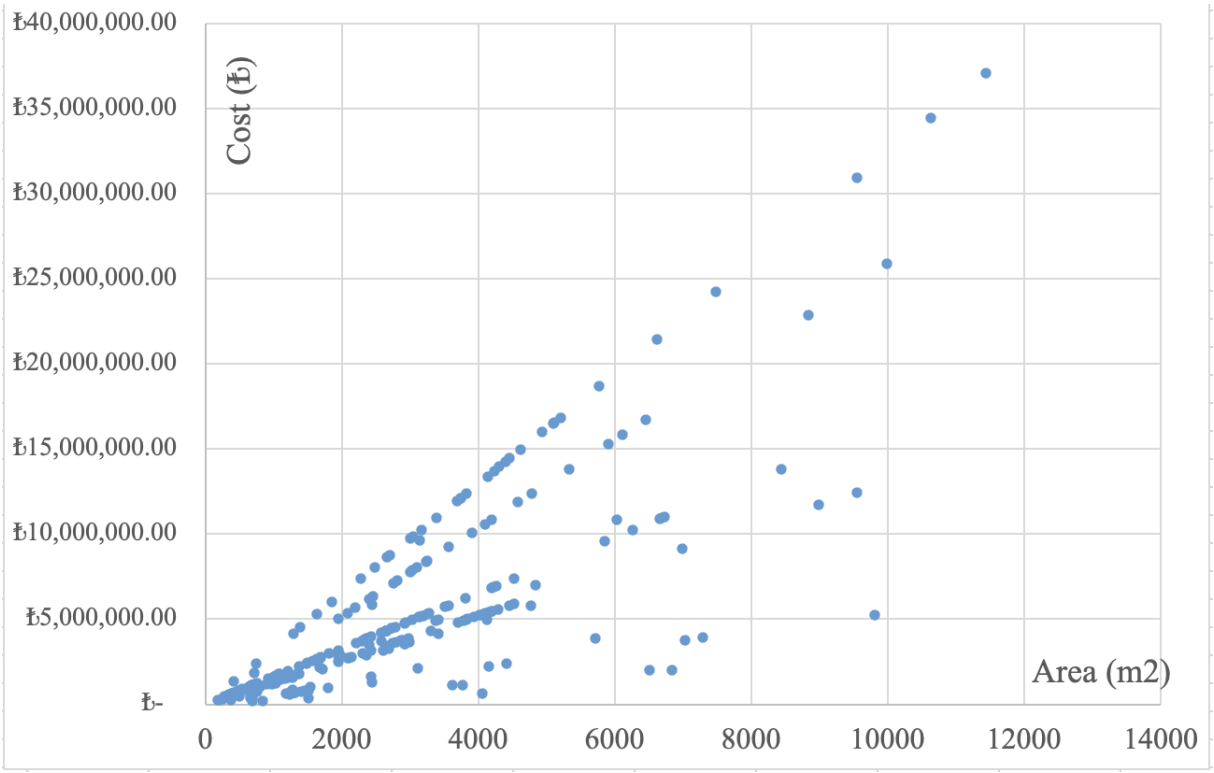


Figure 4: Relationship between construction cost and area.

Conclusion

Since construction projects are specific projects, each stage must be well planned. In special projects such as residential projects, this planning is more important. Because, for example, failure to deliver a house sold during the land period or during the construction phase can lead to various problems. Therefore, issues such as the size of the building construction area, the cost of the building, and the season in which the building will start may become important. The next stage of this study will be to calculate the estimated completion times of the construction based on these issues. In other studies, there are various studies on the factors affecting project success (Al-Tmeemy et al., 2011; Aslan et al., 2021; Chan et al., 2002; Dang et al., 2012; Duy Nguyen et al., 2004; Iyer & Jha, 2006; Mukhtar et al., 2017; Xiang et al., 2013; Yong & Mustaffa, 2013). At the end of this study, the effects of different factors on the project will also be discussed. Naturally, there is the project duration specified in the project, but the important thing is to estimate how many deviations will occur. In this way, both the owner of the building and the buyer or the building inspection firm will learn the estimated completion times and act accordingly.

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Investigation of Effectiveness of Real Estate Advertisements Based on Age of The Customers

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Abstract

Advertisement is critical for the companies to convey their messages to their customers. Although the construction companies were not one of the main advertisers in the past, now they have spent a large amount of money on advertisements with increasing competition among companies. However, most of the advertisements of the construction companies are not effective as expected due to their traditional competition strategies. Therefore, the construction companies should understand how they can improve the effectiveness of their advertisements to avoid the waste of money spent on advertisements. In this study, the effectiveness of the luxury real estate advertisements is investigated considering the age factor, which is considered as one of the important factors that affects the effectiveness of the advertisements. Firstly, four advertisements whose have different advertisement appeals were identified. These advertisements were selected to eliminate the effects of other factors, such as duration and type. Then, a questionnaire survey was prepared . The first part is related to the demographic structure of the respondents, and the other is about the effectiveness of the four advertisements. After the questionnaire survey, a dataset which consists of 216 data was collected. This dataset was analysed using t-test to identify the effects of age on the effectiveness of the real estate advertisements.

Keywords: *luxury real estate advertisements, advertisement effectiveness, age.*

Introduction

Advertisements are an important medium for companies to convey their important messages to the customers. Therefore, the companies spend a large amount of money on advertisements for each year. For instance, in 2021, the companies spent $780.59 billion for advertisement. This amount is close to the total gross domestic product of Turkey in 2021 ($806.8 billion). Also, construction companies have become important advertisers in recent years (Cheng et al., 2016). For instance, based on a review of sector-related television commercials, the construction industry in Turkey had the third-longest amount of ad time in 2017 with 1369 hours. Besides, the construction sector ranks first with 233,516 spots in advertising spots

(MediaCat, 2018). However, advertisement effectiveness is a critical issue for the companies (Maheshwari et al., 2014), since, unfortunately, all the spending money on advertisements does not provide the expected benefits to the companies. Therefore, the companies should understand advertisement effectiveness to allocate their marketing budgets effectively (Bendixen, 1993). Although advertisement effectiveness is a popular topic in the literature, the studies about the construction industry generally overlook this subject. Therefore, limited studies are related to advertisement effectiveness in the construction management.

Advertisement effectiveness is also affected by different factors. Especially, previous studies have shown that the demographic factors should be considered while investigating the advertisement effectiveness (Ansu-Mensah et al., 2013; Keshari & Jain, 2016). Therefore, the companies should understand the demographic differences to have more effective advertisement campaigns. Especially, the effect of age is widely emphasized in the literature since the human beings confront with sensory functioning (vision, hearing, smell and taste, touch), cognitive system (working memory, long-term memory, knowledge-based memory, source memory) and affect and motivation with ageing (Drolet et al., 2019). Therefore, the people with different ages have different thinking structure on decision making (Keshari & Jain, 2016). For instance, opposed to older age groups of people, younger people tend to be persuaded more quickly (Srivastava, 2010). Similarly, different aged customers have different shopping methods. For instance, while younger generations view internet shopping as the most convenient way to acquire anything, older consumers believe that conventional shopping is the most dependable technique (Suman et al., 2019). Consequently, the age factor is a critical factor and should be investigated to reveal the differences between different age groups.

The main objective of this study is to study the effect of age on advertisement effectiveness. In the first part of the study, a literature review is provided for advertisement effectiveness to reveal how the advertisement effectiveness can be measured. Then, the research methodology used in this study is described elaborately. The findings of the analyses performed to understand the relationship between the age groups and advertisement effectiveness are discussed.

Advertisement Effectiveness

Companies always want to measure the effectiveness of their advertisements. Therefore, advertisement effectiveness has been investigated in the literature for a long time. There are different methods for measuring the advertisement effectiveness. One of the earliest studies was conducted by Strong Jr (1925). He proposed a hierarchical model composed of four parameters, namely attention, interest, desire, and action. According to Strong Jr (1925), the advertisement should firstly take the attention of the customer. After achieving the first stage, then it should make the customer interested in the message of the advertisement. Then, it should awake a desire to purchase the product, so the act of buying can start. Lavidge and Steiner (1961) also followed hierarchical logic, unlike the other study, they mentioned three components, namely, cognitive component, the emotional component, and the motivating stage in their model. Based on this model, firstly, the advertisement should address the human logic by conveying the information, then this information should trigger the emotions of the customers. At the last stage, based on how the customer receives the information, the advertisement can affect the customer positively or negatively. This model was also used by sticking to the main structure of the model in other studies such as Kiani (1998), Wisker et al. (2019), and Kong et al. (2019). Alternatively, some of the authors proposed that advertisement

effectiveness should be measured by determining how successfully the advertisement achieve the targets. Schultz et al. (1994) stated three advertisement targets, namely, sales volume, behavioral effects and communication effects. Similarly, Neal and Bathe (1997) suggested that the advertisement effectiveness should be measured by determining the number of customers who prefer this product.

Some tests have been developed to measure the advertisement effectiveness. Starch (1923) proposed a test that consists of three tests, namely, attention test, headline test, and test of text. Wells (1964) also developed another test that measures the emotional appeal. Beerli and Santana (1999) developed a copy test that consists of tests for measuring the memory and attitude. To measure, the memory, they used four tests, namely, unaided recall, aided recall, verbal recognition, and visual recognition. They also measured the attitude toward the advertisement using three tests, namely, liking, emotional quotient and reaction profile.

Research Methodology

The following figure shows the methodology followed in this study. Firstly, a literature survey was performed to determine the tests used to measure the advertisement effectiveness. TV advertisements were selected. Then, a questionnaire was prepared according to the advertisement effectiveness tests used in this study. Data were collected using this questionnaire. At the last stage of this study, t-test analysis was performed using the collected data.

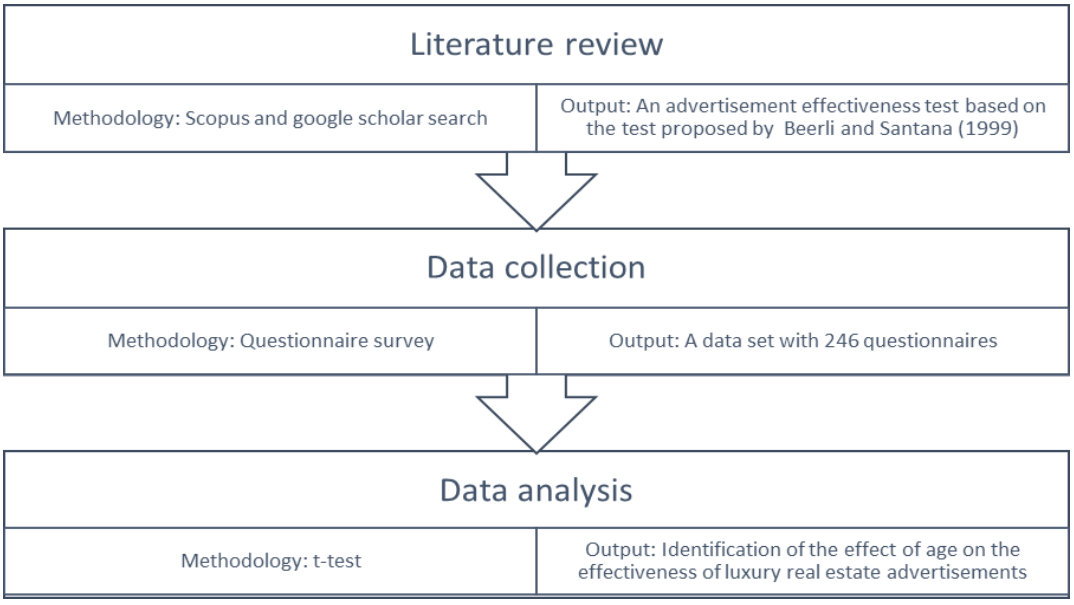


Figure 1: Research methodology.

Questionnaire

In this study, a questionnaire survey was performed to collect the data. The most important part of this questionnaire was developing a test to measure the advertisement effectiveness. In this study, the approach developed by Beerli and Santana (1999) was used. Based on Beerli and Santana (1999), the advertisement effectiveness should be measured by considering the

cognitive and affective effects of the advertisements, therefore in this study, the tests that can measure the cognitive and affective effects of advertisements were considered. Beerli and Santana (1999) used memory tests to measure the cognitive effects. Among the memory tests used by Beerli and Santana (1999), unaided recall test was used in this study. In the unaided recall test, the respondents rate how well they remember the features of the real estate project with a Likert scale from 1 to 7. 1 means that "I remember nothing about the features of the project shown in the advertisement" and 7 means that "I remember all the features of the project shown in the advertisement." For measuring the emotional effects of advertisements, Beerli and Santana (1999) used three tests, namely, liking, emotional quotient, and reaction test. In this study, liking and emotional quotient tests were used to measure the emotional effects of the advertisements. The respondent was asked to rate how much s/he liked each individual advertisement on a 7-point Likert scale to determine the liking level. For measuring the emotional quotient, Wells (1964)'s scale that a widely known and very reliable measure, was applied following the Beerli and Santana (1999)'s study. Besides, the other superiority of this scale is its two-dimensionality (emotional and cognitive components). In this test, 12 statements are given to the customers. The customers can agree or disagree with these statements. While some statements are in favor of the advertisement, on the other hand, some of them are against the advertisement. When the customer agrees to a favorable statement or disagrees to an unfavorable statement, it is considered a positive emotion against the advertisement. Therefore, the number of agreements on favorable statements and the number of disagreements on unfavorable statements are added to each other, then the sum is divided by 12 and multiplied by 100 to produce a score between 0 and 100. However, some of the original statements are not appropriate for evaluating the luxury real estate TV advertisements, therefore, these statements were modified. The following table shows the final list of these statements. Consequently, in the questionnaire, 14 questions were determined to measure the advertisement effectiveness. Also, the age of the respondents was asked. At the end of questionnaire survey, three scores would be obtained for each advertisement. These scores are liking, recall and emotional quotient.

Table 1. The statements used in the questionnaire.

1	This ad is very appealing to me.
2	I would probably skip this ad if I saw on TV.
3	This is a heart-warming ad.
4	This ad makes me want to buy the real estate shown.
5	This ad does not arouse my interest.
6	I don't like this ad.
7	This ad makes me feel good.
8	This is a wonderful ad.
9	This is the kind of ad you can easily forget.
10	This is a fascinating ad.
11	I'm tired of these kinds of ads.
12	This ad turned me off from the idea of buying a real estate.

The other important stage of this research was the identification of the advertisements which would be used in this study. To determine the most appropriate advertisements, two criteria were identified. Firstly, each advertisement should have different advertisement appeals. In this study, the advertisement appeal classification proposed by Davies (1993) was used. According to Davies (1993), there are two main categories for advertisement appeals, namely, rational/informative and emotional/psychological. In this study, two advertisements

representing these two advertisement appeals were used. Secondly, the duration of the advertisements should be longer than 20 seconds to ensure that these advertisements are long enough to inform the customers or invoke emotions of the customers. Based on these criteria, two advertisements were identified. Information on these advertisements is provided in Table 2. The first advertisement represents the rational advertisement appeal because it follows evidence-based marketing and uses an expert's insights to prove the high quality of their product. The other advertisement is an example of an emotional advertisement appeal, and it uses an emotive-based marketing strategy.

Table 2. The advertisements used in this study.

Advertisement	Advertisement appeal	Web link
Queen Central Park Bomonti	Rational	https://www.youtube.com/watch?v=Om9SO9O5MJE
Emlak Konut	Emotional	https://www.youtube.com/watch?v=qyxa_WgWK-w

Data Collection

In this study, the questionnaires were applied face to face to avoid any misunderstandings by providing immediate feedback. In the questionnaire application, at the first step, the first advertisement was shown to the respondent. After watching the advertisement, the respondents filled out the first questionnaire form. The procedure of the first advertisement was over by filling in the questionnaire. The same procedure was followed for the second advertisement. This questionnaire was administered among 221 people living in Istanbul, and the respondents were identified using the convenience sampling method. Following the data collection process, each questionnaire was evaluated, and 5 of the 221 surveys were removed because they gave identical responses to every question. The remaining 216 questionnaires formed the dataset used in this study.

Data Analysis

To examine the effect of age on luxury real estate TV advertisements, independent t-test was performed. Two age groups were identified to perform the analyses. The first group is the age group of 20–35 and the second group is the age group of 35–50. Before applying the independent t-test, the appropriateness of the data for independent t-test should be checked. According to Laerd (2018), the data should comply with six assumptions. The first three assumptions have already been achieved while collecting the data. The remaining three assumptions were also tested. The first assumption is about "no significant outliers." To test this assumption, boxplot method was used. For each age group vs test scores, boxplots were drawn. According to the drawn boxplots, no outlier could not be detected in the dataset. Secondly, the normality of the dataset was tested Shapiro-Wilk test of normality that is more appropriate for small sample sizes. According to the test, unfortunately, none of the data was identified as normal distributed (sig. >0.05). However, independent t-test is quite robust to violations of normality (Laerd, 2018). Therefore, the last assumption was also checked to decide whether the dataset was appropriate for the independent t-test. Levene's test for homogeneity of variances was used to control for this assumption. The following table shows the result of Levene's test. According to the table, only two variables meet the assumption of homogeneity of variance, namely, emotional quotient for ads 1 and 2. However, the

independent t-test also provides results for the variables that violated the assumption of homogeneity of variance. Therefore, in this study, the t-test scores calculated with no equal variance's assumption for these variables were used. Consequently, this dataset was decided to be appropriate for the independent t-test.

Table 3. Levene's test results.

Test scores	F	Sig.
Liking for ad 1	7.518	.007
Recall for ad 1	13.578	<.001
Emotional quotient for ad 1	.671	.414
Liking for ad 2	13.304	<.001
Recall for ad 2	10.326	.002
Emotional quotient for ad 2	2.831	.094

Finally, an independent t-test was applied for each advertisement, and the outputs of this test are shown in Table 3. Also, in this table, the averages of recall, liking, and emotional attraction test scores are shown for each age group with their standard deviations. According to this table, a significant difference between the two age groups in terms of liking was observed for advertisement 1, however, there is no significant difference in terms of liking between the age groups for advertisement 2. The liking level of the younger age group is significantly lower than that of the older age group for advertisement 1.

Both age groups stated that they could recall most of the features of real estate projects. And the differences between the age groups in terms of recall for both advertisements are not significant. Lastly, for advertisement 1, there is a significant difference between the age groups in terms of emotional attraction for advertisement 1. However, this significant difference cannot be observed for advertisement 2. In other words, both groups stated that they were attracted by this advertisement emotionally at a similar level.

Table 4: Independent t-test results.

		20-35		35-50		
		Mean	Std. Dev.	Mean	Std. Dev.	Sig.
Ad 1	Liking	3.37	1.73	3.93	2.01	0.031
	Recall	4.85	1.63	4.52	2.16	0.202
	Emotional Attraction	33.50	27.20	49.16	25.80	0.000
Ad 2	Liking	5.19	1.61	5.00	1.91	0.443
	Recall	5.19	1.45	5.44	1.76	0.238
	Emotional Attraction	55.22	34.91	60.61	31.52	0.235

Also, to investigate the relationship between age and advertisement effectiveness by excluding the advertisement appeal effect, the ANCOVA test was performed by combining the separate test results of these two advertisements. The similar assumptions required for the t-test are also required to perform ANCOVA, therefore this dataset was also determined to be appropriate for this analysis. The result of this test is shown in Table 4. According to this table, the only significant difference between the age groups is observed only in terms of emotional attraction. On the other, no significant differences are observed in terms of liking and recall.

Table 5. ANCOVA Test Results.

		20-35		35-50		
		Mean	Std. Dev.	Mean	Std. Dev.	Sig.
Ad 1 + Ad 2	Liking	4.28	1.90	4.46	2.03	0.294
	Recall	5.02	1.55	4.98	2.02	0.828
	Emotional Attraction	44.36	33.06	54.88	29.30	0.000

Discussion of the Findings

In this study, the effect of age on advertisement effectiveness was investigated. According to the t-test results, the significant effect of age on the advertisement can be observed in one dimension, namely, emotional attraction. However, in other dimensions, no effect can be observed. Therefore, age has a limited effect on advertisement effectiveness. Moreover, in the literature, some conflicting conclusions about the relationship between age and advertisement effectiveness can be seen. For instance, Keshari and Jain (2016) proposed that the age of the respondent does not have any effect on their response to the advertisements. However, Srivastava (2010) stated that age and advertisement impact is correlated strongly.

According to Table 5, the advertisements attract the older age group more emotionally. This effect can be explained by the changes in people's decision-making with aging (Djafarova & Rushworth, 2017). This conclusion does not comply with some studies since they stated that younger people are influenced more quickly compared to older-age groups (Srivastava, 2010). This can be explained by investigating these advertisements separately. Based on Table 4, the emotional attraction score of the young generation is much lower than that of the old generation. This shows that the rationally fragmented advertisement is not emotionally attractive to the young generation. Therefore, the effect of age on advertisement effectiveness should be examined considering the effects of different advertisement appeals. Besides, when the rationally fragmented advertisement is considered, there are significant differences between age groups in terms of liking and emotional attraction. However, no significant differences are observed in any test for emotionally fragmented advertisements. Consequently, to reveal the age effect, the advertisement appeals should also be considered with the effects of advertisement effectiveness.

Based on Table 4, the younger generation does not like the rationally fragmented advertisement compared to the older generation. As stated above, this advertisement uses celebrity endorsement to prove the luxury of the real estate project. This celebrity is an old queen, and the young generation cannot easily perceive her as their ideal self-image and role model. Although studies show that the young generation is more easily persuaded by celebrity endorsers compared to the old generation (Chan & Fan, 2022), the selection of the celebrity is also critical for persuading the younger generation. To persuade the young generation, the celebrity should be selected by considering whether this celebrity can be idolized by the young generation. However, the old generation likes this advertisement more compared to the young generation. Since buying a new real estate is also considered an important investment, the rationally fragmented advertisement is expected to be more effective among the old generation. However, the liking level of this advertisement is moderate. The moderate liking level can be the result of the selection of the celebrity since the respondents can question the realism of the

advertisement and they do not believe that the celebrity will actually live in this real estate project. Whereas customers are more likely to purchase a product if they think the celebrity who is endorsing it genuinely uses it (Jamil & Rameez ul Hassan, 2014). Therefore, in real estate advertisements, a global celebrity endorsement can be an ineffective strategy. Instead of global endorsers, an endorsement of a local celebrity who has popularity, credibility, and a positive image in the target market can be a more effective strategy for the rationally fragmented advertisements in the real estate market. However, in emotionally fragmented advertisements, both age groups are affected at the same level. Also, all test scores of this advertisement are high for both age groups. This shows that the advertisements that trigger emotions are more effective in both age groups. The reason for this finding can be that real estate is more than an investment for many people, and they see their real estate as a relaxed and comfortable haven that can protect them from the dangers around (Madigan & Munro, 1996). Consequently, real estate companies should prefer emotionally fragmented advertisements to increase their advertisement effectiveness.

Conclusion

In this study, the relationship between age and advertisement effectiveness is examined for luxury real estate TV advertisements. The findings show that the effect of age on these advertisements is limited. There are no significant differences between the age groups in terms of liking and recall in these advertisements. In other words, old and young age groups like these advertisements and recall the features of the advertised real projects at a similar level. However, only the emotional attraction test score is determined significantly different between these age groups. The reason for this finding can be explained explicitly when the advertisement appeal is also considered. Therefore, the effect of age on advertisement appeal should be examined considering the advertisement appeal.

In this study, two advertisements with two different advertisement appeals are examined to reveal the effects of age on advertisement effectiveness. This study shows that the effect of age can vary among the different advertisement appeals. In the rationally fragmented advertisement, age was identified as a critical factor that affects advertisement effectiveness. However, such a relationship could not be identified in the emotionally fragmented advertisement. The old generation liked the rationally fragmented advertisement more compared to the young generation. Therefore, real estate companies could use rationally fragmented advertisements when they are targeting the old generation. However, the celebrity used in these advertisements is critical, since when the audiences feel that the possibility of using the advertised product by the celebrity is low, the realism of the advertisement decreases, which in turn decreases the advertisement effectiveness. However, emotionally fragmented advertisements were identified as an effective strategy for both groups. Therefore, the real estate companies can prefer this advertisement appeal to have more effective advertisements.

Finally, this study has some limitations and can be improved by further studies. Firstly, this study was conducted by targeting Turkish customers. Therefore, different findings can be revealed for different countries due to the cultural and economic diversity. Secondly, luxury real estate projects were considered in this study, therefore other studies that focus on budget real estate projects can reach different conclusions. Besides, this study used only the main advertisement appeals, however, there are also subcategories for advertisement appeals. This study can be repeated for more advertisements that have these advertisement appeals; thus, the effects of age can be examined more elaborately. Finally, the selection of celebrities was

identified as a critical factor in the study. This study does not elaborately investigate the effect of celebrity on advertisement effectiveness. Therefore, the effects of celebrity endorsements can also be investigated to select the most appropriate celebrity for different advertisement appeals.

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Investigation of Intended Use of Digital Transformation Applications throughout Construction Projects' Lifecycle

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Abstract

While digitalization has brought radical changes in all sectors, it has also created important transformations in the construction industry. Digitization tools such as BIM, RFID, CPS, IoT, AR-VR, etc., have provided many opportunities to manage construction projects. Especially in large-scale construction projects, digital tools emerge as efficient solutions to problems such as high project workload, the presence of many disciplines and sub-disciplines that need to work together, and the large construction site that needs to be managed. In this context, determining digital tools that are used in the construction industry and revealing their intended use in construction projects throughout the project's lifecycle constitutes the aim of this study. In accordance with the study's aim, a comprehensive literature review was conducted to determine digital tool usage in the lifecycle of construction projects. Findings related to digital tool usage were compiled under eight stages that are strategic definition, preparation and briefing, concept design, spatial coordination, technical design, manufacturing and construction, handover and close out, and in-use stages, respectively. In each stage, samples and estimations that show how the digitization tools use were presented in detail. Results show that even though some digital tools are still in the testing phase or utilized less than expected, the construction industry will be bound to adapt due to the provided opportunities by innovations soon.

Keywords: *construction industry, construction project, digital transformation, digitalization tools, digitization, project management.*

Introduction

Digitization is defined as utilizing digital technologies to change a business model and provide new income and value-creating opportunities (Gartner, 2021). Digitization can also provide better real-time monitoring of operations and results by integrating structured and unstructured data, providing better views of organizational data, and integrating data from other sources (Maskuriy et al., 2019). Digitization has changed many companies' organizational and operational processes due to technology adaptation, and it is also defined as the ability to transform existing products and services into digital versions. In this direction, various advantages are provided by the digitization of the tangible product (Parviainen et al., 2017). The fact that digital data is easily accessible and calculable creates a chance for fast and accurate analysis in many subjects. This approach has simplified business processes in many areas (Kane et al., 2015).

Furthermore, especially in the construction industry, digital tool usage provides simultaneous data distribution, prevention of repetitive work, and faster project deliveries with more efficient tools. These improvements have facilitated cooperation and increased performance in projects with different manufacturing tracking tools. The development of digital tools has prevented wasting time, cost, and material. New employment areas have emerged in the construction industry due to utilizing new digital tools. Digitalization also transforms the leadership in the construction industry. Influential digital leaders in research from MIT Sloan Management Review and Deloitte (2015) are defined as leaders who provide vision and purpose to their organization, create conditions for experimentation, encourage people to think differently, and support people to collaborate beyond their borders. Some companies have managed the transition process by including digital leaders in their teams and developing team members through various training to accelerate digital transformation. While digitalization has brought about radical changes in all sectors, it has also created some transformations in the construction project lifecycle. During that process, many digital tools have been produced as indicated below:

- Simulation and Modelling
- Building Information Modelling (BIM)
- Augmented Reality (AR) - Virtual Reality (VR) - Mixed Reality (MR)
- Cyber-Physical Systems (CPS)
- Radio-Frequency Recognition Systems (RFID)
- Product Lifecycle Management
- Internet of Things (IoT)
- Additive Manufacturing
- Robotics
- Cloud Computing Systems, and
- Big Data (Oesterreich & Teuteberg, 2016).

Although digital tools provide many opportunities for managing high project workload, multi-disciplinary working, and large-scale construction sites, many companies still do not have a holistic transformation approach. Furthermore, many digital tools are still in the testing process. Therefore, the study aims to investigate the intended use of digital transformation applications throughout the construction projects' life cycle.

Digital Transformation Applications in Construction Industry

Advancement in technology provides many digital applications in the construction industry. In this section, all relevant applications have been examined.

- Simulation and Modeling: Simulation can be defined as an area where animations are made from the models, created in line with accurate data. The animations can be made for visual presentation purposes or to create a basis for technical analysis. In addition, the model can measure real effects with simulation programs (Ndekugri & Lansley, 1992).
- BIM: BIM, defined as the digital reflection of a facility's physical and functional characteristics, is used in project decision-making, planning and programming, cost management, and facility maintenance processes (Rokooei, 2015). The BIM model is produced by modelling the building elements in three dimensions and entering the relevant data into the parameters of the model elements. In addition to modelling,

interdisciplinary coordination can also be done on this platform. As Lahdou and Zetterman (2011) stated, BIM enables interdisciplinary work not only with a single model but also by integrating many models. Architectural, static, electrical, and mechanical models are integrated into the main model, and the necessary coordination can be quickly done.

- AR, VR, and MR: The Augmented Reality statement allows "virtual data created in the digital environment to be displayed synchronously on the real world (Şen, 2021). It is a type of experience that is created by combining images of the physical world and interacts with changes in the environment in real-time, adhering to predetermined software limits." With the further development of systems such as BIM and the transition of designs from 2D to 3D, AR technology will become frequently used. Virtual Reality is a set of systems in which the real-world environment can be presented to the person with different alternatives with the help of virtual design space and digital systems in the 3D model made by the designer. The user can experience the designed environment emotionally with the help of electronic devices (Şen, 2021). Mixed Reality is a mixture of the physical world and the digital world. In mixed reality, digital information is represented by holograms (objects made of light and sound) that appear in the space around you (Lindgren & Johnson-Glenberg, 2013).
- CPS: Cyber-physical systems use operating systems, sensors, and actuators to control machines that exist in traditional construction processes. The motion data generated in the machines are received with the help of sensor-like tools and are easily reported. These systems allow computer systems to be integrated into physical systems to maintain, operate and manage production and usage processes more securely and efficiently. The main components are mobile devices, machines, and tools (Eggenreiter, 2021).
- RFID: A radio frequency identification system tracks objects, animals, and people. The RFID system is similar to a kind of barcoding system. RFID Readers receive data over the frequencies emitted by the RFID tags attached to the objects. Supply Chain management, customer relationship management, warehouse management systems, and enterprise resource planning are the processes that utilize the obtained data from the RFID system. RFID technology components include an RFID tag, RFID Printer, RFID reader, and programming tool (Lee et al., 2013).
- Product Lifecycle Management: Product Lifecycle Management is a multi-disciplinary computer-aided technology organization that supports recording the data belonging to a product and the processes from the idea stage to the end of its useful life in the computer environment. This information is quickly accessed and used efficiently (Ötleş et al., 2015).
- IoT: IoT is a structure formed by connecting physical structures to the internet. An existing object receives and transfers data with its IP; in this direction, the objects become usable over the Internet. All objects in the IoT are connected to the internet with a live data transferring system. Technologies such as detection technologies, identification and recognition technologies, hardware, software and cloud platforms, communication technologies and networks, software and algorithms, location technologies, data processing solutions, power and energy storage, and security mechanisms can be defined as IoT tools (Işıkdağ, 2015).
- Additive Manufacturing: Additive manufacturing is generally the production of 3D objects layer by layer. The part designed in the digital environment is converted into the required format and separated into layers, and additive manufacturing machines fuse these layers by creating them additively. The purposes of additive manufacturing systems can be listed as reducing production investment costs, reducing

manufacturing times, manufacturing complex geometries, and being suitable for small-scale and unique production (Sürmen, 2019).

- Robotics: Construction Industry is affected by the rapid advancement of artificial intelligence. Robot creation provides many opportunities in the industry and may achieve successful results in repetitive tasks in a controlled area. On the other hand, the uncontrolled area at the construction sites has risks since robots to adaption. Despite the mentioned obstacles, robotic systems and artificial intelligence solutions are used in construction projects. The most used of these can be listed as 3D printers, drones, and demolition robots (Kafadar, 2021).
- Cloud Computing: Cloud computing is the general name for internet-based adjustable information technologies with high processing power, such as shared data processing, storage, and calculation, which can be used at any time with a computer or mobile device. In this respect, cloud computing is not a product but a service. Cloud Computing technology has a significant contribution in terms of cost, speed, performance, and security. In addition, it reduces expenses such as purchasing software and hardware and setting up data centres (Keleş & Keleş, 2018).
- Big Data: Big data is the collection of data from different sources such as media shares, blogs, photographs, videos, and three-dimensional models produced in the computer environment or 2D drawings, converted into a meaningful and workable format. This technology has been used increasingly in construction and other industries recently. For example, sensors on buildings can collect hundreds of data that help evaluate building performance. In line with that, advanced automation and integration to measure, monitor, control, and optimize building operations and maintenance can be provided (Bilal et al., 2016; Kaya, 2016).

With the indicated tools above, many opportunities have been occurring in the project lifecycle processes in the construction industry. However, every digital application or device has different capabilities in different stages. Therefore, the user should know which tools can be utilized in which stages. Thus, the following section categorizes the utilization of the tools based on the stages.

Investigation of Digital Transformation Applications in Project Management Phases

Royal Institute of British Architects (RIBA) is investigated in various studies to standardize architectural and construction project processes. "Plan of Work" document has been produced to standardize work planning since 2013. As the project processes get more complex, especially the project scales getting bigger, different perspectives on process planning will be involved, which may lead to the emergence of many project management methods. This multi-perspective situation risks creating unsustainable and incorrect planning results in some cases. Therefore, RIBA has standardized the steps related to the work plan processes by examining the approach of many countries. Since the study aims to analyse digital application usage in defined construction processes comprehensively, the standardized process of RIBA was used as a base. Project planning process stages that emerged in line with this approach: 1) Strategic Definition Phase, 2) Preparation and Briefing Phase, 3) Concept Design Phase, 4) Spatial Coordination Phase, 5) Technical Design Phase, 6) Manufacturing and Construction Phase, 7) Handover Phase and 8) Use Phase (RIBA Plan of Work, 2020). Each stage includes procurement strategy, information exchange process, project strategy, protection strategy, cost strategy, fire safety strategy, health and safety strategy, inclusive design strategy, planning

strategy, plan of use strategy, and sustainably organized in line with the energy strategy phases.

RIBA has examined many country approaches to construction and created a standard process for the construction projects. In line with the study's aim that is investigation of intended use of digital transformation applications throughout construction projects' lifecycle Tablo 1 has been produced as a result of literature review (Şapcı & Pektaş, 2021; White et al., 2021; Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; Eggenreiter, 2021; Lee et al., 2013; Ötleş et al., 2015; Işıkdağ, 2015; Sürmen, 2019; Kafadar, 2021; Keleş & Keleş, 2018; Bilal et al., 2016; Kaya, 2016).

Table 1. Digital application usage throughout construction projects' lifecycle.

	Strategic Definition	Preparation and Briefing	Concept Design	Spatial Coordination	Technical Design	Manufacturing and Construction	Handover	Use
Simulation and Modeling	X	X	X	X	X	X		
BIM	X	X	X	X	X	X	X	X
AR /VR /MR			X	X	X	X	X	
CPS						X	X	X
RFID						X	X	X
Product Lifecycle Management								X
Iot / IoS						X	X	X
Additive Manufacturing			X			X		
Robotics						X		X
Cloud Computing Systems	X	X	X	X	X	X	X	X
Big Data								X

As seen in the Table 1, almost all indicated digital tools can be utilized in the manufacturing and construction phases. Besides, BIM and cloud computing systems can be utilized in all phases of construction project management phases. On the other hand, big data seems to be utilized in the only use phase. However, considering the indirect usage potential, big data can be also utilized for other projects' comparative analysis or first feasibility studies as a sample. Detailed explanations related to which digital applications can utilize in which phase can be found below:

- Strategic Definition Phase: At this stage, it is essential to define the employer requirements in detail rather than the design and details. In this direction, strategic thinking, management consultancy, life analysis, sustainability studies, financial modelling, and design thinking are becoming crucial (RIBA Plan of Work, 2020). During this stage, it is seen that using simulation and modelling tools for environmental analyses provides an opportunity for a better understanding of the environment. For example, the digital twin of the Docklands has been created, and the digital twin has provided a better understanding of the city's circulation, usage, and topography with simulations while the new projects are created. This opportunity provides the proper decision-making for the new project creations. Besides, making the correct estimates for the possible revenues obtained and measuring the budget performance value is more manageable with the digital twins. In addition, the fact that estimations related to logistics can be made will ensure that correct estimations about logistics expenses can be made from the beginning of the project. The created opportunities will increase productivity and improve the quality and performance of

the project. In addition, determining the employer's requirements with a holistic perspective by making the necessary analyses will save time in future processes (Ndekugri & Lansley, 1992; Şapcı & Pektaş, 2021; White et al., 2021). When the use of BIM is examined, modelling the project area provides an opportunity to make various analyses. For example, Geographic Information System (GIS) models provide a better understanding of the environment. Such models can be transferred into BIM software and are useful for creating the design, especially if similar projects with the same function plan have been done before in the project area; examining them can indirectly provide ease at this stage. For example, if a multiple-apartment project needs to be implemented in a residential area with a digital twin model, examining similar multiple-apartment BIM projects nearby will ease the determination of the employer's demands. The fact that the data can be easily obtained from digital data models and the analysis can be done easily creates the advantage of accessing the right data and provides time savings (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). Cloud computing is a system that facilitates the storage and sharing of building-related data at all stages of the construction processes and the coordination of all teams in data access. It enables the employer to quickly communicate with the team during the strategic definition phase and to share data simultaneously. As a result, the project team can review the data, necessary updates on the subjects can be provided interactively, and the project's performance increases due to the advantages provided by this interactivity (Keleş & Keleş, 2018).

- Preparation and Briefing Phase: It is necessary to prepare a more detailed summary of the project that was decided in the previous stage. The summary should include the necessary information for the concept design stage. In addition, feasibility studies are done, and following that, whether the area and the planned project are compatible with the client's requirements is checked. It is crucial to make the relevant analyses with the employer team, examine the spatial requirements, associate them with the project budget, and specify them as a summary because the preliminary feasibility study will refer to the project's ongoing processes. Besides, it is necessary to consider new digital technologies and include the information for asset management after the transfer process. The client should determine who will control the compliance with the project in line with the project construction processes. Resources are determined, and the project schedule and execution plan are made at this stage (RIBA Plan of Work, 2020). Simulation and modelling programs can enhance cooperation with the analysis opportunities when we examine the digital applications in the Preparation and Summarization phase. Since the resources are determined, the program is made, and the execution plan is prepared in this stage, the design team is also included in the process to make strategic design decisions. For example, to design an energy-efficient building, the design team can start to determine how to use the sun and natural ventilation methods by examining the area and alternative mass designs. Such approaches have the potential to prevent waste at this stage indirectly (Ndekugri & Lansley, 1992; Şapcı & Pektaş, 2021; White et al., 2021). BIM usage in the preparation and summarization phase provides holistic advancement. Besides, the feasibility of the building can be obtained more easily with the BIM model. Design ideas can be converted into masses as sketch models, and more successful estimations can be made by taking quantities from models in line with requested materials and costs. Since a holistic study is carried out in this process, interdisciplinary cooperation is supported, performance increases, and timesaving is achieved (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al, 2021). The cloud computing system provides simultaneous access to data, data storage, and data sharing

facilities. Besides, the communication of every team member can be achieved easily. Also, the client can efficiently communicate with his team and the design team during the preparation and summary stages. In this direction, the necessary coordination and progress can be achieved, and the project performance increases accordingly (Keleş & Keleş 2018).

- Concept Design Phase: This stage aims to produce the design concept correctly in line with the previous stage's data and create the project in line with the Client's requirements. The most critical issue at this level is determining the information requirements necessary for successfully creating the concept. In addition, making some basic engineering calculations about circulation, toilet usage, and the usage of stairs provides more successful progress in the process. In addition, the concept needs to be decided by the Client. At this stage, providing the detail packages for the complex parts of the project, such as the facade details, is essential for the following chapters (RIBA Plan of Work, 2020). As in the other stages, simulation and modelling tool usage facilitate design-related analysis, coordination, and presentation processes. Besides, design presentations can be easily presented to the Client by showing the project simulation. In addition, the simulation and model can establish a common ground for the project discussions. Therefore, it facilitates the decision-making process and offers the opportunity to produce and examine many more alternatives. Thus, simulation and modelling tools increase project productivity, quality, and performance (Ndekugri & Lansley, 1992; Şapcı & Pektaş, 2021; White et al., 2021). BIM usage in the concept design process provides many opportunities as in the previous stages. For example, creating and presenting many alternative design options according to the analyses, easing coordination and decision-making processes, monitoring quantification changes, and providing many outputs for value engineering processes can be considered BIM benefits in the concept design process. In addition, since the project drawings are obtained from 3D models. Each modelled element, section, plan, and elevation view is updated simultaneously in all drawings, thus providing timesaving (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). AR, VR, and MR technologies provide a suitable marketing method for presenting the design to the Client. In addition, these tools ease clarifying the problems to the relevant responsible person due to the visual presentation. The use of additive manufacturing is a positive tool for presenting the work during the concept design phase, especially in presentations to the Client. An Architectural 3D model created from the 3D printers can be presented to explain the design (Çalışkan & Arpacıoğlu, 2020). In this phase, cloud computing systems also will encourage communication, allowing all disciplines to access the design and changes simultaneously through the models in cloud systems (Keleş & Keleş, 2018).
- Spatial Coordination Phase: The most critical issue at this stage is the completion of the coordination prior to the manufacturing and construction process. At this stage, the necessary coordination should be done in detail to avoid returning to the coordination stage. Decisions of room and function changes regarding the venue must have been completed in the previous process. This process should not be started before the room locations are finalized (RIBA Plan of Work, 2020). In this process, simulation and modelling tools facilitate data transfer and provide data analysis on models related to problem areas. Since the modelling mentioned here is schematic modelling created with 3D modelling programs independent of BIM processes, the benefit of the overlap tests for the project cannot be mentioned at this stage. However, it can be considered a tool that simplifies the process of defining the problematic area in 3D and transferring it to the people in the team. In this direction, it increases performance and

productivity. The site simulations can be prepared at this stage. These simulations can be used while providing and developing occupational health and safety training. These benefits provide better time management, especially in large-scale projects (Ndekugri & Lansley, 1992; Şapcı & Pektaş, 2021; White et al., 2021). BIM usage in this process enables the prediction of construction-related issues. İnterdisciplinary coordination with clash tests provides error minimization before manufacturing. Decision-making is done efficiently, and action is taken fast. Considering the complex nature of large-scale projects, the holistic approach provided by BIM occurs easily controllable projects in terms of cost, time, and occupational health and safety (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). AR/VR/MR usage in this stage effects that facilitate interdisciplinary cooperation in the site and office regarding coordination issues can be revealed. Problems related to coordination issues in design can be examined through models with the help of VR glasses. While this situation supports communication between stakeholders, time can be gained indirectly. Especially when conducting on-site inspections, comparisons of the model and current situation can be made with augmented reality tools (Şen, 2021; Özdemir, 2019). In the spatial coordination phase, using Cloud computing systems has time-saving advantages such as interdisciplinary coordination, simultaneous analysis, tracking change, publishing problems online via add-on programs over models in the cloud, and providing coordination with online discussions. Especially in large-scale projects, the problem of crowded project teams making it difficult to follow and coordinate can be easily avoided with cloud computing systems (Keleş & Keleş, 2018).

- Technical Design Phase: In this section, where the necessary information for the manufacturing and construction phases is produced, the subcontractors employed by the contractor together with the design team detail their projects. At this stage, it is essential to involve the relevant subcontractors in the project so that the necessary field inquiries and audit and reporting processes can progress (RIBA Plan of Work, 2020). The involvement of all subcontractors in the technical design process has risks in terms of control, especially in large-scale projects. Simulation programs can be used in OHS training related to the adaptation process of subcontractors to the field. Using simulation and modelling tools increases efficiency, especially when making logistics plans related to the manufacturing and construction process while determining time-based logistic coordination, determining circulation areas, and making plans related to occupational health and safety (Ndekugri & Lansley, 1992; Şapcı & Pektaş, 2021; White et al., 2021). At this stage, possible changes can be followed simultaneously via BIM models. The revisions required by the technical design and quantity changes can be easily followed through the models, and stakeholder management can be done efficiently (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). AR/VR/MR usage in this stage effects that facilitate interdisciplinary regarding occurred issues can be revealed (Şen, 2021; Özdemir, 2019). Using cloud computing systems at the technical design stage facilitates interdisciplinary coordination and has many opportunities for timesaving and increases cooperation such as simultaneous review, tracking of change, online issue publishing through add-on programs over models in the cloud, and coordination with online discussions. Especially in large-scale projects, due to the crowded project teams, follow-up and coordination become difficult. Therefore, cloud computing systems are becoming crucial (Keleş & Keleş, 2018).
- Manufacturing and Construction Phase: Manufacturing and construction phases take place in this phase. Design works have been completed in the previous stage. Output

can be the completed building structure in line with the drawings as in the traditional process. Also, there can be building information models that include every relevant data for asset management maintenance and use with the completed building. The data in the models must follow the client requirements indicated in the contracts. In addition, inspections related to construction processes are carried out during this process (RIBA Plan of Work, 2020). Real-time monitoring regarding the construction status can be achieved through the simulation models. Besides, logistical coordination and health and safety training can be better managed due to visualization capability. Furthermore, monitoring the project performance, collaborating with the project stakeholders in case of possible delays, and revising the field program with correct data provide an opportunity for gaining time and cost (Ndekugri & Lansley, 1992; Şapcı & Pektaş, 2021; White et al., 2021). BIM in this stage provides the site team to pursue the project, and the team can quickly determine possible changes due to the model and real-status comparison. In addition, the client's inspections are also eased for the same reason. Project and real situation comparisons can also be made with point cloud models, and possible issues are quickly detected. Thus, time and cost-saving can be achieved (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). Regardless of the stage, VR, AR, and MR tool usage provides better management due to real-time monitoring capability. For example, due to the location indicator barcodes at the site, if the site engineer has a digital tablet, she can easily reach the information model for the appropriate location and review it. In line with that, it provides interdisciplinary cooperation opportunities and prevents possible issues (Şen, 2021; Özdemir, 2019). Laser scanning systems can be given as examples of cyber-physical systems. By adding the data scanned from the construction sites with the laser scanner, linked into the models for comparing the actual situation and the requested situation can be made easily (Eggenreiter et al., 2019; Kan & Anumba, 2019; Akanmu et al., 2013). Material tracking during the Manufacturing and Construction phase, controlling the warehouses, and providing warning systems related to occupational safety are managed more efficiently with the RFID systems. For example, controlling the status regarding the reinforcement in the concrete and making material counting in the warehouses are possible with the RFID system. Besides, developing alarm systems when the dangerous equipment on the site works close to the workers using the RFID tags on the helmets can provide better HSE management. In addition, considering the user errors in the indicated process, especially in large-scale construction projects, it is seen that RFID tag systems eliminate these risks with automation (Akanmu et al., 2013; Uygunoğlu & Topçu, 2020; Lee et al., 2013). Internet of Things (IoT) in the manufacturing and construction phase is described as an effective tool for tracking the amount and location of materials on the site using RFID tags. For example, the data received from the RFID tags are transferred from the RFID readers to the databases using IoT. In addition, considering the digital twin of the city of Docklands, created data with sensors is transferred to the database with IoT (White et al., 2021; Uygunoğlu & Topçu, 2020; Işıkdağ, 2015; Ghosh et al. 2020). Additive manufacturing in this phase provides an advantage in producing the building elements, such as precast or modular facade elements. In addition, building elements produced with a 3D printer indirectly saves time and increases project productivity (Sürmen, 2019; Çalışkan & Arpacıoğlu, 2020). The use of robotics in construction and manufacturing processes is not expected since construction sites are considered complex for using robots. 3D printers and drones are the robotic systems that are utilized in construction. Drones facilitate site monitoring and obtaining up-to-date data for site conditions. In addition, structural elements such

as roofs and bridges can also be made with 3d printers (Kafadar, 2021; Sürmen, 2019). Especially in the large-scale projects, cloud computing systems provide convenience in reporting the actual situation on the site, reporting the problems, delivering the reports simultaneously to all stakeholders, notifying the possible revisions to the site, and supporting the stakeholder management, enabling the project to be built with better performance. Besides, with cloud computing systems, tracking can be done simultaneously without being in the working area. In addition, control systems can be created over cloud areas related to material tracking, distribution, and manufacturing tracking (Keleş & Keleş, 2018).

- Handover Phase: In this phase, the building must be completed in line with the requirements specified in the contract. To achieve a successful handover process, the relevant activities can begin at the previous stage. The building is transferred to the client after the occupancy assessment is made (RIBA Plan of Work, 2020). The BIM model produced during the handover process enables process-related controls, and the point clouds obtained by laser scanning make it easier to control the compliance processes with the project. In addition, the As-Built BIM model can be utilized for lighting, noise, etc., reviews. Besides the BIM model and VR-AR devices, new approval processes can be developed without going to the site using the point clouds. In line with that, the approval process can be standardized (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). VR-AR devices can facilitate the handover process for the relevant controls. Furthermore, regarding compliance with the project, productions can be easily checked over the digital drawings at site using VR-AR devices (Şen, 2021; Özdemir, 2019). Cyber-physical systems can be utilized in the handover processes of large-scale buildings since the controls are more complex than the small-scale project while making mechanical and electrical system tests. For example, while performing a noise, fire alarm, and lighting tests, data can be tracked more easily with the CPS systems. Especially in green building handover processes, data reflected on digital twins from CPS systems can be utilized while checking whether the building works in line with required performance values in each season (Eggenreiter, 2021; Kan & Anumba, 2019; Akanmu et al.,2013). During the handover phase, the control of the building elements on the site can be done quickly with the help of RFID tags. Furthermore, if the tags have been attached to the construction elements and model element ID numbers have been defined, the detection of problematic equipment and relevant stakeholder can be managed better. Thus, handover process can be sped up (Akanmu et al., 2013; Uygunoğlu & Topçu, 2020; Lee et al., 2013). Manufactured elements data on the site are transferred to the digital area via the IoT and relevant devices. Besides, RFID tags and readers make controlling the produced elements easier. For example, in the digital twin of the city of Docklands in Dublin, flood analysis in the city has been made using the digital twin. Furthermore, every citizen has a connection with the digital twin to add a comment via applications. User usage and comments are also followed via devices. Development projects can be created based on the data obtained from the analysis. IoT provides better management to ease the data transfer from the sensors or devices for the handover process (White et al., 2021; Uygunoğlu & Topçu, 2020; Işıkdağ, 2015; Ghosh et al. 2020). During the handover phase, cloud computing systems achieve significance with the simultaneous distribution of information regarding the reporting and tracking issues. Due to the time management in large-scale projects approving processes can be quickly in the cloud system (Keleş & Keleş, 2018).
- Use Phase: This process is defined as the period of the building being in use until the end of its life. The project team finalizes their tasks, and the contract is completed. If

requested, separate contracts are prepared to complete After Use Assessment or provide longer-term customer advice. If the building does not meet the customer's expectations during this stage, a new process regarding the renovation or transformation of the building should be started. This situation needs to be considered in the first stage. The client team can request foreseen information about the dismantling or renovation of the structure (RIBA Plan of Work, 2020). The asset information is entered into the BIM model elements during the BIM processes. All data in the model can be easily tracked, assets can be classified, and analyses can be made quickly through these classifications. In line with these data, stakeholders follow building lifecycle and maintenance requirements. Especially in large-scale projects, when the number and diversity of model elements are considered, the importance of holistic tracking, control, and analysis opportunities provided by digitalization becomes crucial (Rokooei, 2015; Lahdou & Zetterman, 2011; Şen, 2021; Ofluoğlu, 2016; White et al., 2021). Cyber-physical system applications can provide an opportunity to analyse the building lifecycle. For example, smart home thermal, maintenance, and energy usage processes can be analysed via data obtained from sensors. Another sample is Docklands, where the city has the digital twin. Many detections are made in line with the data obtained by the sensors and users' mobile devices, which are used for city development. Since data collection in large-scale projects is more comprehensive and complex than in small-scale ones, increasing cyber-physical system usage in large-scale projects is inevitable (Eggenreiter, 2021; Kan & Anumba, 2019; Akanmu et al., 2013). RFID tags provide a complementary approach in this phase. When the maintenance period comes, RFID tags can be utilized to find the element in the large-scale construction area with RFID readers. In addition, material life cycles can be monitored through RFID tags. RFID tags are also essential for the creation of digital twins due to provide a connection between the digital twin and the building. Increasing the project performance, waste-minimization, and facilitation of the follow-up process can be considered the benefits of RFID usage (Akanmu et al., 2013; Uygunoğlu & Topçu, 2020; Lee et al., 2013). IoT creates efficiency in this phase due to providing connections between electronic devices such as RFID, sensors, computer and etc. Besides, when a building is not in use, smart systems regarding heat, light, and ventilation can be controlled from the outside. In addition, various software can automatically adjust the settings of the building when it is not in use, in line with the data obtained with the sensors. Such systems show the importance of IoT in the construction industry due to supporting energy efficiency systems (White et al., 2021; Uygunoğlu & Topçu, 2020; Işıkdağ, 2015; Ghosh et al. 2020). The product lifecycle management process is essential in monitoring the life of the building elements and making the necessary applications for the maintenance and modification processes related to the building easily through this follow-up. In addition to increasing performance, it supports cooperation by making the data available to all stakeholders. Besides, waste minimization can be achieved by following the material processes in the building and extending their life if necessary with the proper intervention (Ötleş et al., 2015; Eigner, 2014; Filik & Yeşilay, 2020; Terzi et al., 2010; Xin & Ojanen, 2017; Li et al., 2015). Robotics systems can be utilized for collecting data regarding the status of the building. Data collection via drones for digital twins can be a sample from this process (Kafadar, 2021). In this phase, cloud systems can be defined as the area that shares and stores process-related analyses and reports simultaneously for every relevant discipline (Keleş & Keleş, 2018). Big data technology is used in the construction industry to monitor fuel consumption and equipment usage. Big data improves many activities in this phase,

such as facility (assets and equipment) management, risk minimization, preventive maintenance, pre-construction foresight evaluation, construction site organization, supply process, and security. With the development of technology and the widespread use of digital tools, the importance of big data will increase much more, and the processes will be advanced in line with the analysis of these data (Bilal et al., 2016; Kaya, 2016).

Conclusion

Rapid advancement in technology affected the construction industry. As a result of digital transformation, many applications have been created, such as BIM, RFID, CPS, IoT, and AR-VR. Furthermore, digital applications have provided many opportunities such as time and cost efficiency, real-time monitoring, and waste-minimization during construction (Oesterreich & Teuteberg, 2016). In the study, the effects of digital transformation on construction have been compiled under the RIBA "Plan of work" stages. It is determined that, as seen in Table 1, the "Manufacturing and Construction Phase" is the most appropriate for digital transformation, and nine digital tools can be utilized. Besides, the "Strategic Definition Phase" and "Preparation and Briefing Phase" are less appropriate due to the three digital tools that can be utilized. On the other hand, BIM and Cloud Computing systems are utilized more than other digital tools in the construction stages. Considering the rapid digital transformation in all sectors, managing this transforming process in construction is becoming crucial. Therefore, a holistic examination of the capability of the digital application compiled on the standardized project processes has formed a basis for better consultation. The study can guide companies and employees trying to adapt to digitalization processes. For example, a firm that expertise in concept design can get an idea by examining the use of digital tools in the "Concept Design" section of the table. The table can also guide digital tool developers to improve or create new tools considering the stage requirements due to RIBA having already defined them (RIBA Plan of Work, 2020). On the other hand, even though digitalization in the construction industry has much potential, still traditional methods have been selected. Therefore, for future development, the construction industry can be examined by comparison of the indicated digital application utilization potentials in Table 1 and the current utilization status. In line with that, every "Plan of Work" stage can be examined in more detail with case works considering cost and time effects. For example, the cost and time difference between the "Manufacturing and Construction Phase" utilizing Cloud Computing Systems or not utilizing them can be researched to inform the Construction Industry.

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Critical Challenges of BIM Implementation in AEC Industry in Turkey

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Abstract

Building Information Modeling is capable of responding the expectations of well-managed complex design and construction processes, enhanced sustainability, low cost and high efficiency, and effective building operation and maintenance in contrast to traditional project delivery process. Owing to the benefits it provides, BIM has been highly adopted in many developed countries and its adoption rate is increasing in developing countries. As in many developing countries, the implementation rate of BIM in the Turkish AEC industry is increasing, but many difficulties are still encountered in BIM implementation. Therefore, this research aims to determine the critical challenges of BIM implementation in Turkish AEC industry. To achieve this aim, the objectives are to; identify the BIM implementation influencing challenges (ICs) and determine the critical challenges of BIM implementation. Through a systematic literature review of 563 articles, 46 ICs were identified under four categories: BIM practices (13 items), BIM awareness (9 items), BIM organization (18 items), BIM education (6 items). The questionnaire was designed by the 46 ICs with 5-point Likert scale as measuring instrument and applied to 600 architects and engineers occupied at construction companies that do not use BIM technology. A total of 141 valid questionnaire were returned, representing a 23.5% response rate. Obtained data analyzed using reliability analysis, and mean score ranking. Mean score ranking was conducted to each group individually to identify the critical challenges specific to category, and among the 46 ICs, 24 of them determined as critical challenges for BIM implementation in AEC industry in Turkey. Considering these critical challenges, the suggestions have been developed to improve the current situation.

Keywords: *building information modeling (BIM), critical BIM challenges, BIM implementation, Turkish AEC industry.*

Introduction

The rapid growth in the AEC industry is an important factor in the formation of an intense competitive environment. The intense competition environment in the AEC industry increases the importance of completing construction projects with maximum efficiency in minimum cost and time. The competitive environment requires companies/project stakeholders in the industry to follow technological developments and to benefit from them by adapting to technological innovations.

Building Information Modeling (BIM) enables the creation of digital models that can contain all data of life cycle processes of a facility. With this aspect, it facilitates information management and sharing, supports interdisciplinary communication and interoperability of project stakeholders, and that provides better management of complex design and construction processes (Sacks et al., 2018), can be described as an information management system (Alizadehsalehi et al., 2020). BIM technology, with its advanced sustainability with nD models, schedule time planning, cost estimation and many features, while provides safe construction processes and providing a solution to the need for low cost and high efficiency, also with as-built modeling it is effective in building operation and maintenance.

BIM has the potential to meet the expectations for the AEC industry and competitive environment with the possibilities it offers. With its potential to meet expectations, the adoption of BIM has been high in many developed countries and this rate is increasing in developing countries in recent years. Mandatory use in public projects by various countries (Finland, Norway); publication of various guides (USA, UK); the creation of programs for the gradual transition (Germany, Italy); (McGraw Hill, 2014) that was realized by the government's awareness of the benefits of BIM implementation.

While the adoption of BIM in the global AEC industry is increasing rapidly, the Turkish AEC industry is still in its infancy (Aladag et al., 2016; Elmalı & Bayram, 2022). Although Turkey ranked 2nd in terms of the number of companies in the list of the world's largest contracting companies between 2017-2019, the targeted growth could not be achieved, and it ranked 3rd in 2020. In this case, the effect of the pandemic is obvious and should not be ignored, but it is necessary to follow the technological developments and innovative approaches in the national and international competitive environment. For the Turkish construction industry, increasing the communication and cooperation between the project stakeholders and ensuring the high level of coordination of the activities are among the important development goals. However, it is important to closely follow the technological developments in the world and to determine various strategies by adapting them to the conditions of the country. Among the strategic solutions to be determined for the sector, the areas of activities for research and development should be determined as a priority. (Construction, Engineering-Architecture, Technical Consultancy and Contracting Services, Specialization Commission Report, 2018). At this point, BIM is among the technologies that are of vital importance for the Turkish AEC industry to remain competitive in parallel with the global trend (Ezcan et al., 2013). It is necessary to expand its use by ensuring the adaptation of the sector as soon as possible. In this respect, it is important to investigate the influencing and critical challenges that BIM implementation, especially in countries where the adoption rate of BIM technology is low.

The prevalence of BIM adoption and use in developed countries (i.e., United States of America, Canada, United Kingdom, France etc.) has significantly extensive. As in many developing countries (i.e., Iran, Malaysia, Nigeria, Pakistan etc.), the rate of BIM implementation in the Turkish AEC industry is increasing, but many challenges are still encountered in BIM implementation. Although there are many studies on BIM in Turkey, especially on the adoption of BIM technology, there are limited studies on identifying the main challenges of BIM implementation in Turkey. Therefore, this research aims to identify the critical challenges of BIM implementation in the Turkish AEC industry. The current study identified the influencing challenges (ICs) in 4 categories through a systematic literature review to identify the limitations of BIM implementation, and the critical challenges (CCs) by ranking the mean score for each category.

Based on this background, the main objectives at the current study are threefold: (1) determining the critical challenges of BIM implementation. (2) identifying the importance of each critical challenge for the construction industry. Identified critical challenges can contribute to action plans to overcome the difficulties encountered in the implementation of BIM. Finally (3), addressing the research and knowledge gap by identifying the critical challenges of BIM implementation at Turkish construction industry which can be generalised to almost all developing countries.

Research method

To determine and emphasize the critical challenges of BIM implementation in Turkey, a quantitative research design was carried on. Following a four-staged methodological framework potential influencing challenges were determined, the questionnaire was designed and administrated, data were collected and statistically analysis were carried out to reach the study's aim.

Identifying the Potential Influencing Challenges Restricting the BIM Implementation

The first stage of current study was the identification of the ICs that effect of BIM implementation for all building life cycle phases regarding BIM practices, BIM awareness, BIM organization, BIM education. Conducting systematic literature review (SLR) the comprehensive literature is examined into.

Web of Science database was used to access scientific papers related to BIM. The search parameters in the database were determined using keywords. The search parameters were assigned as keywords: (1) for population, "construction professionals"; (2) for outcomes, "BIM adoption challenges", "BIM adoption obstacles", "construction industry" publications with a range of 2007-2020.

A total of 563 journal articles were found in the initial search and by filtering to certain fields, this number was decreased. Based on Web of Science categories, engineering civil, construction building technology, management, engineering multidisciplinary, and architecture were selected as search fields. There were 426 articles residual after filtering. The corresponding author then reviewed and examined each of the 426 articles abstract, introduction, and conclusion parts. The journal articles were removed when the study aim was irrelevant or did not fit. Finally, 40 articles were chosen for a thorough examination for identifying the influencing challenges. The 40 selected articles coded to regarding the key study findings to specific challenges categories taking into consideration BIM practices, BIM awareness, BIM organization, BIM education. Finally, 46 ICs that are directly related to these four categories were determined (Table 1).

Table 1. Influencing challenges ICs limiting the BIM implementation.

Challenges Categories	Coded as	Challenges	Sources
Challenges related to BIM practices	P1	The thought that BIM technology will increase to design duration and cost	[1- 5]
	P2	The thought that workflow, productivity, and efficiency will be affected in the transition to BIM technology	[2], [6-9]
	P3	Fear of abandoning the traditional project delivery system	[2], [5], [9-13]

	P4	Lack of government support for BIM technology/lack of obligation with legal legislation	[5], [7], [9], [11], [13-24]
	P5	Lack of government-led initiatives to promote BIM technology	[15], [17-18], [20-22]
	P6	Stakeholders/companies and subcontractors he works with have little/no use of BIM technology	[5], [8-9], [13], [17], [19-20], [25]
	P7	Require BIM technology knowledge sharing within stakeholders	[2], [4-5], [7], [9], [18-20], [26]
	P8	Requires the participation, coordination, and control of the project stakeholders in the project at the design stage	[2-5], [7], [20-21], [25], [27-29]
	P9	Difficulty of learning BIM-based programs	[8], [11-12], [20-21], [24- 25]
	P10	License problem of BIM-based programs	[8], [13], [21], [25-26]
	P11	Possibility of data loss in file transfer between different BIM-based programs	[2], [5], [9-10], [14], [23], [26]
	P12	Increasing the workload due to BIM library preparation at the beginning of the project	[9], [19], [24],
	P13	Possibility of occurring difficulties in version control due to model updates	[7-10], [16], [21], [25], [27]
Challenges related to BIM awareness	A1	Unknown accessibility of design, schedule, and budget data during the design stage with the BIM technology	[1], [3-4], [20], [24]
	A2	Unknown accessibility of quality, schedule, and cost data during the construction stage with BIM technology	[1], [3-4], [20], [24]
	A3	Unknown accessibility of performance, usability, and financial data during the management stage with BIM technology	[1], [3-4], [20], [24], [28]
	A4	Unknown that alternative design options can be analyzed, and the most suitable project can be selected with BIM	[1-4], [20-21], [30-31]
	A5	Unknowing improve the quality of work in and adaptation to the planned time can be achieved with BIM technology, accurate quantity and cost estimation can be made with the building information model	[1-3], [20-21], [31]
	A6	Unknown clash detection capabilities of BIM technology between project	[2-3], [7], [21-22], [27], [32]
	A7	Unknowing the possibility of controlling all systems instantly and automatically in 3D model with BIM technology	[1], [3], [20], [27]
	A8	Unknown ability of BIM to standardize the information structure and support for a wide range of file formats	[7], [26], [28]
	A9	Unknown with BIM technology adaptability to graphically illustrate potential failures, leaks, evacuation plans, etc.	[1-3], [12], [24]
Challenges related to BIM organization	O1	Not supporting the use of BIM technology by top and mid management	[7-8], [11], [16], [19-22], [31], [33-35]
	O2	Not being yet include in use of BIM technology to competitive environment in the industry	[2], [5], [11], [20], [32], [36]
	O3	Too few be qualified personnel who can use BIM technology	[7], [9-10], [16-21], [37]
	O4	Additional expenditures of consultant support required for the use of BIM technology	[16], [26-28], [33], [37]
	O5	Seeing/considering the need for BIM training for personnel within organization as an extra expenditure and waste of time	[2], [13-14], [18], [27], [35]
	O6	High of initial investment cost (software, hardware, training) and inadequate financial resources of the organization for the transition to BIM technology	[2], [7], [9], [13], [20-21], [27], [35], [38]
	O7	Probability that the investment made for the transition to BIM technology cannot respond the expected economic impact (return on investment)	[14], [19], [27], [39]
	O8	Require individual and group motivation from top management to the lowest level employee in the organization for BIM adoption	[9], [11],[18], [20], [22], [34]
	O9	Thought difficult of adoption of personnel to BIM technology	[11-13], [18]
	O10	Client's/user's not enough BIM technology knowledge and demand	[2], [13], [17-18], [20], [31], [33], [36-39]
	O11	Need to significant change in the organizational structure for integration into BIM technology (size of the organization type, structure, culture, etc.)	[8], [18], [20], [27]
	O12	BIM use/new business model causing a change in the decision mechanism and workload distribution	[9-10], [12]
	O13	Lack of dedicate time for learning and developing BIM technology due to fast paced nature of the construction industry, work overload and tight deadlines	[8-9], [12-13], [25]
	O14	Lack of able immediately pass implementation after the trainings of during the transition to BIM	[8], [17], [29]

	O15	Legal disputes, software updates and require additional funds for other expenses	[5], [7], [16], [20], [27]
	O16	Rising the workload with data transfer after the transition to BIM technology	[2], [7], [16], [27]
	O17	Lack of organization's BIM project experience and the possibility of negative consequences	[5], [7], [16-17], [19-21], [27]
	O18	Desire to switch to BIM technology, however, the lack of/low number of units to provide consultancy or training on this subject	[11], [15], [17], [39]
Challenges related to BIM education	E1	Unavailable or not enough courses for BIM technology in the education programs of the architecture/engineering departments of universities	[2], [13], [17], [40]
	E2	Lack of faculty members who have knowledge of BIM applications/technology in universities	[2], [10], [13], [26]
	E3	Insufficient studies aimed at understanding the differences in the design process of the traditional methods and BIM applications of the professional bodies related to the construction sector in the country	[6], [13], [24]
	E4	Insufficient studies of the professional bodies/government regarding the construction sector in the country for introduce the transition process to BIM technology to companies	[5], [17], [22], [26]
	E5	Being inadequate Turkish resources on BIM technology	[12-13], [17], [40]
	E6	Lack of sectoral or academic training opportunities related to BIM in the city he lives in	[2], [13], [17-18], [28]

Note(s): [1] Ganah and John (2015); [2] Aladag et al. (2016); [3] Antwi-Afari et al. (2018); [4] Olanrewaju et al. (2021); [5] Chan et al. (2019a); [6] Morlhon et al. (2014); [7] Chien et al. (2014); [8] Amuda-Yusuf (2018); [9] Khoshfetrat et al. (2020); [10] Gu and London (2010); [11] Takim et al. (2013); [12] Tan et al. (2019); [13] Evans and Farrel (2020); [14] Howard and Björk (2008); [15] Succar (2009); [16] Won et al. (2013); [17] Ozorhon and Karahan (2016); [18] Chan et al. (2019b); [19] Ma et al. (2020); [20] Tsai et al. (2014); [21] Attarzadeh et al. (2015); [22] Bouguerra et al. (2020); [23] Dao et al. (2021); [24] Tam et al. (2021); [25] Olawumi and Chan (2018); [26] Aibinu and Ventkatesh (2014); [27] Bryde et al. (2012); [28] Kivits and Furneaux (2013); [29] Boktor et al. (2014); [30] Ahn et al. (2014); [31] Lee et al. (2015); [32] Gokuc and Arditi (2016); [33] Linderoth (2010); [34] Ding et al. (2015); [35] Park et al. (2019); [36] Lindblad and Guerrero (2020); [37] Succar et al. (2013); [38] Hosseini et al. 2018; [39] Vass and Gustavsson (2017); [40] Türkyılmaz (2016).

P: practices, A: awareness, O: organization, E: education

Organizing and Administrating the Questionnaire

Based on SLR, a questionnaire was composed for architects and engineers current working in architectural offices and construction companies that do not have BIM implementation in Turkey and was conducted. To measure all the challenges affecting the prevalence of BIM implementation, the survey is consisted of four sections that can be summarized regarding BIM practices, BIM awareness, BIM organization and BIM education, and demographic variables. The survey contained 46 ICs (13 for practices, 9 for awareness, 18 for organization and 6 for education) to be rated on a 5-point Likert-type scale, with a “not severe” limitation represented by 1 and a “most severe” limitation represented by 5.

The sample group contains architects and engineers who working companies that do not use BIM. The questionnaires were sent to 600 people via e-mail, consisting of architects and engineers from 07.07.2020 to 14.11.2020. A total of 152 questionnaires were returned that 11 of them extracted due to missing data, finally 141 completely completed were used as material of the current study that represents a response rate of 25.3%.

Data Analysis

First the responses of the participants were coded, and then various statistical tests, including reliability analysis and mean score ranking were analysed using the Statistical Package for Social Sciences (SPSS).

To determine the internal consistency among questions as using the Likert scale in a survey, reliability should be measured (Nunnally & Bernstein, 2007). Cronbach’s alpha (α)

coefficient was used to determine the statistical reliability and validity of participants' replies. The α coefficient values range from "0" to "1"; the minimum acceptable reliability threshold was determined as 0.7 (Cronbach, 1951; Tavakol & Dennick, 2011).

It was important to determine the ranking of ICs of BIM implementation, to realize the main objective of this study. Therefore, the mean score ranking method was used. Furthermore, normalized mean values (NMVs) are significant to determine the criticalities of the 46 ICs for BIM implementation. The calculation of NMVs for each success ICs follows Eq 1. Any challenge with an NMV exceeding 0.5 is considered to be an CC (Liao & Teo, 2017; Zhou et al., 2019). Four groups of the dataset were normalised to the interval (0-1) to identify the ICs ranked as most critical to BIM practices, BIM awareness, organisation, and BIM education.

$$Normalized\ mean\ value = \frac{(mean\ of\ IC - lowest\ mean)}{(highest\ mean - lowest\ mean)} \quad (1)$$

ICs with normalized mean values not less than 0.50 are identified as the CCs.

Findings

To determine the internal consistency of the questionnaire reliability analysis was conducted using Cronbach α coefficient. The α coefficient of the data set for the 46 ICs affecting the BIM implementation was determined to be 0.961, which is above the minimum threshold of 0.7 (Tavakol & Dennick, 2011).

Mean score ranking was conducted to each group individually to identify the critical challenges specific to category. When the findings of this study analyzed, it is determined that among the 46 ICs, 24 (6 of practices, 7 of awareness, 7 of organization, 4 of education) of them determined as critical challenges (challenges with normalization values ≥ 0.50) for BIM implementation in AEC industry in Turkey (Table 2-5).

Regarding the BIM practice critical challenges, the means, normalized mean values (NMV) and standard deviations (SD) of ICs related to BIM practices were computed to responses of questionnaire (Table 2).

Table 2. Ranking of ICs related to BIM practices.

Challenges Categories	Coded as	Challenges	Mean	Sd	NMV[a]	Ranking
Challenges related to BIM practices	P1	The thought that BIM technology will increase to design duration and cost	2,49	1,252	0,000	13
	P2	The thought that workflow, productivity, and efficiency will be affected in the transition to BIM technology	2,67	1,308	0,165	12
	P3	Fear of abandoning the traditional project delivery system	3,07	1,35	0,532[b]	6
	P4	Lack of government support for BIM technology/lack of obligation with legal legislation	3,2	1,408	0,651[b]	4
	P5	Lack of government-led initiatives to promote BIM technology	3,46	1,393	0,890[b]	2
	P6	Stakeholders/companies and subcontractors he works with have little/no use of BIM technology	3,58	1,335	1,000[b]	1
	P7	Require BIM technology knowledge sharing within stakeholders	3	1,429	0,468	7
	P8	Requires the participation, coordination, and control of the project stakeholders in the project at the design stage	2,86	1,353	0,339	10

	P9	Difficulty of learning BIM-based programs	2,88	1,363	0,358	8
	P10	License problem of BIM-based programs	3,32	1,5	0,761[b]	3
	P11	Possibility of data loss in file transfer between different BIM-based programs	2,76	1,282	0,248	11
	P12	Increasing the workload due to BIM library preparation at the beginning of the project	3,07	1,272	0,532[b]	5
	P13	Possibility of occurring difficulties in version control due to model updates	2,85	1,198	0,330	9

Sd = Standard deviation, NMV[a] = normalized mean value = (mean - minimum mean)/ (maximum mean - minimum mean)
[b]Indicate the challenge is a critical challenge (normalization value ≥ 0.50)

The results show that the ICs of the criticality of the challenge range from 2.49 to 3.58. Challenges with NMVs not less than 0.50 are identified at the CCs. The results indicate that six challenges have normalized values greater than 0.50 in this group among 13 challenges, therefore, assumed as CCs. "Non-use of BIM technology by stakeholders" (P6) is determined as the most critical challenge for BIM practice (Table 2).

The means, NMV and SD of ICs related to BIM awareness were computed to responses of questionnaire and presented at Table 3.

Table 3. Ranking of ICs related to BIM awareness.

Challenges Categories	Coded as	Challenges	Mean	Sd	NMV[a]	Ranking
Challenges related to BIM awareness	A1	Unknown accessibility of design, schedule, and budget data during the design stage with the BIM technology	2,89	1,249	0,000	9
	A2	Unknown accessibility of quality, schedule, and cost data during the construction stage with BIM technology	2,93	1,232	0,095	8
	A3	Unknown accessibility of performance, usability, and financial data during the management stage with BIM technology	3,24	1,271	0,833[b]	3
	A4	Unknown that alternative design options can be analyzed, and the most suitable project can be selected with BIM	3,31	1,231	1,000[b]	1
	A5	Unknowing improve the quality of work in and adaptation to the planned time can be achieved with BIM technology, accurate quantity and cost estimation can be made with the building information model	3,25	1,322	0,857[b]	2
	A6	Unknown clash detection capabilities of BIM technology between project	3,13	1,233	0,571[b]	6
	A7	Unknowing the possibility of controlling all systems instantly and automatically in 3D model with BIM technology	3,19	1,299	0,714[b]	4
	A8	Unknown ability of BIM to standardize the information structure and support for a wide range of file formats	3,14	1,22	0,595[b]	5
	A9	Unknown with BIM technology adaptability to graphically illustrate potential failures, leaks, evacuation plans, etc.	3,1	1,281	0,500[b]	7

Sd = Standard deviation, NMV[a] = normalized mean value = (mean - minimum mean)/ (maximum mean - minimum mean)
[b]Indicate the challenge is a critical challenge (normalization value ≥ 0.50)

The results show that the ICs of the criticality of the challenge range from 2.89 to 3.31. The results indicate that seven challenges have NMVs not less than 0.50 in this group among nine challenges, therefore, assumed as CCs. "Not knowing the alternative design options can be analysed and the most suitable project can be selected with BIM" (A4) is determined as the most critical challenge for BIM awareness (Table 3).

To identify the critical challenge regarding the BIM organization the means, NMV and SD of ICs related to BIM organization were computed to responses of questionnaire (Table 4).

Table 4. Ranking of ICs related to BIM organization.

Challenges Categories	Coded as	Challenges	Mean	Sd	NMV[a]	Ranking
Challenges related to BIM organization	O1	Not supporting the use of BIM technology by top and mid management	3,24	1,212	0,283	13
	O2	Not being yet include in use of BIM technology to competitive environment in the industry	3,25	1,179	0,300	12
	O3	Too few be qualified personnel who can use BIM technology	3,61	1,144	0,900[b]	2
	O4	Additional expenditures of consultant support required for the use of BIM technology	3,48	1,167	0,683[b]	5
	O5	Seeing/considering the need for BIM training for personnel within organization as an extra expenditure and waste of time	3,52	1,197	0,750[b]	4
	O6	High of initial investment cost (software, hardware, training) and inadequate financial resources of the organization for the transition to BIM technology	3,45	1,203	0,633[b]	6
	O7	Probability that the investment made for the transition to BIM technology cannot respond the expected economic impact (return on investment)	3,35	1,201	0,467	8
	O8	Require individual and group motivation from top management to the lowest level employee in the organization for BIM adoption	3,2	1,252	0,217	17
	O9	Thought difficult of adoption of personnel to BIM technology	3,33	1,163	0,433	9
	O10	Client's/user's not enough BIM technology knowledge and demand	3,55	1,194	0,800[b]	3
	O11	Need to significant change in the organizational structure for integration into BIM technology (size of the organization type, structure, culture, etc.)	3,42	1,088	0,583[b]	7
	O12	BIM use/new business model causing a change in the decision mechanism and workload distribution	3,21	1,207	0,233	15
	O13	Lack of dedicate time for learning and developing BIM technology due to fast paced nature of the construction industry, work overload and tight deadlines	3,67	1,263	1,000[b]	1
	O14	Lack of able immediately pass implementation after the trainings of during the transition to BIM	3,31	1,17	0,400	10
	O15	Legal disputes, software updates and require additional funds for other expenses	3,31	1,22	0,400	11
	O16	Rising the workload with data transfer after the transition to BIM technology	3,07	1,249	0,000	18
	O17	Lack of organization's BIM project experience and the possibility of negative consequences	3,2	1,155	0,217	16
	O18	Desire to switch to BIM technology, however, the lack of/low number of units to provide consultancy or training on this subject	3,24	1,249	0,283	14

Sd = Standard deviation, NMV[a] = normalized mean value = (mean - minimum mean)/ (maximum mean - minimum mean)
[b]Indicate the challenge is a critical challenge (normalization value ≥ 0.50)

The results show that the ICs of the criticality of the challenge range from 3.07 to 3.67. The results indicate that seven challenges have normalized values not less than 0.50 in this group among 18 challenges, therefore, assumed as CCs. “Lack of time to learn and develop BIM” (O13) is determined as the most critical challenge for BIM organization (Table 4).

The means, NV and SD of ICs related to BIM education were computed to responses of questionnaire (Table 5).

Table 5. Ranking of ICs related to BIM education.

Challenges Categories	Coded as	Challenges	Mean	Sd	NMV[a]	Ranking
Challenges related to BIM	E1	Unavailable or not enough courses for BIM technology in the education programs of the architecture/engineering departments of universities	3,75	1,308	1,000[b]	1

	E2	Lack of faculty members who have knowledge of BIM applications/technology in universities	3,74	1,296	0,967[b]	2
	E3	Insufficient studies aimed at understanding the differences in the design process of the traditional methods and BIM applications of the professional bodies related to the construction sector in the country	3,71	1,251	0,867[b]	3
	E4	Insufficient studies of the professional bodies/government regarding the construction sector in the country for introduce the transition process to BIM technology to companies	3,69	1,153	0,800[b]	4
	E5	Being inadequate Turkish resources on BIM technology	3,45	1,277	0,000	5
	E6	Lack of sectoral or academic training opportunities related to BIM in the city he lives in	3,45	1,374	0,000	6

Sd = Standard deviation, NV[a] = normalized mean value = (mean - minimum mean)/ (maximum mean - minimum mean)
[b]Indicate the challenge is a critical challenge (normalization value ≥ 0.50)

The results show that the ICs of the criticality of the challenge range from 3.45 to 3.75. The results indicate that four challenges have normalized values not less than 0.50 in this group among six challenges, therefore, assumed as CCs. “Lack of courses on BIM applications in the architecture and engineering curriculums” (E1) is determined as the most critical challenge for BIM education (Table 5).

Conclusion

Current study reveals the critical challenges of the implementation of BIM in the Turkish AEC industry in terms of challenges in use of BIM technology by architects and engineers who working in companies that do not have BIM implementation using data from 141 questionnaire respondents in industry.

Through a systematic literature review, 46 ICs were identified under four categories: BIM practices (13 items), BIM awareness (9 items), BIM organization (18 items), BIM education (6 items). Among the 46 ICs, 24 of them identified as CCs by mean score ranking analysis.

“Non-use of BIM technology by stakeholders” (P6) is determined as the most critical challenge for BIM practice, in this group among 13 challenges. Since the construction process is a complex process with different levels and many participants, the relationships between the participants at each stage of this process is significant. Indeed, use of BIM technology by stakeholders/companies and subcontractors is essential to ensure the successful implementation of BIM technology.

“Not knowing the alternative design options can be analyzed and the most suitable project can be selected with BIM” (A4) is determined as the most critical challenge for BIM awareness, in this group among nine challenges. The most suitable project can be selected via evaluating alternative design options, energy, thermal, acoustic, environmental analysis, and simulations such as air flow, water, carbon emissions (Attarzadeh et al., 2015) over the building information model created with BIM implementation. In addition, Aladag et al. (2016) states that "efficient monitoring and reporting" and "advanced budgeting and cost estimation" capabilities are the most important factors among the project gains achieved by BIM implementation. Recognize the ability of the sector to use BIM to achieve maximum quality at minimum cost and time is an important factor in the adoption of BIM technology.

“Lack of time to learn and develop BIM” (O13) is determined as the most critical challenge for BIM organization, in this group among 18 challenges. Time, cost, and quality are very

significant factors for the stakeholders in the project delivery process in the construction industry. Due to the fast-paced nature of project construction, heavy workload, and tight deadlines, it is often not possible for staff to devote time to learning and developing BIM technology. Furthermore, Aibinu and Ventkatesh (2014) remarked the necessity of learning time for BIM adoption.

"Lack of courses on BIM applications in the architecture and engineering curriculums" (E1) is determined as the most critical challenge for BIM education, in this group among six challenges. It has been determined that having BIM knowledge and training in education life before entering professional life has a significant effect on the prevalence of use in the current study.

It can be concluded from these findings that there are several critical challenges for BIM implementation in Turkish construction industry. With regard to these findings;

- First, universities and the government should take responsibility for BIM education. Related departments of universities, particularly architecture and engineering departments, should update their education curricula and increase the number of BIM-related courses. Higher education institutions and the government should collaborate to develop a national BIM curriculum to fulfil the need for BIM proficiency among graduates entering the workforce.
- It is recommended that the up-down management create a dedicated BIM department to handle or support BIM deployment in their projects in the long run. Moreover, top management in construction organizations are urged to address gaps in their employees' skill sets by supporting them in attending appropriate BIM seminars, workshops, or conferences to improve their BIM capacity and knowledge.

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Analysis of Industry 4.0 Technologies from a Lean Construction Perspective

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Abstract

The concept of lean production, which is the basis of lean management, was first introduced with jidoka in 1930s and emerged in the manufacturing sector. The relationship of lean production with the construction sector was established in 1992 and started to be expressed in the construction sector approximately 60 years later. It took a long time to adapt to construction practices. Although targets such as reducing waste, increasing customer satisfaction by optimizing time, cost and quality, etc. are thought to be approaches that will increase productivity for the construction sector. The term Industry 4.0 was first mentioned in 2011. Informatics and industrial applications are brought together. It has been developed in order to keep up with the changes experienced on a global scale and to provide a competitive advantage in the increasing competitive conditions. It is aimed to reduce production time, costs, increase production quantity and quality. With the development of technology, Industry 4.0 has begun to be considered together with lean construction applications since the goals of lean construction and industry 4.0 are similar. In this study, it is aimed to explain Industry 4.0 technologies and to reveal how they can benefit from lean construction with a literature study.

Keywords: *construction industry, industry 4.0, lean construction, technology.*

Introduction

With the correct use of rapidly increasing technological developments, many sectors have benefited, gained competitive advantage and increased their productivity. Especially thanks to the industry 4.0 revolution that emerged in the manufacturing sector, the direction of technological developments has changed, automation of machinery and processes has been ensured, and progress has been made on digitalization and integration of digital systems. On the other hand, lean construction helps to reduce waste, increase productivity and ensure customer satisfaction. The construction sector is lagging behind other sectors in accepting technological developments. Considering the benefits it provides; it is foreseen that the application of lean construction principles and the use of industry 4.0 technologies will provide advantages to the construction project processes since industry 4.0 and lean construction have similar goals. There are literature studies that bring these two issues together and examine their integration. However, in many studies, industry 4.0 technologies have been studied on a large scale and their scope has been broadened. No study has been found that examines how industry 4.0 technologies will benefit against the waste of lean, in

terms of industry 4.0, where the technologies were born, construction and lean construction by examining more deeply.

This study consists of 6 chapters. After this introduction section, there is the lean construction section. Information about lean construction, its development process, waste and principles are explained. In the third chapter, the industry 4.0 development process and its benefits are emphasized. In the fourth section, the method is explained, and in the fifth section, the literature study is included. Finally, the sixth chapter is the conclusion part of the study.

Lean Construction

According to Lean Construction Institute's the last studies, thanks to the use of lean methods in production, the waste rate in the manufacturing sector decreased to 26% and the waste rate in the construction sector to 57% (Bajjou & Chafi, 2020). The concept of lean first emerged in the manufacturing sector and then began to spread in other sectors. The oil crisis in 1973 dealt a great blow to the entire world economy. Unlike other companies, Toyota Motor Company in Japan survived this crisis with a high profit rate. It has reached a high profit rate from companies in both Japan and countries such as Europe and USA. Toyota attracted the attention of the whole world and there were people from different countries who came to examine it. It is described as the Toyota Production System in 1988 (Paslawski & Rudnicki, 2021; Pereira et al., 2019). Just-in-time production (1950s-to prevent overstock) and jidoko (1930s-autonomation-to prevent error in the production line) formed the cornerstones of this system (Paslawski & Rudnicki, 2021). In this system, it is aimed to keep the cost, time, equipment and space usage at the lowest level, to spend less effort and to make maximum production (Womack & Jones, 2003). Later, its name started to be used as "lean production" (Pereira et al., 2019).

In order to increase efficiency in lean production, it is aimed to reduce activities that do not add value. There are 8 types of waste that lean manufacturing defines. ***Overproduction;*** these are the wastes that are produced more than necessary and are considered as surplus production. ***Unnecessary transportation;*** refers to inefficient workflows, unnecessary transportation of machinery, equipment, and materials. ***Unnecessary motion;*** it refers to unnecessary movements of workers in their daily work due to poorly organized work areas. ***Excess inventory;*** this includes anything that is more than necessary for the work. ***Waiting;*** it represents all kinds of waste that will require waiting, such as the lack of resources such as workers, materials, equipment. ***Defects;*** re-manufacturing in production, repair, etc. works is a type of waste that negatively affects time, cost and efficiency. ***Over-processing;*** all kinds of unnecessary high-quality actions that do not create added value in the production processes and do not create value for the customer are in this waste group. ***Unused employee creativity;*** means that the talents, development and learning opportunities of the employees are not used efficiently. (Bajjou & Chafi, 2020; Liker, 2004; Nassereddine et al., 2022-a).

It was revealed by Koskela (1992) that wastes defined for lean production, in other words, activities that do not produce added value, also cause low productivity in the construction sector. Koskela (1992) published a report on the application of lean manufacturing methods in construction. He stated that this method, which provides a competitive advantage in the production sector and reduces waste, should also be applied in the construction sector. "Major development efforts in construction, like industrialization, computer integrated construction and construction automation have to be redefined to acknowledge the need to balance flow

improvement and conversion improvement" (Koskela, 1992). Thus, the concept of lean construction emerged.

Lean construction has 5 principles. The first of these is ***specify value***. Identifying activities that add and do not add value for the customer. The second principle is ***value stream mapping***. It is determining how value is generated, when it is delivered, and where improvements can be made. It allows to identify where the waste occurs. The third principle is to create a ***continuous stream of value***. It is to make the flow continuous by reducing unnecessary waiting, movement, error, etc. wastes. The fourth principle is ***pull value***. It means the delivery of necessary materials, workers, information in construction, on time. It is to pull the necessary material in case of need instead of a continuous stacking situation. The fifth and final principle is to ***pursue excellence***. It means continuous improvement by eliminating waste and increasing transparency on construction sites (Aziz & Hafez, 2013; Bajjou & Chafi, 2020; Womack & Jones, 2003).

Technological developments are taking place in the construction sector that will facilitate the use of lean methods, make the lean construction process efficient, reduce the waste defined by lean, and facilitate the realization of lean principles. Industry 4.0 technologies will contribute to the implementation of lean principles in construction.

Industry 4.0

The term Industry 4.0 (Fourth Industrial Revolution) was first used in 2011 at the Hannover Fair. In 2013, a report was prepared and officially announced that it was a revolutionary initiative in the manufacturing industry (Xu et al., 2018). There is no standard definition of industry 4.0 in the literature. Industry 4.0 enables the development, access and integration of information and communication technologies with automation technologies in order to ensure complete system integration (Ferreira et al., 2020). It facilitates access to technology, enables price reduction and the use of sensors in value chains, and removes barriers to supply chain integration and management (Ferreira et al., 2020).

In order to understand the development process of the fourth industrial revolution, the first three revolutions are mentioned in this study. ***The First Industrial Revolution*** emerged towards the end of the 18th century. In this revolution, mechanical production systems using water and steam power began to be used. ***The Second Industrial Revolution*** emerged in the late 19th century. With the use of electrical energy, mass production has begun. ***The Third Industrial Revolution*** emerged in the middle of the 20th century. Automation and microelectronic technology have started to be used in the production sector. The use of computer aided systems has started. Finally, ***The Fourth Industrial Revolution*** emerged at the beginning of the 21st century. With the contribution of cyber physical system and internet of things, it has developed in the automation of machines and processes. It focuses on digitization and integration of digital systems (Xu et al., 2018). In the cyber physical system, the physical and digital components are intertwined, integrated and coordinated. Thanks to the cyber physical system, communication is established between the machines and the control system becomes decentralized to ensure efficiency in production. Thanks to the Internet of things, virtual networks are created between objects and their integration is ensured (Xu et al., 2018).

Industry 4.0 technologies shorten the development process and increases innovation skills. It provides flexibility in production processes. It helps to use resources efficiently and increase production and efficiency (Lasi et al., 2014). It provides standardization, thus preventing mistakes and misunderstandings (Xu et al., 2018). Such benefits of industry 4.0 technologies show that they will contribute to lean construction. Both lean construction and industry 4.0 technologies aim to increase efficiency and standardization and reduce waste.

Methodology

Aim. It is foreseen that lean construction applications will be facilitated with some industry 4.0 technologies and these technologies will benefit construction projects. For this reason, studies that relate these two concepts in the literature have been examined.

Scope. There are many industry 4.0 technologies in the literature. Within the scope of this study, industry 4.0 technologies, which facilitate the realization of construction projects according to lean principles, which are suitable for construction projects in terms of way of doing business, and which are the most mentioned and emphasized in the literature, have been examined. These technologies are simulation, RFID, AR.

Method. In the literature study, the Scopus database was searched. The words "lean construction" and "industry 4.0" were scanned together. Industry 4.0 technologies such as simulation, Radio Frequency Identification (RFID) and Augmented Reality (AR) have been encountered the most in use with lean construction. With this method, articles related to the subject were reached. Later, in some sections, other articles related to the subject were obtained from the references of the relevant articles.

Literature Review

In this part of the study, industry 4.0 technologies, which are most frequently associated with lean construction in the literature and where lean principles are most applicable, are examined. In this review, first of all, lean construction and industry 4.0 concepts were searched together and frequently encountered technologies in the literature were revealed. After the industry 4.0 technologies were determined, the concepts of "simulation", "RFID", "Augmented Reality" were searched one by one along with the concept of "lean construction". For each of them, what these technologies mean in terms of industry 4.0 is explained in the first paragraph, the use of this technology in the construction sector is explained in the second paragraph, and these technologies are examined together with lean construction in the third paragraph.

Simulation

Simulation means "a model of a set of problems or events that can be used to teach someone how to do something, or the process of making such a model" in Cambridge Dictionary (URL-1, 2022). Scheidegger et al. (2018) defines simulation as the real or hypothetical model for analyzing and describing the system's behaviors. In this definition, modeling refers to the model production process; the model is a simplified and abstract representation of the real; the system is the analyzed process; process refers to elements that are related to each other;

simulation refers to the operation of the model over time. Thanks to the simulation, products, processes and system design that have not yet been physically produced are experienced. It helps in decision making, reducing costs and cycles, and shortening time before materialization (Negahban & Smith, 2014). Ferreira et al. (2020) said that in addition to these, simulation enables companies to see the obstacles to implementation, costs, risks, and the impact on their performance.

In the construction industry, simulation technology is used for many purposes. Some of these are risk analysis, maintenance operations, planning, process developments, and claims. Simulation in construction projects helps to test decisions virtually before real-life implementation and to support construction project management (Abdelmegid et al., 2019). According to Bajjou and Chafi (2020) simulation enables decision-making construction professionals to experiment with a low-cost and controllable system, enabling processes to be effectively designed, analyzed and improved. Thanks to the simulation, the workflow is better understood. In addition to Abdelmegid et al. (2019) and Bajjou and Chafi (2020), Fischer et al (2021) also stated that simulation benefits visualization in construction projects, it can be used in weather forecasting, field logistics and routing strategies can be tested by visualizing, the productivity of workers can be monitored, and possible errors can be predicted.

In the literature, there are studies in which simulation technology and lean construction are used together. Nassereddine et al. (2022-a) stated that the most effective way to see the impact of lean construction principles on construction processes is simulation. In addition, Halpin and Kueckmann (2002) stated that lean thinking and simulation are very similar. It is efficient to analyze and test processes before they happen so that non-value-added activities can be defined and reduced. According to Bajjou and Chafi (2020), the two main reasons for applying the simulation are to identify and measure the waste in the construction process, to reveal possible improvements and developments in risk, cost and time. In Paslawski and Rudnicki (2021)'s study, in addition to lean construction, distance and road type possibilities were evaluated by using simulation to reach the construction site. These two differing cases are analysed to reveal how the efficiency of the concrete pavement set is at the highest level. Thanks to the simulation, productivity increased by 56%, the implementation process was improved, and the pull feature of lean construction was also used by placing orders without interruption in deliveries. Halpin and Kueckmann (2002) made case studies by simulating the movements of crane and crews to ensure minimum waste in wall frame assembly and to pour concrete in the wastewater treatment plant with lean construction methods.

In many literature studies, it is stated that thanks to the simulation technology applied with lean construction, it increases the productivity, flexibility, provides continuous improvement, time and cost savings, increases communication and information sharing (Bajjou & Chafi, 2020). The simulation provides accurate quantitative information such as the duration of the cycle, the amount of work to be done per day, productivity, team utilization. By revealing this information, wastes of lean construction (unnecessary transportation, waiting, unnecessary movement, etc.) can be measured. Activities that do not add value are identified and eliminated (Halpin & Kueckmann 2002; Pereira et al., 2019).

RFID

Radio Frequency Identification (RFID) means “a system of fixing a small electronic device to something or someone that sends out a radio signal, so that a computer can find out where they are or other information about them” (URL-2, 2022). RFID technology is used in the recognition and tracking of all kinds of living and inanimate objects from a distance without touching them (Uygunoğlu & Topçu, 2020). RFID technology is generally used in logistics management and inventory control (Liu et al., 2022). Thanks to RFID, communication between tags and readers can be achieved without line of sight, unlike traditional barcodes and codes (Liu et al., 2022). RFID system usually consists of tags, reader(s) and backend server. Every physical object in the system has a tag and this ID is unique. In order to automatically perform inventory management with RFID, the IDs of all tags in the system are defined and the need for intensive manual processing is reduced (Liu et al., 2022). For example; suppose a manufacturer wants to take back the faulty goods it produces after it is shipped to the warehouse. If the labels of these faulty products are known, they will be able to access the products easily. In RFID technology, there are three categories in inventory processes: tag identification, tag detection (missing or unknown) and tag search. With tag identification, it is ensured that all tag IDs entered into the system are defined correctly. With tag detection, missing and unknown tags in the information stored in the database are revealed. With the tag search, it is possible to find the desired tags from the system (Liu et al., 2022). The work done with RFID technology reduces the costs considerably, speeds up the workflows, and increases efficiency and quality (Uygunoğlu & Topçu, 2020).

It has been explained in the literature that RFID is used for many purposes in the construction industry.

- The first purpose is on supply systems. Ju et al. (2012) stated that it can be used in the distribution of materials brought to the construction site to the relevant locations. The usage area in material distribution gains importance especially in precast structures. Cai et al. (2014) stated that RFID technologies are used successfully in precast elements. It provides the opportunity to reduce costs, to show the originality and quality of the product to the customer. Real-time data on the condition of each precast element can be accessed, inventory and quality information is recorded, and this technology can be used in product shipment (Cai et al., 2014).
- The second purpose is on quality management (Wang, 2008). Lee et al. (2009) stated that the tracking of deformation in reinforced concrete structures, the quality of concrete, the corrosion status of reinforcements in reinforced concrete can be tracked with RFID tags. In Turkey, before the concrete is poured, RFID chips are placed in the mold and the concrete quality is collected electronically in the ministry system (Uygunoğlu & Topçu, 2020).
- Another purpose is determining the materials inside the building and their usage areas, and in defining the places of duty of people (Montaser & Moselhi, 2014).
- At last, the field of occupational health and safety is also included in the purposes. Kelm et al. (2013) stated that by attaching RFID tags to the helmet used by the workers and the tools and equipment that cause the accident, they contribute to the worker's health and safety in the construction, the workers are warned when they are in the risky area and the accidents are minimized.

In the literature, there are studies in which RFID technology and lean construction are used together.

- Sahin et al. (2017) examined the use of lean construction and RFID technology in supply systems of small to medium size construction companies. In this study, it is aimed to reveal how the communication and information flow between the main

office, construction site, factory area and suppliers can be coordinated with RFID. For this, firstly, 3D drawings were made and barcodes were created for the ducts and pipes, and their information was entered in the computer. By monitoring the ducts and pipes produced in the factory with these barcodes, it is aimed to ensure the supply-demand balance between the field and the factory during the procurement process. It was also desired to prevent excess stock, which lean construction defines as waste. In addition, with the pull principle of lean construction, it is aimed to produce just in time and to bring the material to the construction site when necessary. It has been concluded that it has advantages such as real-time tracking and visualization, the delay of the work decreases, the average completion time of the work decreases, the average completed work increases, and the annual investment costs decrease (Sahin et al,. 2017).

- Chen et al. (2019) also worked on improving the coordination of prefabricated elements with the factory and field, such as Sahin et al. (2017). Chen et al. (2019) conducted a study at the local level by examining this issue on the basis of China. In Chen et al. (2019)'s case study, a 3D model was created during the design phase of the project, the combined use of 3D model and RFID technology in prefabricated production was examined, and simulation technology was used to evaluate the risk situation related to the schedule. As a result of this study, it was informed that productivity can be increased, uncertainty can be reduced, and waste, which is one of the principles of lean construction, can be prevented thanks to the combined use of 3D model and RFID technology.
- Li et al. (2018) also examined lean construction with RFID in prefabricated elements such as Sahin et al. (2017) and Chen et al. (2019). Simulation technology was used in this examination. In the simulation, the process of bringing prefabricated elements from the factory to the site and assembling them is tested with the traditional method in the first part, and with the lean construction principles, RFID and 3D modeling in the second part. In the second part of the simulation, it has been concluded that it has the advantages of providing real-time tracking, reducing uncertainties and complexity, facilitating information transfer, and shorter cost and time.

In many literature studies, it is stated that thanks to the RFID technology applied with lean construction, time and cost savings are achieved, uncertainty and complexity are reduced, RFID tags attached to materials or workers provide ease of tracking, and faulty and overproduction, excess inventory, and waiting, which are wastes of lean, can be prevented.

Augmented Reality

Augmented reality (AR) means that reality is modified and augmented by computer. Unlike virtual reality, which creates a virtual environment instead of the real one, AR strengthens the virtual information by bringing it to the real world. AR means that reality is modified and augmented by computer. Unlike virtual reality, which creates a virtual environment instead of the real one, AR strengthens the virtual information by bringing it to the real World. The information produced and created in the computer environment is transferred to the user's view in the real World. AR not only allows users to passively view information on the computer, but also to interact with published information and collaborate with people on the other side of the computer in real time. AR can be applied in different sectors such as gaming, pharmaceuticals, military, automotive, entertainment, engineering, construction,

manufacturing and aerospace and provides users with a competitive advantage (Nassereddine et al., 2022a).

As Nassereddin et al (2022a) mentioned, AR can be applied in construction industry. In the literature, there are studies describing what AR technology can be used for in construction projects and what benefits it will provide to construction projects. Thomas et al. (1998) designed a wearable system for visual navigation aid at the construction site, thereby facilitating on-site navigation. Dunston et al. (2000) designed an AR system integrated into a two-dimensional drawing program to assist in the design of the mechanics discipline. Park and Kim (2013) integrated AR and geolocation and tracking technologies to ensure occupational safety in the construction field. Nassereddine et al. (2022a) stated that with the use of AR during the construction phase, different discipline elements can be coordinated, mock-ups can be seen, it will be possible to see how the drawings on the computer will look in the field, the construction process can be visualized and followed, the integration between the field and the factory can be ensured, It allows planning how heavy and difficult to transport elements can be placed before transportation, detecting defaults and monitoring the material supply in the field. All these areas of use have allowed the construction projects to be produced leaner.

In the literature, there are studies in which AR technology and lean construction are used together. AR technology can be used to correctly implement geometrically drawn projects in the computer environment and to establish a correct relationship with space. Although it can be seen in three dimensions on the computer, mistakes can be made in the field during the manufacturing phase. AR can be integrated with the drawing on the computer to detect or avoid errors. Thus, it prevents the waste of faulty manufacturing defined by lean construction (Oskouie et al., 2012). AR provides monitoring and visualization of business processes. The progress of each construction activity can be monitored and proactive action can be taken in case of delay. (Nassereddine, 2022b). Waiting, which is one of the wastes of lean, is reduced (Dallasega et al., 2020). Thanks to visualization, repeatable works in activities can be revealed and flow can be created. Another benefit; It facilitates different suppliers working for the same field to understand the common area, visually perceive their scope of work and facilitate cooperation with other suppliers (Nassereddine, 2022b).

Conclusion

It has been stated in many studies in the literature that when lean construction principles are applied in construction projects, efficiency will increase, waste will be reduced, and customer satisfaction will increase. Industry 4.0 technologies emerge in the manufacturing sector and provide benefits for other sectors as well, increasing efficiency and facilitating business methods. Within the scope of this study, lean construction applications in construction projects and industry 4.0 technologies, which are most frequently mentioned with lean in the literature, were examined together. And these studies have revealed that construction projects will save time and cost, reduce the rate of uncertainty and complexity, reduce the waste defined by lean, increase visibility and visualization, provide more accurate results, increase coordination between teams, and ensure continuous improvement and development.

Today, there may be some obstacles in using these two methods together in construction projects. In construction projects, the number of stakeholders is high, there are different contractual relations and different interests. It can be difficult to get everyone to agree and

implement a new method. The lifetime of construction projects may be short for technological structuring. Companies may avoid this technology as the initial investment cost may be high and it may take a long time to explain the lean construction practices to all project teams and to ensure the correct application. For this reason, the coexistence of stakeholders who have worked together before and are familiar with lean construction practices and have experienced these practices will be factors that will facilitate the implementation in projects that will take longer than an average construction project (such as large-scale projects). This is true for today. But technology is developing day by day. As it develops, it both becomes cheaper and spreads in the sector. Technological advances increase exponentially, then exploding. It is thought that lean construction practices and industry 4.0 technologies can be applied together in all types of construction projects in the future, and this study is encouraged for construction companies to experience these applications.

In this study, lean construction is discussed with 3 technologies, but there are many other industry 4.0 technologies. Construction companies should follow the developing technologies and improve their business practices by keeping up with the developing technologies.

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Determination of Construction 4.0 Awareness in Project Management Processes: The Case of Kayseri

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Abstract

New technological production forms have emerged with the development of the concept of Industry 4.0. While the digitalization of production systems has been improved in all areas, the construction industry has also been affected by this situation; the concept of construction 4.0 has emerged. Construction 4.0 involves the digitalization of the construction industry by working together with different technologies such as the internet, sensors, software, lasers, and drones. The widespread use of construction 4.0 technologies in the construction industry, which has a production network that is becoming more complex day by day, will allow the solution of possible problems in the project process and the efficient execution of the processes by the desired quality & occupational safety standards. The scope of the study is to determine the awareness of construction 4.0 technologies by surveying senior employees such as architects and civil engineers from the construction industry in Kayseri, Turkiye. The determination of awareness will be utilized to reveal the aspects where Construction 4.0 can be developed in the industry. Thus, a perspective for the future can be developed. It is aimed that the findings will contribute to the management actions such as planning, design, decision-making, control, and communication in the project production process at the national and international levels.

Keywords: *industry 4.0, construction 4.0, construction industry, project management, Kayseri.*

Introduction

The change in economy, environment, and civilization has a significant impact on the construction industry that shapes the built environment. In recent years, with the advancement of technology and the differentiation of needs that determine the quality of life, construction projects have also become more complex; while quality potentials have grown, budget and program weights have increased. However, when compared to different industries, the construction industry generally gets behind in integrating the innovations brought by technology (Alaloul et al., 2018). This situation reduces the efficiency of the construction project management processes. The fact that the construction industry is not integrated with advanced technologies such as computer-aided construction, automation, prefabrication, and the lack of attention to research and development (R&D) studies are the most important causes of productivity losses (Oesterreich & Teuberg, 2016; Razkenari et al., 2018).

Construction 4.0 technologies such as building information modelling (BIM), prefabrication, modular systems, cyber-physical systems, internet of things (IoT), robots, augmented reality/virtual reality (AR/VR), 3D printers, big data, cloud computing systems, and drones should be adapted to the construction industry in order to increase the productivity. As these modern technologies will be adapted in the industry, sustainable construction practices will increase, time and cost savings will be achieved, occupational safety precautions will be taken, occupational accidents will be reduced, waste generation will be minimized, and communication problems between project parties will be eliminated, and real-time data will be obtained with minimum error and high accuracy (Osunsanmi et al., 2018).

Within the scope of the study, the technologies discussed in the context of construction 4.0 were determined by literature review, and the relationship of these technologies with construction project management was examined. In the next stage of the study, a survey was conducted with senior employees working in the construction industry in Kayseri, which is the most investment-friendly province of the construction industry in the Central Anatolia Region. In the survey study, the participants' awareness of construction 4.0 technologies and their use of technology were determined and their views on the effects of technologies on project management were determined. This study, which is specific to the Kayseri construction industry, aims to increase the efficiency in the construction project management processes with the use of technology in the construction industry at national and international levels.

Construction 4.0 Technologies

Technological and scientific opportunities have been increased with the development of Industry 4.0, which focuses on the integration of computer and cyber-physical systems. The construction industry has also benefited from these developments and the term “Construction 4.0”, which has gained importance in recent years, has emerged (Forcael et al., 2020). The concept of Construction 4.0 is that all equipment in the construction worksite is connected to the internet and each other; it is based on the creation of a digital construction site where each part of the construction project can be monitored and managed through different technologies. In this context, Construction 4.0 is the digitalization of the construction industry and the use of all digital technologies in building products in communication and interaction with each other (Oesterreich & Teuteberg, 2016).

Significant improvements have been observed in the technologies that form the basis of Construction 4.0. However, it is difficult to generalize its widespread use in the construction industry. Therefore, it is necessary to examine the interaction between technologies and their application dynamics in other areas to improve this situation (Karmakar and Delhi, 2021). BIM technology includes design, planning, decision-making, performance estimation, cost estimation, scheduling, etc. Three-dimensional models are used to operate the building throughout the construction lifecycle. It enables the collection of data and their communication (Çetiner, 2010). Three-dimensional printing of buildings via 3D printers is a challenge between the countries. Big data on the other hand is the conversion of all data collected from different sources on the internet into a meaningful and workable format. Cloud computing is the storage of data and applications in the source on a server called a cloud (EBSO, 2015). Cyber-physical systems are the connection between interconnected computers and physical systems. Radiofrequency identification is a technology in which data is carried through radio waves (EBSO, 2015). Augmented reality (AR) and virtual reality (VR) technologies combine real and virtual objects and provide simultaneous interaction between them (Parlak Biçer et al., 2021). The internet of things (IoT), on the other hand, is that smart objects with digital networks and the internet gain a virtual identity and interact with their environment in a physical and social context (EBSO, 2015).

There are limited studies in the literature that describe and classify Construction 4.0 basic technologies (Perrier, 2020). Oesterreich and Teuteberg (2016) classified the technologies for Construction 4.0 and divided them into three groups: smart factory, simulation, and modeling, digitization, and virtualization (Figure 1). According to Oesterreich and Teuteberg (2016), technologies in the smart factory group are the technologies for creating “smart construction sites”. Technologies in the simulation and modeling group are aimed at improving complex “construction operations” such as worker performance, supply, and weather. Technologies in the third group are technologies for managing construction documents in real-time and improving “communication” between project stakeholders (Oesterreich & Teuteberg, 2016).

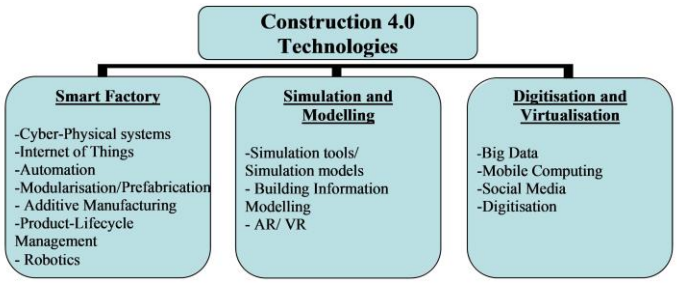


Figure 1: Construction 4.0 technologies (Edited from Oesterreich & Teuteberg, 2016).

Dallasega et al. (2018) divided the construction 4.0 technologies into six basic groups in their study. These were classified as digitization, cloud computing, BIM, 3D printing, tracking & localization, and e-supply chain management. The application examples from the construction companies were discussed by considering the organizational, geographical, and cognitive contexts of technologies (Dallasega et al., 2018). Forcael et al. (2020) classified the Construction 4.0 technologies as BIM, common data environment (CDE), drones, cloud-based project management, AR/VR, artificial intelligence (AI), cyber security, cyber-physical systems, big data and analytics, block chain and laser scans (Forcael et al., 2020). Boton et al. (2021) stated that BIM is the main source in the digitalization of the construction industry. The other technologies were classified as 3D printers, big data, cloud computing, cyber-

physical systems, cloud computing, radio frequency identification, AR/VR, and the IoT, (Figure 2).

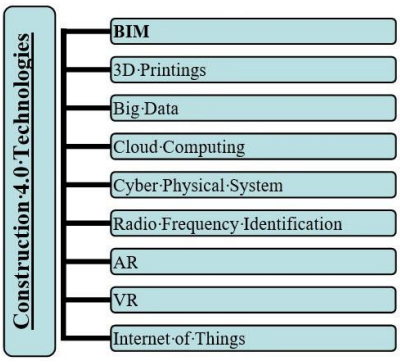


Figure 2: Construction 4.0 technologies (Edited from Boton et al., 2021).

Many studies in the literature classify technologies for Construction 4.0 and discuss their contribution to the construction industry as mentioned. It can be concluded that the basic technologies for Construction 4.0 are BIM, cyber-physical systems, VR/AR, IoT, cloud computing, big data, radio frequency identification, 3D printers, drones, and robots. Apart from these, it has been observed that wearable technologies and autonomous robots are also included in a limited number of studies (Forcael et al., 2020; Gao et al., 2022). In this context, in the survey study conducted within the scope of the study, research was conducted on the awareness, use, and benefits of these technologies in the project management processes in the Kayseri construction industry.

Impacts of Construction 4.0 Technologies on Project Management

Project management is the planning, implementation, and control of all the steps necessary for the project to reach the determined time, scope, quality, and cost targets. Different organizations are required for the project to reach its goal by the duration, quality, cost, and size of the project (Kömürlü & Toltar, 2018). The importance of project management in the construction industry has increased since different disciplines are involved in construction projects. The projects are unique, and their complexity is increasing. Basically, the project management process consists of actions and factors (Figure 3). In this process, actions and factors are in a constantly transforming relationship with the building design, production, and use. However, currently, the use of traditional project management methodologies, especially in the production of large-scale structures, has begun to be insufficient to optimize the process. It has become a necessity for building production processes to adapt to the transformations and technologies brought by Construction 4.0 for this reason (Taner & Parlak Biçer, 2021).

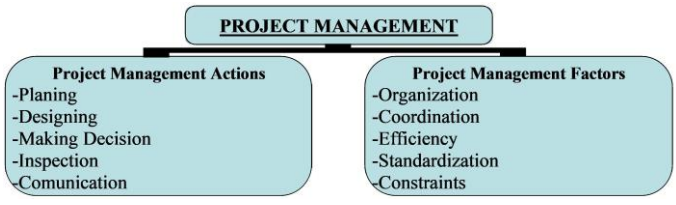


Figure 3: Actions and factors in the project management (Edited from Gültekin, 2007).

The goal of project management is to efficiently build and deliver a construction project. The efficiency of the project is the ratio of resources (inputs) to the products (outputs) (Akbıyıklı & Dikmen, 2019). The most common problems in the construction industry are low productivity due to delays, budget overruns, and unskilled labour; less frequently experienced problems are remakes and metering errors due to quality problems (Gürkan, 2019). Alaloul et al. (2020) underline that productivity in the construction industry can be improved through construction 4.0. Soto et al. (2020), on the other hand, state that with the widespread use of technology, new opportunities can be created such as reducing waste and repetition, as well as improving quality, reducing time, and completing projects within budget.

Construction project management starts with the analysis of large amounts of data (inputs) obtained during the planning process of the project before the design process (Schönbeck et al., 2020). Perrier et al. (2020) state in their study that real-time processing of collected data will increase efficiency. In this context, it is important to use big data technology that processes data and draws conclusions from it and to create a virtual construction site with BIM in the process of building. In addition, continuous digital processing of building data from planning to delivery of the building with cloud computing and radio frequency identification can identify delays and contribute to project management processes by preventing time and financial losses (Schönbeck et al., 2020; Hamledari et al., 2018).

According to Schönbeck et al. (2020), Construction 4.0 concepts cover not only new technologies but also project management factors such as organizations, management, and processes. However, there will be difficulties at the beginning, as the implementation of these factors will require extensive changes and new skills. The application potentials of different technologies in project management actions such as operation, planning, design, decision-making, and construction should be well investigated to overcome these difficulties. The widespread use of construction 4.0 technologies in project management actions will contribute to project management factors and thus to the entire project process. For this purpose, the potentials were analyzed by classifying different construction 4.0 technologies into three groups. (Figure 4). As a result, labor and material losses decreased; it has been stated that a long-lasting life cycle is provided (Schönbeck et al., 2020).

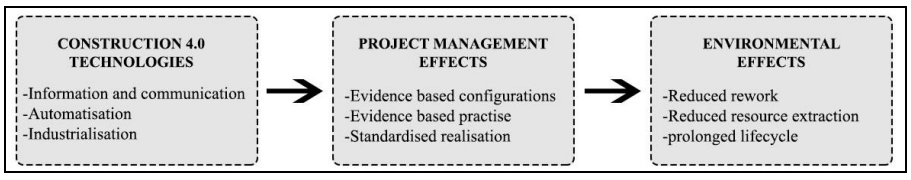


Figure 4: Impact of construction 4.0 technologies on project management (Edited from Schönbeck et al., 2020).

In the context of construction projects, the value of digital processes, automation, and technology remains unexplored. It is predicted that the widespread use of Construction 4.0 technologies in construction project management actions and factors will increase the quality in the construction sector and reduce time and cost.

Research Methodology

Kayseri has a rich potential in terms of capital accumulation, industrial opportunities, transportation modes, underground resources, labor force, consumption habits, and housing

needs. In Kayseri, one-fourth of the total industrialists invest to the construction industry. The importance of occupations related to the construction industry in the province of Kayseri continues to increase over the years (ORAN, 2014).

A survey study on the awareness, use, and possible contributions of Construction 4.0 technologies to the construction industry were applied in the province of Kayseri. 39 people, including 21 architects, 16 civil engineers, and 2 civil technicians, participated in the survey study. Although the survey study was sent to more employees, the returns did not exceed the specified numbers. Therefore, even if this situation is seen as a weak aspect of the study, the study will contribute to this field. The results obtained from the survey are examined in the findings section.

Within the scope of the study, a questionnaire form was used as a data collection tool. The questionnaire form was created by using the literature and was prepared via Google forms. The relevant link has been conveyed to the employees of the construction industry in Kayseri. The contact information of the participants obtained from the relevant professional chambers was used. Within this scope, a total of 46 questions were asked to the participants related to the level of awareness of Construction 4.0 technologies, the use of Construction 4.0 technologies in the workplace, and the contribution of Construction 4.0 to project management. The survey study consists of four sections. In the first section, 10 questions related to the demographic characteristics of the participants were prepared. In the second section, 12 questions were asked related to the level of awareness about Construction 4.0 technologies. In the third section, 12 questions about the use of Construction 4.0 technologies by workplaces are included. In the fourth and last section, 12 questions were prepared about the impact of Construction 4.0 on project management. In the survey study, the questions were prepared using a five-point Likert scale. The statistical data of the survey were calculated with the MS Excel 2016 software and visualized in graphics. The data obtained were presented under the figures.

Findings

The sample consists of 54% (21) architects, 41% (16) civil engineers, and 5% (2) civil technicians. 46% of the participants are male, and 54% are female. 26% of the participants work in the public sector and 74% in the private sector. 31% of the participants are in the managerial position, 31% in the employer position, and 38% in the employee position. 2% of the participants are between 20 and 25 years old, 13% are between 26 and 30 years old, 41% are between 31 and 35 years old, 15% are between 36 and 40 years old, and 28% are 41 and older. 5% of the participants have associate degrees, 41% undergraduate, 33% master's degrees, and 21% doctorate degrees. 13% of the participants have 1-5 years, 31% 6-10 years, 25% 11-15 years, 8% 16-20 years, and 23% have 21 or more years of professional experience. 51% of the workplaces of the participants operate in housing/mass housing, 5% in industrial buildings, 20% in commercial and institutional buildings, 3% in infrastructure projects, and 21% in other projects. In this case, it can be stated that the workplaces of the participants are more active in housing/mass housing projects. The 44% of the workplaces of the participants are in the local sector, 18% in the regional sector, 23% in the national sector, and 15% in the international sector. The 23% of the participants' workplaces have been operating in the sector for 1-5 years, 23% for 6-10 years, 16% for 11-15 years, 5% for 16-20 years, and 33% for 21 years or more. Considering the data obtained here, the fact that the participants of the survey

study have valuable experience in the field and that they have been in the sector for a long time. This situation increases the reliability of the study.

In the second section of the survey study, the awareness levels of the participants for Construction 4.0 technologies were measured. The opinions of the participants about BIM technology are as follows: 16% completely know, 46% know, 10% neutral, 23% do not know, and 5% never know. For cyber-physical systems technology, they responded as follows: 5% completely know, 18% know, 8% neutral, 31% do not know, and 38% never know. For virtual reality/augmented reality (VR/AR) technologies, they responded as follows: 10% completely know, 54% know, 8% neutral, 15% do not know, and 13% never know. For internet of things (IoT) technology, they responded as follows: 8% completely know, 36% know, 23% neutral, 15% do not know, and 18% never know. For cloud computing technology, they responded as follows: 10% completely know, 54 % know, 8% neutral, 13 % do not know, and 15% never know. For big data technology, they responded as follows: 10% completely know, 41% know, 18% neutral, 10% do not know, and 21% never know. For radio frequency identification technology, they responded as follows: 5% completely know, 26% know, 23% neutral, 28% do not know, and 18% never know. For additive manufacturing/3D printing technology, they responded as follows: 13% completely know, 21% know, 15% neutral, 20% do not know, and 31% never know. For autonomous vehicles technology, they responded as follows: 8% completely know, 41% know, 18% neutral, 18% do not know, and 15% never know. For wearable technologies, they responded as follows: 13% completely know, 54% know, 5% neutral, 13% do not know, and 15% never know. For drones, they responded as follows: 25% completely know, 49% know, 10% neutral, 8% do not know, and 8% never know. For robots, they responded as follows: 21% completely know, 56% know, 8% neutral, 5% do not know, and 10% never know (Figure 5).

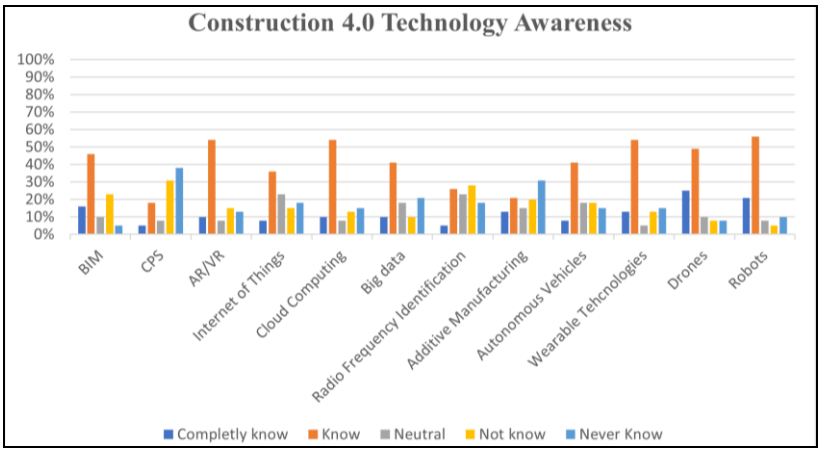


Figure 5: Awareness of construction 4.0 technologies according to the survey study.

In the third section of the survey, the use of Construction 4.0 technologies in the workplaces of the participants was evaluated. Accordingly, the opinions of the participants about the BIM technology are as follows: 20% want to use for the future project, 21% use, 28% neutral, 10% do not want to use, and 21% never want to use. For cyber-physical systems technology, they responded as follows: 10% want to use for the future project, 5% use, 41% neutral, 16% do not want to use, and 28% never want to use. For virtual reality/augmented reality (VR/AR) technologies, they responded as follows: 23% want to use for the future project, 20% use, 26% neutral, 8% do not want to use, and 23% never want to use. For internet of things (ıoT) technology, they responded as follows: 18% want to use for the future project, 10% use, 36%

neutral, 13% do not want to use, and 23% never want to use. For cloud computing technology, they responded as follows: 26% want to use for the future project, 18% use, 26% neutral, 10% do not want to use, and 20% never want to use. For big data technology, they responded as follows: 23% want to use for the future project, 13% use, 28% neutral, 13% do not want to use, and 23% never want to use. For radio frequency identification technology, they responded as follows: 15% want to use it for the future project, 8% use it, 36% neutral, 15% do not want to use, and 26% never want to use it. For additive manufacturing technology, they responded as follows: 21% want to use for the future project, 15% use, 26% neutral, 15% do not want to use, and 23% never want to use. For autonomous vehicles technology, they responded as follows: 15% want to use for the future project, 8% use, 38% neutral, 13% do not want to use, and 26% never want to use. For wearable technologies, they responded as follows: 18% want to use for the future project, 18% use, 28% neutral, 13% do not want to use, and 23% never want to use. For drones, they responded as follows: 31% want to use for the future project, 13% use, 28% neutral, 8% do not want to use, and 20% never want to use. For robots, they responded as follows: 23% want to use for the future project, 21% use, 20% neutral, 10% do not want to use, and 26% never want to use (Figure 6).

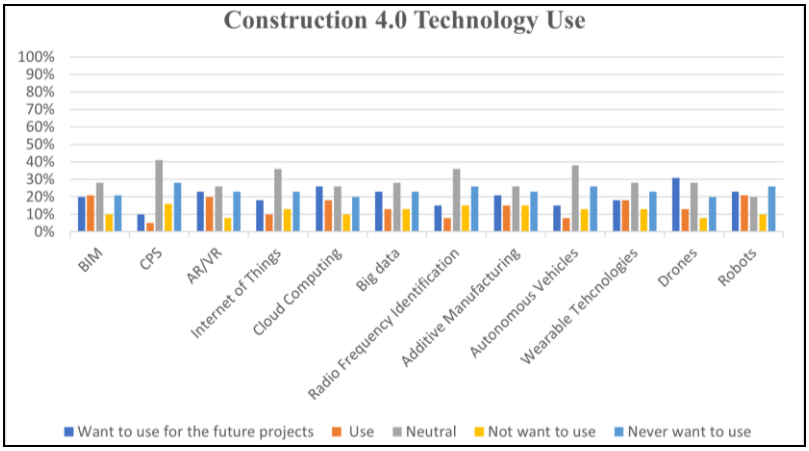


Figure 6: Usage rates of construction 4.0 technologies according to the survey study.

Within the scope of the survey, the Relative Importance Index (RII) method was used for the answers responded to each question, to determine the relative importance perceptions of the sub-dimensions of the section "The impact of Construction 4.0 on project management". RII values were calculated using the following formula (Gündüz et al., 2013):

$$R\ddot{O}E = \frac{\sum W}{AxN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5xN} \quad (1)$$

Where;
W: The weight value of the answers given to each question (between 1 and 5),
A: The highest weighting coefficient (5 in this study), and
N: the total number of samples.

The degrees of importance are as follows: RII<0.6 low indicator, 0.6≤RII<0.8 medium indicator, and 0.8≤RII ≤ 1 high indicator (Artan İlter, 2017). In the last section of the

application, participants were asked to evaluate the impact of Construction 4.0 on project management. In line with the answers given, the degrees of importance were determined.

According to Figure 7, the most significant factors within the scope of the impact of Construction 4.0 on project management are respectively; making construction 4.0 technologies easier to plan, design, monitor and execute projects (Question 3, RII=0.83), improving the quality of the building by preventing errors in the early stages with the use of BIM and other simulation technologies (Question 12, RII=0,82), improving communication, coordination and collaboration among project stakeholders of big data and cloud-based project management tools use (Question 4, RII=0,81), decreasing project delivery time/contributing to budget with the use of BIM (Question 11, RII=0,81) and determining production standards with the use of BIM/Additive manufacturing/Augmented reality technologies (Question 6, RII=0,80), have been determined. The medium indicators of importance, respectively; managing highly complex technical projects with Construction 4.0 technologies (Question 2, RII=0,78), increasing the security of AR/VR-based education and wearable technologies (Question 8, RII=0,78), preventing the problems experienced in machine and workforce by using autonomous robots in the building production process (Question 5, RII=0,77), minimally affecting the management process from external factors with the use of cloud computing/additive manufacturing systems (Question 7, RII=0,77), obtaining real-time data of building components and workers by using the internet of things (Question 9, RII=0,77), protecting information on product standards with the use of cyber-security systems (Question 10, RII=0,77), and identifying and solving of problems in real-time with construction 4.0 technologies (Question 1, RII=0,75), have been determined. As seen in Figure 7, the importance index of all sub-dimensions is between the 75%-85% band. According to these findings, the factors have high and medium importance (Figure 7).

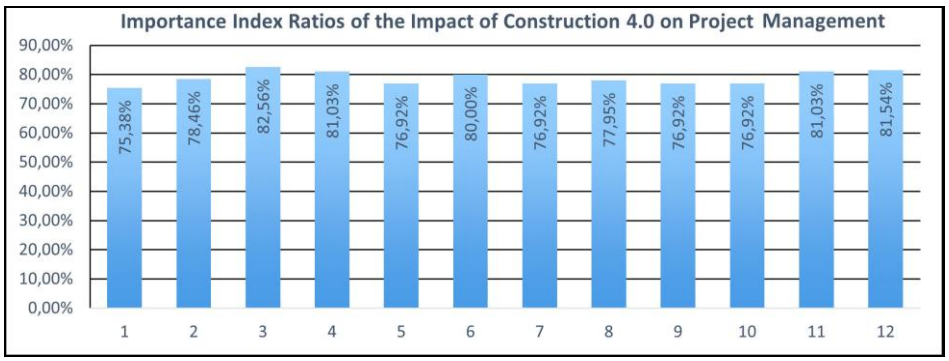


Figure 7: Impact of Construction 4.0 technologies on project management.

Discussion

There are a number of increasing studies discussing the use of Construction 4.0 technologies and their effects on project management processes. Ebrahimi (2019) conducted a survey with construction professionals in her work on the integration of Industry 4.0 technologies into the construction industry. The findings indicated that although the awareness of Industry 4.0 technologies is low, BIM technologies and smart factory technologies are widely used in the industry. As a result of her work, Ebrahimi (2019) has proposed a five-stage roadmap that covers industrial transformation and implementation from a technical and strategic point of view.

Adepoju and Aigbavboa (2020) examined the threats and opportunities of Construction 4.0 technologies in the construction industry in their study. Within the scope of the study, a survey was conducted with 40 project managers and project supervisors. As a result, the use of BIM and prefabrication technologies creates new opportunities for collaboration, creativity, and employee productivity. However, it has also revealed negative consequences such as a decrease in the workforce. In the study, it is suggested that construction 4.0 technologies become widespread in practice, but it is emphasized that it should be controlled by laws. Nagy et al. (2021), on the other hand, stated that Construction 4.0 is not only a technology but also a management and strategic challenge. To overcome these difficulties and make the construction industry more sustainable, management strategies for Construction 4.0 should be established. In this context, a survey was conducted with construction industry professionals. As a result, technologies not only create opportunities in the sector but also create new problems in the context of human resources, management knowledge, and competence, organization. In the solution to these problems, sector managers and the government should work together to produce new value chains.

Results

This study was carried out to examine the awareness of the Construction 4.0 technologies concepts in the construction industry of Kayseri, their use in the public and private sectors, and their effects on project management. For this purpose, a survey consisting of 46 questions was applied to architects, civil engineers, and construction technicians. Considering the 12 concepts in which the awareness level of construction 4.0 technologies is determined, the most known technologies by the participants are respectively; robots, drones, wearable technologies, cloud computing, augmented reality/virtual reality (AR/VR), building information modeling (BIM), big data, autonomous vehicles, internet of things (IoT), additive manufacturing, radio frequency identification and cyber-physical systems. In the third section of the study, the use of Construction 4.0 technologies by the participants was evaluated. The top five technologies that workplaces use and intend to use are as follows: drones, robots, cloud computing, AR/VR, and BIM. In the last section of the study, the effect of Construction 4.0 on project management was evaluated with 12 questions asked to the participants. While making this evaluation, the Relative Important Index (RII) values were taken into consideration, and it was concluded that 5 of the 12 sub-dimensions were of high importance. The highly important effects of technologies are respectively; easier planning/designing/monitoring of projects, increasing the quality of the building by preventing errors in the early stages, improving communication/coordination/cooperation among project stakeholders, reducing project delivery time/helping budget, and determining production standards, is in the form.

It is obvious that the widespread use of Construction 4.0 technologies will contribute to project management actions such as planning, designing, decision-making, supervision, and communication, and factors such as organization, coordination, standardization, and productivity. For this, the managers of the construction industry should make an effort and the managers of the country should support this. This study, which contributes to the studies to be carried out on this subject, is important in this respect. Despite the low number of responses to the survey sent as the weakness of the study, it is seen as the strength of this study that it contributes in terms of quality and practice, especially due to the small number of studies in the field. It is thought that the data obtained from this study, which was applied on a

provincial basis and conducted for the occupational groups in the sector, is valuable in terms of being encouraging and creating a resource for future studies.

In this study, an original study was carried out in terms of the awareness of technologies in the construction industry of Kayseri, Turkiye. Moreover, this research, it is significant in terms of determining the benefits of technology to project management processes and raising awareness of its use in the industry. It is aimed that this study will contribute to future similar scientific studies.

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BIM Based Automated Code Compliance Checking System: TRegCheck Program

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Abstract

In this study, the presentation of the TRegCheck (Turkish Regulation Checking System) program, which automatically performs the code compliance checking of the BIM based residential architectural projects according to the rules determined from the building legislation in Turkey is presented. TRegCheck is a rule-based control system that automatically checks compliance with the legislation by computer, considering the IFC data of the building model drawn based on BIM and the rules of the relevant building regulations. With this program, story height calculation, Building Coverage Ratio (TAKS) calculation, Floor Area Ratio (KAKS) calculation, minimum building parking area calculation and minimum building shelter area calculation are made according to the relevant regulation, and compliance with the legislation is automatically checked. The TRegCheck program provides convenience to both architects and engineers at the design stage and especially those working in the municipality, in the automated code compliance checking of BIM based designed buildings.

Keywords: *automated code compliance checking, BIM, IFC.*

Introduction

In the architecture, engineering, and construction (AEC) industry, checking the compliance of a building's architectural design with building codes is a manual process that often depends on the experience and skills of the inspector. This process requires considerable effort and time and is error prone. In addition, uncertainties, and inconsistencies in the evaluation of the auditor cause delays in the construction process. Automatically checking the compliance of the building design according to the regulations is a process that includes faster, more consistent, and more transparent audit procedures.

The ability to automatically check compliance with the regulation of a building in the design phase comes to the fore and is realized with BIM, which started a digital transformation and technological revolution in the AEC sector today. BIM can be defined as a digital representation of a building, an object-based three-dimensional model, or a digital repository of project information to facilitate interoperability and information exchange between related software applications (Miettinen & Paavola 2014). Interoperability and digital information exchange between BIM programs is possible with the IFC data file (Nisbet et al., 2009). With the IFC data file, it has provided a standard method and generally agreed upon protocol for

the computable representation of a building (Nawari, 2018). In this way, necessary data can be obtained from the BIM model for rule control. Advances in BIM technology and the availability of the IFC data file also provide opportunities for new software tools that can perform automated regulatory compliance checks. With this opportunity, the efficiency and accuracy of the compliance control processes of a project designed for designers such as architects, engineers and control staff working in administrative institutions such as municipalities will also increase. Thus, in the near future, BIM will become an important digital asset not only in design, but also in software that automatically checks compliance with regulations and obtaining building permit approval from legal institutions such as municipalities (Raslan & Davies, 2006).

Advances in BIM technology and the availability of the IFC data file also offer opportunities for new software tools that can do ACCC. In this way, designers and administrative institutions will increase the efficiency and accuracy of control processes, especially for municipalities. Thus, in the future, BIM will become an important digital asset not only in design, but also in software that automatically checks compliance with regulations and obtaining approval from legal institutions (such as municipalities) (Raslan & Davies, 2006).

The first successful attempt in the AEC industry to automate the control of design conformity was the application of a decision table representing the standard specifications of the American Institute of Steel Construction (AISC) carried out by Fenves in 1966. After this study, various control systems have been developed in the field of ACCC in many different countries until today (Pesquera et al., 1984; Noland & Bedel, 1985; Jaeger & Harelik, 1985; Fenves et al., 1987; Huuskonen & Kaarela, 1995; SMC, 2021; Han et al., 1998; NovaCITYNETS, 2002; Han et al., 2002; Haraldsen et al., 2004; Ding et al., 2006; AEC, 2006; Eastman et al., 2009; Tan et al., 2010; Fiatech, 2012; Kim et al., 2013; Lee et al., 2016; Dimyadi et al., 2018; Beach et al., 2020). These systems developed in the field of ACCC are generally country-based, and each system has been developed by their own countries, either by private or public institutions. In addition, although the target of all these systems is building regulations, many of them deal with specific regulations (fire, security, occupancy permit, zoning, wheelchair access regulation, etc.) or non-regulatory issues (design automation, bridge design, etc.). For example, Han et al. (2002) a simulation approach for accessibility control for the use of wheelchairs by persons with disabilities according to the American Disability Act (ADA); Eastman et al. (2009), on the other hand, the Design Assessment Toll (DAT) was developed for the circulation and security of courthouses in the USA.

In addition to the important studies carried out worldwide on automatic regulatory compliance inspection systems, there are limited academic studies in this field in Turkey (Balaban, 2012; Macit, 2014; Türkyılmaz, 2016; Yapıcı Topuz, 2018; Akbaş, 2019; Demir Altıntaş, 2020; Bayer, 2020; Balku, 2021; Işıklı Aktaş, 2021; Aydın, 2021).

According to the current academic studies in the literature, research on BIM-based automatic regulatory compliance auditing systems in many developed countries dates back years. As a result of these researches, there are many systems that have been developed and started to be used. However, these systems either took the legislation of the countries where they were developed as reference or allowed simple rules to be defined manually. Many developing countries such as Turkey have started to develop automatic regulatory compliance audit systems for their own building legislation in recent years; however, it has not been actively

implemented yet. When the studies are examined, it is seen that the developed systems are made within the framework of simple rules.

Aim of the Research and Methodology

In this study, it is aimed to introduce the program that automatically performs regulatory compliance audits of residential architectural projects drawn on the basis of BIM, according to the rules determined from the Turkish building legislation. This program named TRegCheck (Turkish Regulation Checking System) covers the floor height calculation, building coverage ratio (TAKS) calculation, Floor Area Ratio (KAKS) calculation, minimum building parking lot and shelter calculation rules selected from the Planned Areas Zoning Regulation (PAZR), Parking Lot and Shelter Regulations included in the building legislation in Turkey.

With the developed program, an automation system infrastructure will be created that will eliminate the time-consuming, error-prone, paper-based, and manual compliance inspection process of two-dimensional CAD projects drawn with traditional methods, and instead instantly evaluate and report the compliance of BIM-based projects according to the legislation. Thanks to the automatic regulatory compliance audit, the audit of the designed projects will be carried out in a short time and without errors.

In the study, first of all, the existing building legislation concerning the construction sector in Turkey was examined in detail and the rules that could be automatically checked for compliance with the legislation were selected from these legislations. Afterwards, drawing rules to be followed while creating BIM models were determined in order to perform automatic regulatory compliance checks over IFC data files of BIM-based building projects. At the same time, the content and relationships of the IFC data files of BIM-based building models were analysed. Thus, it has been determined where and in what order the data required for automatic regulatory compliance audits are generated in the IFC file. According to the information obtained, algorithms have been created in order to extract the necessary data from the IFC file and to carry out compliance checks for the determined rules. As a result, TRegCheck program, which is a program with an interface, has been developed, tested and its efficiency has been determined to demonstrate its effectiveness.

In this context, Figure 1 shows that TRegCheck program checks the rules of which legislation and which calculation subjects.



Figure 1: The rules that TRegCheck program checks.

Rules Selected from the Building Legislation and Reasons for Choosing

The rule sentences for the control of building floor heights in PAZR are simple and understandable. With these aspects, it is easy to integrate into the TRegCheck program and sets an example for the process and stages of adapting the controls of all other simple and understandable rules in the building legislation to the program. For example, floor height calculation and control has been chosen as an example of how this and similar type of rules can be controlled easily with a single rule expression such as door, window, corridor widths and do not have logical and computational relations with other rules.

In PAZR, KAKS is defined as "the ratio of the total of all the floor areas of the building to the area of the zoning plot", and the principles and rules for the calculation of KAKS are detailed in various parts of the building legislation. KAKS is the calculation subject that has the most complex and open to interpretation rules in the building legislation and is the most likely to make mistakes.

In PAZR, TAKS is defined as "the ratio of the floor area to the area of the zoning parcel", and the principles and rules for TAKS calculation are detailed in various parts of the building legislation. TAKS calculation was chosen because it has the most complex rules after KAKS calculation in PAZR and contains the most time-consuming and error-prone set of rules.

When we come to the minimum building parking area calculation and minimum building shelter area calculation rules, since these calculation rules have the rules based on the most logical relations between the various articles of the regulation and the annexes of the regulation, and checking these calculations takes more time and error-prone than the other rules in the relevant regulation. Minimum building parking area calculation and minimum building shelter area calculation rules were chosen because they contain a clear set of rules.

Creating BIM Based Building Models

Autodesk Revit software was used to create BIM models and IFC data files of building projects within the scope of the program. In order to carry out error-free compliance checks in TRegCheck program, a BIM model of a building must be created with the Revit program according to some drawing rules. All the determined drawing rules were given to 3 people, an interior architect, an architect, and a civil engineer, who can make BIM-based designs, and they were asked to design the building with Revit. In this way, the final version of the rules was created by correcting the incomprehensible, missing, or incorrect parts of the determined rules.

Analysis of IFC Data File

First of all, it is necessary to determine which data is needed from the IFC file of the BIM model in order to carry out the checks for the calculation rules selected from the building legislation.

Explanations on what data is needed from the IFC file of the building model in order to carry out automatic regulatory compliance checks for the rules of the calculation subjects selected from the building legislation with the TRegCheck program are given in Table 1.

Table 1. Information to be obtained from the IFC data file according to the calculation subjects selected from the building legislation in order to carry out compliance checks with the TRegCheck program.

Information from the IFC data file	**Calculation Topics**				
	Story height	TAKS	KAKS	Minimum building parking area	Minimum building shelter area
Story names	+	+	+	+	+
Story height values	+				
Floor building construction area names		+	+		
Floor building construction area values		+	+		
Zone (space) names		+	+	+	+
Zone (space) area values		+	+	+	+
Single space names		+	+	+	+
Single space area values		+	+	+	+
Tree data structure (Hierarchical structure)	+	+	+	+	+

In order to develop a system that performs automatic regulatory compliance checks of BIM-based building projects, it is necessary to analyse the IFC data file of the BIM model, that is, to know the file structure, the meaning of the data in the file and the relations of the data with each other. Because the necessary information about the building to automate regulatory compliance audits is contained in the IFC data file. This information, on the other hand, can be filtered with the software coding to be developed and extracted out of the file, and conformity checks can be made according to the rules determined within the building legislation.

As the drawing detail level of the BIM model of any building project created with Revit increases, the content volume of the IFC data file increases in direct proportion. Data lines with unique parametric encodings in the ".ifc" extension data file of each object such as columns, beams, walls, doors, windows, stairs, floors, and each feature such as the name and material defined for these objects, belonging to the BIM model created in Revit, and IFC entities are formed within these data rows.

Each IFC entity created in the IFC data file has a meaning, attributes that make up this entity, and relationships with other entities. For example, any location defined in the BIM model has a corresponding IFCSPACE in the IFC data file. Each part separated by commas between the two parentheses following the entity in the data line defines the attributes of that entity. Attributes of the IFC entity that start with # between the two parentheses refer to the entities in the relevant data rows in the file.

A view of the content of the data file with the ".ifc" extension of any building design whose BIM model was created with the Autodesk Revit program is shown in Figure 2.

The referencing structure in the IFC data file describes the order in which the components that make up the building come together. For example, the project consists of the land, the land from the buildings, the building from the floors, the floors from the quarters, columns, walls, doors, etc. It creates a tree data structure (hierarchical spatial breakdown) showing that it

consists of a sub-elements in the form of a tree. In the IFC data file, the tree data structure of the BIM model is formed by the IFCRELAGGREGATES entity.

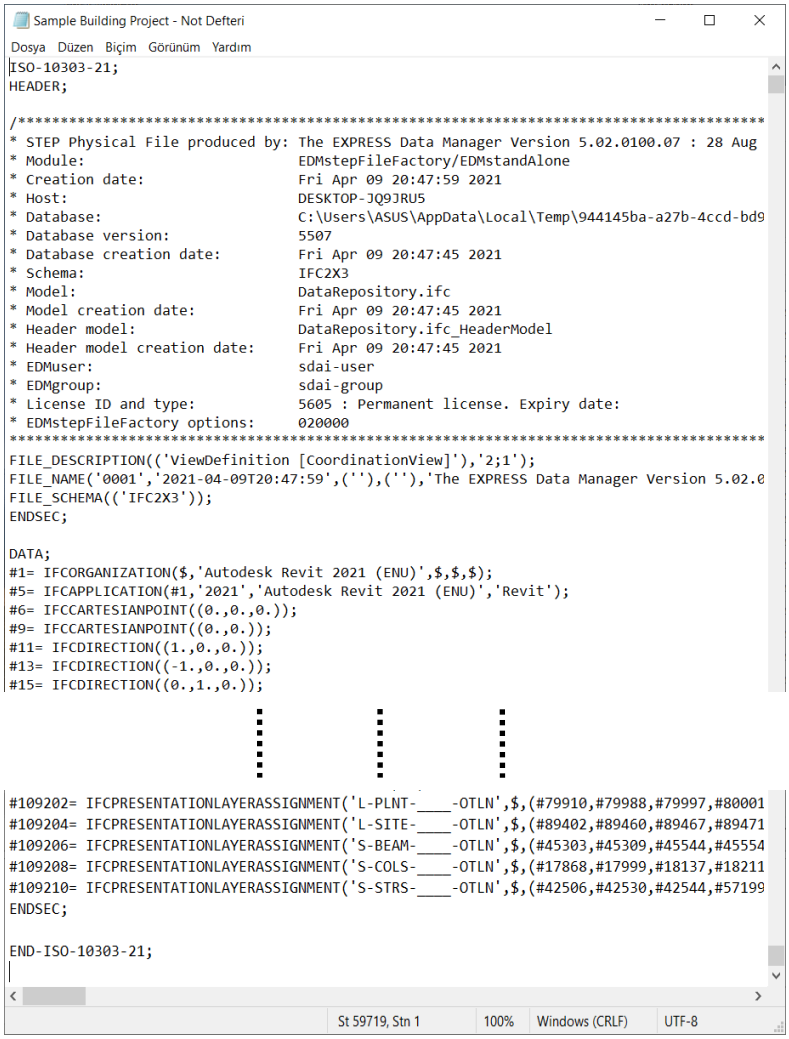


Figure 2: An example view of the ".ifc" extension data file.

If we talk briefly about the features of the IFCRELAGGREGATES entity:
- This entity consists of 6 attributes separated by commas between two parentheses.
- The 5th attribute defines which object to collect the elements,
- The 6th attribute indicates which elements will be collected.

The numerical information and properties of each element of the building modelled in Revit are accessed by the IFCRELDEFINESBYPROPERTIES entity in the IFC data file.
This entity consists of 6 attributes.
- 5th attribute to which objects or object the property definition will be applied,
- The 6th attribute refers to the set of properties that will be applied to the target object or objects.

In the floor plan of an example building project shown in Figure 3, the branching representation of how to reach the area value of 3.24 m² for the area named "BATH (BB01)" and which assets and which attributes are required are shown in Figure 3.

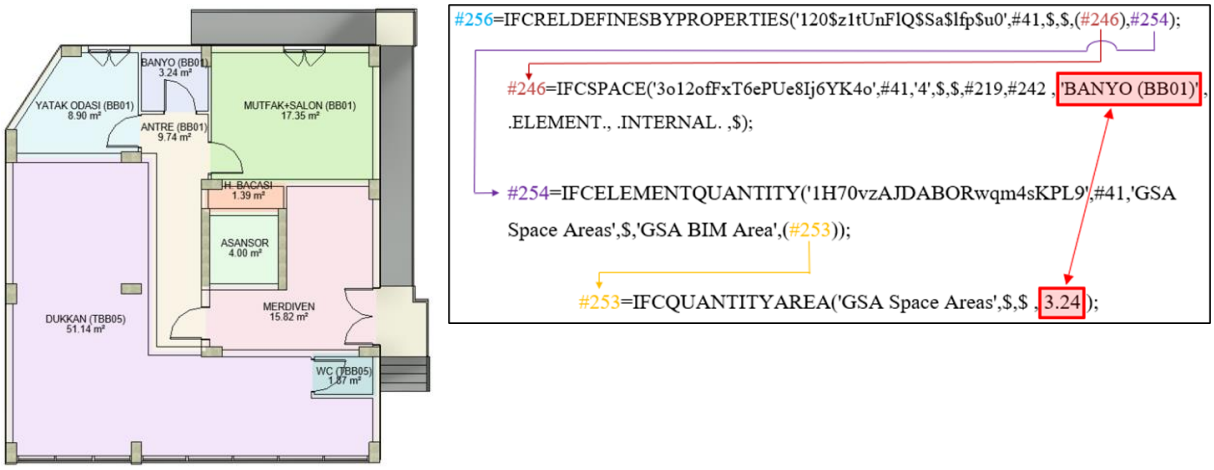


Figure 3: Branching display of how to reach the area value of 3.24 m² for the area named "BATH (BB01)" in the floor plan of a sample building project and which assets and which attributes are required.

Shortly, the desired data from the IFC data file of the BIM model can be transferred to the outside of the file with the software prepared by establishing algorithms based on these examinations described above. Thus, with the TRegCheck program for the control of the determined rules, the data of the BIM model, which is the most important step for automatic regulatory compliance control, is obtained.

Development of TRegCheck Program

The algorithms established for the software coding running in the background of the TRegCheck program were carried out in two stages. In the first step, in the Analysis of the IFC Data File section, based on the analysis and branching algorithms, all the lines in the IFC data file are read one by one within the scope of the information obtained from the IFC entities and relationships to be considered in the IFC data file, and the data lines containing the required IFC assets are automatically found from the IFC file. It is filtered out of the file and separated to be used in calculations and controls at a later stage. In this context, all IFC assets required from the IFC data file of BIM models are ".txt." extension Notepad files are filtered according to a certain order in order to retrieve the necessary data from the IFC entity. According to the algorithms performed in this way, all the data that should be taken from the IFC file of the BIM model were obtained by using the data in the lines separated in each txt file and in line with the relationships between the entities.

In the second stage, software operations were carried out by establishing algorithms for each calculation topic selected within the scope of the thesis for the realization of the calculation, audit and result reports of the TRegCheck program with the data obtained in the first stage.

A view of the Compliance Check/Data Entry section, which is opened when the Conformity Check icon is clicked on the vertical ribbon menu on the left after the user login of the TRegCheck program is given in Figure 4.

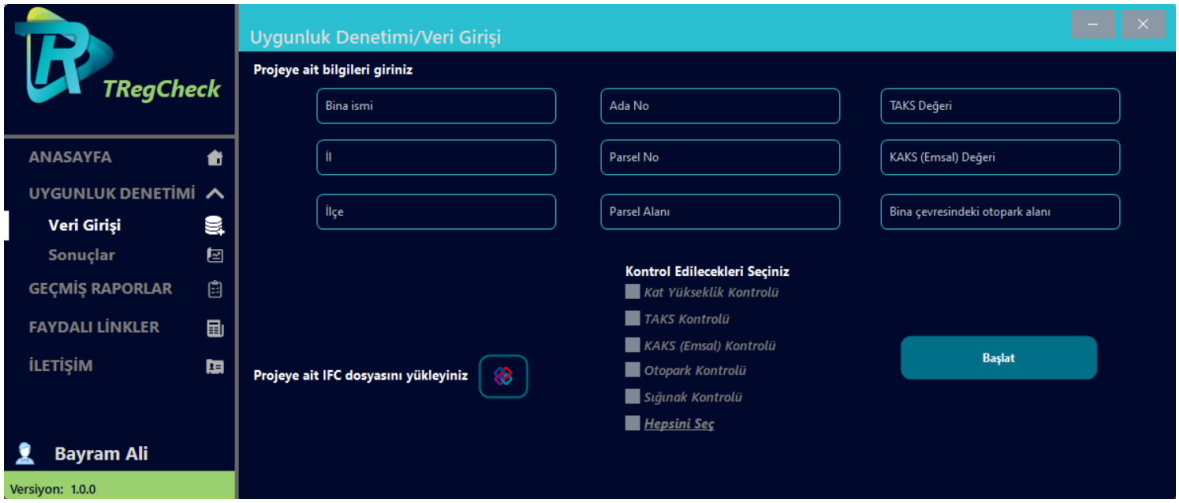


Figure 4: A view of the Compliance Check/Data Entry section of the TRegCheck program

In the data entry section, data entry cells where the information about the project to be checked for compliance will be entered; file upload section for uploading the project's ".ifc" extension file to the program; In order to determine which calculation rules the compliance audit is for, there is a selection section of the items to be checked and a Start button to start the compliance audit processes.

Testing the TRegCheck Program

At this stage, studies were carried out to test the TRegCheck Program, that is, to determine the accuracy of the results obtained from the compliance audits of the program. For this purpose, four building projects that had previously obtained construction permits were determined within the scope of the thesis and BIM models were created with the Revit program.

After the BIM models of the projects determined within the scope of the thesis were created with Revit, automatic regulatory compliance checks were carried out with the TRegCheck program over IFC data files, and both the program's operation was checked, and the calculation and audit results were obtained. Afterwards, these four building projects were manually calculated and checked in Microsoft Excel program. The results obtained both with the TRegCheck program and manually were the same.

Results and Discussions

With the TRegCheck program, the auditing process, which is more time-consuming, prone to errors, and carried out manually by traditional methods, can be carried out automatically within seconds and error-free for BIM-based projects prepared in the computer environment.

It is thought that manipulations and abuses encountered in compliance audits by municipalities will be reduced with TRegCheck, and pressure by third parties to approve building projects that do not comply with the legislation by the people working in the municipality.

With the TRegCheck program, convenience is provided for both architects and engineers at the design stage, and especially for those working in the municipality, in the automatic regulatory compliance inspection of buildings.

With the TRegCheck program, the building permit and building occupancy permit inspection will be carried out by the municipalities in a short time, and both the employees will lose less time in the project review task during the working hours and the demands of the citizens waiting for service will be answered earlier.

It is thought that the problems faced by designers and controllers in understanding the updated rules and not being able to follow the updated articles in the building legislation will be at the lowest level with the TRegCheck program.

Thanks to the developable and updatable feature of the TRegCheck program, the regulations for the control of the changing rules in the legislation and other rules to be selected according to the requests by the users will be easily defined by the program administrators to the system.

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Handling Imbalanced Data in Building Energy Benchmarking

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Abstract

The energy demand of the building stocks reached a critical value by almost covering 30% of the world's overall energy consumption. Therefore, the importance of building energy benchmarking gains importance. Building energy benchmarking might suffer from imbalanced datasets as a classification model. Using an existing dataset to observe the effectiveness of several machine learning models in predicting the energy benchmark label of the buildings in Seattle, several classification algorithms are first utilized to predict the buildings' energy benchmark label over an imbalanced dataset. Cost-sensitive loss functions and several decision thresholds are then introduced to the artificial neural network (ANN) models, and their effectiveness in handling imbalanced data is examined. Finally, several classification evaluation metrics are analyzed. The results display that the cost-sensitive approach with an empirical decision threshold slightly improved the loss of the ANN models and classification of the minority class. This study shows that the cost-sensitivity concept in ANN is a promising study field, and significant improvements in loss reduction can be achieved through empirical testing. Another prominent result is that machine learning could render building energy benchmarking possible at the urban scale as their results are repeatable for different scopes and regions. Therefore, this study underlines the importance of data-driven methods in district energy performance assessment.

Keywords: *automation in construction, building energy benchmarking, cost-sensitive learning, machine learning.*

Introduction

Building energy performance assessment emerges as a necessity considering the massive greenhouse gas (GHG) emissions caused by the built environment (Hong et al., 2020). Owing to the population growth and consequently the expansion of cities, the energy demand of the building stocks reached a critical threshold by almost covering 30% of the world's overall energy consumption (Ritchie, 2018). This brings the following questions: Is it possible to correctly forecast the consumption behavior of the built environment in urban areas, and if so, how to conduct the energy estimation of the urban building stocks with various characteristics? Even though the answer is ambiguous, one thing is certain that the digital twins of the urban building stock with the real-time consumption patterns would potentiate the sustainable environment practices over the retrofit and urban planning actions. Here, one of the essential actors is the building energy benchmark models. Building energy benchmarking is a process that evaluates the internal and external performance of a building

and whether the building complies with the relevant regulations (Ohlsson & Olofsson, 2021). This forms a classification task for the modelers with the features of the building's energy-related parameters and the target variable, showing the building's energy benchmark label. Classification models in machine learning suffer from imbalanced datasets. While training such models, the imbalanced distribution of the class labels might induce misclassification. This is due to the update of the model parameters occurs inevitably according to specific classes with numerical superiority (Khan et al., 2015). Despite the rapid advancements in the deep learning domain, the class imbalance problem, which is frequent in real-world data collection scenarios, remains challenging for most classification tasks. In the literature, the research on the class imbalance problem is investigated from two central angles: Data Level Approach and Algorithm Level Approach (Hou et al., 2021). In data-level approaches, balanced datasets are acquired via either oversampling the minority classes or undersampling the majority classes. On the other hand, algorithm-level approaches operate in the training phase and try to amplify the effect of minority class representation in the optimization process. Loss functions are critical components of every optimization problem, as they define an objective on which the model's performance is evaluated. Loss functions measure the overall distance, or error, between the estimated and actual value of a specific input set. Based on this evaluation, internal updates of the model weights are affected when performing backpropagation in artificial neural network (ANN) models. Depending on the scenario, different loss functions are used for developing a well-defined objective. Therefore, there is no ground truth in concatenating loss functions to algorithms in machine learning. The most important factors to be considered when deriving a loss function are the selected model, the optimization approach with the derivatives' property, and the dataset's characteristics. One of the most popular loss functions used in machine learning is cross-entropy loss, a metric used to evaluate classifier performance. However, as mentioned above, the cross-entropy loss might be paralyzed when handling imbalanced datasets. As an algorithm-level approach to dealing with an imbalanced dataset, cost-sensitive loss functions might be an alternative. The cost-sensitive approach minds the distribution of the class labels in a dataset and calculates the error of the model's prediction regarding those distributions (Takase et al., 2018). With this approach, cost-sensitive models can classify the datasets through a balanced training process. For example, Focal Loss, which is a modified version of the cross-entropy loss, down-weights the examples that are easy to train (majority classes) and focuses on learning complex examples (instances from minority classes) with tunable controlling parameters (hyperparameters) (Lin et al., 2017).

Using an existing dataset, this study analyzes the relationship between the building-specific parameters and the energy efficiency and performs the followings: (1) Data preprocessing is applied to remove the unnecessary features and outliers. (2) Several classification algorithms are then performed to predict the buildings' energy benchmark label over imbalanced data. (3) Cost-sensitive loss functions with several decision thresholds are introduced to the ANN models, and their effectiveness in handling imbalanced data is examined. (4) Finally, several classification evaluation metrics are analyzed to determine the optimal classifier.

Methodology

Data Preprocessing

A building energy benchmarking dataset was obtained from an open-source platform by the city of Seattle (2020 Building Energy Benchmarking, n.d.). The recordings are from 2020, with 3628 specific buildings and 42 energy-related features. Although there are similar datasets in the same platform between 2015 and 2019, the 2020 dataset reserves the richest content with more buildings and features. In the data imputation part, mean and median values of the relevant features were used to deal with the missing values of the numerical features, including the largest property use type and the site energy use. The categorical variables were then encoded into binary expressions since the classification algorithms could only work with numerical values. In this sense, the target variable, concluding whether or not a building is compliant for energy benchmarking, is transformed into one (1) for compliant and zero (0) for not compliant. The next topic was the distribution of the classes. In the dataset, 97.2% of the instances were compliant, while 2.8% were not compliant. This indicates that the dataset is highly imbalanced. Such imbalanced distributions might cause undertraining of the model for the minority class, zeros, since the model's parameters are destined to be updated according to the majority class, ones. To lessen this issue's effect, 60% of the classes with compliance statutes were removed from the model. The updated distributions were 93% and 7% for the compliant and not compliant classes. Even though the numbers are still imbalanced, decreasing the number of the dataset might induce additional problems. Plus, this study aims to observe the power of different machine learning models in handling imbalanced data. Therefore, the authors assumed this distribution well enough to perform the following classification task. Finally, the processed dataset was divided into the training and test sets as 25% of the data for testing purposes.

Model Development

The classification models examined in this study are as follows: Support Vector Machine (SVM), Multinomial Naive Bayes, Logistic Regression, K-Nearest Neighbors, Decision Tree, Random Forest, and Multilayer Perceptron (MLP). These classifiers have various settings and parameters that may lead to utterly different outputs. Therefore, automating the process and obtaining the best hyperparameter settings for each classifier was necessary. To do this, the grid search procedure was utilized. A grid search is a framework that analyzes the power of the machine learning models according to their hyperparameters enabling statistical calculations. It performs cross-validation over the distinct parameters and provides the users with the optimal settings. The grid search mechanisms were established for each model according to their characteristics, and the classification process was initiated. The analysis was performed in Python using the following libraries: ***Scikit-learn*** for the classical machine learning models and ***PyTorch*** for the MLP models.

The first model was the SVM Classifier. SVM models create a hyperplane that discriminates different classes in the best manner (Shalev-Shwartz & Ben-David, 2014). This separation is achieved using a loss function that maximizes the distance between each class's hyperplane and extreme data points. The regularization parameters and kernel types were the hyperparameters evaluated in the grid search. Here, the regularization parameters, ranging between 0.01-1.0, form the minimum threshold for the algorithm to make an accurate

prediction, while the kernel types (e.g., linear or polynomial) determine the numerical approach that the algorithm will follow. The second model was the Multinomial Naïve Bayes Classifier. The Bayes decision theory is based on observing the prior distributions of classes to derive posterior distributions. It is a very naïve assumption that the data dataset has a particular distribution and the features are statistically independent (Alpaydın, 2020). In the case of this study, neither the dataset had a particular distribution nor the features are not correlated. Therefore, the Multinomial Naïve Bayes model was employed since it can handle multinomially distributed data. Next, the Logistic Regression model was created and tested in the grid search. Logistic Regression models calculate the probability of occurrence of classes using the sigmoid function. The output for each class is a probability ratio. The model updates its parameters using the gradient of the calculated loss calculated between the output and the actual probabilities. The tested hyperparameters of the Logistic Regression were the regularization parameters, ranging from 0.01-0.6, and the solver parameters used in result optimization. The third model was the K-Neighbors Classifier. The grid search observed the following hyperparameters: the number of neighborhoods and the measurement tools for the weight and metric. The class label of a data point is determined according to the nearest points' label with a certain number of neighbors set in this classification model. The uniform or distance weights identify the method used in calculating the impact of the nearest data points on the observed data. Finally, the metrics, such as Euclidean, Manhattan, and Minkowski, indicate the methods used in calculating the distance between data points. The fourth model was the Decision Tree Classifier. Decision Trees are non-parametric models that evaluate the dataset in a hierarchical order. This means that the model sets some initial weights over the first observed data points, increases the number of weights, and updates their values as it progresses on more data points. Each iteration generates decision boundaries for the model (Hastie et al., 2009). The hyperparameters tuned in grid search were the criterion that calculates the loss of each split, the splitter strategy according to the calculated loss, and the class weights that balance the learning process. The Random Forest Classifier was the following algorithm analyzed through the grid search. The parameters observed in the mechanism were the number of estimators and the criterion types for data splitting. The number of the estimator, ranging between 10-100, is the number of trees (decision trees) created by the model to split the data points into clusters and measure the aggregated accuracy. The criterion parameters, such as the Gini Index and entropy, are used to detect the impurity level of the dataset (Hastie et al., 2009).

The final model was the MLP Classifier. MLP is the perceptron algorithm having multiple hidden layers. This is also called Artificial Neural Network (ANN) model. MLP functions differently than most other machine learning models. In MLP, features are evaluated as single sets (input layers) rather than the dataset as a whole (Figure 2). This enables MLP to update model weights in each iteration according to the loss calculated over the utilization of each input layer. This process is called Online Learning (Alpaydın, 2020). For a classification task in machine learning, let us say a set of x represents the inputs of a single instance, the set of w represents the corresponding weights, and the n represents the total number of data points, then the probability of each output y is calculated using Equation 1:

$$y_i = \sum_{j=1}^{n} w_{ij} x_j + w_{i0} \quad (1)$$

The weighted sums are then placed in activation functions that transform the relationship into a non-linear form. Following this path, the final process is to put the activated sums into the

final activation function, which will return a value specific to the aim of the analysis. For example, if the analysis is a regression, the final activation layer should return a linear value, whereas if it is classification, the final outputs might be a probability value for each class. After calculating the possible outcomes in forward-pass calculations, the MLP model determines the loss between the outcomes and actual values and updates the model parameters using Stochastic Gradient Descent. This is called backpropagation (Dong & Yang, 2018) (Jeewajee & Kaelbling, 2020). This update lasts until achieving a certain amount of convergence. In the grid search structure, several hyperparameters of the MLP model were tested to create a baseline model. The hidden layer size and the number of units in each hidden layer determine the complexity of the MLP model. In this study, considering the computational complexity, the authors decided to develop a simple layer setting with nine hidden units. However, an empirical analysis should be done with the advanced test setups to decide the optimal layer settings.

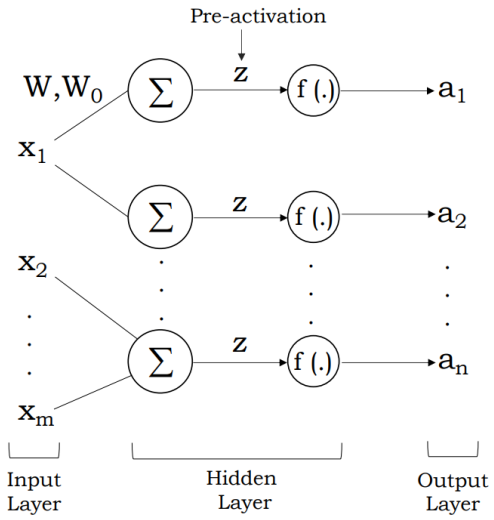


Figure 1: Multilayer perceptron (MLP) architecture.

Once creating a baseline architecture for the MLP, the aim was to increase the accuracy of the classification of the imbalanced dataset through a more advanced hyperparameter tuning. This tuning includes the following hyperparameters: the activation function, learning rate, weight initialization, momentum, and loss function. The activations functions were the sigmoid and tanh functions. Learning rate α is the parameter ranging between 0-1.0 that determines the scope of the update along with the gradient of the loss (Equation 2):

$$\Delta w_i = -\alpha \times \frac{\partial Loss}{\partial w_i} \tag{2}$$

To initialize the weights of the MLP, three different initializations were tested. The first was the random initialization that creates weights according to the Gaussian distribution with zero mean and one standard deviation. The second one is Xavier initialization which produces a uniform distribution with an exponential term based on the number of inputs (He et al., 2015). The last one is the He Initialization generating weights according to the Gaussian distribution, where the mean and standard deviation are both the square root of the input numbers (He et al., 2015). Weight generalization in ANN is a crucial topic since initial weights might have an enormous effect on the results. For example, a proper initialization might yield faster

convergence. On the contrary, randomly initializing the weight in deep networks might cause a vanishing gradient problem (Marion et al., 2022). When this happens, the model's loss stops improving, and the weights get stuck at certain values. Therefore, these three methods in weight initialization were tested in this study. Another hyperparameter tested in multiple scenarios was momentum. When the weights update for each iteration varies significantly from the others, the change in the model's loss exhibits fluctuant patterns. Momentum helps prevent this fluctuation and provides a stable convergence. The value for the momentum is usually taken between 0.5-1.0 (Alpaydın, 2020).

Finally, and most importantly, different loss functions were evaluated to understand the cost-sensitivity concept in ANN. The most common loss function for classification is the Cross-Entropy (CE) Loss. Assume that n is the number of classes, which is two in our case, r is the target (actual) label, and y is the predicted label. Then, the binary CE Loss for each iteration is calculated using Equation 3:

$$\text{CE Loss} = \sum_{i=1}^{n=2} r_i \times log(y_i) \tag{3}$$

CE Loss provides an efficient learning process for classification problems. However, when the data is imbalanced, the model cannot update its parameters according to the minority class, zeros. Even though the accuracy might be high, the cost raised by the misclassification of the minority class would cause some significant problems. For example, the effect of misclassification can be more evident in cancer detection (Qader et al., n.d.) or fraud detection in the banking sector (de La Bourdonnaye & Daniel, 2022). There are some cost-sensitive approaches in the literature accordingly. One of the most famous cost-sensitive loss functions is called Focal Loss (Lin et al., 2017). Focal Loss is created through an empirical process, and its assumption is based on a random constant updating the loss, called gamma γ (Equation 4):

$$\text{Focal Loss} = (1 - e^{-CE\ Loss})^{\gamma} \times CE\ Loss \tag{4}$$

To improve both the CE Loss and Focal Loss, two distinct class ratios were derived from the class distribution of the dataset: *one-ratio* (0.933) and *zero-ratio* (0.067). These ratios were then used in different loss functions. According to the efficiency of the tested functions, the authors chose to continue with only one loss function: Cost-Sensitive Exponential CE Loss (Equation 5):

$$\text{Cost-Sensitive Exponential CE Loss} = \begin{cases} CE\ Loss^{(1+zero_{ratio})}, & r = 1 \\ CE\ Loss^{(1-one_{ratio})}, & r = 0 \end{cases} \tag{5}$$

It should be remembered that the update of the ANN models is performed over the gradient of the loss, and the cross-entropy loss is a function of the model's pre-activated output. If the class ratios are introduced in the loss function as exponential terms, the gradient term would have two constants with two class ratios. In this case, on the assumption that z is the pre-activated output, and the target label r is one, the multiplier term aims to increase the loss where the exponential term gets negative and has a decreasing effect (Equation 6). However, as the class distributions are getting more imbalanced, this exponential term cannot decrease the overall loss but balance the increment of the loss caused by the multiplier. Thus, it might provide an adaptive and more balance learning process. The inverse effect of this assumption applies to the cases when the target label is zero.

$$\frac{\partial CE}{\partial w_i} = (1 + zero_{ratio}) \times f(z)^{(-zero_{ratio})} \times \frac{\partial f(z)}{\partial z} \times \frac{\partial z}{\partial w_i} \quad (6)$$

In addition to the loss functions, ANN models were equipped with different decision thresholds. In machine learning, estimations are made over probabilistic terms. In the case of binary classification, as in this study, the estimator determines the class labels if the occurrence probability of a class is bigger than the other. In other words, the instance is labeled according to the class whose occurrence probability is higher than 0.5. Considering our dataset is highly imbalanced, a 0.5 decision threshold might be useless. After experimenting with several scenarios, the authors decided to continue with a 0.65 decision threshold. This way, ANN models only make estimations when the calculated probability of the majority class (ones) is higher than %65. This might restrain the misclassification of zeros as the models favor ones only when they are confident.

Classification Evaluation Metrics

Evaluating the reliability of classification models with imbalanced data requires intense attention that is far beyond merely examining the accuracy of the results. This is because the models' behavior might result in favor of the majority classes. In such cases, as in our case, the class label of the truly and falsely predicted labels might be more important than the absolute accuracy of the model. Therefore, one should consult multiple evaluation metrics to comprehend the reliability of the classification. To that end, the authors read the classification results over the following metrics: Accuracy, F1 Score, and Brier Score Loss (Table 1). Lastly, confusion matrices were introduced as visual tools to summarize the classification, showing the truly predicted labels in the diagonals.

Table 1. Classification evaluation metrics.

Evaluation Metric	Formula
Accuracy	$\frac{1}{n_{samples}} \times \sum_{i=1}^{n_{samples}} \begin{cases} 1, & y_i = r_i \\ 0, & y_i \neq r_i \end{cases}$
F1 Score	$\frac{TP}{TP + \frac{1}{2}(FP + FN)}$
Brier Score Loss (Mean-Square Difference)	$p_i = \Pr(y_i = r_i)$ $\frac{1}{n_{samples}} \times \sum_{i=1}^{n_{samples}} (r_i - p_i)^2$

Results

In the first part of the analysis, six classical machine learning models were initiated with their optimal hyperparameters, and their performance in classifying the imbalanced dataset was observed. For each classification metric, including the Accuracy, F1 Score, and Brier Score, the Random Forest Classifier outperformed the other eight classifiers (Table 2). However, these metrics cannot be merely sufficient to interpret the misclassification of different classes. Therefore, the confusion matrices should also be examined.

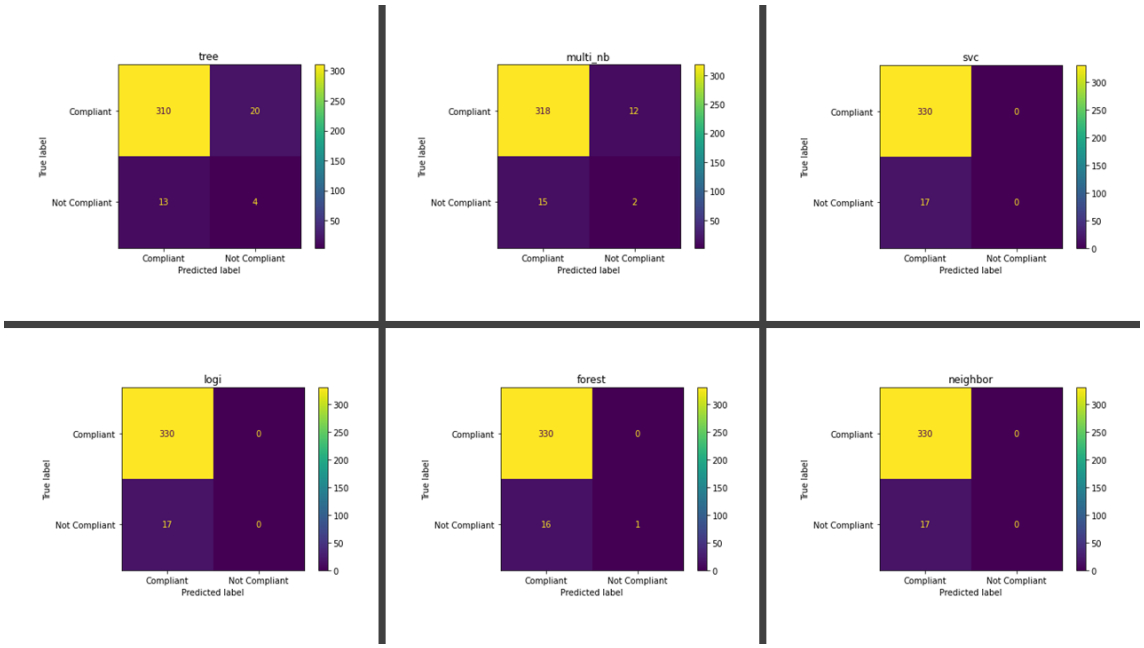


Figure 2: Confusion matrices of the classical models.

Even though the classical models exhibited satisfactory results in terms of standard evaluation metrics, it is seen that most models poorly predicted the labels of the minority class, zeros (Figure 2). These models falsely predicted most zeros since the models considered a specific distribution (e.g., Gaussian) and made estimations over the distribution parameters, where the assumed distribution was not perfectly Gaussian for each feature distribution. Plus, it was almost impossible to manipulate their framework in calculating the final loss. This is very natural because these models were trained based on the weights of the ones as they occurred almost fourteen times more than the zeros in the analysis. However, there are outliers for the classical models: The Decision Tree and Multinomial Naïve Bayes. These models performed slightly balanced in predicting different class labels. For example, the Decision Tree classifier faintly learned the weights in favor of the minority class, zeros, as it predicted four (4) true negatives (Figure 2). Nevertheless, it only predicted 310 true positives, significantly affecting the model's overall accuracy (Table 2). On the other hand, the MLP models were not the optimal ones in terms of standard evaluation metrics (Table 2). However, considering the number of true positives and true negatives, MLP models provided the most balanced distribution between classes (Figure 3). This is because the ANN structure enables modelers to conduct extensive hyperparameter tuning. In this study, an empirical analysis was performed for the hyperparameters of the MLP models, including the loss functions and decision thresholds. The MLP models were trained to classify labels for the benefit of the minority class, zeros. These models were integrated with loss functions that penalize the final loss when the instance label is one. This way, they can update the weights according to the minority class, zeros. Plus, an experimental decision threshold of %65 enabled models to make classifications only when they were confident. It should be noted that experimental decision thresholds were also assessed for the classical machine learning models. However, the authors did not record any improvement for the models with such an arrangement. In this context, it can be said that MLP models are more inclined to learn the instances from the minority class, zeros, owing to the cost-sensitive loss functions. Among the MLP models, the one with cost-sensitive exponential loss produced the best results. It predicted three (3) true negatives and 320 true positives (Figure 3).

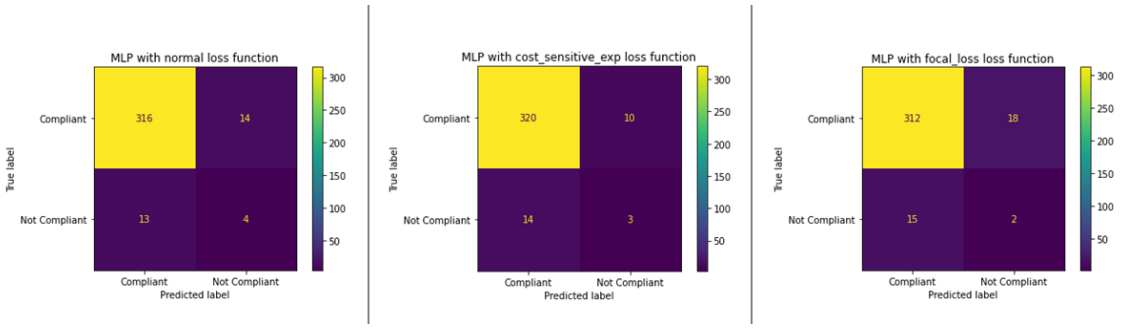


Figure 3: Confusion matrices of the MLP models with different loss functions.

Table 2. Classification results.

Classifier	**Accuracy**	**F1 Score**	**Brier Score**	**TP**	**FP**
Support Vector Machine	0.951	0.975	0.048	330	0
Multinomial Naive Bayes	0.951	0.975	0.047	318	2
Logistic Regression	0.951	0.975	0.047	330	0
K-Nearest Neighbors	0.951	0.975	0.052	330	0
Decision Tree	0.905	0.949	0.095	310	4
Random Forest	0.954	0.976	0.045	330	1
MLP with Normal Loss	0.922	0.959	0.105	316	4
MLP with Focal Loss	0.905	0.95	0.127	312	2
MLP with Cost Sensitive Exponential Loss	0.931	0.964	0.103	320	3

Discussion

This study utilized different classification metrics and confusion matrices to interpret the results. Among the classification evaluation metrics, the Brier Score Loss appears to be the most reasonable metric to compare the results. This is because the Brier Score evaluates the probability of the class labels that the models make and in calculating the loss. Such a loss value holds excellent insights into the confidence level of the models in making predictions. Hence, looking at the Brier Score Loss, it is evident that the Random Forest Classifier outperformed the other models in classifying the building energy benchmark label. However, considering the estimations on the minority class, the MLP models, especially the one with cost-sensitive exponential CE loss, exhibited the most balanced distribution between classes (Figure 3). In this sense, it is evident that MLP models are powerful in handling imbalanced datasets.

This study contains some limitations. The first one is the lack of computational power. When developing MLP models with optimal hyperparameters, more than 300 million scenarios can be tested over several hyperparameters, including the learning rate, initialization type,

activation functions, number of epochs, momentum, hidden layer size, and loss functions. ANN is a nascent field that offers independence in performing empirical studies. This makes it possible to improve the model's predictive capacity via hyperparameter tuning. However, in this study, only a limited number of scenarios were tested on the model's hyperparameter settings. The authors believe the results could display remarkable improvements with sufficient computational power. The other limitation is the size of the dataset. Available datasets are separated into training, validation, and test sets in machine learning studies. At first, the model is trained using a training set, and its performance is observed over the validation set. This part generates the validation curve (Figure 4), which is very helpful in analyzing the change in the loss calculated for each epoch. Once the optimal hyperparameters are determined, and the model is trained once more using these hyperparameters. The trained model's weights are then used to analyze the model's performance over the test set. This is the final process where the analysis report with the accuracy curve (Figure 4) is published using the test results. In our case, the original dataset had around 3300 instances. This number was reduced to around 1400 instances to balance the class distribution slightly. Due to the limited data and, more importantly, the size of the minority class (zeros), this study only divided the datasets into training and test sets. Then, the test set was both used in model validation and testing. This assumption forms an internal consistency for the results as it can represent the training and test sets fairly. However, when new instances are appended to the model, the predictions might not cover the actual labels, and thus the generalization capacity of the model might suffer. This suggests that the dataset should be big enough to be divided into training, validation, and test sets to provide an external consistency for the model's results.

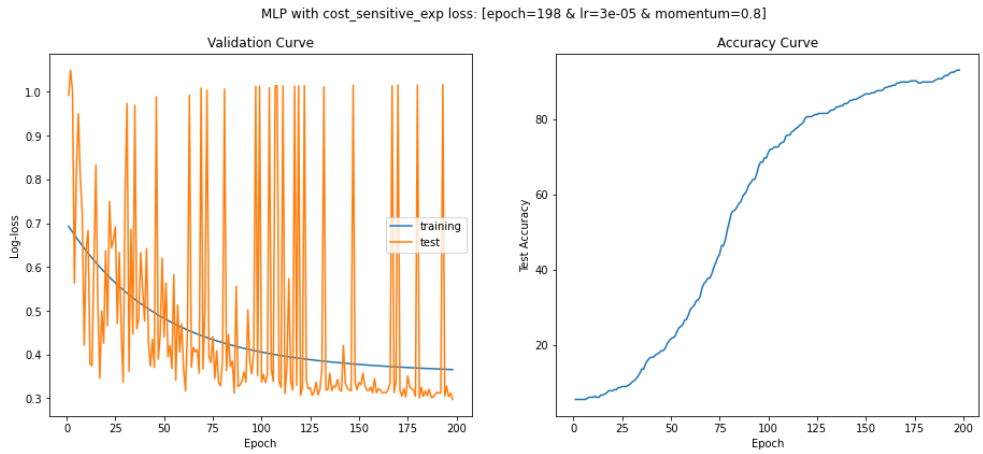


Figure 4: Validation and accuracy curves of the MLP model with cost-sensitive exponential CE loss.

There is a significant fluctuation in the validation curve in Figure 4. Most features in the dataset do not have the Gaussian distribution, and they include many outliers. This complicates the accurate prediction of the labels with the parametric approach, analyzing the distribution parameters (e.g., mean and variance) and making estimations accordingly. Moreover, the size of the test set is significantly small. When the variance of the test set is high due to the small number of samples, the trained model cannot fit the test set, and steady patterns in the loss reduction cannot be observed for the test set. This explains the oscillation in the validation curve. Creating synthetic data to increase the number of samples or employing non-parametric methods, which do not require information derived from the feature distributions, might solve this problem.

Conclusion

Building energy benchmark labels were predicted via several classification models in this study. Six different machine learning models were tested with their optimal hyperparameters settings, which were automatically found via the grid search. The MLP models were then manually examined to decide on the best hyperparameters. Here, the most significant part was to analyze the power of different cost functions in handling imbalanced data. To do this, three MLP models were integrated with different loss functions. Overall result interpretation was performed using different classification metrics. Here, the Random Forest was the best model from the point of the standard evaluation metrics (Table 2), where the MLP models were the winning models in truly predicting instances from the minority class, zeros (Figure 3). This study showed that the cost-sensitivity concept in ANN is a promising study field, and significant improvements in loss reduction can be achieved through empirical testing. Even though the number of accurate predictions for the minority class by the cost-sensitive loss functions is not great, the assumption of this study can be comprehensible and enhanced with a large dataset. Therefore, a possible future work of this study could be working with a large dataset to decrease the variance between training and test sets and increase the generalization power of the classification. Another future work could be utilizing an advanced computational configuration to conduct extensive hyperparameter tuning for the MLP models. This study also showed that machine learning models could make accurate building energy benchmarking. Therefore, this study underlines the importance of data-driven methods in district energy performance assessment.

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Contributions of Augmented Reality Applications During Sustainable Building Life Cycle

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Abstract

Completion of the projects in the construction industry within the predetermined quality, time, and costs both ensures the achievement of the project goals and supports sustainable development. The length of manufacturing and usage processes in the construction industry causes the industry to intervene the environment too much. Therefore, sustainable development is also important in the construction industry. "Augmented Reality" is defined as the enrichment of real-world products, systems or environments by making use of virtual data. Augmented reality applications while widely used in many industries such as education, health and manufacturing, it has only recently been used in the construction industry. The purpose of this study; to reveal the contributions of the use of augmented reality applications during the construction phase in the sustainable building life cycle. Within the scope of the study, augmented reality applications under construction were examined. SWOT analysis was carried out with the samples examined and the results of the analysis were evaluated together with the sustainability goals. As a result of the study, it has been revealed that augmented reality applications during the construction phase are in line with the goals of the concept of sustainability.

Keywords: *augmented reality, building life cycle, sustainability, swot analysis.*

Introduction

Multidisciplinary structure of the construction industry; requires cooperation and coordination. Each step depends on the previous action step, and it affects the next action step. The correct and efficient implementation of construction activities from start to finish is dependent on this cooperation and coordination. For this reason, the margin of error should be as low as possible, and compliance should be ensured between approved projects and implementation projects. Hence, project manufacturing processes can be completed within the anticipated time and cost, with high quality. In addition to all of these, construction industry is one of the industries with high energy and resource consumption when compared with other industries. When the usage process of the resulting product is taken into consideration, it is understood how long the activities of the construction industry affect the environment in which it is situated. Increasing environmental problems have revealed the requirement for a sustainable approach in the construction industry as well as in every other field (Huovila & Koskela, 1998). Adopting sustainable construction principles, starting from the design stage of the buildings, throughout their lifetime and beyond will contribute to sustainable

development processes (Kibert, 2005). In addition, that the limitation of the natural resources, energy and raw material is a global problem, so this shows that the adoption of sustainable development is a necessity. For this reason, ensuring sustainability in the construction industry is becoming a global goal (Gökçe et al., 2018).

Augmented reality applications are defined as enriching real-world products, systems, or environments by using computer-assisted data and presenting them to the user experience; While it is widely used in many industries such as education, health and manufacturing, it has only recently been used in the construction industry (Altınpulluk, 2015).

It can be stated that the augmented reality applications in the construction industry are in line with the sustainable construction goals in terms of ensuring the compliance between the approved project and the application project, protecting the resource consumption with the least intervention to the environment, and contributing to the field of occupational health and safety. In the literature, there are various studies on sustainability in the construction industry (Geçim, 2018; Hoşkara, 2007; Huovila & Koskela, 1998; Kibert, 2005; Sev, 2009; Şenel, 2010). Some studies have also addressed augmented reality applications in the building industry (Arslan et al., 2019; Behzadan & Kamat, 2009; Behzadan & Kamat, 2013; Chen et al., 2013; Chi et al., 2013; Fazel & Izadi, 2018; Kwon et al., 2014; Lee et al., 2011; Park et al., 2013; Talmaki et al., 2010; Tsai, 2014; Wang, 2007; Wang & Dunston, 2007; Wang et al., 2013). However, there is not enough study in the literature that deals with sustainability and augmented reality applications in the construction industry together. Hence, the purpose of this study is to reveal the contributions of the use of augmented reality applications during the construction phase in the sustainable building life cycle. Within the scope of the study, the augmented reality applications that are used in the construction industry were examined and SWOT analysis was made about these applications. Sustainable building life stage is examined in three stages: pre-construction phase, construction phase and post- construction phase. Scope of the study were determined as the construction phase applications in the building phase. It is important to state that augmented reality applications are related to their contribution to the construction phase and sustainability goals.

Material and Method

The purpose of this study is to reveal the contributions of the use of augmented reality applications in the construction phase of the sustainable building life cycle consists of 4 stages. In the first stage, the concept of "sustainability" has been discussed and the concepts of "sustainable architecture" and "sustainable construction" were mentioned in relation to the concept of sustainability. Building life cycle, being one of the three principles of the concept of sustainable construction, has been examined. Concepts of traditional building life cycle and sustainable building life cycle, which are two different approaches in the building life cycle, are explained and the importance of sustainable building life cycle is emphasized. Within the scope of the study, the "construction phase", which includes construction site applications, was discussed within the scope of the "construction phase", being one of the phases in the sustainable building life cycle. In the second stage, the concept of augmented reality was explained and augmented reality applications in the construction industry were discussed with examples. In the third stage, SWOT analysis was performed by the authors according to the second stage analysis. Within the scope in the SWOT analysis, only augmented reality applications were evaluated during the construction phase. In fourth stage, results of third stage and first stage were evaluated together.

Concept of Sustainability

The concept of “sustainability” has the meaning of "continuity" and "sustainability", which was first discussed on a global scale at the United Nations Conference on Environment and Development held in Stockholm in year 1972 and entered the literature at this point (Durmuş, 2010). The concept of sustainability, which deals with the need to evaluate "environment" and "development" together, was defined by the World Commission on Environment and Development (WCED) in year 1987 as "the ability of humanity to continue with its development with the needs of present generations without compromising the needs of future generations" (WCED, 1987).

The concept of sustainability has three dimensions as economic, social and environmental. The situation where all three dimensions can be evaluated together is defined as the most ideal situation (Sev, 2009). Environmental sustainability is an approach purposing to protect the natural environment as much as possible and to interfere with it at the least. Environmental sustainability is to leave the earth to future generations in a much better way than its current state (Sev, 2009). Social sustainability means leaving the necessary resources to the future so that future generations can protect and sustain their existence by ensuring equality between generations. According to this understanding, both the needs of today's societies will be met and the right to life of future generations will be protected. (Sev, 2009; Şenel, 2010). Economic sustainability is defined as providing high performance growth by using less resources against increasing population and industrial manufacturing. Economic sustainability is related with ensuring a regular public and private investment flow with effective use and management of resources, evaluating economic efficiency with social criteria instead of operating profitability (Hoşkara, 2007; Sev, 2009).

The concept of sustainable architecture came to the fore within the scope of sustainable development. In addition to the manufacturing of design and construction processes with a certain time, quality and cost, it also anticipates that the buildings should be environmentally friendly, consuming less energy, not polluting the environment, and increasing the quality of life of the users. The concept of “sustainable construction” that emerged in this case is defined as the equivalent of sustainable development in building design and construction. Sustainable construction offers a holistic approach to the construction and management of the built environment together with the building life cycle framework (Şenel, 2010). The concept of sustainable construction is considered as a response given by the construction industry in the sustainable development process (Huovila & Koskela, 1998). Sev (2009) specified that design and construction in sustainable architecture is comprised of three basic principles: resource management, life cycle design and design for human beings. This study focuses on the construction phase in the building life cycle.

Building Life Cycle

In the traditional sense, the building life cycle is a linear process consisting of design, construction, use-maintenance, and demolition stages (Geçim, 2018). In the traditional approach, as factors such as the environmental effects that occur during the material construction phase of the building life cycle, the lack of waste management, and the ignoring of recycling after the use phase are realized, in the building life cycle, the need for a

sustainable approach has emerged. In the concept of sustainable building life cycle, the environmental effects and consequences of all processes, from the acquisition of resources in nature to their return to nature after their useful life is over, are taken into account. The principle of sustainable building life cycle is based on the understanding that resources can transform from one form in which they will be beneficial to another form in which they will be beneficial and that their useful life can continue without ending (Şenel, 2010).

The life cycle of a structure is examined in three phases as pre-construction, construction, and post-construction. The pre-construction phase is comprised of stages of design, construction phase; construction and use, and post-construction phase is comprised of stages of destruction and recycling in the post-construction phase (Sev, 2009). Within the scope of sustainable architecture, the methods that should be applied at the construction stage in the building life cycle can be listed as reducing the impact of construction site works and equipment on the environment, waste management, preventing environmental pollution, ensuring the health and safety of workers in construction, using non-toxic maintenance and repair materials, and choosing materials that will not harm the health of users. (Sev, 2009; Şenel 2010).

The construction phase, that starts with the phase where the building is produced in the building life cycle process is the process that continues with the use of the building (Şenel, 2010). During the construction phase, considering that the structure is built permanently and has been in use for many years, it can be said that this phase has an important place in the sustainable building life cycle.

Augmented Reality

Augmented reality is achieved by enriching real-world objects and spaces through virtual items produced in computer systems. As Altınpulluk (2015) quotes from Craig (2013), Augmented reality is not just a technology, it is an environment that contains some components and values and has artistic and philosophical value. From this perspective, it can be stated that defining augmented reality only as technology is equivalent to limiting the possibilities of augmented reality.

In the theory which Milgram and Kishino (1994) name as “Reality-Virtualism Continuity”; the concepts of virtual reality, augmented reality and mixed reality are expressed (Figure 1). While there is a world that we perceive with the naked eye without using any hardware at one end of this continuum, there is a completely computer-generated world at the other end (Arslan et al., 2019). As per these concepts, virtual reality (VR) can be defined as an environment encountered in computer-based three-dimensional games, where the user's relationship with the world completely disappears when he enters this environment. Augmented reality (AR) can be expressed as an environment that maintains its connection with the real world, where data and images can be added to real world images and enables real and virtual objects to be perceived together in the same environment (İçten & Bal, 2017b). While virtual reality is based on the virtual world, augmented reality is based on the real world (İçten & Bal, 2017a).

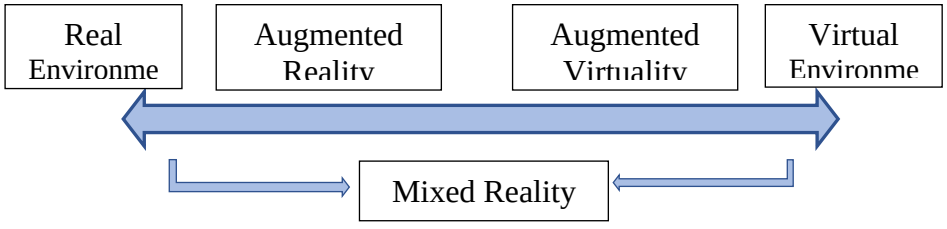


Figure 1: Milgram's reality-virtuality continuity (İçten & Bal, 2017a).

Augmented Reality in Construction Industry

Although the studies on the application of augmented reality technology in the construction industry have increased in the last few years (Li et al., 2018; Wang, 2007), the construction industry is one of the industries that have not used this new generation technology adequately, yet (Arslan et al., 2019).

As quoted by Arslan et al. (2019) from Van Berlo et al. (2009), augmented reality can be used in 3 main categories being on-site experience, on-site verification and on-site warning system. With on-site experience, it is possible to predict how a building will be settled in the place where it will be built before it is constructed, with the conditions and geography surrounding it. With on-site verification, a 3D building model is fitted with a virtual image on the constructed building relative to a given reference point. Hence, it can be controlled whether the application project is compatible with the designed project or not. With the on-site warning system, in the presence of potential hazards at the construction sites, the warning signs on the construction site become more attractive and their safety can be increased by being warned as necessary. With the use of augmented reality by means of these three methods, the suitability of the project for its purpose, the harmony between the approved project and the application project, the quality of the application project, its compatibility with its environment, and occupational health and safety can be managed effectively in real time (Arslan et al., 2019). In Figure 2, on-site experience, on-site verification and on-site warning system and augmented reality application examples are seen respectively.



Figure 2: Respectively; on-site experience, on-site verification and on-site warning system and augmented reality application examples (Arslan et al., 2019).

As quoted by Arslan et al. (2019) from Hammad (2002), Hammad has developed MARSIFT for site engineers and technicians working on infrastructure projects and checking the location of structural members. By means of this system, the necessary information can be obtained in real time within the scope of the work to be done depending on the users' locations and duties. The use of augmented reality applications in the planning of virtual construction site environments was revealed by Wang (2007). Wang predicted that with augmented reality, planning errors could be prevented, and productivity will increase in this process. Again, Wang and Dunston (2007) purposed to train the operator in a real construction site equipped with real construction equipment, virtual materials, and virtual targets, instead of impractical real field training, with the augmented reality model called ARTS which they developed. One

of the situations frequently encountered during excavation works at the construction site is related with the damage occurring in relation to infrastructure systems. In order to minimize negative situations, Behzadan and Kamat (2009) integrate augmented reality and GPS; They superimposed live video of real images with CAD models of infrastructure facilities. Thus, the equipment operator will be able to view the virtual images of the infrastructure systems in real time at the real excavation site and ensure that the excavation operations are carried out without damaging the infrastructure systems. As quoted by Arslan et al. (2019) from Han (2009), Han (2009) created a formula according to OSHA standards, arranged augmented reality over real pictures and used it for occupational health and safety training. Talmaki et al. (2010) used augmented reality applications to increase the safety conditions of workers who were excavating in the city. Lee and Akın (2011) aimed to increase the field performance of construction equipment with the AROMA-FF model they developed by using augmented reality applications. Again, as Arslan et al. (2019) quoted from Zhao (2012); Zhao (2012) used augmented reality applications to prevent electrical accidents in construction works. As Arslan et al. (2019) quoted from Kim et al. (2012), Kim et al. (2012) modelled the possible scenarios of construction equipment on construction sites with augmented reality applications and predicted that these models could provide potential improvements in the construction planning process. Chen et al. (2013) designed a program called SAVES with augmented reality applications. In this program, firstly, various risks in the construction site were determined and classified. Afterwards, a model of the construction site was prepared with building information modelling (BIM) and was used to raise awareness of workers on occupational safety with various training scenarios. Behzadan and Kamat (2013) organized occupational health and safety training targeting civil engineering students by making use of augmented reality applications. Park et al. (2013) developed a security management and visualization system (SMVS) by integrating augmented reality, GPS, BIM and gaming technologies. In this way, it is purposed to be aware of the accidents that may occur at the construction site and to avoid the accident. Chi et al. (2013) investigated potential future application areas of augmented reality applications in the construction industry. According to the results of the research, it is stated that the use of mobile devices will be more effective and cost-effective in the future, and the applications of augmented reality applications on these devices will increase. A model where augmented reality applications are integrated with BIM, was put forward by Wang et al. (2013). In this model, it is focused on how augmented reality applications can realize real-time communication on construction sites. Tsai (2014) developed a system called MERIS. This system includes the workers working in the open air to ask for help with their mobile phones when they are faced with a dangerous situation or work accident. The research conducted by Kwon et al. (2014) is one of the studies carried out for quality control in construction projects. With this system, it is purposed to control the dimensional errors of the construction site productions during the construction phase. Kwon et al. (2014) stated that the limitations of augmented reality applications can be avoided by adapting more advanced technologies to the system. Fazel and Izadi (2018) built modular surfaces on construction sites by using augmented reality applications. Figure 3 shows the modular surface construction at the construction site.

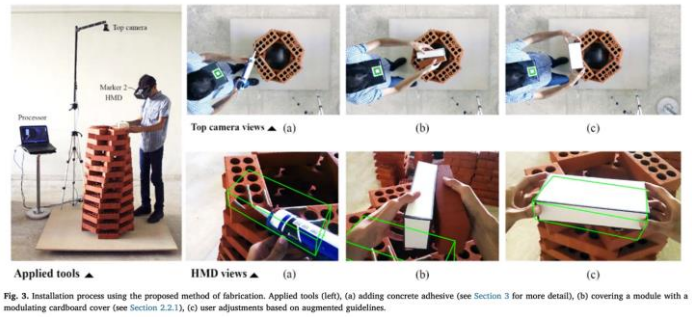


Fig. 3. Installation process using the proposed method of fabrication. Applied tools (left), (a) adding concrete adhesive (see Section 3 for more detail), (b) covering a module with a modulating cardboard cover (see Section 2.2.1), (c) user adjustments based on augmented guidelines.

Figure 3: Construction of modular surface construction at the site (Fazel & Izadi, 2018).

Arslan et al. (2019) have developed a system that will minimize errors during the application phase of the project with the combination of point cloud display and AR application. Figure 4 shows the overlapping of the approved project and the application project in real and virtual environments.



Figure 4: Overlapping of project applied with approved project in real environment and virtual environment (Arslan et al., 2019).

Results

In this section, SWOT analysis of augmented reality applications was made during the construction phase. SWOT analysis was performed by the authors in line with the examined samples. SWOT Analysis is a technique used to identify the strengths and weaknesses of the institution, organization, project, or situation where the analysis will be conducted, and to identify opportunities and threats that may arise from the external environment (Erol, 2019). In this study, a SWOT analysis was carried out in order to reveal the current situation of augmented reality applications within the scope of the construction industry. The current contributions of augmented reality applications constitute the strength of the system. Strengths benefit the operation of processes and the whole industry. Weaknesses are aspects that need improvement and can take their place in the system as strengths when developed. Opportunities reveal other possibilities that can be achieved Through augmented reality, in a sense, it reveals the potential of augmented reality applications. The threats indicate situations where action should be taken beyond the weaknesses of the system. Strengths, weaknesses, opportunities and threats of augmented reality applications in construction are discussed in line with the examples included in the study. Table 1 shows the results of the SWOT analysis.

Table 1. SWOT Analysis.

STRENGTHS	WEAKNESSES
• Ability to view the building model in real time • Ability to quickly and accurately detect errors between the approved project and the application project • Real-time alignment between the approved project and the application project • Minimum margin of error • Progress in project construction processes without the need for on-site solutions • Less control needed in approved project-application project processes • Minimal intervention to the land • To be able to complete occupational health and safety training more effectively • To be able to benefit from occupational health and safety measures more effectively	• Due to being a new generation technology, encountering various technical problems • Continuously meeting the energy needs of the devices • The need to transfer data to the system correctly • The margin of error is related to the user experience
OPPORTUNITIES	**THREATS**
• It is predicted that the use of augmented reality applications in the construction industry will become widespread in the future and will become more specialized according to the needs. • Facilitating multidisciplinary studies • To be able to benefit from advanced technology opportunities in the construction industry efficiently • Contributing to the technology-human relationship in the construction industry • Setting an example for other industries	• Decrease in employment • Software security requirement • Being open to technological vulnerabilities • Excessive reliance on technology • The need to adapt to constantly renewed technology • Obligatory dependence on technology • Difficulty returning to previous systems in case of failure to adapt to updated technology and devices

One of the strengths of augmented reality applications under construction is the real-time viewing feature, which is one of the main features of augmented reality applications. In this way, real-time visualization of the building model is provided. Through real-time imaging, the differences between the approved project and the application project are detected quickly and accurately, and high-quality construction can be achieved with minimum error margin. Again with the real-time viewing feature, real-time viewing is provided between the approved project and the application project. With the rapid detection of differences between the approved project and the application project with augmented reality applications, progress is achieved without the need for an on-site solution based only on the application. The need for less control in the project manufacturing process is also one of the strengths of augmented reality applications. With the use of augmented reality applications during the application of the building to the land, it is possible to interfere with the land at minimum level. Again, in the field of occupational health and safety, it is possible to complete the trainings in real time and in a wide variety of scenarios with low cost and shorter time, and to benefit from occupational health and safety measures more effectively. All of these constitute the strengths

of augmented reality applications in the construction industry. Through these strengths, it is possible to complete the projects within the stipulated time and cost, with high quality.

In addition to all these strengths, augmented reality applications in the construction industry also have weaknesses. Due to the new generation technology, various technical problems can be encountered. In addition, meeting the constantly existing energy needs of the devices can be considered as one of the weaknesses of the system. The more accurately the data is transferred to the system in augmented reality, the more smoothly the processes will proceed. For this reason, it is very important to transfer the data to the system correctly. As errors in data transfer will cause for augmented reality applications to affect the accuracy of the results, precision required in data transfer is also one of the weaknesses of the system. User experience is also one of the factors affecting the results of augmented reality applications. This is because of the fact that the margin of error depending on the user experience can also be counted as one of the weaknesses of the system. Elimination of all these weaknesses will increase the strengths of the system.

Existing applications of augmented reality applications in the construction industry also includes potentials for the future. These potentials can be considered as opportunities for augmented reality applications in the construction industry. For example, it is foreseen that the use of augmented reality applications in the construction industry will become widespread in the future, as in every industry, and it will become more specialized according to the needs. With the widespread use of augmented reality applications in the construction industry, it can be counted as an important step for efficient use of advanced technology opportunities in the construction industry and for digital transformation in the industry. In this way, it is foreseen that it will contribute to the human-technology relationship in the long run. Just as augmented reality applications in other industries set an example for the construction industry; In the future, the construction industry will set an example for other industries.

Apart from the above-mentioned strengths, opportunities and weaknesses that need to be eliminated, there are also threats to consider. With the spread of augmented reality applications in the construction industry, there is less need for people and the decrease in employment constitutes one of the risks. With the widespread use of technology, being open to technological vulnerabilities and ensuring software security are also factors that threaten the system. With the widespread use of technology, it is possible for the workers in the field to rely too much on technology and accordingly become more insensitive about the tasks they have to do and the precautions they should take. The need to adapt to the constantly renewed technology and depending on this technology, the difficulty of returning to the previous systems in case of not adapting to the updated technology and devices are among the factors that threaten the system.

Discussion

With augmented reality applications during the construction phase, high quality construction, cost and time completed within the stipulated limits, it is ensured that the construction activities reach their targets efficiently. Staying within the scope of the foreseen cost and time also provides benefits such as preventing unnecessary resource use and minimal intervention to the environment. Behzadan and Kamat (2009); have shown that the excavation process can be advanced by minimally intervening in the field with the augmented reality applications they applied during the excavation works. Chen et al. (2013) have revealed that occupational

health and safety measures can be implemented effectively by using augmented reality applications. In this and similar studies in the literature, it is seen that augmented reality applications contribute to the effective resource use phase. Since the effective use of resources is among the principles of sustainable construction, it can be said that augmented reality applications contribute to sustainable construction through their strengths.

Since augmented reality applications are still new technologies in the construction industry, encountering technical problems has been identified as the weakness of these applications. In addition, it is necessary to work meticulously at every stage to reach the end product of augmented reality applications without errors. In this case, user experience is very important. In their study, Kwon et al. (2014) have revealed that user experience affects the end product. With the development of technology, elimination of technical problems and meticulous work in the use of the system, the weaknesses of augmented reality applications can evolve into strengths. It is thought that it will contribute more to the principles of the sustainable building phase by evolving the weak aspects into strengths.

When sustainable building phase principles are associated with the opportunities of augmented reality applications in construction, it should be considered that augmented reality applications are still developing technologies. In the future, as technology develops, augmented reality applications will also be developed, and their contribution to the construction phase in the construction industry will increase and become more efficient. In their study, Fazel and Izadi (2018) have revealed that they have succeeded in providing construction with less margin of error with augmented reality applications. In addition, in the application phase of projects with augmented reality applications, Arslan et al. (2019) have demonstrated that construction compatible with the approved project can be achieved. The increase in the use of augmented reality applications in the construction stages with the developing technology in the future will prepare a common ground for the stakeholders participating in the industry from many different fields. This holistic approach that augmented reality applications provide to the construction phase can be associated with the holistic nature of sustainable building phases.

With regards to the sustainable building phase principles, when augmented reality applications under construction are associated with threats, the need to become dependent on technology and to be technologically secure comes to the fore. In all the examples examined, it is seen that the augmented reality applications contribute to the construction phase with the technological infrastructure. It is predicted that with the spread of augmented reality applications in the construction industry, commitment and dependence on technology will increase. While augmented reality applications are used in the construction phase and are developed in line with the sustainable building phase principles, these threats should also be taken into consideration.

Conclusion

In this study, regarding the contribution of augmented reality applications to the construction phase within the scope of the sustainable building life cycle, academic studies examining augmented reality applications in the construction phase were examined and a SWOT analysis was made. As a result of the study, it has been determined that augmented reality applications during the construction phase have significant contributions to the building phase in terms of time, cost, and quality within the scope of the sustainable building life cycle. Although

augmented reality applications have contributed to the construction phase, the technological weaknesses and threats that emerged as a result of the SWOT analysis should also be considered.

This study reveals that augmented reality applications during construction contribute to the field within the scope of sustainable building life cycle. The limitation of the study is the construction stage in the building phase within the scope of the building life cycle. Dealing with the subject throughout the cycle or at different stages would provide a different perspective to the field.

There isn`t enough study in the literature that deals with the relationship between augmented reality applications in construction and sustainability. Therefore, it is thought that revealing the relationship between the augmented reality applications in the construction phase and the sustainability building life principles could contribute to the field of science.

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Using Web Crawling for Risk Assessment of International Construction Projects

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Abstract

Obtaining timely and accurate host country information is vital for an effective and successful country risk assessment of international construction projects. This information may appear in the form of unstructured textual data such as news, editorials, reports, and official documents and could be extracted from documents available on the Internet. There are several methods of acquiring country data for use in the assessment process. These contain tedious processes and necessitate qualitative and quantitative assessments that depend on hundreds of factors. Getting current and accurate information is required throughout the project's lifecycle. However, current country risk models may fail to properly contain countries' continually changing economic and political environment, especially in the construction industry. Furthermore, it mainly relies on subjective appraisal and is prone to subjective interpretation, misunderstanding, and biased judgment. In order to minimize human errors and to facilitate the country risk assessment, an automated process can be utilized. Despite the promising results of previous approaches to automating the process of extracting useful information and facilitating information retrieval processes, there is insufficient research on the country information acquisition from the Internet for country risk assessment. This research questioned effective country risk acquisition methods and proposed usage of web crawling. In this paper, the web crawling algorithm, designed for repetitive actions so that browsing is automated, was explained, and its potential for country risk assessment was discussed. A demonstrative case was given to reveal its benefits and challenges. Utilization of web crawling is expected to contribute to collecting and organizing the latest and most accurate country information and facilitate an in-depth understanding of country-related documents.

Keywords: *automation, country risk assessment, international construction, web crawling.*

Introduction

Information is the most significant input for any assessment process (Lehner & Maier, 2000). For an effective and successful country risk assessment of international construction projects, obtaining timely and accurate host country information is crucial. The related country information and the knowledge can be in different formats (in the form of structured and mostly

unstructured textual data). These data could be extracted from the documents in companies' databases, from institutes that provide country-related information, and from the documents available on the Internet (e.g., news, articles, editorials, research papers, interviews, reports, and official documents) (Moon et al., 2018; Shin, 2015; Pathirage et al., 2007).

There are various methods for gathering country information for use in the assessment process. Specifically, documents from the Internet may be utilized as one of the most valuable resources for an effective risk assessment of a country (Pathirage et al., 2007). As a result of the rapid growth of the Internet, a large amount of country data has been collected, and the volume of the related country data is continuing to increase over time (Shin, 2015; Hjelt & Björk, 2006). On the other hand, manually obtaining timely, precise, and accurate information about host countries from the Internet can be challenging, contain tedious processes, require qualitative and quantitative assessments that depend on hundreds of factors, also is prone to errors (Moon et al., 2018).

Despite the promising results of previous approaches to automating the process of extracting useful information and improving information retrieval processes, there is insufficient research on information acquisition from the Internet specifically for the country risk assessment. An automated process of gathering data from Internet websites (i.e., web crawling) needs to be utilized to minimize errors and facilitate the country risk assessment. While some research has been carried out on web crawling for the construction industry, no studies have been found focusing on using web crawling in country risk assessment. This research aims to propose web crawling as one of the emerging technologies for effective country risk identification to get a better country risk assessment process. In this paper, first, web crawling and its procedure were explained, and then the potential of web crawling was discussed. Finally, a demonstrative example was illustrated to explain how country-related data is automatically retrieved by web crawling.

Web Crawling

A web crawler (also referred to as a robot or a spider) is a program that automatically collects and stores Webpages' content from the Internet. It automatically searches information pertinent to a selected particular subject by visiting/navigating the Web on demand while keeping the indexes (Pinkerton, 1994; Cho, 2001; Olston & Najork, 2010).

Basically, the web crawling procedure has two parts: list page parsing and target page parsing, which can be seen in Figure 1 (Manning et al., 2008; Moon et al., 2018). The list page parsing process includes retrieving target pages' URLs from the Web. Following this step, the actual data on the webpage (data from target pages), which is built using Hypertext Markup Language (HTML), is retrieved throughout the target page parsing process. (Moon et al., 2018). This process is based on accessing page content via HTML, a standard language to define the structure of websites' content. HTML assigns each element a certain tag on a web page. Thus, the crawler may extract particular information from the target elements as long as it is able to access the website's structure (Moon et al., 2018).

In other words, when a set of URLs is provided, all of which are kept and prioritized, the web crawler visit all web pages addressed by those URLs and collects hyperlinks from those pages. It downloads the webpages' content iteratively until it finally stops when the predefined criteria are satisfied (Cho, 2001; Olston & Najork, 2010).

In more detail, a web crawler performs according to several policies, including a "selection policy" that sets out which pages to download, an "e-visit policy" that specifies when to check for page changes, a "politeness policy" that defines how to prevent overloading Web sites, and a "parallelization policy" that specifies how to coordinate distributed web crawlers. (Castillo, 2004).

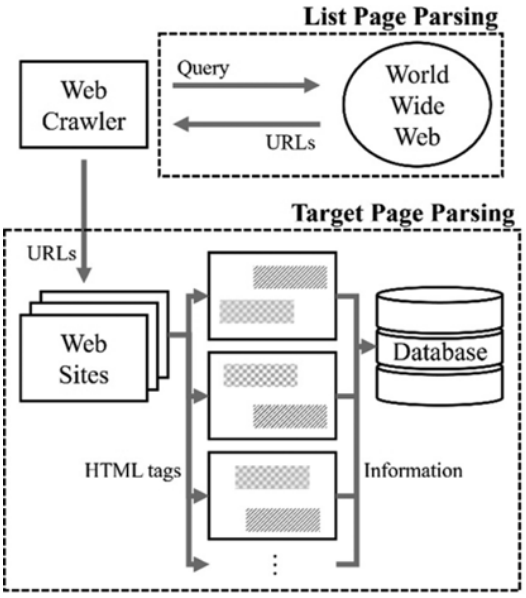


Figure 1: Procedure of Web Crawling (Moon et al., 2018).

Related Work

Web crawlers have had a variety of uses, commonly as a Web search engine, since the 1990s (Patil & Patil, 2016). General-purpose crawlers (e.g., Historical web crawlers, in-house web crawlers, commercial web crawlers, open-source crawlers), their architectures, and the implementation details which are out of the scope of this paper, have been frequently discussed in the related literature. As the main focus of this paper, potential applications of web crawling in the construction management area are investigated.

Although extensive research has been carried out in general, the potential of web crawling is not revealed yet in the construction research area, and there have been only a limited number of studies. The amount of data on the Web relating to construction has rapidly expanded due to a significant increase in construction-focused websites. Thus, it is not easy to identify and gather up-to-date Internet data relating to the global construction market; therefore, automated data collection methods are required to accelerate the procedure and benefit the construction sector.

To date, study of Moon et al. (2018) is the only study on utilisation of web crawling for international projects. They have attempted to investigate the usage of web crawling algorithms to obtain country information. They created a construction document management system for information acquisition of international construction projects for global contracts. They sought to gather the most recent information on the target country in the international construction market in a timely manner. Therefore, they utilized the web crawling algorithm in their developed system to promptly acquire text data that includes the latest information.

Kim et al. (2021) explored patterns and causes related to fire accidents on construction sites. Through web crawling and deep learning approaches, they identified the fire accident factors in construction accidents using news media data (i.e., news reports) on various fire accidents on construction sites. Hong et al. (2019) focused on sustainable development issues and green building certifications, mainly related to information management of building materials. They presented an automated approach for gathering and categorizing Green Building Material Information (GBMI) utilizing web crawling and ontology to increase productivity, improve work efficiency, reduce human mistakes, and decrease the time needed for material information management. Jeon et al. (2021) focused on the Purdue Indicator for Construction (Pi-C), a composite index comprised of five factors to examine the situation of the construction sector and support/assist data-driven decision-making. They stated that there are still missing in Pi-C. To find new metrics for the development and quality factors of the Pi-C, they developed a Latent Dirichlet Allocation-based method. To this end, they employed a web crawler to gather more than ten thousand abstracts of research papers from academic search engines. Dou et al. (2019) presented a new media-driven metric for the prefabricated construction (PC) industry's level of development in China. They claimed that the absence of PC-related statistics might prevent related study, so data gathered from new media (e.g., Weibo and WeChat) may be utilized. As a result, they used web crawling and text segmentation using Python programming language in order to get index data. Zhou et al. (2021) reported that the majority of building codes are kept in unstructured text-based documents and introduced a method that automatically acquires and formalizes building codes and transforms them into a knowledge graph representation. Web crawling was performed in their study to obtain building codes from the Web automatically.

So far, very little attention has been paid to implementing web crawling as a method for identifying country risks to assist the *country risk assessment* process in international markets. Within the scope of this research, potential usage of web crawling was investigated for the assessment of country risks considering the information about the global market. A demonstrative example is illustrated below to explain how web crawling automatically obtains country-related data.

An Application of Web Crawling

A hypothetical case will be used to demonstrate how web crawling can be used for country risk assessment. It is assumed that company professionals want to investigate country conditions to understand what and how country-related factors may affect project success or lead to failure. Therefore, they need to assess identified country risks considering the country-specific information. In a traditional way, company professionals enter and browse all related websites one by one, to find a particular information and then enter the retrieved information down on a spreadsheet manually, which is tedious, time-consuming, also prone to mistakes. In this example, rather than manually searching and collecting the necessary country data, web crawling was used which would provide a more efficient and faster way.

It is assumed that responsible departments such as risk management, business development or bidding identified the URLs of websites where country-specific information exists. Beautiful Soup, a popular Python library for pulling data out of HTML, was used (Hajba, 2018). Two data sources were chosen for demonstrative purposes: International Monetary Fund (IMF) website and The World Fact Book in Central Intelligence Agency (CIA) website, considering

that they address up-to-date and comprehensive country-related data regarding the international construction market. XPath expressions were used in this example to easily find any element in an HTML DOM page.

In this example, information on “climate”, “location”, and “projected real GDP (% Change)” were planned to be extracted from the data sources, identifying “Turkey” as the country in which the case company aims to collect information about. First, the selected country-related web pages and their URLs were determined by investigating the structure of the web page (in HTML). Then, by inputting URLs and XPaths, the programmed web crawler accessed each data page, parsed and processed the webpage to “crawl” the target data needed, and then collected relevant data from the page. Finally, the data was saved in a CSV format to be more readable in Microsoft Excel. Each website’s data extraction date ranged from 21 March 2022 to 01 Sep 2022. The screenshots of the webpages that were used for data sources (Figure 2, Figure 3, and Figure 4) can be seen below.

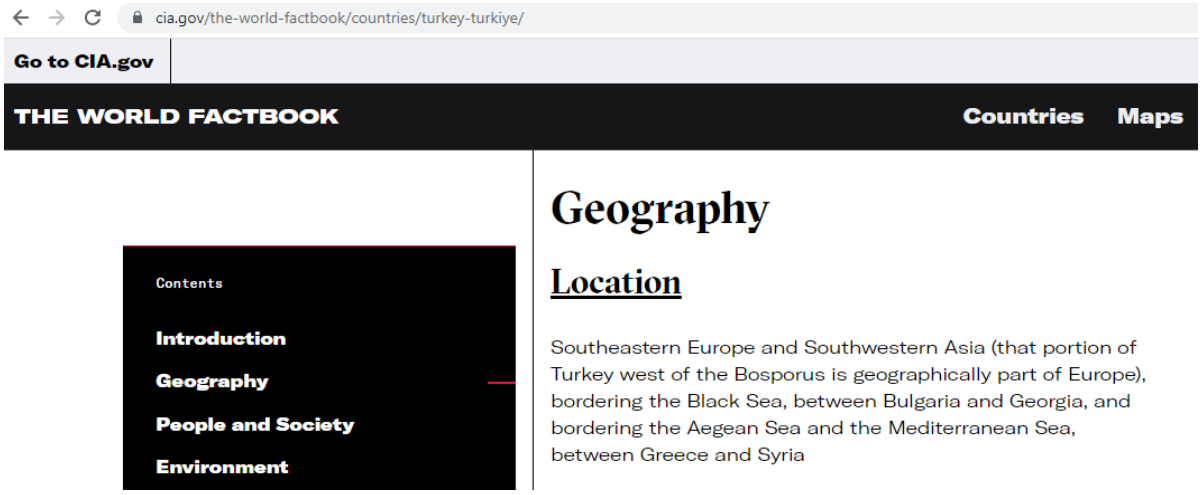


Figure 2: Information on the “location” from CIA website.

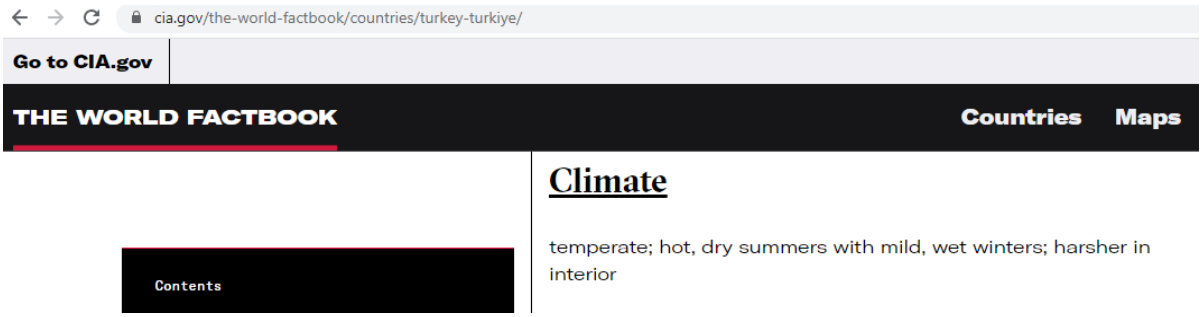


Figure 3: Information on the “climate” from CIA website.

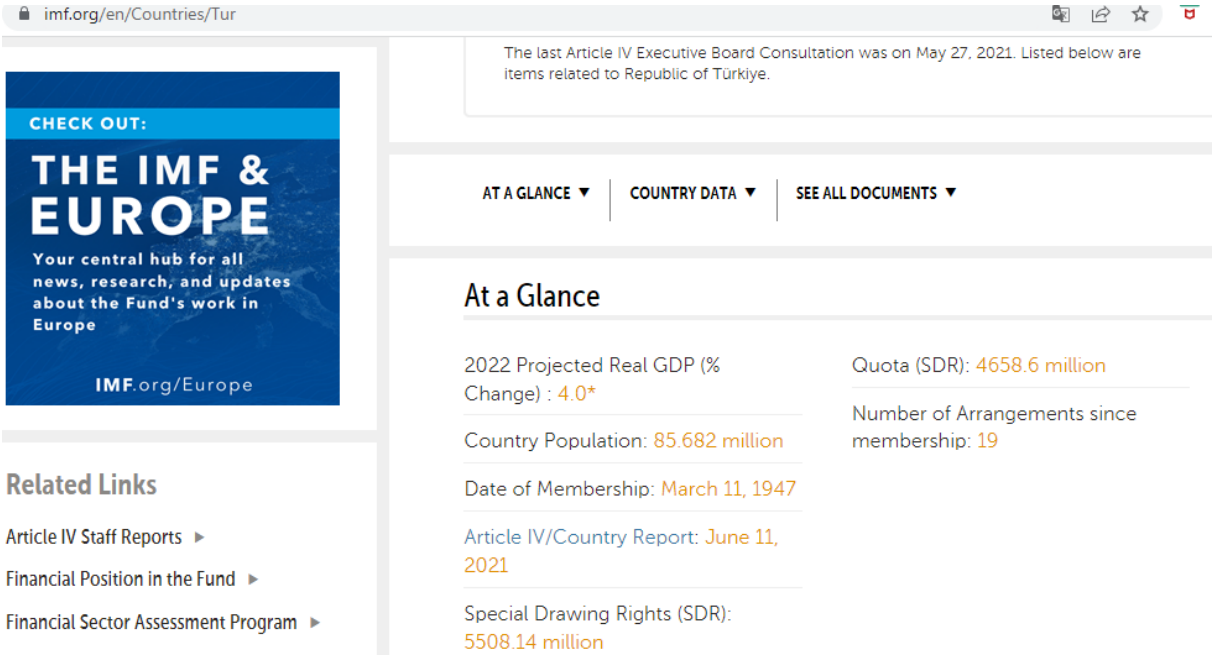


Figure 4: Information on the "projected real GDP (% Change)" from IMF website.

The output of this simple example is given below (in Table 1) to be used in the country assessment process to help users to understand the country's current situation.

Table 1. The output of web crawling, for the example of Turkey.

Country	**Turkey**
Location	"Southeastern Europe and Southwestern Asia (that portion of Turkey west of the Bosporus is geographically part of Europe), bordering the Black Sea, between Bulgaria and Georgia, and bordering the Aegean Sea and the Mediterranean Sea, between Greece and Syria"
Climate	"hot, dry summers with mild, wet winters
GDP (% change)	4.0

Web crawling may help company professionals to gain access to the information of several countries at the same time, in case there is more than one target country and make comparisons. To demonstrate this, the web crawling algorithm was used to get information from multiple countries, URLs of the websites were formatted using text placeholders to be replaced of specific country codes (e.g., IND for India and DZA for Algeria).

When the URLs of the data sources websites and country codes were supplied to the web crawling algorithms, the web crawler generated results of related countries' data. The output of multiple countries was received and grouped in an automated manner. Comparative results are presented in Table 2.

Table 2. Comparative results of Algeria and India.

Country	Location	Climate	GDP (% change)
Algeria	"Northern Africa, bordering the Mediterranean Sea, between Morocco and Tunisia"	“arid to semiarid; mild, wet winters with hot, dry summers along coast; drier with cold winters and hot summers on high plateau; sirocco is a hot, dust/sand-laden wind especially common in summer"	2.4
India	“Southern Asia, bordering the Arabian Sea and the Bay of Bengal, between Burma and Pakistan"	“varies from tropical monsoon in south to temperate in north"	7.4

Similar comparative tables could also be prepared considering data that belongs to different years to see the trends. It is apparent that more data would be needed for risk assessment such as political, economic and social indicators, which can be easily done using the same web crawling algorithm.

Discussions

The hypothetical case study demonstrates that, by using web crawling, searching on websites and extracting the related information from the related webpages can be performed automatically among the massive amount of information existing on the Internet.

In order to use the data automatically gathered with web crawling for the purposes of risk management, first a country risk taxonomy should be defined, and then indicators corresponding these risks should be identified. After determining the web sources that contain data/information about these indicators, web crawling can be used to automate information gathering process and facilitate risk assessment. For example, the data about climate can be used to assess “weather risk” and location can be used to assess accessibility and logistics risks. Similarly, % change in GDP can be used as an indicator of economic conditions whereas a time series of GDP values could be used to assess economic stability. More research is needed about potential utilisation of web crawling for risk management purposes.

Conclusions

Acquiring recent and accurate information is highly required, especially for the country risk assessment of international construction projects under countries’ continually changing economic, social, and political environments. Up to now, automated data gathering through web crawling has not received much attention in the construction management literature. Similarly, the application of web crawling for use in *country risk assessment* of international construction projects has not been investigated.

By employing an automated web crawling process, useful information during international construction projects could be extracted, collected, sorted, and analysed systematically. Besides, it can be repeatedly updated and utilized at any time in construction phases by the construction companies' professionals.

We assert that, rather than manually gathering country data, web crawling can be more efficient and faster. It facilitates the planners and managers to review web pages in the country risk assessment, which enhances the project management processes. In the example in this paper, only three country information categories ("climate", "location", and "projected real GDP (% Change)") were selected to demonstrate how web crawling could be employed easily. More comprehensive applications could be made, and more studies on how web crawling may be used to support risk-informed decisions can be conducted in future studies.

Web crawling may appear to be a good method of breadth-first-search; however, there are various difficulties and concerns, such as management of very large data structures, the decision of what pages the crawler should download as data sources, and the frequency of revisiting the content sources in the web pages (Olston & Najork, 2010). Furthermore, the HTML structure of the selected websites may change, and/or data retrieving may be blocked/restricted by the webpage server provider. In addition, finding the answers to theoretical questions of web crawling implementation might also be another issue for construction company professionals. Additionally, designing a robust web crawler may be challenging since the data on the Web is large, and continually growing.

In this study, attention has been paid to copyright issues. Similarly, while applying web crawling in the future, websites and the target data should be selected with due consideration to copyright. The web crawler method in this paper required the data based on human input, which determined the necessary details. In the future, web crawlers could be commonly utilized more automatically and properly.

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Application of IoT Technology on Health and Safety in Construction

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Abstract

A new technology concept, Internet of Things (IoT), has drawn a significant interest in several industries. This technology is a network of sensors, actuators, or machines to facilitate real-time communications between these items in the environment of computer applications. The construction industry may have a great potential to experience IoT's advantages in several aspects. However, studies on IoT in the construction industry are relatively new. The purpose of this research is to analyze the IoT technology and its application in the construction industry from the perspective of health and safety issues. To this aim, a detailed literature review was conducted, and current applications of IoT on health and safety implications were revealed. Thus, the results obtained are expected to be beneficial for both industrial practitioners and academic researchers to adopt the IoT technology and to improve the health and safety performance of the construction industry.

Keywords: *construction industry, health and safety, internet of things.*

Introduction

The Internet of Things (IoT) has been widely investigated with the development of sensor technology and wireless internet. This technology interconnects intelligent objects or devices such as sensors, communication devices, and computing devices through wired and wireless communication networks to collect, share, and utilize information without human intervention (Kim et al., 2019). Moreover, the IoT is a network of sensors, actuators, or machines to facilitate real-time communications between these items in the environment of computer applications. It has been applied to many industries such as health care, production logistics, manufacturing, and mining, as well as the construction industry (Yeo et al., 2020). The construction industry may have a great potential to experience IoT's advantages in several aspects. It is a novel technology and has a potential to be used in the construction industry to improve several issues under the construction management topic (Arslan et al., 2019). However, studies on IoT in the construction industry are relatively new. IoT network technology has been applied in various types of workspaces such as warehouses, exhibition centers, and commercial buildings, however, there is a lack of discussions on the application of this technology to the construction site in terms of health and safety (Chung et al., 2020). Although various IoT technologies have been studied for safety management, their applications on construction sites have stagnated (Yeo et al., 2020). The purpose of this research is to analyze the IoT technology and its application in the construction industry from

the perspective of health and safety issues. To this aim, a detailed literature review was conducted, and current applications of IoT on health and safety implications were revealed.

The IoT Concept

IoT is a network of physical objects. The IoT concept was coined by a member of the Radio Frequency Identification (RFID) development community in 1999, and it has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics (Patel et al., 2016). IoT is a connection of three things: (i) people to people, (ii) people to machine/things, (iii) things/machine to things/machine. The goal of the IoT is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service (Fig. 1).

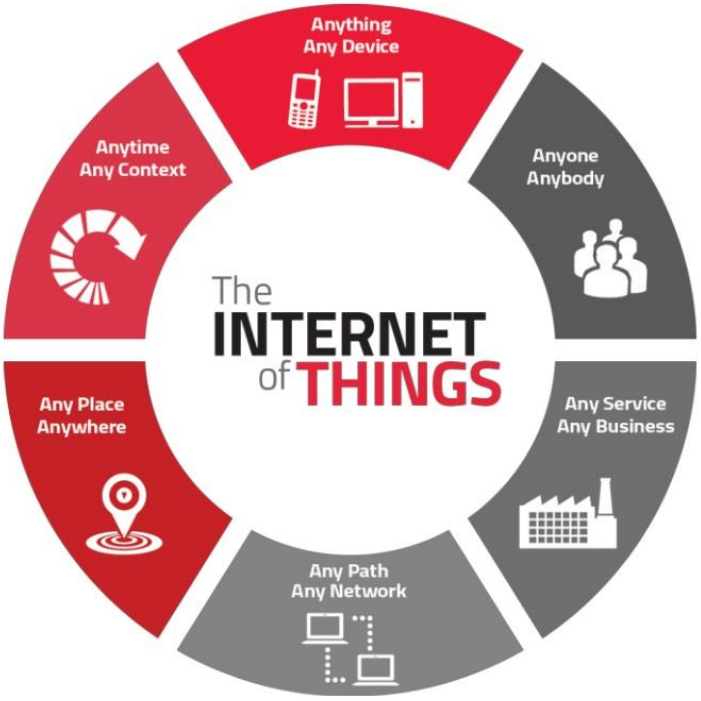


Figure 1: The IoT concept (URL 1).

IoT architecture consists of different layers of technologies. Sensor layer is the lowest layer and made up of smart objects integrated with sensors. The sensors enable the interconnection of the physical and digital words allowing real-time information to be collected and processed. Gateways and Networks layer is a robust and high performance wired or wireless network infrastructure as a transport medium in order to process produced massive volume of data by these tiny sensors. Current networks, often tied with very different protocols, have been used to support machine-to-machine networks and their applications. The management service layer renders the processing of information possible through analytics, security controls, process modeling, and management of devices. Lastly, the IoT application layer covers smart environments in domains such as: transportation, building, city, lifestyle, retail, agriculture, factory, supply chain, emergency, healthcare, user interaction, culture and tourism, environment and energy (Vermesan & Friess, 2014).

Literature Review

Jiang et al. (2013) introduced wireless network and built a security supervision system based on the IoT, which is an effective way to solve a series of problems in the present construction site safety supervision. The construction safety supervision system based on the IoT is constituted by construction site monitoring device, the construction site wireless signal transmission, server platform where site lead, and access internet network.

Sui et al. (2014) researched the monitoring and safety early warning technology of bridge health aiming at the bridge safety, based on the perception, transmission, knowledge, and application of IoT. The system of the monitoring and safety early warning of bridge health consists of data acquisition system in the outfield, the service system of data center, and application system. The general idea of constructing the model of monitoring and safety early warning for the bridge health is evaluating different working state according to the different categories of bridge structure (double curved arch bridge, rigid arch bridge, beam bridge) and the monitoring value in different parts, to make an objective assessment and early warning.

Zhong et al. (2014) proposed a practical application combining a WSN and the IoT in the construction industry, named as Safety Management System for Tower Crane Groups (SMS-TC) (Fig. 2).

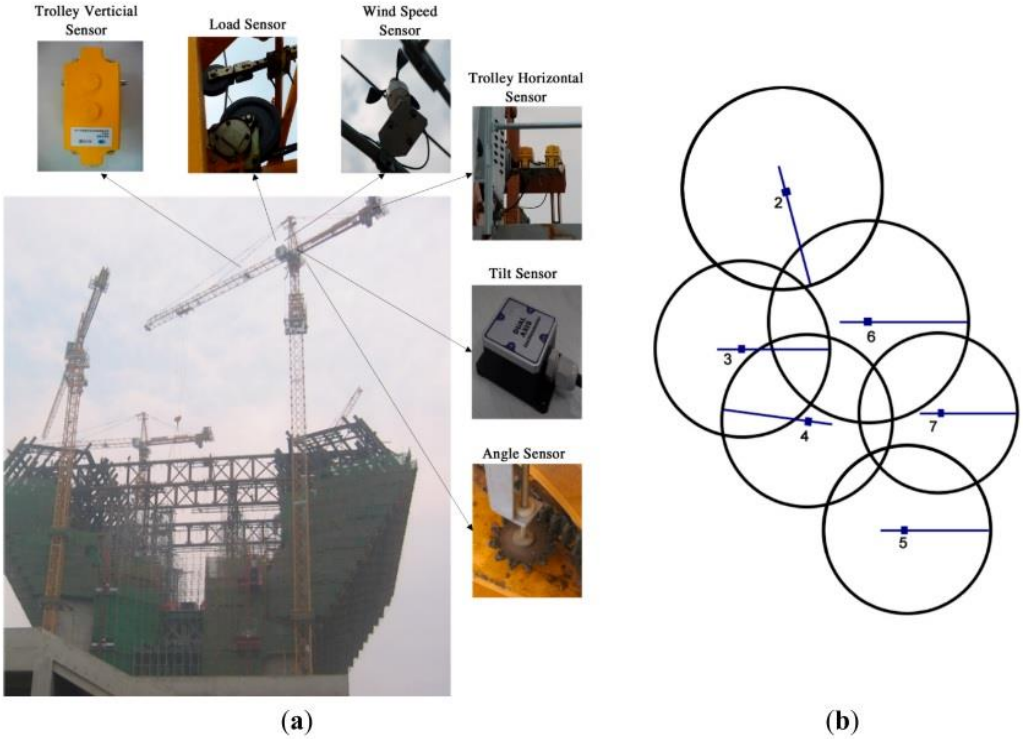


Figure 2: (a) The tower crane group in the worksite of Famen Temple Dagoba (FTD) and the actual assembled positions for six types of sensors; and (b) Schematic plan of a tower crane group. Number 2-7 represent six tower cranes with their netIDs.

In this system, there are three layers of the IoT, (i) perception layer, (ii) network layer, and (iii) application Layer. A set of customized sensors were utilized to obtain the complex real-time status of each tower crane. The WSN was used to fulfill wireless communication

between each tower crane and the Local Monitoring Terminal (LMT) at the ground worksite, which can avoid interruptions during the construction process and realize high-speed stable communication among the tower crane group. Based on the global status data of the whole group, an anti-collision algorithm was executed to ensure the safety of each tower crane during construction. As a system with mechanics, electrics, algorithms and network communications all in one, SMS-TC could be considered as a practical application that demonstrates the promising prospects of WSN and IoT in China's building industry and engineering in the near future.

Zhou and Ding (2017) described a new safety barrier early warning system for hazard energy on construction site using IoT technologies. They developed an IoT-based hazard energy monitoring framework to collect safety status data and isolate hazard energy with safety barriers (early warnings and warnings) efficiently and dynamically for underground metro construction (Fig. 3). The IoT-based safety barrier warning system was designed for collecting, analyzing, and managing multisource information, automating monitoring and warning, and minimizing the hazard energy coupling by using IoT. The portable warning device integrated with IoT tag was installed on the safety helmet, which is designed by RFID-based positioning technology.

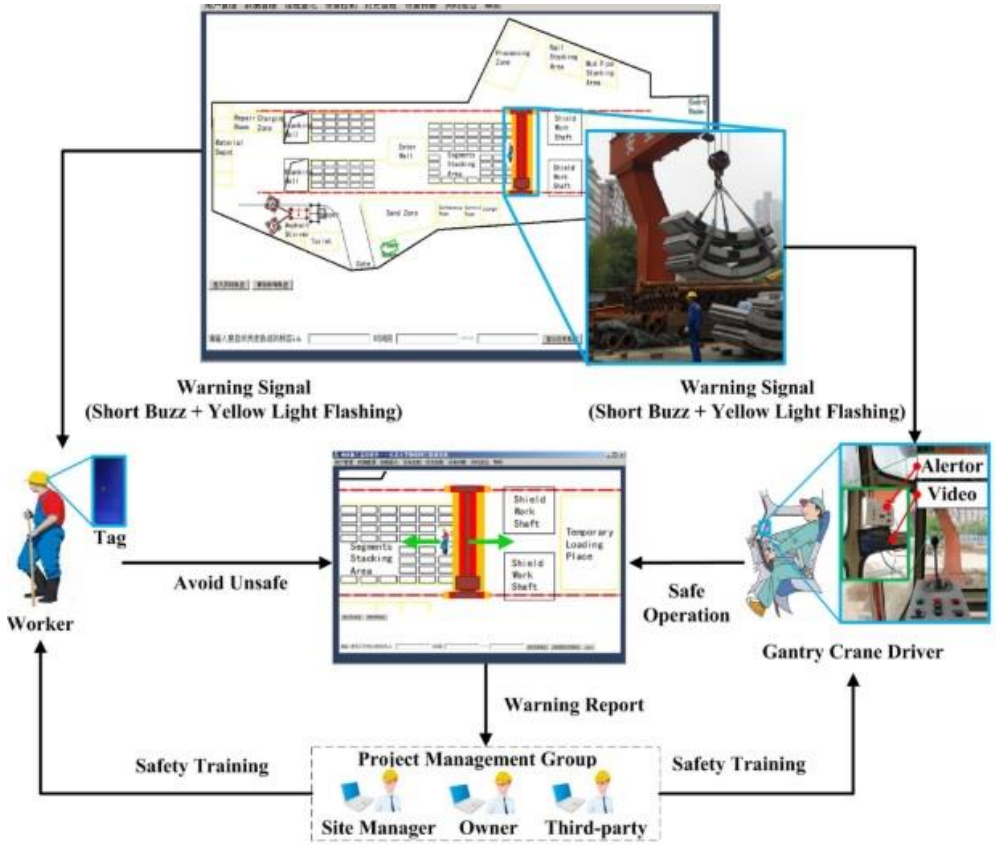


Figure 3: Early warning and alarming process (e.g. gantry crane).

The identified hazard energies and their coupling mechanisms were analyzed to provide safety barrier strategies and scenarios for avoiding unsafe behaviors and unsafe status of construction equipment and workers' environment. This system not only gathers the monitoring data of workers and "things" in real-time, but also generates the early warning

signals as spatiotemporal safety barriers to participants on and off construction site automatically.

Cheung et al. (2018) integrated BIM and WSN technologies to enhance the safety management of hazardous gas in an underground construction site, where the hazardous gas concentrations and environmental conditions (temperature & humidity) of different site regions were collected and integrated on the site BIM model. The corresponding model components will dynamically display all conditions collected from sensor nodes with changing colors and indicate the safety status, which enables the complete safety status to be mastered on an "active" BIM model. In particular, the WSN-integrated BIM model provides a visual and active platform for monitoring, the risk status of different site regions can be efficiently mastered by a colored and spatial display interface, and the real time safety status of different regions also provides important reference information for evacuation or rescue in emergency events.

Lam et al. (2018) presented a new concept in improving safety in construction and civil engineering works using IoT technologies. The IoT monitoring system consists of 4 building blocks, (i) sensing unit, (ii) communication backbone, (iii) server, and (iv) user devices. Sensing units continuously take site measurements and send them to a communication coordinator (CC) at the site in an encrypted digital format. The communication backbone of the system consists of the CC and the communication channel between the coordinator and server, and between the server and user devices. The CC manages sensing units at the site and transmits sensor measurements to the server either through WiFi or cellular network. After storage and analysis of data, the server sends the latest measurements and also warning signals to users' devices to enable users to always be aware of real time site conditions. With support from the industry and government in adopting IoT technologies, the system was gradually being accepted into the local industry. Codes of practice and regulations pertaining to construction and civil engineering works will then be updated to keep up with the latest technology. In the long run, implementation of the monitoring system in the industry was expected to greatly enhance construction safety, preventing injuries and casualties due to structural failures while at the same time minimizing the associated economic losses.

Su et al. (2018) studied a monitoring method for scaffold shoring system during concrete formwork with the IoT technology, and then the method was applied to practical formwork project to verify its validity. Four parameters were monitored during concrete placement, (i) slab settlement, (ii) overall lateral displacement, (iii) column axial force and (iv) column tilting angle. In the monitoring system, all these parameters were measured by sensors and transmitted with IoT technology. With the characteristic of the IoT technology, the monitoring system was designed to consist of wireless sensors, wireless monitor, wireless alarm, intelligent monitoring cloud platform and the wireless monitoring mobile client. In the practical application, the breaking of a slab was detected by the monitoring system, proving the validity and reliability of the IoT based monitoring system to ensure safety during concrete placement.

Zhou et al. (2019) aimed (i) to design a CPS-based SMS (CPS-SMS) for blind hoisting in underground construction to prevent accidents given the complex environment and challenges in hoisting and (ii) to apply this novel system on a real construction site and determine the potential value or practical improvements of the results after implementing the proposed system. The main advantage of this system was portability and agility. Several types of sensors were adopted for data acquisition and transition to detect and monitor the hoisting at

the construction site in real time. Various balancing and optimizing designs have been implemented in different aspects of system equipment, which involves power dissipation, accuracy, volume, weight, installation, protection, deployment, debugging, operation, and maintenance, to successfully use these IoT sensors and devices. To be specific, the safety risks relative to the blind hoisting in underground construction has a significant impact on the overall safety performance on the construction site. The CPS-SMS was designed for blind hoisting in metro and underground construction, including safety warning sensing, transmission, analysis, and control. For verifying the applicability, the Sanyang Road tunnel of Wuhan Yangtze Metro Tunnel in China was used as a case study. To date, the CPS-based safety monitoring system has shown promise in the real-time monitoring of blind hoisting. CPS offers an opportunity to address the safety issues and risks associated with blind hoisting in underground construction. In particular, CPS applications have potential in the simulation and procedures of underground hoisting and can help improve the safety and avoid hoisting failures.

Kim et al. (2019) proposed an IoT-based construction site safety management system that can effectively prevent safety accidents of field workers in both large-scale and small- scale construction sites. The proposed system has been developed with a prototype using sensors, smartphone, management server, and short and wide-range wireless communication systems such as Zigbee, WiFi, and Long-Term Evolution (LTE), etc. Moreover, the system can setup, suspend, and release the hazard zones and provide the access information of field workers and outsiders through a manager's smart application. Furthermore, the system was designed considering the system requirements, in which the system consists of IoT, worker safety check devices, the mobile gateway, the safety management server, and the safety manager application. It was expected that the developed prototype may drastically reduce the number of accidents when applied to the construction sites.

Zhang et al. (2019) studied to implement real-time alarming, monitoring, and locating for non-hard-hat use (NHU) in construction by applying nonintrusive sensors, and mobile, web, cloud, and other modern information techniques (Fig. 4).

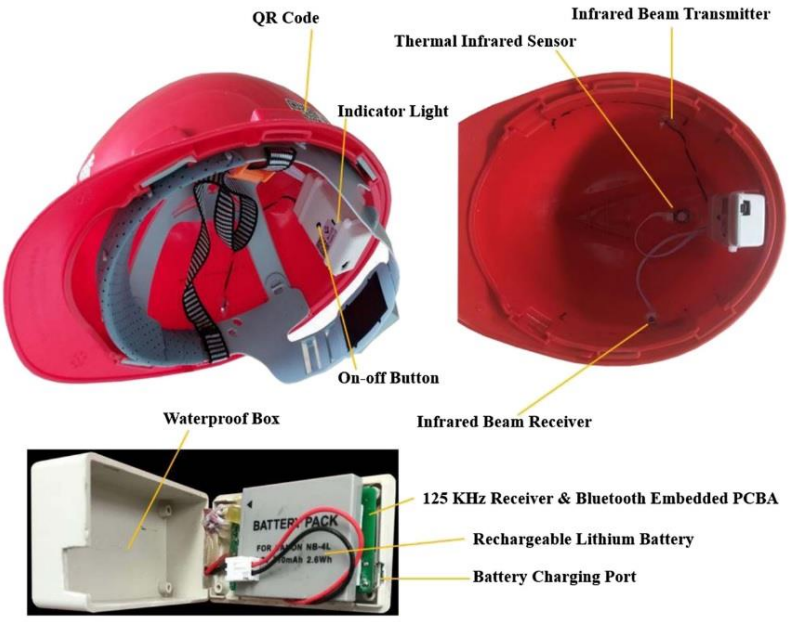


Figure 4: Major components of the NHU detector.

A smart hard-hat system was developed to automatically detect and locate NHU and provide real-time targeted warnings to both man- agers and workers when NHU occurs. The smart hard-hat system consists of a network of waterproof and rechargeable RFID triggers, a waterproof and rechargeable NHU detector, and active RFID receiver in a hard hat, a smartphone app, a web app, and a cloud server. An IoT-based smart hard-hat system was developed for NHU detection and locating in the construction industry.

Mehata et al. (2019) worked to build wearable devices such as smart band and helmet for monitoring the construction workers and to provide them a safer and secure working environment. The devices may help in keeping track of the pulse, and body temperature of the worker. Moreover, care was also taken to provide emergency alert during any slip or fall of the worker. There were various factors to be examined while designing the proposed system for seamless functioning of the device. These include (i) comfortability, (ii) portability (iii) reliability. The proposed system ensures the good fall detection taking into account of the complex conditions to provide safety of the workers and to monitor their health. However, in the other case (after exercise) the displayed output had a slight variation than the expected results.

Park et al. (2019) proposed a system that monitors workers' situation and informs about a dangerous situation such as falls for the safety of construction site workers using sensors acquired from IoT devices based on the deep learning system implemented in previous research. They categorized two situations changing heat or humidity (it related to worker's heatstroke or frostbite) and a worker's falls as the most important and usual safety issues in common construction sites. And then implemented SensorTag for detecting two features. They constructed a deep learning framework for experiments and used tensorflow-gpu1.13.1 at the back end of the framework. In the neural network library, Keras 2.24 was used. For the data set used for the test, SGAD obtained from the sensor tag was divided into x, y, and z-axes and used as input. The total number of records acquired was 500. To that end, they constructed a Sub 1 GHz sensor network which is suitable for construction sites with various radio interference factors. Based on the data obtained it was hoped that objective safety guideline will be established to workers at the construction site using environment and activity data. In addition, they built a service that provides appropriate post-response when notified of workers' perceived dangerous movements, through worker's fall detection using deep learning.

Guzman and Mezovari (2019) demonstrated the design of a scalable, driverless bulldozer prototype using IoT-based technologies. They illustrated the design process of the overall system and enhanced a preliminary version with new GPS tracking capabilities and remote monitoring functions. Generalizing from this particular case to the generic design of IoT-based cyber-physical systems, they recommend a preliminary safety and security risk assessment from the early stages of the design process to promote a safe design. Using the CPS master diagram, designers and engineers can identify and protect the security vulnerabilities as well as the human use cases that could potentially lead to hazardous scenarios.

Lam et al. (2019) introduced a falsework monitoring system utilizing IoT to detect and report abnormalities prior to the occurrence of an accident. IoT monitoring system is capable to provide continuous and real-time measurements, with both the load and inclination data actively monitored. The design was able to allow both common types of falsework for construction and demolition supports to be fitted, thus maximizing potential usage.

Okpala et al. (2020) was set at exploring the perceived opportunities and barriers for the use of wearable sensing devices (WSDs) in enhancing the effectiveness of construction safety management systems (SMS). First, a literature review was conducted to identify the perceived opportunities and barriers for the use of IoT (particularly WSDs) for implementing SMS in construction. Second, based on the identified opportunities and barriers, an online survey was created and distributed to construction professionals in the US construction industry to assess the usefulness of WSDs in SMS. The integration of WSDs could play an essential role in enhancing construction SMS. This study also highlights the key benefit and challenges to the adoption of WSDs for construction safety management. It is believed that WSDs can be integrated successfully into construction SMS based on their attributes for multi-parameter monitoring of safety performance.

Chung et al. (2020) evaluated the effectiveness and weakness of mandatory basic safety training in Hong Kong. Firstly, a questionnaire survey was conducted and over 80% of questionnaire respondents were able to pass the quiz. Then, using criteria weighting calculation calculated through AHP analysis, the weakness of respondents were located. After that, an IoT network model design was created for a real-time construction site safety monitoring system and suggested the basic infrastructure of the system, operation flowchart, and the optimal sensors' locations. This research provides a guideline for further investigation of innovative IoT networks' application networks and the data collection methods from the IoT sensors.

Yeo et al. (2020) targeted to develop a method to evaluate the effectiveness of IoT-based technologies in preventing accidents on construction sites. They proposed a method to quantify the effectiveness of an IoT-based technology in preventing different types of accidents occurring on construction sites. The applicability of this method was tested with two different IoT technologies. The technologies considered in this study were technology automatically identifying hazardous areas and technology monitoring the worker's heart rate with a photoplethysmography sensor on a real-time basis. According to the findings, practitioners can quantify the effectiveness of certain IoT technologies which can be utilized for construction works.

Yang et al. (2020) proposed a personal protective equipment (PPE) tool pair system for on-site construction safety. The PPE-Tool pair system was established at three levels: sensing level, application level and storage level. The sensing level consists of three modules: (i) PPE module was made up of a human sensor and a Wi-Fi sender. They detect whether the user was wearing suitable PPE and broadcast the information via wireless technology; (ii) the non-power hand tool module contains a Wi-Fi receiver, a processor, a speaker, or a vibrator. When the receiver receives the signals from PPE modules, the processor immediately checks safety regulations and determines whether a warning should be raised by the speaker or the vibrator; and (iii) the power tool module was another version of the non-power hand tool module without self-power and was embedded on the motherboard of the power tool. The application level refers to the mobile devices and applications, providing a customized interface for monitoring and management. At the storage level, the collected data are uploaded and saved on a cloud server by WiFi or GPRS so that any user can access the historical records online. This system ensures that all required PPE were properly equipped by users prior to using dangerous construction hand tools. Such a system for protection was composed of a wearing sensor, a battery, and a Wi-Fi module; each tool consists of a buzzer, a vibration motor, and a Wi-Fi module (Fig. 5).

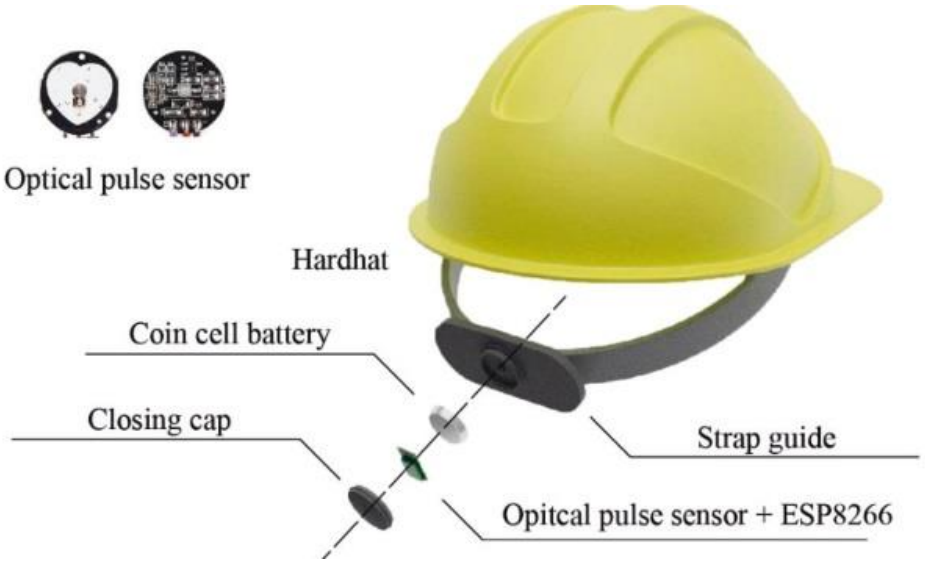


Figure 5: The sketch of helmet for wearing detection.

Yuan et al. (2021) focused on how to use IoT technologies to monitor the project implementation process in prefabricated building (PB) construction, which will help optimize the construction schedule and ensure the quality and safety of PB construction. Design changes affect component production, and many quality and safety risk control issues must be faced during on-site assembly. Applying IoT technologies to managing the whole process of PB construction will greatly improve construction efficiency. The IoT monitoring in the off-site manufacturing phase focuses on increasing the visibility of the manufacturing process and monitoring the manufacturing capabilities. Different from traditional construction, the main safety risk factors in the on-site assembly process of PB construction are the component installation risk, environmental risk, hoisting risk, and technology risk. This system can reduce safety risk at PB construction.

Prabha et al. (2021) utilized IoT to create a framework that will provide them with a better and more stable working environment. They suggest a method for predicting incidents before they happen. The proposed system consists of four modules. The modules are (i) database connectivity (ii) motion sensing (iii) alarm Intimation and (iv) webpage retrieval. If the worker reaches the hazardous zone, the sensor will alert the device. The message is then sent to the APR by the Arduino microcontroller. APR then sends out a voice-based warning to alert the staff and avoid the accident. The message will also be posted on a website. It senses any movement inside the hazardous zone and alerts them using APR. APR offers a voice-based warning system, in which a voice message was recorded and played whenever an alarm was required. This voice-based warning was more effective and helpful in relaying messages to staff, which can help them better understand the situation and avoid an accident.

Del Carmen Rey-Merchan et al. (2021) demonstrated an IoT infrastructure combined with Fuzzy Markup Language on JFML as an effective tool to prevent fall from height at construction environments. Several sensors and actuators, a broker based on the MQTT protocol, an instance of JFML and a FML file have been used to define the system. Concretely, they proposed to use the MQTT protocol to send data from sensors over the IoT architecture. They also used distance and proximity sensors, altimeters and anemometers to provide real time input data in a construction scenario and a color led to represent the output as the level of fall from height risk.

Khan et al. (2022) introduced an integration of vision and the IoT to develop an intelligent smart safety hook to monitor construction workers within the risk zone (scaffolding) and ensure compliance to PPEs. The proposed system was experimented and deployed on a single fall from height scenario, i.e., fall from scaffolding. This system relies on automated vision and an IoT-based system while providing an accurate, efficient, and fast solution. Through the development of WBMP and BCS, the site manager can readily monitor multiple workers' safe or unsafe behavior in real-time and later reward them for complying with the safety regulations. The obtained results show that this system provides an effective and timely communication platform to alert the safety manager in case of any unsafe behavior.

Discussion and Conclusion

Past studies reveal that IoT has a potential to be utilized in order to reduce health and safety problems in the construction industry. Sensors and monitoring systems enable researchers to develop IoT-based precaution applications to minimize work incidents. In this respect, smart PPEs, autonomous and GPS tracked construction equipment, false work detection systems, prefabricated building production, temperature and humidity conditions, and workers' heart beat and pulse monitoring systems were studied by several researches. Up to date, most of the IoT-based safety precautions seemed to be a single-case scaled. However, past studies reveals promising results for future studies and applications in terms of IoT-based health and safety practices.

Consequently, by applying the IoT technology, the construction industry may benefit from its application practices in a positive manner. The system of IoT can be integrated with different applications which are already in use in construction. From the perspective of IoT technology, wireless connection, sensors, smart devices, GPS tracking systems, and tags are most critical factors in order to develop a successful system to minimize or eliminate occupational incidents in the construction industry. Thus, past studies are expected to guide both industrial practitioners and academic researchers to adopt the IoT technology and to improve the health and safety performance of the construction industry.

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Digital Transformation Era in Construction Management: Blockchain Technology – a Systematic Literature Review

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Abstract

The acceleration of the worldwide transition to Industry 4.0 has increased the digitalization process. This digital process has many functional tools such as blockchain, artificial intelligence, and big data. The construction sector is attempting to benefit from the structure of this process that is called Construction 4.0. One of the emerging and popular tools in digitalization in the construction industry is blockchain technology. Blockchain holds data and transactions by providing decentralized, traceable, and immutable digital networks. It can be used for solving various problems in different knowledge areas of construction management such as payment methods, supply chain management, information management, facility management, contract management. Although blockchain is an emerging technology for various knowledge areas, academic studies are at their pre-mature level and sporadic. This condition enables the adaptability and utilization of blockchain in construction. Therefore, this research aims to classify and present blockchain research in terms of the knowledge areas and integration between other digital tools. For this purpose, blockchain and its related technologies have examined by systematic-bibliometric review was conducted in Scopus, Sci-direct and Web of Science database and analyzed by using VoSviewer. The outcome was classified by thematic clusters to perceive and utilize blockchain applications in construction management comprehensively. Presenting integrative perspective provides the original value to study.

Keywords: *blockchain, construction, digitalization.*

Introduction

Digitalization process has gained momentum in all sectors through Industry 4.0. Industry 4.0 is the digital transformation of manufacturing and related industries and value creation processes (Pech & Vrchota, 2022). The applications of digitalization can be defined big data analytics, artificial intelligence (AI), Internet of Things (IoT), cyber security, blockchain, cloud computing, machine learning, autonomous robots, and additive manufacturing. To certain extent, these technologies have already changed most industries, still there are industries are far away from adopting the full potential of the 4IR (4th Industrial Revolution). (Begic & Galic, 2021). Construction industry, the one of the leading sectors in worldwide, lags behind other sectors in adapting to the digitalization process (McKinsey & Company, 2018). Several existing digital technologies such as Building Information Modelling (BIM) and Mixed Reality (MR) lack to experience the digital transformation era.

The rate of annual increase of productivity by digitalization is 2.8% globally; where is rate increases to 3.6% in the production sector. Nevertheless, the construction industry's productivity rate in the last 20 years is 1% (McKinsey & Company, 2020). Therefore, digitalization opportunities in the construction industry, have the potential to increase productivity and cost reduction. It is predicted that the digital transformation studies to be carried out in the construction sector will provide a 14-15% increase in productivity, 15-40% cost reduction, effective time & conflict management, and young – skilled new workforce creation (McKinsey & Company, 2020). In addition, it is argued that digital transformations in the construction industry can increase the value of the industry by up to $1.6 trillion. (McKinsey Global, 2020; Forbes, 2021). Moreover, trust in the construction industry is crucial. In some cases, trust relations between the various stakeholders such as information exchange and contract documents cannot be managed efficiently. Poor communication and collaborative information sharing are one of the causes of many failed projects worldwide (Schepper et al., 2014). Different digitalization tools can assist to overcome these issues. One of the emerging and popular tools in digitalization in the construction industry is blockchain technology. Blockchain is a distributed data storing mechanism to replicate, share, and synchronize data spread across different geographical locations, such as multiple sites, countries, or organizations (Hewavitharana et al., 2019). These features make this technology attractive for the construction processes to become more efficient, traceable, transparent, and accountable across all stages of the project life-cycle (Institution of Civil Engineers, 2018).

Current research on blockchain technology has been executed in different sectors such as healthcare, and finance. In construction literature, blockchain research has been clustered construction management knowledge areas such as supply chain management, information management, contract management, facility management, payment management, project management, delivery, regulations and compliance, dispute management, and technological systems. Blockchain-enabled technologies such as BIM, IoT are popular research trends in these management areas. However, although blockchain and blockchain-enabled technologies are on the rise, academic studies are pre-mature and disconnected from each other. For this problem, this paper aims to identify five popular themes of blockchain applications in construction and its relations with knowledge areas through systematic-bibliometric review. These popular themes were selected as supply chain management, payment management, information management, facility management, and contract management from the prominent nodes of the 'blockchain' main keyword's science mapping by VOSviewer. Each theme was defined as a cluster and analyzed to understand current capabilities, technological tools combined with blockchain, and future developments. For this study, Web of Science, Scopus and Sci-direct databases were combined and examined together; thematic science-mapping and citation analysis were conducted through VOSviewer software.

Blockchain Technology and Its Applications

Blockchain is a distributed database (ledger) that maintains a list of records (transactions, information, etc.) (Dakhli et al., 2019). Each block can have some records limited by the megabyte. Unlike traditional transactions which rely on the central authentication such as banking system, blockchain is a decentralized P2P (person to person) network connected via a consensus protocol, which means transactions on the network are validated and shared among all participating nodes (computers) in the network (Koulouri-Fyrigou, 2019). The algorithmic hash key of each blocks defines the trust relationship by offering secure solutions. Any user of

the blockchain can easily trace any previous transactions by accessing any node in the distributed network, and all of the transactions are recorded with a timestamp. In the blockchain, although the view of existing data and adding new data is possible, changing the information that is already there is impossible. Because if any node in the network discovers an exchange, it checks consensus protocol and, if necessary, replaces itself with the consensus. Blockchains have many benefits; reducing costs and time, lowering the barriers to entry in several sectors, providing security in technological systems (Turk & Klinc, 2017). To understand the concept of blockchain, the study was clustered around the main keyword "blockchain" by including all industries. The research areas using the "blockchain" keyword in Scopus can be seen in Figure 1. According to Figure 1, the most researched areas of blockchain are seen as Computer Science (37,2%), Engineering (20,5%) in 27,133 papers. Besides, China can be seen as a pioneer country in blockchain literature (<7k documents), it is followed by the USA with <4k documents.

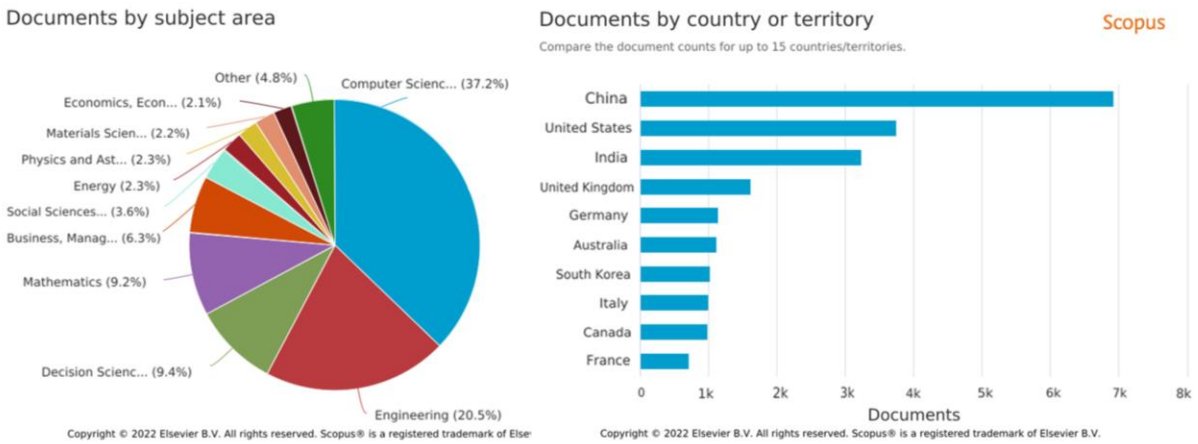


Figure 1: The research areas of Blockchain (a) and their country distributions (b).

As can be seen in Figure 2, blockchain technology has widespread research network by the other technological tools such as IoT, big data, BIM, cloud computing, machine learning, smart contracts. Also, it is seen that the most of the relevant digital tools are similar to the selected management themes. In order to understand the reflections of these relationships in the construction industry, the sub-keyword 'construction' was added as a focus to each theme.

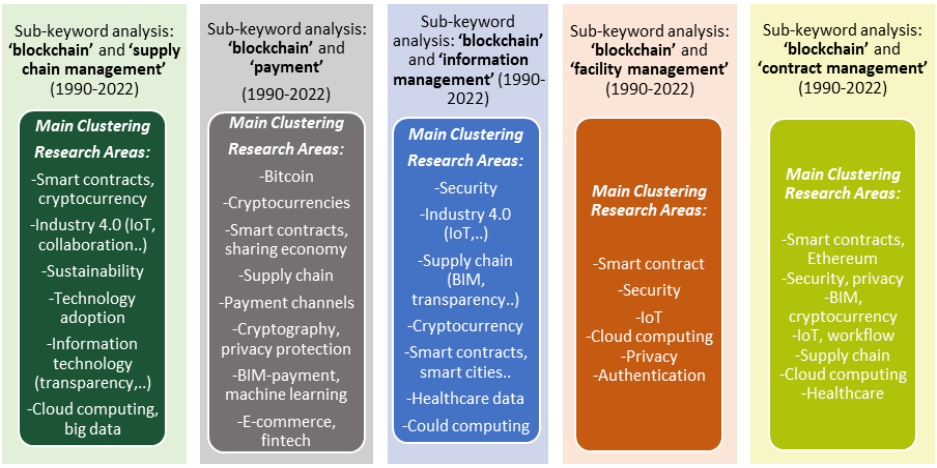


Figure 2: The clustering of sub-keywords about blockchain technologies by VOSviewer science mapping.

Research Methodology

The approach of a systematic-bibliometric literature review was selected for this paper to perceive the current level of research of blockchain and its applications in construction industry, and to guide development of research questions to further the body of knowledge. Systematic reviews allow a researcher to identify gaps in the research used to direct further investigation; offer background to support framework development in the case of new research; and support or challenge theoretical hypotheses (Tranfield et al., 2003).

All blockchain applications literature from 1990-2022 were collected through Web of Science, Scopus, and Sci-direct databases. The collections were created with 27,133 papers in Scopus, 19,833 papers in Web of Science, 9,754 papers in Science-direct by 'blockchain' main keyword. These papers were analyzed according to their sectors, countries and related research areas that were defined as sub-keywords. These sub-keywords' relations were shown in VOSviewer science-mapping by clustering. For VOSviewer science mapping, three different databases were combined so that the combination contributes to the originality of the study. Science mapping is a methodology that combines quantitative analysis, classification, and visualization to identify the composition and inter-relationships between bibliographic objects (Andersen & Swami, 2021). Besides, it presents the cluster analysis of the keywords & occurrence, time, country and journals according to the imported data. In the systematic-bibliometric research process shown in Figure 3, in the first stage, the main keyword 'blockchain' was examined according to the prominent nodes in VOSviewer science mapping that was in the scope of the main keyword analysis. The prominent studies in this process were grouped by five sub-keywords of management areas in all sectors: supply chain management, payment management, information management, facility management, and contract management. These prominent nodes were identified as five popular themes in the research. It can be inferred that the most researched sub-keyword related with blockchain is information and contract management regardless their sectors. At the result of this step, thematic science mapping by VOSviewer was created to identify the relationships with blockchain-related technologies. In the following stage, sub-keywords were disaggregated by the focused keyword which was the construction. These clusters were shown by VOSviewer's science mapping. Besides, bibliometric analysis was conducted through the number of citations and journals for each theme. Papers' contents and types of each theme were compared and discussed. In the last step, a discussion of the findings and gaps in the literature, the limitations of this study in terms of its utility and recommendations were performed.

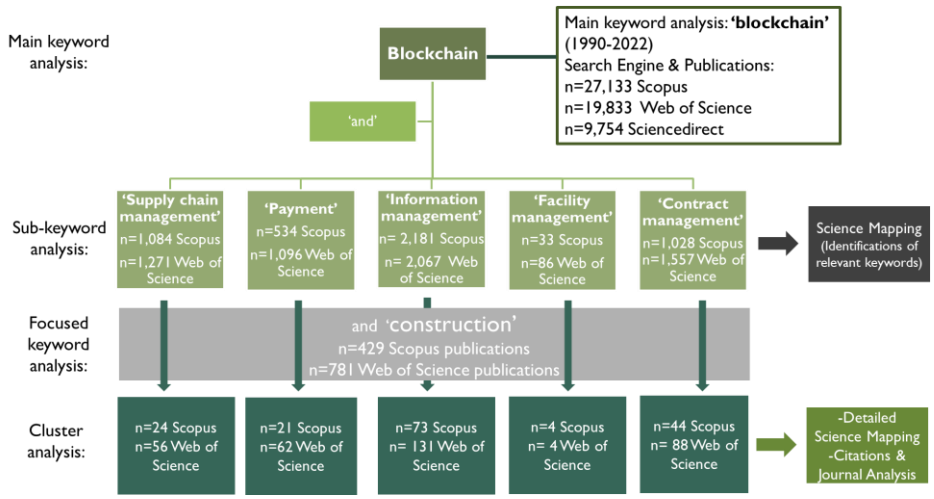


Figure 3: An overview of the literature review and research process.

In the first stage of the research that was executed with the keywords of blockchain and construction, 429 publications were found in Scopus and Sci-direct, 781 publications were investigated in Web of Science that can be seen in Figure 3. According to these findings, science mappings including blockchain-related keywords & occurrence and timeline were created and shown in Figure 4 and Figure 5.

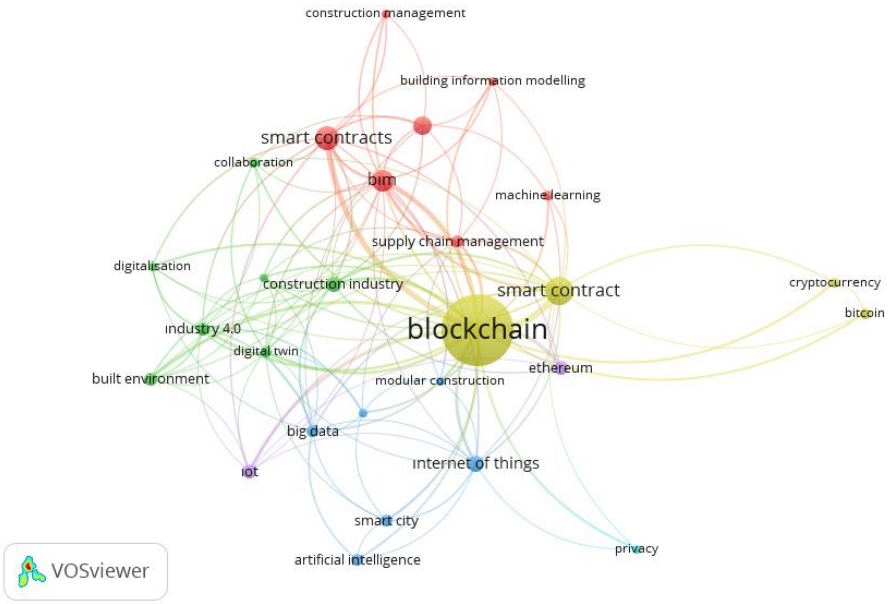


Figure 4: The science mapping of blockchain-related keywords & occurrence by VOSviewer.

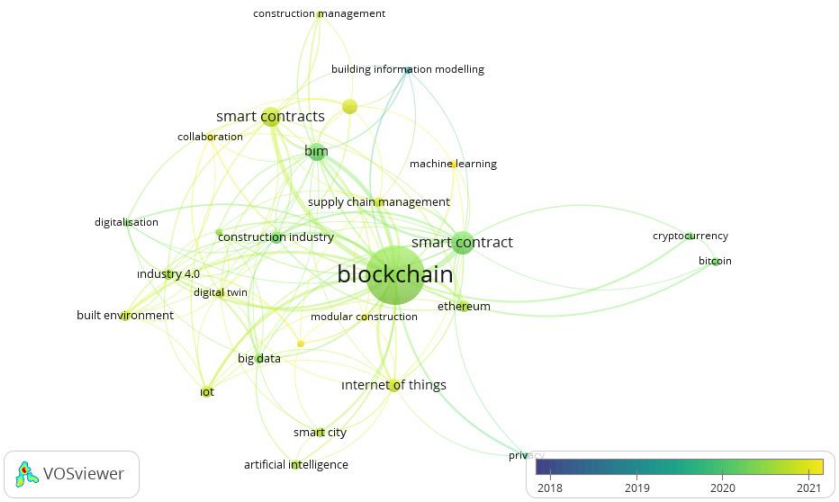


Figure 5: The timeline science mapping of blockchain-related keywords by VOSviewer.

As can be seen in Figure 4, smart contracts, BIM and IoT have wide bibliometric network in construction literature according to the size of nodes. Besides, Figure 4 presents the research clusters that are shown in different colors help to discover the relationships between the keywords. For example, it can be understood that smart contracts are associated with cryptocurrencies and BIM in construction. Figure 5 shows the timeline of popular researches related with blockchain technology. According to this bibliographic network, yellow nodes represent the trending topic in construction in nowadays such as IoT, digital twin, machine learning. In the next section, this bibliographic analysis was deepened by selecting five popular cluster themes; supply chain management, payment management, information management, facility management, contract management in construction.

Findings

Blockchain in Construction & Supply Chain Management: Blockchain technology can provide new solutions for supply chain management problems such as delays and mistakes in construction. This theme represents that there are 14 studies received the most citations in 80 publications. It is determined that 4 of the 14 most cited studies are literature reviews. Three of the remaining ten studies are semi-structured interviews. The methods used in the remaining studies are summarized as follows: Wang et al. (2020) developed a blockchain-based real time information model for precast component supply chain and designed a smart contract algorithm for its implementation. Lanko et al. (2018) combined blockchain technology with RFID in a case-based model to track the delivery of construction materials to construction site. Luo et al. (2019) studied on a case-based model to automate construction payment through smart contract-based blockchain framework for disputes, lack of trust and cash flow problems. Tezel et al. (2021) developed three payment prototypes for supply chain management. These are project bank accounts (PBAs) for payments, reverse auction–based tendering for bidding, and asset tokenization for project financing. Lu et al. (2021) explored blockchain-based construction supply chain system by smart construction objects enabled blockchain oracles framework. Li et al. (2022) investigated a case-based model that includes the integration of IoT and BIM to blockchain system in supply chain management for modular construction. Fitriawijaya et al. (2019) created a simulation of supply chain management using BIM, CDE, and blockchain, also, the smart contract system validated

every material and configuration of components within the model. According to Figure 6, smart contract technology is the most trending tool in supply chain financing. In addition, the sustainability of this system is another matter of discussion in terms of Industry 4.0. Also, the integration of BIM, IoT, and artificial intelligence can be seen as a new way of blockchain-enabled supply chain management with their yellow colors. The analysis of citations and journals that interested in these issues is shown in Figure 7. According to Figure 7, Automation in Construction has 142 citations, Frontiers of Engineering Management has 204 citations, Engineering Construction and Architecture has 49 citations and Building has 37 citations.

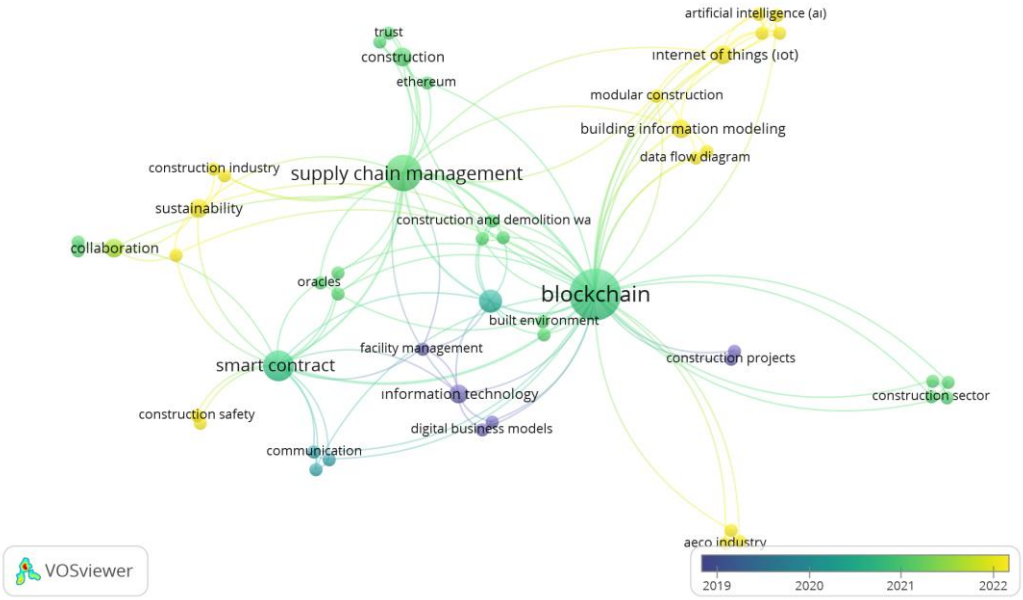


Figure 6: The science mapping of blockchain-related keywords in supply chain management by VOSviewer.

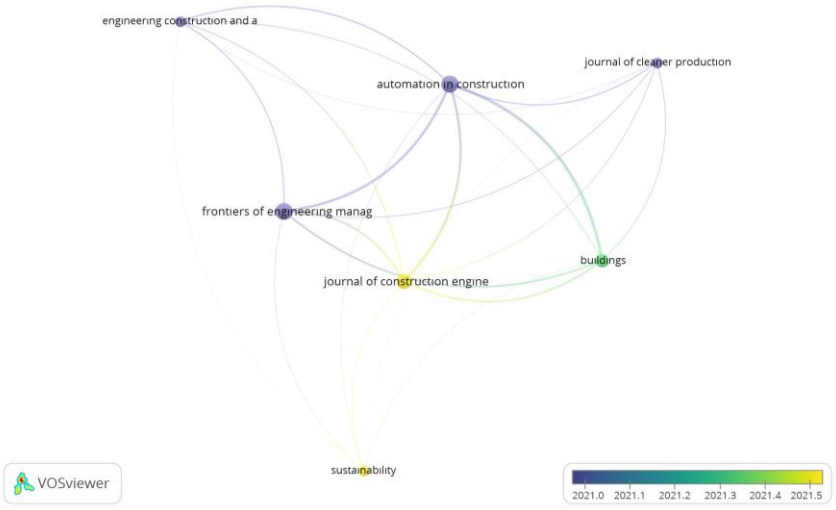


Figure 7: The analysis of journal and citations in supply chain management theme by VOSviewer.

Blockchain in Construction & Payment: Poor payment and contract problems have been causing numerous disputes and business failures. For this problem, digital contractual clauses can be developed and coded into blockchain-enabled smart contracts. Smart contracts can

work with fiat currencies and cryptocurrencies. In this theme, it is investigated that 14 studies obtained the most citations in 83 publications. The one of the fourteen most cited studies is literature review. The methods used in the remaining studies are developing models and the most cited remaining works summarized as follows: Elghaish et al. (2020) developed a payment model that executes all financial transactions by IPD smart contracts for IPD projects. Das et al. (2020) investigated an automated blockchain-based payment method for interim payment, sharing payment records at project-level transparently and securely. Ahmadisheykhsarmast and Sonmez (2021) focused on security system in smart contract payment named SMTSEC is presented for reducing payment problems. Hamledari and Fischer (2021) created an autonomous payment solution, integrating blockchain-enabled smart contracts and robotic reality capture technologies, payments with cryptocurrencies/tokens and non-fungible tokens (NFT) and implemented this model to implemented to seven subcontractors in two real-world commercial construction projects. Shojaei et al. (2019) developed a sample model including BIM, blockchain and current fiat currencies in transactions for dispute resolution. Lu et al. (2021) explored a blockchain based payment model for governmental supervision of construction work (GSCW) for policymakers, practitioners, and researchers to develop governance policies. According to Figure 8, smart contracts, cryptocurrency, asset tracking, digital signature, automated transactions and BIM keywords can be seen as popular research areas in construction payment theme.

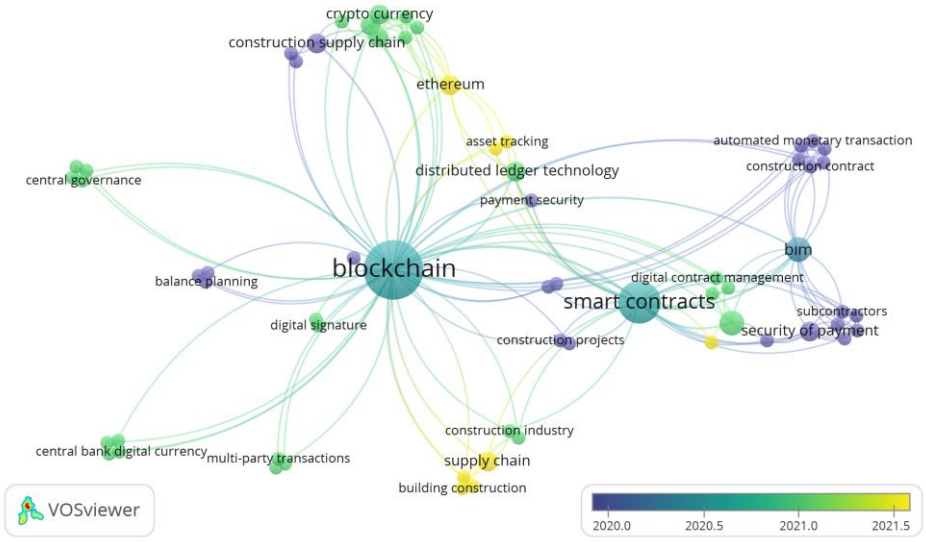


Figure 8: The science mapping of blockchain-related keywords in payment by VOSviewer.

Figure 9 shows the analysis of journal and citations network. In this analysis, it can be seen that Automation in Construction has 133 citations, IEEE Access has 32 citations, Informatics has 13 citations, Journal of Construction Engineering and Management has 10 citations. Moreover, Figure 9 can be interpreted as a timeline of this cluster. According to this timeline, it can be seen that blockchain-related tools have started to be published in the literature from 2019.

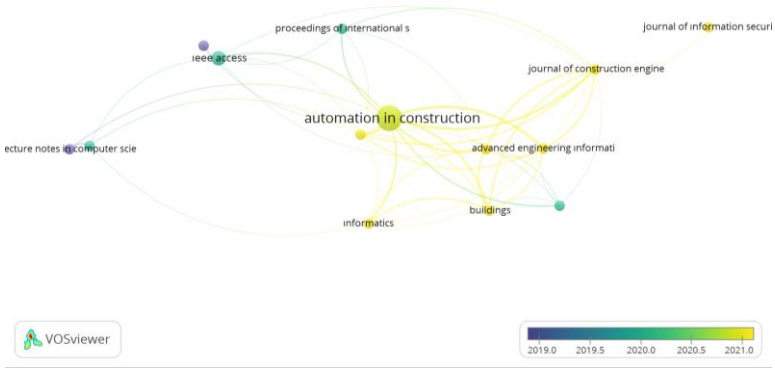


Figure 9: The analysis of journal and citations of payment theme by VOSviewer.

Blockchain in Construction & Information Management: Blockchain enables the storage of a wide range of know-how information in the construction in high security. In this cluster, 14 studies were investigated as the most cited works in 206 publications. Seven of the fourteen most cited studies are literature reviews. The methods used in the remaining studies are developing models and these works summarized as follows: Zheng et al. (2019) proposed BIM data organization based on blockchain model (BcBIM), to facilitate BIM data audit for historical modifications by blockchain with big data sharing on private and public blockchain. Sheng et al. (2020) developed a blockchain-based framework for managing quality information by smart contracts, referred to as "qualityChain". Lee et al. (2021) explored a model and implemented to a hypothetic case for traceable data communication by integration of digital twin and blockchain framework. Ye and König (2021) improved a billing model for checking the contract are defined on the basis of the building elements, determined quantities and defined construction works. Lokshina et al. (2019) designed a system that employs the blockchain as a measure to secure and control the information framework that involves integrated IoT and BIM technologies and this system was implemented to a case. Liu et al. (2019) developed a conceptual model to explore the potential roles of an integrated BIM-BC and smart contract approach for sustainable building design information management. As can be seen in Figure 10, the most popular research areas related information management are BIM, IoT, big data, smart contracts, digital twin, artificial intelligence and autonomous technologies. Also, construction safety and data management are trending issues in blockchain technology. Moreover, Figure 10 can be seen as a timeline of this cluster. According to this timeline, it is shown that blockchain-related tools have started to be published in the literature from before 2019.

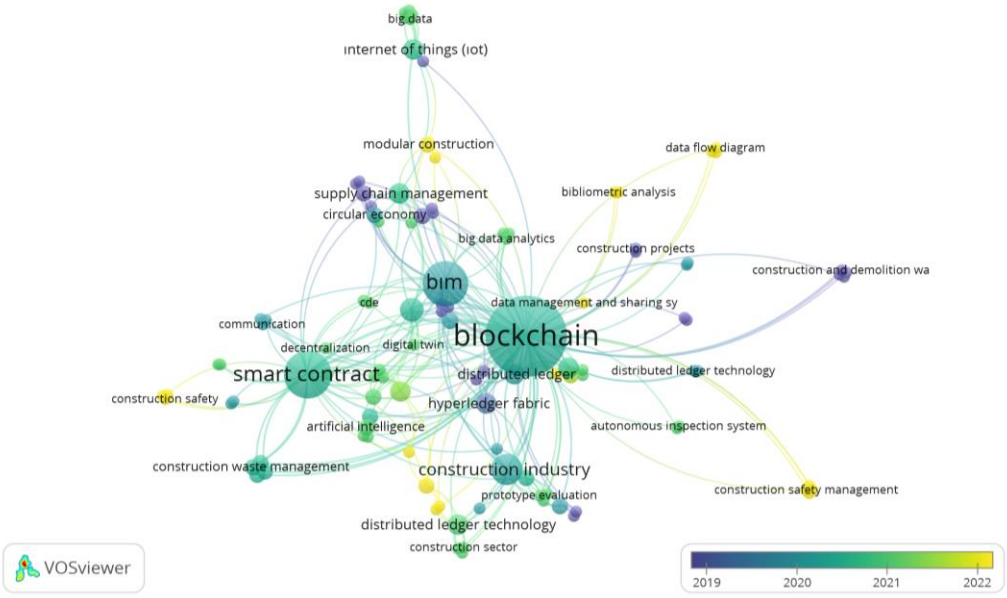


Figure 10: The science mapping of blockchain-related keywords in information management by VOSviewer.

Figure 11 presents the analysis of journal and citations network. According to this network analysis, it is clear that Automation in Construction has the highest citations that are 322, Journal of Building Engineering has 72 citations, Advanced Engineering Informatics has 53 citations, Engineering, Construction and Architecture has 48 citations, Journal of Information Technology in Construction has 47 citations.

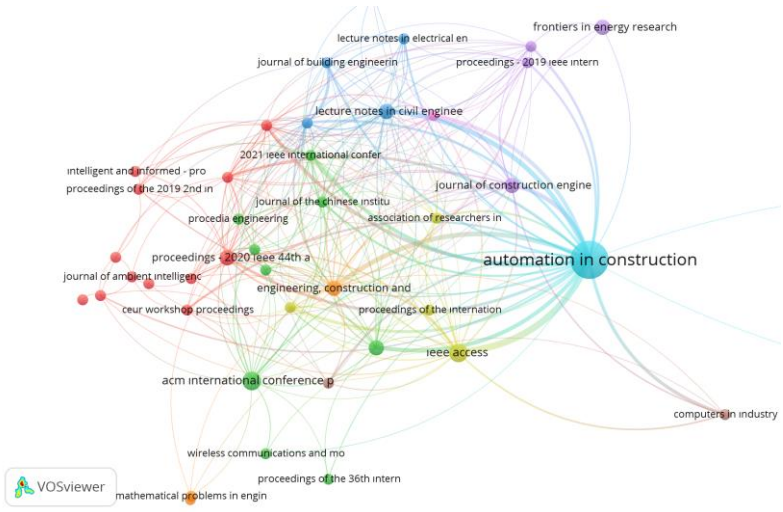


Figure 11: The analysis of journal and citations in information management theme by VOSviewer.

Blockchain in Construction & Facility Management: Blockchain in facility management is important for real-time data access, visualization and marketing, checking maintainability, creating and updating assets with the integration of IoT and RFID technologies. This issue is one of the latest topics in blockchain technology. Therefore, the least number of studies in this theme were found in databases. Four studies were discovered as the most cited works in 8 publications. All of these are literature reviews instead of developing the model. The most cited works are Turk and Klinc (2017) and Ye et al. (2018) suggested the integration of

blockchain-BIM-IoT; Shojaei (2019) added this framework to smart contracts for facility management.

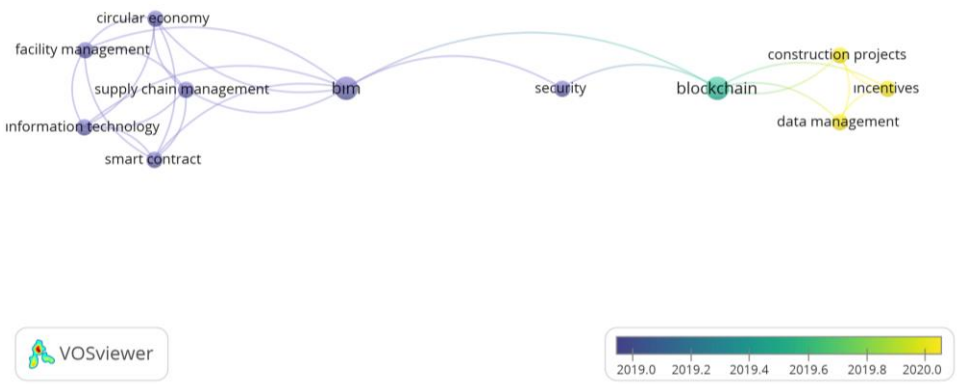


Figure 12: The science mapping of blockchain-related keywords in facility management by VOSviewer.

As shown in Figure 12, BIM is a tool between blockchain and facility management. In addition, smart contracts and circular economy are trending topics that are connected to facility management. According to the analysis of journal and citations network, it is found that there are four journals that are Proceedings of the 35th International Symposium on Automation and Robotics in Construction has the highest citations that are 33, Proceedings of International Structural Engineering and Construction has 24 citations. Science mapping analysis' of this theme cannot be shown since there was no citation link between the journals.

Blockchain in Construction & Contract Management: During the contract management procedure, any missteps throughout the bidding process can cause project delivery problems or planning and scheduling mistakes. These issues lead contract management to a fast, secure, immutable technology called blockchain and smart contracts. In this theme, 6 studies were examined as the most cited works in 132 publications. A literature review, a questionnaire model and four developing model were discovered in these six studies. The most cited researches were analyzed: Kim et al. (2020) made a questionnaire to experts to identify potential blockchain application areas in construction lifecycle and project management knowledge areas especially 'Procurement', 'Contract', and 'Cost'. Nawari and Ravindran (2019) developed a model for considering the potential incorporation within the BIM process to address post-disaster rebuilding problems and improving smart contract. Das et al. (2022) investigated a prototype of the proposed smart contract framework for document management. Sigalov et al. (2021) discovered a model and implemented a case that includes improving BIMcontracts, the blockchain container-based data exchange, and the digital contract management workflow. Ciotta et al. (2021) proposed a model and implemented a case that encompasses a proof-of-concept for the integration of blockchains and smart contracts into information flows used in various CDEs, information exchanged with data gathered by IoT sensors on site. Including these papers, 44 papers in Scopus and Sci-direct; 88 papers in Web of Science database were discovered and visualized by VOSviewer science mapping in Figure 13.

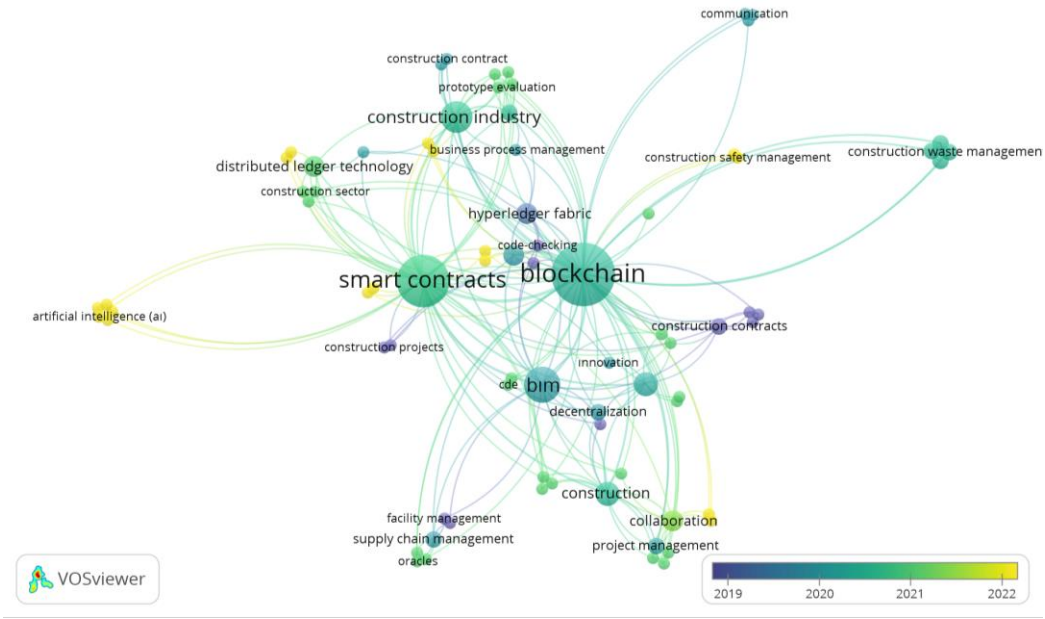


Figure 13: The science mapping of blockchain-related keywords in contract management by VOSviewer.

As shown in Figure 13, smart contract, artificial intelligence and BIM are seen the most trending digital tools related to blockchain technology. Also, smart contract is associated with business process management keyword. According to the journal and citations analysis that can be seen in Figure 14, Automation in Construction has 336 citations, Procedia Engineering has 176 citations, Journal of Building Engineering has 72 citations, Advanced Engineering Informatics has 53 citations.

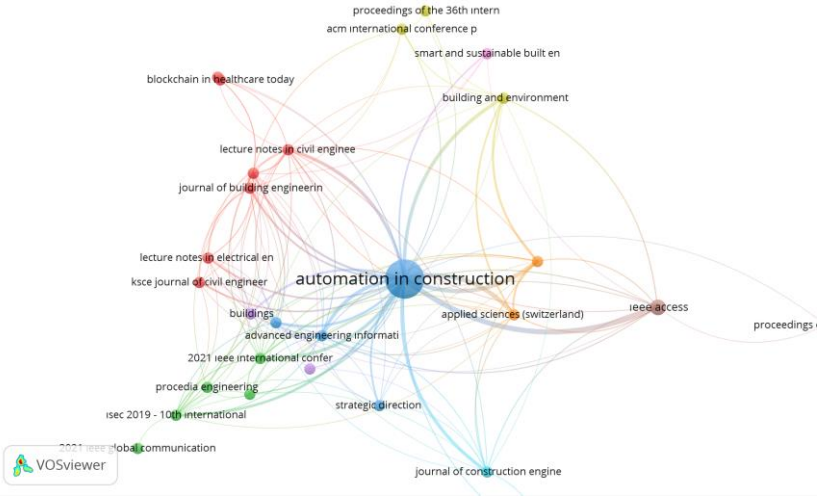


Figure 14: The analysis of journal and citations in contract management theme by VOSviewer.

Discussion and Conclusion

Digitalization era through Industry 4.0 was reflected in the construction industry as Construction 4.0. This era has various digital tools such as blockchain, big data, artificial

intelligence, IoT in construction. Despite the most of the sectors adopted digital tools, the construction sector lags behind the other industry. In order to implement these technologies, tools should be known in the sector and academia. In this purpose, this paper aims to identify blockchain technology that is the one of the popular digital tools and its five popular themes of applications in terms of Construction 4.0. In the research methodology, blockchain and related applications were clustered according to the main 'blockchain' keyword analysis in VOSviewer science mapping, and as a result of this step, five sub-keywords were grouped from prominent nodes in terms of management field. These are: supply chain management, payment management, information management, facility management, contract management. In the next step, five sub-keywords were refined by the keyword "construction". This phase demonstrated the thematic place of popular sub-keywords of the blockchain in the field of construction management. Various science mappings were generated in each theme by VOSviewer software. In addition, the analysis of journal and citations of studies were conducted by bibliometric network.

As a result, according to the cluster analysis of blockchain and selected five popular themes, it is found that most publications are in the fields of information management, payment, supply management, contract management, and facility management, respectively. These findings show that blockchain applications in facility management are limited and the information management area is a more trending issue than the others. Among the sources of these researches, China, the USA, India, and the UK stand out compared to other countries.

According to another result of the cluster analysis, the most popular and common blockchain-enabled tool in payment and supply chain management is smart contracts while the most trending blockchain-enabled topics in information management are BIM, smart contracts, IoT, digital twin and big data. Moreover, in payment theme, cryptocurrency, automated payments, asset tracking, and digital signature keywords seem to be open to development. In the cluster of facility management, the most trending blockchain-enabled tools are perceived as BIM and BIM related smart contracts. In the cluster of contract management, the most emerging tools are discovered as smart contracts, BIM, artificial intelligence and distributed ledger technology. As can be understood from cluster analysis, there are a few technological tools that come forward: blockchain-enabled smart contract, BIM, IoT, artificial intelligence and their combinations in hypothetical and real models.

In addition, according to the bibliometric analysis of five popular themes that are the limitation of the study, the number of articles developing a model and the number of the literature review articles were similar. But, in the facility management cluster, many literature reviews were found instead of developing a model based on blockchain. It has been inferred that there is a lack of model development in this area. The other clusters have developed hypothetical and real models. However, some of these hypothetical models can be interpreted as immature and open to development. As another result of the study, it has been determined that other technological tools such as IoT, artificial intelligence, big data and BIM in the literature can be linked with blockchain in various ways. For future works, it is recommended that thematic clusters can be expanded and detailed by using different software to understand blockchain's functions comprehensively. Moreover, it is suggested that to merge related technological tools within real prototypes by using thematic clusters to increase productivity of the construction industry in terms of Construction 4.0.

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Evolution of the Building Sector from Building Catalogs to BIM Catalogs

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Abstract

Mass production that emerged with the Industrial Revolution has radically changed both the production and circulation of building elements and components in the market, as in all sectors and products. Since 1870, building elements have been produced in factories, cataloged, exhibited in fair areas, and begun to be sold in construction markets. Important developments in information technologies have revealed developments in computer software. Building Information Modeling (BIM), one of the important developments in the construction industry, has become the technology that enables the building system to be modeled with "BIM Objects" based on the building components that set up the building. Today, manufacturers design building components as "BIM Objects" and present them to users in international BIM libraries. In this study, the continuity of the international classification and standards of building elements formed in the printed catalog process in BIM catalogs was emphasized, and the studies were reached in terms of literature research. This has become a new marketing strategy for manufacturers. Throughout the historical development of the building industry, it is aimed to reveal the importance of the development of the tools of access to the building elements together with the technology for the manufacturer and the designer.

Keywords: *BIM library, building classification systems, building components, building information modeling, building products catalogs.*

Introduction

A building is the result of physically conflate many products together and is the final output of the production process. Building products constitute the physical corpus of the building. These products are classified according to their function, production and finish: material, piece, component, element and unit. The properties and classification of building products are important in terms of organizing information, comparison and selection (Balanlı, 1997).

With the Industrial Revolution that started in England at the end of the 18th century, social and individual values changed, and the effects of mass production showed themselves in architecture as well as in every field. Architectural practice required more housing and new building types. This situation has led to the development and standardization of existing materials, the discovery of new building materials and the emergence of new building production methods (Güvenli, 2006).

After the mass production, with the separation of the assembly processes from the design processes, the building elements, which are the main objects of architecture, were mass produced in the factories, identification with printed catalogs, and thus presented to the designer. Classification systems have been used since the 1950 to ensure coordination in industrial building production (Serter, 2020). Firms needed systems that process information and data in order to adapt to the constantly and rapidly changing environment and to reduce the uncertainties in their environment (Tarçın, 2007).

The development of Computer Aided Design (CAD) software in the 1980 enabled the computer to be used more effectively in architectural design and assembly. In today's widely used CAD software, the geometry of all parts of the building is defined based on a certain marking system. The architect benefits from representation techniques within this system. CAD software is built with a system that imitates previous analog drawing and modeling techniques. Building components are not defined separately in this type of CAD software (Karadağ, 2011).

Building Information Modeling (BIM), which started a new era in CAD software with the emergence of new technologies in the field of architecture, engineering and construction (AEC) industry, has become an integrated methodology that brings a new approach to design and documentation in building projects. BIM is a major technological and theoretical development for the AEC industry. Sacks et al. (2010) define BIM as a transformative information technology, as it is the integration of parametric AEC and Information Management which both took off concurrently in the late 1990s (Wierzbicki et al., 2011). Unlike the widely utilized CAD tools, BIM enables visualization of form, behaviour, function and various other information of building design and construction with its object-oriented properties. BIM, which enables the control of the life cycle of the building consisting of design, production and maintenance processes, also provides documentation and visualization by extracting the model containing all the information about the building (Bentley, 2011). BIM allows all actors involved in architectural design, production and maintenance to work together. At the same time, it models their relations with each other based on the components that make up the building (Yaman, 2010). The main building blocks of the BIM system are parametric BIM objects, which are model elements. In the BIM system, each object represents a building component and each building component has its own attributes (Baldwin, 2021).

The main features of BIM are that it works with a digital database that keeps all the data defining the building together, that the revisions are processed into the database and reflected to all other documents automatically, and that all data collected during the design process creates a forward looking information repository. Traditional drawing and CAD software portray a design as geometric shapes. BIM software defines design as smart objects and components such as walls, columns, work programs, plan views. All these parametric components and objects are gathered in a single model. BIM systems can be used not only as a digital visualization tool, but also as tools that can highlight the natural capacities of materials, manufacturing and construction processes (Karadağ, 2011). In BIM technology, it is not the architect's choice of building materials to be used as a product from a catalog, but the design of the building with the product presented in line with the technical data of the material and the possibilities of the tools used (Jensen et al., 2009).
With the use of BIM in the construction industry, the need for the formation and use of standards has emerged. In 2013, a Publicly Accessible Standard (PAS) was published by the British Standards Institute (BSI) with the sponsorship of the Construction Industry Council.

Standards play an important role in ensuring the same accurate data is available throughout the supply chain, enabling wider adoption of BIM technologies, processes and collaboration (BSI, 2013). The common goals of standards, classifications, codes of practice and regulations regarding BIM are to increase the performance of a process. Codes related to classification systems such as Omniclass or Uniclass related to BIM are used to code building components. The purpose of BIM classification systems is to advance the entire lifecycle of the vertical and horizontal built environment by providing a means to organize and classify electronic object data. It is desirable to increase regular communication between building owners, designers, material suppliers, builders, facility managers and all proprietary associated with the built environment. The purpose of the guidelines developed for all professionals in the industry is to encourage more efficient practices by all members of the team of architects, designers, engineers, contractors, owners and operators throughout the lifecycle of a project (NBIMS, 2015).

The building components that compose BIM systems are included in this technology with their classification systems. The BIM objects of the manufacturers of the building components can be accessed from the international online BIM libraries. The products in BIM libraries contain the information of many classification systems according to different criteria. BIM libraries work as online resources to create and share product models with users. These online resources are databases for building.

In this study, with the emergence of the BIM system by means of the technological developments in the building sector, the situations in which the information does not change, increasingly transforms, and the tools to access the information change in the system where the building components are defined as BIM objects are examined through classification systems and BIM libraries.

The literature studies consists of scientific articles, international classification systems, building catalogs, international online BIM libraries, BIM reports and books published by independent organizations. After the literature review, the content analysis method was used to examine the classification systems. Content analysis is one of the qualitative research methods. “The basic process in content analysis is to gather similar data within the framework of certain concepts and themes and to organize and interpret them in a way that the reader can understand” (Yıldırım & Şimşek, 2006). The study was carried out by following the principles of content analysis. For the examination, first of all, the classification systems of building components developed with the existence of building catalogs, and then the classification systems that continue to be used in BIM systems were investigated. The classification systems, which are in common use, were determined and their contents were compared. Various findings were reached by revealing similarities and differences.

Developments in the Building Sector

Mass production, which emerged with the Industrial Revolution, radically changed both the production and circulation of building elements and components in the market, as in all sectors and products. It not only changed the traditional understanding of architecture, but also caused a radical change in the role of the architect and architectural practices with new construction systems, material types, the use of computer technology and scientific studies. In the consumption oriented social structure created after the Industrial Revolution, it was expected that the buildings would be built faster, like all other production objects. This

situation, along with other factors, brought industrialization and standardization in building construction (Karadağ, 2011).

With the spread of innovations and inventions peculiar to modern times, the main phenomenon that left its mark on the transformation experienced by modern industrial societies after the 19th century was mass production. Since the beginning of mass production in the 1950s, the way in which user needs and demands are handled in the design, production and marketing processes of products has changed. In the 19th century, England pioneered the circulation of building materials in the market and innovations related to sales methods. In the past, the material was generally produced by the builders at the construction site, but now it is produced by the manufacturers in the workshops, introduced with catalogs, displayed in the exhibition and fair areas and sold in the construction markets. Catalogs issued by large companies, called Builder's Manual, have begun to replace the construction manuals prepared for contractors and builders (Bilgin, 1994). With the transition to industrial production after the developments in the building industry, the necessity of building centers has emerged. Building Industry Center (Yapı Endüstri Merkezi – YEM), which has an important place in the information center and building materials sector in Turkey, was established in 1968. In 1973, Building Industry Center established a publication order with the Building Catalog (Yapı Kataloğu), then the building magazine and professional books. Technical sheets of building materials produced in Turkey are classified according to the "SfB System" in the Building Catalog and are published every two years (Sey, 2008).

From the 1970s onwards, the Post-Fordist production system started to show its effects. With the production approach called "just in time production", it is aimed to produce maximum consumer satisfaction with minimum resources and time (Sarıyar, 2008). This production model aimed to be product-oriented rather than process-oriented.

With the development of computer technologies, the use of information technology tools in production has increased. Information technologies and flexible production methods that developed in the 1980s gave companies the ability to respond to the demand that has become fragmented. The common feature of these companies is that they divide their product systems into smaller components and then combine them to meet different consumer demands. In the 2000s, the rapid development of computer and communication technologies and the expansion of information networks accordingly increased the interaction between the supplier-manufacturer-consumer in the production processes and enabled the consumer to have an active role. The concept of mass production and standardization has been replaced by the idea of "mass individualization" as consumers differentiate and customize the product they buy according to their own needs and expectations (Sarıyar, 2008).

Building Components Information Systems

Companies need systems that process information and data in order to adapt to the constantly and rapidly changing environment and to reduce the uncertainties in their environment. Information systems have emerged to meet this need. It has been observed that reliable information support, a processing method that will ensure the usability of information, an effective arrangement and marking system, ease of use and a properly functioning distribution path are expected from information systems. The most powerful of these tools are CAD technologies and the internet that come with the use of computers today. The most important elements that ensure that the data is organized and transmitted correctly; classification method

and coding systems. Information systems have become a necessity in order to adapt to the development of technology, to provide the right information, to process and evaluate it, to determine the place where it will be used, to transmit the information, and to manage the projects in the basic sense. The use of information systems in the construction industry began in the 1940s. In Turkey, the information systems used or recommended to be used in the building sector first started in the 1970s (Tarçın, 2007).

Table 1. Chronological classification systems and BIM libraries.

CLASSIFICATION NAME	COUNTRY	YEAR	BUIDING CATALOG YEM / TR	INTERNATIONAL ONLINE BIM LIBRARY						
				BIMforum List			BIM Object	NBS BIM Library	ARCAT	MEP Content
				2019	2020	2021				
SfB	Sweden	1950	+							
CSI MASTERFORMAT	North America	1963					+		+	
BSAB	Sweden	1972								
CI/SfB	United Kingdom	1976								
CAWS	United Kingdom	1987								
UNICLASS	United Kingdom	1997				+	+	+		
UNIFORMAT	North America	1998		+	+	+	+			
ISO 12006-2:2015	Swiss	2001								
OMNICLASS	North America	2006			+	+	+	+		+

In Table 1, commonly used classification systems for building products are; short names, country and year of development are shown. At the same time, the classification systems used in the Building Catalog (Yapı Kataloğu - YEM) and BIM libraries, which are the most preferred by designers, are given in the table. Systems that continue to be used in common are indicated in bold. Within the scope of the study, common classification systems are included.

SfB system consists of three separate parts. In the first part, the functional elements of the building, the production method in the second part, and the classification of the resources in the third part are defined (Taş, 2002).

Masterformat is a master list of classified topics and numbers to organize information about construction conditions, products and activities. This system divides building production into 2 main groups, then these groups into 5 subgroups and subgroups into 50 classes in total (Tarçın, 2007).

Uniclass is a product-based classification system. Containing the arrangement of specifications, cost information, project information structure, library documents; It is a classification system that can be used at every stage of the design and construction process (Serter, 2020).
Uniformat is a classification system in the building sector that aims to establish the link between the building-construction process, project specifications and cost calculations. In the Uniformat system, there are 5 stages created in the form of tables to classify the construction process (Tarçın, 2007).

Omniclass classification system is designed to classify all information about the production. The system is used in many execution, from classifying the structure of electronic databases to organizing product literature, project information and library materials. The system contains tables of used systems such as Uniclass, Masterformat, Uniformat, EPIC (Electronic Product Information Cooperation) (Serter, 2020).

The Relation of Building Information Modeling with the Building Components Classification System

The term of BIM first emerged with the development of solid modeling systems in the 1970s, but it became widespread in the 2000s (Eastman et al., 2011). BIM enables dynamic and direct collaboration, quick and accurate testing and validation of design decisions, participation of all project stakeholders, integration and analysis. It facilitates communication between project teams and supports quality management by automatically detecting design errors and clash detection. It is a project management tool that enables project teams to accurately estimate cost, reduce material waste, optimize work schedule, and streamline construction activities by simulating construction activities. It is also a mechanism designed to support contract management, monitor by assigning tasks, and plan and report on project progress by managing job changes (Baldwin, 2021).

In addition to the digital visualization of various forms, BIM software also contains all the information about the structure in the model elements. Thanks to the Computer Numerical Control (CNC) method, this information is sent directly to the machines and enables the production of building products. The transformation of the designs created in the free virtual environment offered to the designer by computer software to the final product can be realized as much as the materials, production tools and methods allow (Karadağ, 2011). BIM objects, which are the building blocks of the BIM system, are parametric. Computational infrastructure of material systems, which are constructed with complex relationships such as the combination of different parameters and data from material tests, is primarily created in the digital environment. However, the computational infrastructure based on material system logic should be able to integrate the geometric behavior, possibilities and limits of production methods, combination logic and material character, which are the main elements of material systems (Jensen et al., 2009).

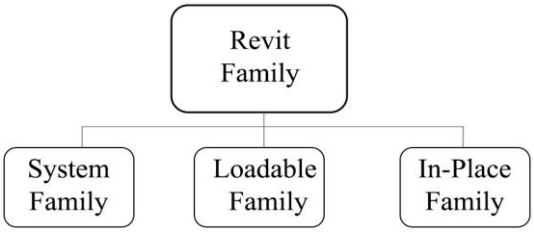
The Revit software, which is one of the BIM based software and widely used in current BIM projects, was developed in the early 2000s and was purchased by Autodesk. The Revit software has an interface that facilitates the editing of parametric 3D building components. A change made in the 3D model can be reflected to all areas at the same time, such as images created in the program, annotations on the sheets, and lists.

In the BIM system, each object represents a building component. Each building component has its own qualities. Object defines the building component with its physical dimensions, material properties, function, cost and approval status. BIM objects have development levels. The levels of development of BIM objects are briefly defined as LOD (Level of Development). LOD defines the representation of the object for a particular phase or state. With the LOD levels, the detail levels of the model elements are defined, the geometric and textual information data that the model should contain is leveled. The LOD definition, created by the American Institute of Architects, uses a five-stage system associated with the five key phases of the project: concept design, design development, construction documentation,

fabrication drawings, and as-built. This is a fairly broad grouping that describes both the geometric and informational content of an object and its potential uses. Categories are not only a measure of object detail, but also their suitability for their intended use (Baldwin, 2021).

BIM objects are grouped as object families in the Revit software according to the function of the building components they represent. System families are used in building construction to represent basic building elements such as walls, roofs and floors manufactured on site. Loadable families are mostly used to represent building elements such as doors, windows, furniture, which are purchased ready-made and assembled on site. In-place families are used for objects modeled in the desired geometry and features within the project, according to the project (Autodesk Help, 2022) (Table 2).

Table 2. Object families with different properties in Revit software.



In BIM systems, designers access the building components of manufacturers through online BIM libraries. BIM object libraries work as online resources for creating and sharing product models with users. Products in BIM libraries can contain information of many classification systems or can be customized according to different criteria. BIM libraries present categorized information objects to users online. In the BIM library, the user can examine, download, and use objects from many manufacturers belonging to the same type of product. These online resources are databases for building. Objects in the online environment are updated quickly and the user can always access up to date content. Creating manufacturer specific BIM objects creates an online marketing environment for product manufacturers. Some of the commonly used BIM libraries and their subdisciplines are shown schematically below (Table 3).

BIM softwares classify objects by class and type. Class is the highest category level of a building product. Primary relationships are defined at the class level. Type is a subcategory of model objects. Instance refers to individual occurrences of an object type in a project model.

“Class, Type, Instance” classifications (Table 4) explained over wall types are shown with wall examples in Revit program (Figure 1). Wall & Curtain Wall types belonging to different manufacturers were filtered from the “BIM Object” library and BIM objects were downloaded. Downloaded wall components are available as “basic wall” and “curtain wall” objects of different types.

Table 3. International BIM libraries and manufacturer sectors.

	BIM LIBRARY			
	BIM Object	NBS BIM Library	ARCAT	MEP Content
Architecture	+	+	+	
Structure	+	+	+	
Mechanical Electrical Plumbing	+	+	+	+

Table 4. Revit software classification systems.

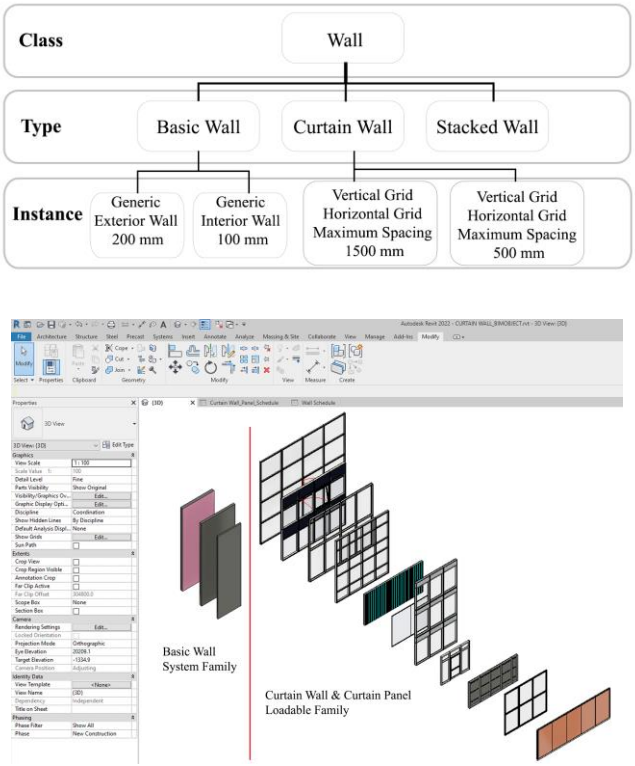
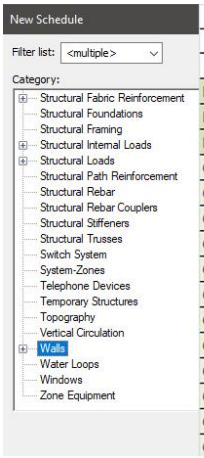


Figure 1: Wall examples in Revit program with BIM object.

Revit program, the material list of the building components seen in the model; can be given automatically thanks to shared parameters containing geometric and text information. The important point is that the objects are created in the right category and with the right classification code. As can be seen in Figure 2, BIM objects are listed in the first step by selecting the "walls" class category from the schedule list. After this filtering, the Revit program gave the subcategory types of the wall elements created as "system family" as "basic wall (type) - curtain wall (type)".

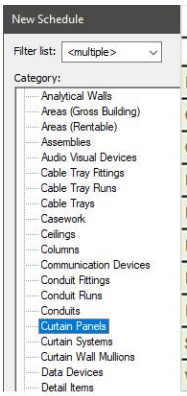


WALL SCHEDULE

Family	Family and Type	Manufacturer
Basic Wall	Basic Wall: 3.1.2_Tabique Pladur® 240 (150) 6F MW	PLADUR
Basic Wall	Basic Wall: AU Hebel Powerpanel XL External Wall D=186 Mm R=2	HEBEL
Basic Wall	Basic Wall: SK Ytong Internal Wall U=0	YTONG
Curtain Wall	Curtain Wall: Laminam 1000x3000x3.5mm_Vertical Mechanical Fixing	RIVENTI FACHADAS ESTRUCTURALES S.L.
Curtain Wall	Curtain Wall: RIVENTI_System-R50SG_H70-V100	RIVENTI FACHADAS ESTRUCTURALES S.L.
Curtain Wall	Curtain Wall: Aluprof MB-SE75	ALUPROF SA
Curtain Wall	Curtain Wall: Wicona - WICTEC 50 - Double Glazed - Demo Frame - RAL 7016	WICONA
Curtain Wall	Curtain Wall: Curtain_System-CRL-3250-Curtain_Wall_System	C.R. LAURENCE - U.S. ALUMINUM
Curtain Wall	Curtain Wall: Curtain_System-CRL-3250-Curtain_Wall_System	C.R. LAURENCE - U.S. ALUMINUM
Curtain Wall	Curtain Wall: Curtain_System-CRL-3250-Curtain_Wall_System	C.R. LAURENCE - U.S. ALUMINUM
Curtain Wall	Curtain Wall: Aluprof MB-EXPO	ALUPROF SA
Curtain Wall	Curtain Wall: KINGSPAN COLDROOM VERTICAL	ALUPROF SA
Curtain Wall	Curtain Wall: Walls_Curtain-Walls_İnteral_MN60_Mullion-Transom	CUHADAROGLU
Curtain Wall	Curtain Wall: Ponzio WS 50 Curtain Wall	PONZIO
Curtain Wall	Curtain Wall: Lindner Logic 100-Situation4(A)_F30	LINDNER AG

Figure 2: List of system family models found in the wall category.

As seen in Figure 3, BIM objects are listed in the second step by selecting the "curtain panels" type category from the schedule list. After this filtering, the Revit program listed the “curtain panel” wall elements created as “loadable family” and the objects belonging to different manufacturers as “instance”. Since the selected BIM objects are designed after the "curtain panel" category is selected correctly in the Revit program, the same "OmniClass" codes can be seen even if they belong to different companies. The omniclass number of the curtain panel “23.25.20.14.11.11.17” consists of these codes.



REVIT_CURTAIN WALL_PANEL_SCHEDULE

Manufacturer	Family	OmniClass Title	OmniClass Number
KINGSPAN	Coldroom_Microcold_V	Infill Panels	23.25.20.14.11.11.17
C.R. LAURENCE - U.S. ALUMINUM	Crl-3250-Center_Glazed	Infill Panels	23.25.20.14.11.11.17
CUHADAROGLU	Interal_UCW72	Infill Panels	23.25.20.14.11.11.17
LAMINAM	Laminam Panel_Curtain Wall Vertical	Infill Panels	23.25.20.14.11.11.17
LINDNER AG	Logic100_Wood Panel_L-Corner(A)	Infill Panels	23.25.20.14.11.11.17
LINDNER AG	Logic100_Wood Panel_Spacer	Infill Panels	23.25.20.14.11.11.17
PONZIO	Pannelli Vetro_Glass Panes	Infill Panels	23.25.20.14.11.11.17
RIVENTI FACHADAS ESTRUCTURALES S.	Riventı_Curtain-Panel_System-R50sg_Glass-Pane	Infill Panels	23.25.20.14.11.11.17
SCHUECO INTERNATIONAL KG	Schueco_Fws-Glazing	Infill Panels	23.25.20.14.11.11.17
WICONA	Wicona - Wictec 50 - Single Glazing	Infill Panels	23.25.20.14.11.11.17

Figure 3: List of loadable family models found in the curtain panel category.

The OmniClass codes seen in Figure 4 after selecting the necessary steps to create a "curtain panel" object in the Revit program are as follows. The structural setup of the Revit program is

designed with the “OmniClass” classification system. This system contains tables of existing systems such as Uniclass, Masterformat, Uniformat.

In BIM technology, the appropriate classification system that the BIM object will contain can be selected according to the project objectives and country. Required classification codes can be added with text parameters to BIM objects that work with parameters. In this way, the code system of more than one classification system is contained in the digital BIM object (Figure 5).

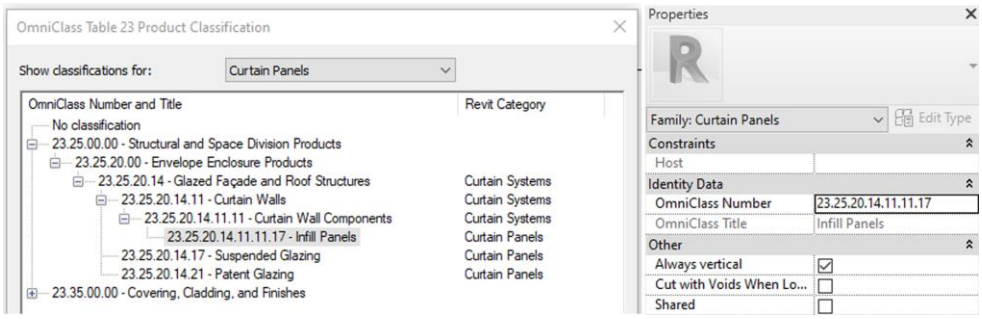


Figure 4: Omniclass code system within the Revit program.

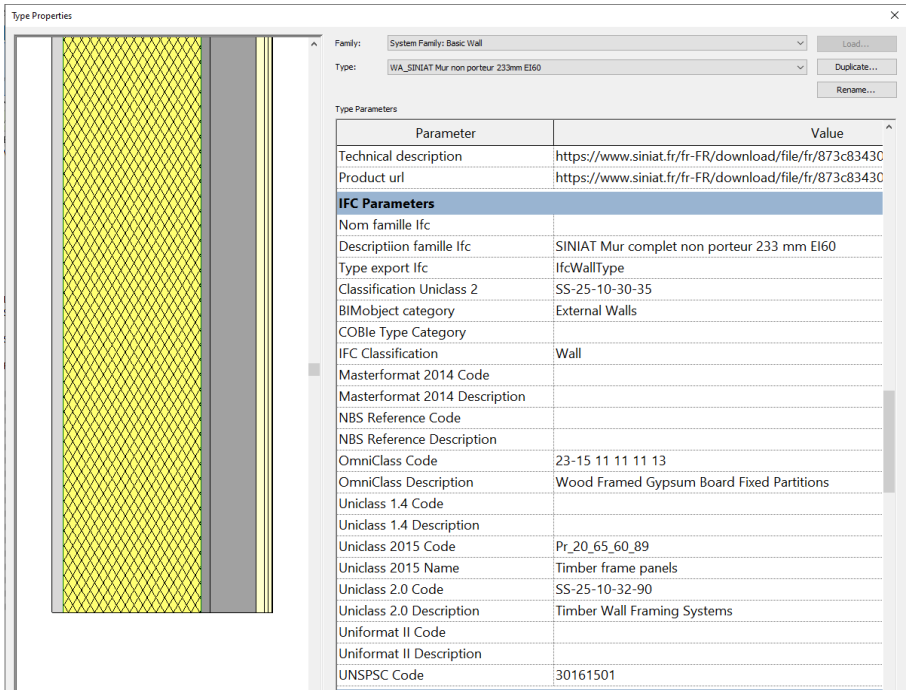


Figure 5: BIM object with different classification code parameters.

Conclusions

With the increase in the use of BIM technology thanks to the technological developments in the building sector, the work has progressed through classification systems and BIM libraries from past to present within the system where building components are defined as BIM objects.

Along with the industrial developments in the building sector, catalogs and brochures that provide information to users about building materials are presented as online resources instead of printed resources in order to be updated at the speed of new building materials that are rapidly spreading in the market. Today, with the widespread use of BIM technology, BIM libraries serve to share building components as BIM objects.

Within the scope of the study, classification systems and code data of BIM objects downloaded from the "BIM Object" library were examined. Thanks to BIM libraries, building components belonging to many different companies that can provide the same service in the

online environment can be used as BIM objects with 3D information, with correct technical and alphanumeric data. In this way, designers can reach manufacturers and their products from any location in the world. These conveniences may affect the decision of the designer from which company to choose the building element. Likewise, manufacturers can continue their competitive strategy on BIM platforms by expanding their market network. BIM libraries provide analytical data to manufacturers, giving data such as which product the user downloaded, when, how many times, from which location.

After the content analyzes made within the scope of the study, it was found that the use of building elements according to classification systems continues to be used in the structure of electronic databases. The classification systems used in the catalog system or traditional CAD systems continue their continuity in BIM systems. In BIM technology, these classification systems have added many values to digitalized building technology. In BIM technology, codes related to classification systems such as OmniClass are used to code building elements. Thanks to codes, electronic object data is organized. The classification data in the building elements enable the data shared on the common data environment to be used efficiently in the production of information, and the result information to be made into regular tables. Systems that classify building components with different methods can be used for classification of building elements. Categorizing by classification system in the BIM system details search and grouping activities, supporting subsequent sub-uses such as cost estimation and work schedule for objects that may be based on the same classification system. Data containing objects allow building elements to be produced and can directly initiate the fabrication process. Building data can be easily understood and shared among project participants thanks to digital parametric objects. Regular communication is maintained between building owners, designers, material suppliers, builders, facility managers and all stakeholders associated with the built environment.

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Using Blockchain Technology in the Construction Industry

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Abstract

The construction industry is trying to adapt to the developing technologies day by day. One of these technologies is blockchain, a distributed ledger technology (DLT). DLT is a type of database that is decentralized in nature, eliminating the need for an intermediary to process, validate or authenticate transactions. This article aims to highlight the critical issues regarding the use of blockchain in the construction sector by analyzing the literature and shedding light on current research limitations and gaps. Blockchain technology provides advantages to different parts of the construction industry like quality inspection, smart contracts, supply chain management, intelligent transportation, project payments, tendering for bidding, knowledge management, sustainable waste management, and energy industry, etc., due to its decentralized, encrypted, and secured functionality. Integrating blockchain into construction works improves quality, efficiency, and capability through security and transparency. On the contrary, blockchain technology is not widely used in the construction sector for being costly, time-consuming, and cyber-attackable.

Keywords: *blockchain technology, digital authentication, knowledge management, online payment, project management, smart contracts, supply chain management*.

Introduction

Blockchain is a type of the distributed ledger technology (DLT) that can record data, assets, and all related transactions executed and shared between network participants with the characteristics of decentralization, immutability, transparency and traceability. There are key advantages in its inherent immutability, transparency, and the way it redefines the

trust relationship by offering fast and secure solutions that can operate publicly or privately (Underwood, 2016). Blockchain technology was devised from the first cryptocurrency known as Bitcoin. It was soon noted to have a much more full range of applications beyond serving as the platform for the digital cryptocurrency (Nawari & Ravindran, 2019). The adoption of blockchain technology in the construction industry takes time. Due to the fact that blockchain technologies are costly, time-consuming, and vulnerable to cyber-attacks, their use in the construction industry is not at a sufficient level. However, in recent years, an increase has been observed due to the severe impact of this technology on quality, efficiency, and capability. This study investigates what, how, and why blockchain technologies are used in the construction industry, such as digital authentication, knowledge management, online payment, project management, smart contracts, supply chain management, etc.

Literature Review

Studies on a blockchain between 2017 and 2022 were examined using the American Society of Civil Engineers (ASCE) and ScienceDirect (Automation in Construction) databases. As a result of a detailed scan, the branches of the construction industry with an application of blockchain technology have been classified into nine subject areas, which are (1) smart (intelligent) contracts, (2) financial management (payment), (3) design (BIM), (4) project management, (5) real estate management, (6) power engineering, (7) supply chain management, (8) urban management, and (9) knowledge management. The classification of studies is explained below:

Smart (Intelligent) Contracts

A smart contract is an executable code that runs on the blockchain to facilitate, execute, and enforce the terms of a contract. The main purpose of a smart contract is to automatically execute the terms of a contract when the specified conditions are met. Over the past decade, research into smart contracts has increased significantly with tremendous efforts from computer science and engineering fields. Smart contracts have received less attention in construction and engineering than in other areas. Using smart contracts increases productivity and transparency, reduces corruption, and contributes significantly to the project's success (Owusu et al., 2020). The study's hypothesis that the contributions of intelligent contract applications in the construction industry emphasize that certain aspects of the construction contract cannot be fully intelligent. Further, smart contracts should be considered part of the BIM-led revolution in construction and not considered separately from it (Mason, 2017). When a comprehensive literature search was conducted, applications of smart contracts in different areas in the construction industry were found.

Some of these applications are as follows:

- Energy Internet: The Energy Internet is a collection of networks covering clean and coal energy systems, power systems, energy transportation logistics networks, and natural gas and oil pipeline networks. Decentralized, open and transparent, secure and reliable distributed by blockchain technology, shared mechanisms, and smart contracts technologies, such as energy production and consumption that users can only reshape effectively reduce energy costs but also allows the use of energy (Zheng et al., 2019).
- Greenhouse Gas Emissions: Many countries have tried to reduce greenhouse gas emissions by implementing various mitigation plans. Blockchain applications in the

construction industry have a considerable potential to advance building energy performance and reduce fossil fuel consumption. With the energy use monitoring feature of the blockchain, fossil fuel use in the construction industry can be limited. In addition, the smart contracts feature of this technology makes it easier for contractors to fulfill their environmental obligations (Woo et al., 2020).

- Quality Inspection: Generally, on-site construction quality inspection is carried out manually, and its effectiveness largely depends on the self-discipline and evaluation criteria of the inspector. A prototype system was developed to vividly demonstrate the theoretical feasibility of using blockchain technology which records information immutable and transparently and automates some businesses with smart contracts (Wu et al., 2021).
- SC-based Planning Platform: The Ethereum Blockchain approach was chosen to create a Smart Contract (SC)-based planning platform since it can accurately and quickly get the preferences of project managers and transmit the resulting regulation to transactions. The research findings will help project managers to react quickly to unexpected changes in management preferences in manpower, field, or schedule by developing adaptive resource utilization solutions (He et al., 2022).
- Construction Business Process and Information Integration: The aim of the study is to investigate the feasibility of implementing both public blockchain and private blockchain technologies in the construction industry using two industry cases. This pilot study also demonstrates the process, benefits, and challenges of adopting private and public blockchain technologies in the field of construction (Yang et al., 2020).

Financial Management (Payment)

For the successful completion of construction projects, the project participants must be paid on time. In the construction project, participants with different financial capacities belonging to different organizations depend on contractual relations. Due to the organizational structure of such projects, the project participants do not completely trust each other, which prevents the adoption of centralized, automated frameworks available for pay decoupling (Das et al., 2020). Blockchain provides a reliable decentralized peer-to-peer electronic cash pay network with minimal transaction costs, providing a platform for digital transactions and applications to proceed using a trusted intermediary party (Berglund et al., 2020). When a comprehensive literature search was conducted, financial management applications in different construction industry areas were found.

Some of these applications are as follows:

- Blockchain Tokenization: Tokenization is the process of replacing sensitive data with unique identification symbols that retain all the essential information about the data without compromising its security. Tokenization in the construction industry is an innovative method of financing infrastructure. Tokenization as a derivative of blockchain technology and a creative means of financing improves transparency, increases access to alternative sources of capital and liquidity, and reduces counterparty risk through decentralizing the infrastructure project financial system (Tian et al., 2020).
- Payment Tools: Within the scope of smart city programs, electronic payment systems are used in parking lot routing systems, transportation agencies, and bicycle-sharing systems.

- Blockchain offers a platform for digital transactions and applications that new electronic payment systems are based on cryptographic proof rather than trust (Berglund et al., 2020).
- Governmental Supervision of Construction Work (GSCW): Blockchain technology has been explored for governmental supervision of construction work due to its merits of traceability, immutability, and transparency. The study states that across-sectoral learning is performed between GSCW and digital currency electronic payment systems. In addition, the authors adopted a design science research method to develop a dual-layer blockchain-based GSCW model integrated with an incentive mechanism. The model developed in this study can serve as a valuable reference for policymakers, practitioners, and researchers to develop governance policies or blockchain applications (Lu et al., 2021).
- Distributed Blockchain-Based Framework for Payment: This paper presents a distributed blockchain-based framework that does not require to be trusted for automatically enforcing the terms and conditions related to interim payments and sharing payment records at the project level transparently and securely. The proposed management strategy is designed to dynamically generate cryptographic keys from publicly sharable parameters so that storage and management overheads are reduced (Das et al., 2020).
- Integrated Project Delivery (IPD): The study aims to develop a framework proposing blockchain technology utilization in IPD projects. The presented automated financial system increases trust and transparency among IPD team members, providing them with the assurance that all approved transactions are immutable and allowing each team member to control the cumulative values of the paid cost, profit, and cost savings (Elghaish et al., 2020).
- Smart Contract Payment Security System (SMTSEC): Paying participants on time in construction projects is very important for the successful completion of projects. Few studies have proposed methods for eliminating the problem when studying the causes and consequences of the payment problem. The authors stated that SMTSEC provides for eliminating or reducing payment issues in the construction sector. The main contribution of SMTSEC is that it provides a new method of paying for construction projects on time and transparently, guaranteeing the payment security of works under construction without the need for administrative costs and burdens of trusted intermediaries such as lawyers or banks (Ahmadisheykhsarmast & Sonmez, 2020).

Design (BIM)

Having a more collaborative process in design holds the potential for more problems related to the ownership of the intellectual property of the design. Therefore, by moving to the new era of digital-based design, that is, building information modeling, the ownership problem may become more complicated as BIM-based designs involve more people in the design process (Adibfar et al., 2020). Existing platforms for collaborative BIM design, the design, and manipulation of data are exposed to cyber security risks such as denial, traceability, loss of data, and project delays, which can lead to a decline in productivity and a central design system architecture. Blockchain is a promising technology for solving such risks by providing decentralized and immutable data storage (Tao et al., 2021). When a comprehensive literature search was conducted, applications of design (BIM) in the construction industry were found.

Some of these applications are as follows:

- Design Development by Blockchain Concepts: By developing blockchain frameworks, researchers propose the potential application of blockchain technology in the design development phase of architecture, engineering, and construction (AEC) processes. One of them is aimed at categorizing the design data generated from the design development software and log files in order to have a secure ledger that has the potential to provide validation to an argument and determine the data encryption flow using blockchain concepts (Singh & Ashuri, 2019).
- Cyber-Physical Systems (CPSs): The study focuses on evaluating supporting technologies for CPSs in AEC projects. The study supports using the blockchain to verify shared information and thus maintain trust in information exchange by providing cybersecurity (Linares et al., 2019).
- Integration of Blockchain to BIM-based Design: The research aims to investigate how digital-based design can be protected from unauthorized use, including what considerations practitioners may take into account to ensure the protection of their intellectual property. Blockchain and BIM-based design improve security and prevent AEC industry copyright infringement (Adibfar et al., 2020).
- Technology Maturity Gap between Academia and Industry: The researchers investigated the acceptance levels of emerging technologies by the industry of academic research and architecture, engineering, construction, and facilities management through an on-site and online survey and classified the identified technologies as suitability and maturity. Technologies to consider high use in the near future were found to be blockchain, AR, and modularization, accounting for 47%, 44%, and 40%, respectively (Cho et al., 2019).
- Blockchain Technology-Based Solution in BIM (BIMCHAIN): The exchange of information in a BIM environment is critical but complex due to the multilateral cooperative nature of a construction project. The study explores a blockchain technology-based solution to increase trust in data exchange in BIM following a case study analysis of a commercial tool called BIMCHAIN. BIMCHAIN's analysis has concluded that it has fulfilled, inter alia, many of its objectives, such as improving data reliability, limiting the scope of responsibility, and clarifying stakeholder responsibilities (Paradeep et al., 2020).
- Semantic Different Transition (SDT) Model: A new Semantic Differential Transition (SDT) model has been developed by researchers to capture and block BIM changes instead of all BIM files. This model minimizes information redundancy and supports BIM and blockchain integration. While the traditional idea is to store an entire BIM model or its signature code on the blockchain, SDT captures local model changes as SDT records and combines them into a BIM modification contract. In this way, the version history of a BIM project becomes a time-stamped BCC chain, and stakeholders can instantly synchronize BIM changes on the blockchain (Xue & Lu, 2020).
- Distributed Common Data Environment (DCDE) Framework for Design: Existing platforms for collaborative BIM design, the design, and manipulation of data exposed to cyber security risks such as denial, traceability, loss of data, and project delays, which can lead a decline in productivity and a central design system architecture. A blockchain transaction data model and a smart contract have also been developed to support the DCDE functions in the proposed framework, blockchain, and the Interplanetary File System (IPFS) (Tao et al., 2021).
- Designing liability control and increasing claims and disputes: Although the parties cooperating in the project design are contracted with the client, they agree without any direct contractual relationship between themselves when using BIM and other

collaborative applications. It leads to a lack of design responsibility control and increased claims and disputes. The researchers have argued that with three project processes (design review, design coordination, and request for information), it will demonstrate the ability to record snapshots of individual design inputs to the overall project design and provide a clear and long-term record of significant change processes (Erri Pradeep et al., 2021).

Project Management

Inspection and project management are important construction processes that ensure that construction work and workers comply with the prescribed codes, standards, and construction progress. In addition, delays occur in most construction projects due to the fact that the project management is not done correctly. Therefore, improving the project management and control processes directly affects the project's success. In-depth study of blockchain articles in the construction industry for applications in project management. After reviewing the available literature, five categories were identified for blockchain technology in the construction industry: (1) secure data transmission and data ownership, (2) IT in construction, (3) quality information management, (4) stakeholders' collaboration, and (5) construction payments and trust. The findings indicated that BCT presented high promises to improve the overall efficiency of the construction industry (Wahab et al., 2022). When a comprehensive literature search was conducted, project management applications in the construction industry were found.

Some of these applications are as follows:

- Smart Construction Systems: The paper discusses smart construction top-level design and its system, summarizes its functions and application processes, focusing on the cost, quality, schedule, contract, safety, etc. The function of smart construction systems contains a capital chain management system and ID labor management system based on blockchain technology, a material procurement management system based on blockchain technology, and an intelligent contract (Shi et al., 2019)
- Adoption of Innovative Tools to Preplanning and Design Phases: The study analyzes the differences in perceptions between academics and construction industry practitioners regarding the 17 emerging technologies through survey data and identifies potential technologies for high cooperation from an academic perspective. Based on results, blockchain is useful for preplanning and design phases agreed upon between academia and industry (Jang et al., 2021).
- Delay Analysis: The article aims to create a step-by-step protocol for a delay analysis that will focus on combining two built-in techniques to fill the gap while combining their known advantages. It happens through a monitoring process that uses the floating-path interface on the Primavera P6 for an automated process. When paired with secure blockchain technology, an updated backlog of project delay information and an updated reserve are securely allowed for interested parties to access (Elazhary, 2021).
- Inspection of Construction Processes: Traditional examination is characterized by physical exertion and laborious paperwork. However, the COVID-19 pandemic has made it difficult to dispatch inspectors and encouraged governments worldwide to explore alternative inspection approaches that take advantage of the latest tamper-proof and traceability technologies, such as blockchain. The research reports the

urgent need for e-inspection 2.0 to guarantee construction quality, compliance, and progress amid pandemic conditions (Lu et al., 2022).

- Digital Transformation for Construction Management: The effect of digital transformation on the construction management process has been studied. The study contributes to the construction industry's digital transformation and adds to the literature of the related scholarship domain. The framework developed is generalizable, thus, entrancing its significance and impact in different jurisdictions (Owusu et al., 2022).
- Risk Assessment for Construction Projects: In order to receive risk input from multiple stakeholders, different systems have been developed to support collaborative risk assessment. In the study, the need for a new blockchain-based methodology for collaborative risk assessment is analyzed (Chung & Caldas, 2022).

Real Estate Management

One such area that can benefit from the benefits of blockchain technology is the real estate sector. Like many other sectors, real estate also faces major administrative problems such as high transaction fees, lack of transparency, fraud, and the effects of an intermediary, including undue influence and commissions. When a comprehensive literature search was conducted, real estate management applications in the construction industry were found.

Some of these applications are as follows:

- Benefits of Blockchain Technology in the Real Estate Sector: The real estate industry must be harmed by blockchain technologies to deal with major problems such as high transaction fees, lack of transparency, fraud, and the effects of an intermediary, including excessive penetration and commissions. The blockchain allows supporting technologies to overcome the obstacles inherent in the real estate investment market (Ahmad et al., 2021).
- Startups in Built Environment Sector: Startups have had an impact in recent years through the often innovative products and services they provide. While information and communication technologies form the core of innovative products and services, the built environment sector has also experienced a good share of benefits. However, the construction and real-estate industries have been rather conservative. The study mentioned the rise of blockchain technology, which may impact contracts in the real estate market, making them self-executable (Lam & Fu, 2019).

Power Engineering

Blockchain technology contributes to sectors such as energy storage, energy trading, efficient energy production and distribution, renewable energy and power systems, and internet technology. When a comprehensive literature search was conducted, power engineering applications in the construction industry were found.

Some of these applications are as follows:

- Using Blockchain in Energy Trading: For power engineering, a tremendous amount of data is collected from different devices, different geographical locations of the power grid, and different time scales, which creates a research opportunity for large power data. An article conducted a thorough current literature review and a preliminary

discussion of this emerging research topic. Using the blockchain, energy trade contracts negotiated by producing consumers can be automatically authorized and concluded in a cyber-secure manner, providing a promising solution to the second problem (Zhang et al., 2019).

- Smart Grid: A smart grid is a two-way communication distributed energy network that provides efficient energy generation and distribution. Blockchain is recognized as a promising approach to producing and transferring reliable decentralized energy using blockchain technology. The study proposes a new blockchain-based decentralized green energy distribution system for reliable energy exchange in a smart grid that is not reliable (Talat et al., 2020).
- Energy Sharing Platforms: The rapid growth of renewable distributed generation requires further development of the electricity market for distributed energy. Article distributed battery energy storage systems and renewable energy and distributed generation and energy management as a model of platform sharing; this platform proposes energy users, energy producers, energy producers, and energy storage devices, both Energy Transfer and price. The process is referred to as the blockchain method and the P2P energy trading model (Han et al., 2020).
- Feasibility of Blockchain Technology for Energy Trading: The article includes the feasibility of implementing blockchain technology as an accounting system for energy trading within each island and between interconnected islands. The feasibility of the proposed energy trading system has been confirmed using a realistic example of Egypt's Alexandria distribution system. The simulation results show the positive effect of blockchain-based energy trading on the cost of energy (El-Zonkoly, 2021).

Supply Chain Management

Supply chain management in the construction industry is the relationship between the suppliers and the contractors involved in the project. This integrated approach is the foundation of success whereby all the stakeholders fully understand of the resources, logistics, and people involved to ensure the project is delivered on time and within budget. Blockchain can significantly improve supply chains by enabling faster and more cost-efficient delivery of products, enhancing products' traceability, improving coordination between partners, and aiding access to financing. When a comprehensive literature search was conducted, supply chain management studies in the construction industry were found.

Some of these studies are as follows:

- Supply Chain and Intelligent Transportation: As a solution to difficulties in exchanging pallets through different information platforms, it has been put forward to realize the exchange of different platforms and pallets using blockchain technology. A more efficient pallet pooling logistics business system has been proposed. Finally, it is proposed to use blockchain technology, which can effectively solve the problems of difficulty in exchanging pallets between different information platforms in the pallet pool system (Chen et al., 2020).
- BIM+RFID+GIS+blockchain System for Industrialized Construction (IC): The effects of supply chain weaknesses and capabilities in industrialized construction are modeled with increasing challenges for supply chain resilience (SCR). An integrated software package (BIM+RFID+GIS+Blockchain) would increase supply chain capabilities and quality (Ekanayake et al., 2021).

- Reliable Digital Deliverable (RDD) Model: The aim of this study is to analyze the construction supply chain (CSC) data delivery challenges by providing a reliable digital delivery (RDD) with the integration of BIM and blockchain. The RDD model is an important step for construction enterprises to maintain their competitive advantage (Hijazi et al., 2021).
- Three blockchain-based Models for the Supply Chain of Construction Projects: In this study, some conclusions have been reached about the three blockchain-based models used for the supply chain of construction projects. Project bank accounts (PBAs) for payments, a ban on auctions based on reverse auctions, and asset tokenization for project financing are the three bases of the model. As a result, problems related to bidding processes can be solved with blockchain technology, and smooth and transparent payments can be made. In addition, easier access to project financing can be provided (Tezel et al., 2021).
- Off-site Logistics of Modular Construction: Off-site logistics, including complex module production, storage, and transportation processes, is very critical for the supply chain of modular building projects. The study aims to identify and classify the sources of uncertainty affecting the off-site logistics of high-rise modular building projects in high-density cities; a blockchain-based process management platform has been adopted for quality control and process management (Yang et al., 2021).
- Blockchain-Enabled IoT-BIM Platform (BIBP): The demonstrative case study in a modular student residence project evaluates the proposed BIBP system prototype with the performance analysis of storage cost, privacy, latency, throughput, and feedback from stakeholders. The results indicate that BIBP has an effective system architecture with acceptable throughput and latency, can save storage costs to achieve a single point of truth in BIM, and avoid a single point of failure for IoT networks with privacy and security-preserving mechanisms (Li et al., 2022).
- Precast Supply Chain: The study establishes a new blockchain-based information management framework for a prefabricated supply chain that expands blockchain applications in the field of construction supply chains. The performance of this framework is confirmed by a case study in which a visualization system is presented to provide (1) information sharing management, (2) real-time scheduling control, and (3) information traceability. Results show that the proposed framework facilitates the timely delivery of precast components (PCs) and tracks the causes of disputes in the precast supply chain, focusing on PCs (Wang et al., 2020).
- SCOs-enabled Blockchain Oracles (SCOs-BOs) Framework: This study provides an innovative solution that takes advantage of intelligent construction objects (SCOs). It develops a blockchain oracles (SCOs-CS) framework in which SCOs are active. To embody this framework, the system architecture of a blockchain-enabled construction supply chain management (BCSCM) system was developed and validated using a case study, whereby the four main smart contracts were examined in the context of off-site logistics and on-site assembly. The evaluation results show that the correct data were obtained for each request, and the corresponding reputation scores were successfully recorded (Lu et al., 2021).

Urban Management

Urban Management is a discipline that focuses on addressing the challenges of urban life and realizing opportunities. The few articles related to urbanization and Sustainable Urban Development discuss the unique characteristics of the blockchain-related challenges as well as implementation risks and explore potential blockchain applications in addressing the

challenges. For successful urban planning, human-centered approaches and robust business processes must also consider the capacity adequacy, including financial resources, human resources, local culture, infrastructure, and governance systems, while minimizing the exacerbation of inequality in access and benefits. When a comprehensive literature search was conducted, urban management studies in the construction industry were found.

Some of these studies are as follows:

- Urban Intelligent Transportation: Based on blockchain technology, smart urban transport big data platform, merging data from different sources of data and other advanced technologies, including unified control and operation, compatibility with many important should resolve the problem. In order to solve the problem that complicates data sharing, a large urban intelligent transportation data platform has been created using blockchain technology in the article. In this big data platform, block data is used as the core, thus eliminating the centralized data management of each organization (Gong & Liao, 2019).
- Blockchain Water Platform: Over the past decade, there has been a huge increase in the use of artificial intelligence technologies for hydrological and hydraulic modeling in the implementation of water resources management. The blockchain water platform approach to urban stormwater management integrates data collection, stormwater modeling, and automation of hydraulic structures. This approach will be the non-structural solution to rainwater management to improve the urban-regional ecology system and water quality and reduce the risk of flood hazards and the cost of operation (Cheng et al., 2020).
- Municipal Solid Waste (MSW) Projects: MSW projects require mixed bundling or unbundling to achieve efficiency by technologies such as blockchain instead of pure bundling. The researchers have presented a framework in which practitioners can begin to embark on the goal of supplying effective projects in the MSW sector based on detailed understanding (Dolla & Laishram, 2020).
- 3-Dimensional Printing (3DP): The speed with which families recover from natural disaster disruptions and return to normal daily operations is very important. The loss of housing and the need for temporary housing is the situation immediately after the impact of a natural disaster. When blockchain-based 3DP technology is evaluated and compared with traditional construction processes, it is found to be useful in five areas: duration, cost, environmental impact, security, and transportation logistics (Subramanya & Kermanshach, 2022).
- Blockchain-Based Telecommunication System: The article is aimed at creating theoretical foundations for a new decentralized and infrastructure-free communication system using a temporary mobile network, distributed ledger, and blockchain technology, as well as studying its performance (Ilbeigi et al., 2022).

Knowledge Management

Information management has been recognized as an important tool for improving organizational effectiveness (Jafari et al., 2013). According to the National Association of Professional Engineers, the lack of interaction between construction managers and project stakeholders made the flow of project information difficult and chaotic. Their contracts are generally weird and not comprehensive (Engineers, 2014). Implementing Knowledge Management (KM) processes at both the organizational and national levels requires innovation. With high security, blockchain can serve as a distributed, programmable and encrypted database for transferring, protecting, storing, and quickly accessing information

from one place to another (Tian, 2016). Blockchain technology can be used as a method to manage trust in the generation, storage, sharing, protection, and implementation of various information (Akhavan & Mahdi Hosseini, 2016). Several studies about blockchain application for knowledge management in construction projects were evaluated below:

- Modern data models with Industry Foundation Class (IFC): The industry basic class (IFC) dominates the architectural engineering and construction (AEC) industry as an open BIM standardized data model for storing and exchanging information. The purpose of this article is to analyze the current AEC data standards and propose a conceptual framework using modern data standards such as JSON and RDF with traditional IFC as a basis for different building automation system (BAS) use cases (Tang & Shelden, 2020).
- Regulatory Changes on Capital Projects: The purpose of the study is to help construction industry organizations match the regulatory compliance process with their capital projects better. Implementing a comprehensive and intelligent model allows companies to more effectively comply with regulatory changes to reduce risks and other commercial impacts. The construction industry is moving towards automation and adopting other technologies, such as artificial intelligence and blockchain (Rasoulkhani et al., 2020).
- Hydropower Projects: The uncertain construction of hydropower projects and fierce market competition impose more stringent requirements on the accuracy and competitiveness of cost forecasting for contractors. With the progress of construction technology, information about the construction process is gradually being shared. For example, the application of blockchain technology is changing the current state of engineering information. The information between the owner and the contractor becomes more transparent and robust (Chen et al., 2020).
- Cybersecurity of Operational Technology: Digital transformation in the construction industry affects how information is exchanged and disrupts the way construction sites work. The motivation of this study was to understand the current recent situation and identify gaps to propose future OT-related guidelines in construction from a cybersecurity perspective. Construction companies should consider the cybersecurity implications before utilizing blockchain technology to enhance their processes (Sonkor & Soto, 2021).
- Integrated Safety Management (ISM) System: A successful Construction Safety Management Process should include Security records of stakeholders, risk assessment, risk analysis, preventive control tasks, inspection procedures, and daily event reports. The study aims to develop a new information management framework for construction safety processes using blockchain. The results of this study contribute to the current knowledge and current state of practice in integrated safety management (ISM) systems aimed at protecting construction workers and the public by providing timely, reliable, and complete information to all organizations involved in a project (Morteza et al., 2022).
- Onsite Assembly of Modular Construction (OAMC): The study, which adopts the design science research (DSR) method, aims to investigate the use of blockchain technology to improve the accuracy of information sharing in the on-site assembly of modular structure (OAMC). It can serve as a valuable reference for future efforts to leverage the power of blockchain technology to mobilize information approval mechanisms, especially for various value-added applications (Wu et al., 2022).
- Integrated Digital Twin and Blockchain Framework: The study aims to develop and test an integrated digital twin and blockchain framework for traceable data

communication between stakeholders and project managers. The authors tested the framework with a case project in which virtual positioning data from a prefabricated brick is transmitted to the digital twin in almost real-time and recorded on the blockchain with time stamps. The results show that the integrated digital twin and blockchain framework makes all data transactions traceable (Lee et al., 2021).

Discussion

An exploratory approach was implemented in this review to understand which categories in construction are most studied by blockchain. Based on categorized subject areas, the potential and challenges of blockchain technologies are examined. The potentials of blockchain technologies are providing transparency, trust, and using and storing data securely. Moreover, this technology provides cost and time efficiency and workflow with its features of disintermediation, automation, and decentralization.

Table 1. Potentials and challenges of blockchain technology.

POTENTIALS	
Transparency	Savelyev (2018)
Trust	Rodrigo et al. (2018); Underwood (2016)
Data security	Coyne and Onabolu (2017)
Cost efficiency	Boonpheng et al. (2020); Sharma et al. (2020)
Work flow and time efficiency	San et al. (2019)
Disintermediation	Notheisen et al. (2017); Sun et al. (2019)
Automation	Nawari and Ravindran (2019); Kandiye and Artan (2021)
Decentralization	Dorri et al. (2016)
CHALLENGES	
Policy	Kiviat (2015)
Scalability	Jesus et al. (2018); Notheisen et al. (2017)
Privacy Leakage	Perera et al. (2020)
Initial cost	Kouhizadeh et al. (2021); Kandiye and Artan (2021)
High transaction confirmation time	Sunny et al. (2022)
Understanding	Gatteschi et al. (2018); Bag et al. (2020)
Storage problems	Lo et al. (2017); Lu and Xu (2017)
Cyber attackable	Penzes (2018)

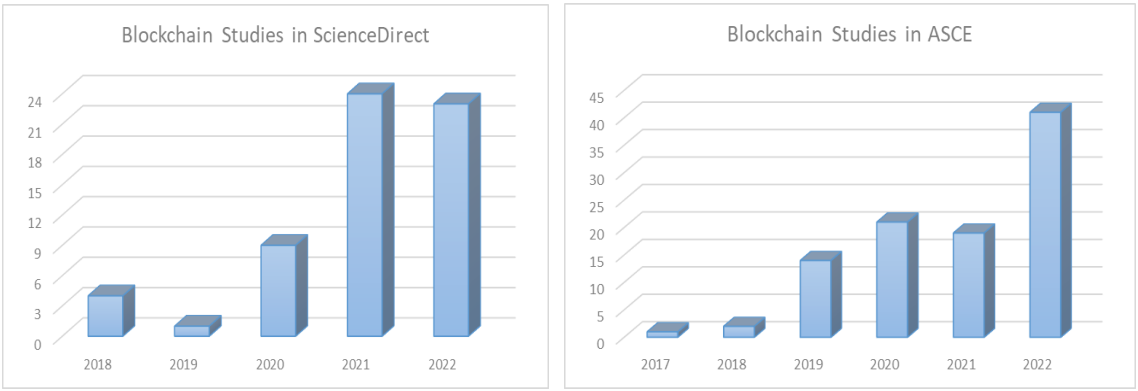
On the contrary, blockchain technologies face some policy challenges due to the high initial investment cost, complexity, and vulnerability to cyber-attacks. Furthermore, its use has not become widespread in the construction industry due to problems such as high data storage requirements, privacy leakage, and high transaction approval times. The potentials and challenges of blockchain technology in the construction industry are listed in Table 1.

The exploratory approach was carried out by using the ASCE and ScienceDirect databases. In the ScienceDirect database, the count of review articles is 18, and the count of research articles is 43 in 61 studies related to blockchain technology between 2018-2022. In addition, when the ASCE database was scanned between 2017 and 2022, chapters/proceedings papers (35) and technical studies (26) constituted the majority of the 97 studies, as shown in Table 2.

Table 2. Article types and counts about blockchain in ScienceDirect and ASCE.

Databases	Article Type	Count
ScienceDirect	Review articles	18
	Research Articles	43
ASCE	Chapters/Proceedings Papers	35
	Technical Paper	26
	Front Matter	11
	Case Study	7
	State of the Art Review	6
	Editorial	4
	Technical Note	3
	Forum	2
	Back Matter	1
	Editor's Note	1
	Review article	1

Figures 1 (a) and (b) illustrate the count of blockchain studies of the two databases by year. The scanned blockchain studies on ScienceDirect between 2018 and 2022 show that the highest rank is in 2021 with a number of 24 articles, and in 2019 only one article was published. Additionally, when the studies related to the blockchain between 2017 and 2022 were scanned on ASCE, the highest count of articles with 41 were in 2022, and only one article was in 2017 (as shown in Figures 1 (a) and (b)).



(a) (b)

Figure 1(a), (b): The count of the article in ScienceDirect and ASCE by years.

The annual number of relevant literature analyses proves that the research results in this field have grown particularly rapidly in recent years. Then based on previous studies, the application topics are divided into; smart (intelligent) contracts, financial management (payment), design (BIM), project management, real estate management, power engineering, supply chain management, urban management, and knowledge management and the content is analyzed respectively. Figure 2 demonstrates that studies of blockchain technology in the construction industry published in 2022 highest article count were found to project management, smart (intelligent) contracts, and knowledge management which accounted for 6, 5, and 4, respectively. A total of 22 studies were carried out in 2022. In 2021, 19 studies were conducted in total, and 6 of these studies are related to supply chain management in the construction industry. In 2020, the highest blockchain studies were carried out with 23 studies, and 6 of them were published in the field of both financial management (payment) and knowledge management. In total, the subject areas with the highest number of blockchain

studies published are knowledge management (13), smart (intelligent) contracts (12), design (10), supply chain management (10), and finance management (9). On the contrary, the subject areas with the least study between 2017 and 2022 are real estate management (1), power engineering (5), and urban management (5). In 2018, no studies were conducted on these subject areas, as shown in Figure 2.

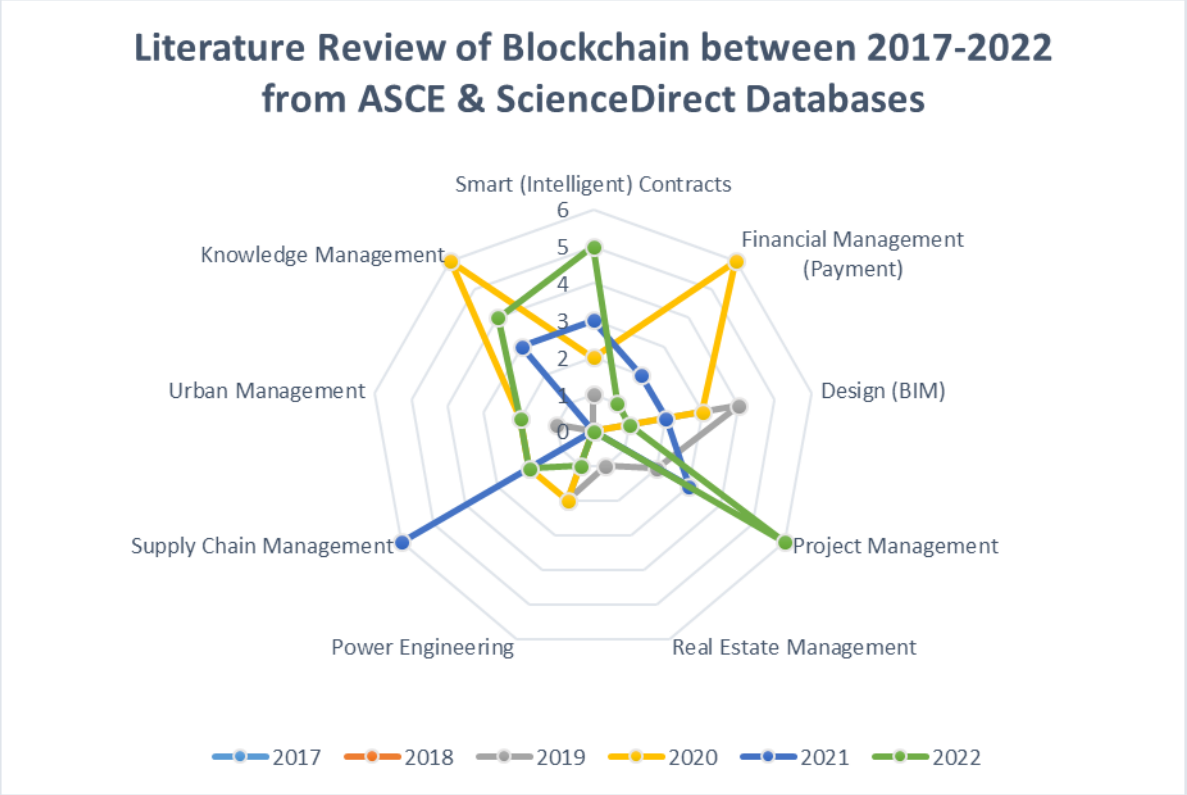


Figure 2: Categorized nine subject areas.

Most analyzed literature is qualitative, describing possible applications and intended effects. Only a few systems are applied to the construction sector. It is worth noting that the classification of the literature may not be correct due to the intersection of blockchain application in the field of civil engineering. At the same time, the lack of a specific research topic does not mean that there is no place for blockchain to play. On the contrary, this is the lack of the current research topic. Therefore, comparing the overview of blockchain application ideas with classified topics can help identify research gaps (Fu et al., 2021). The main contributions of this paper are: (i) to identify current blockchain applications in the construction industry; (ii) to help future researchers explore potential blockchain solutions.

Conclusion

Developing technologies play an important role in increasing overall productivity in the construction industry. Due to the advancement of technology usage in the AEC industry, more and more research is being conducted to explore the application of new technologies such as blockchain. Blockchain as a technology framework has the potential to solve some problems in the AEC industry by supporting processes related to data verification and advanced cybersecurity. Countries are trying to make the necessary legal and regulatory

changes to adapt to the new environment and make this change a reality. In the future, blockchain seems to be something we will hear a lot more about. It is evidenced by the fact that the number of articles on blockchain in the scientific literature in various scientific fields, including engineering, has been growing rapidly in recent years.

This study briefly examined the technical details, main concepts, and aspects of blockchain technology. It aimed to formulate a picture of the current state and application of its use in areas related to construction, architecture, and civil engineering. The study also has the potential to offer new solutions to construction industry-specific application areas, and related future performance, sustainability, and safety are outlined to improve how they are adopted. We identified nine important application areas and examined the relevant challenges and potentials ahead, namely in 1) smart (intelligent) contracts, 2) financial management (payment), 3) design (BIM), 4) project management, 5) real estate management, 6) power engineering, 7) supply chain management, 8) urban management, and 9) knowledge management. The conclusion of the study is that although blockchain technology is new and there are several early challenges that definitely need to be overcome, it has the potential to be an extremely positive force for change in the construction industry. As engineers, the construction industry must facilitate the digital transformation of the industry and prepare it for the challenges and potentials of the future. Blockchain must play a crucial role in this transformation.

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Use of Visualization Technologies for Increasing Efficiency of Construction Industry

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Abstract

While efficiency increases in many industries with increasing technology, efficiency decreasing is being seen in the construction industry year by year. The most effective way of increasing efficiency is to increase technology adaptation in the construction industry. In the last decade, virtual reality technologies have been at the attention of the biggest technology companies and users. Using visualization technologies to adapt technology may be a great opportunity for the construction industry. Researchers, around the world, modelled projects with 3D virtual reality technologies and brought together stakeholders in the virtual environment. They tried to develop management and installation skills for projects. Many studies investigate the use of augmented reality technologies in the construction industry. The purpose of this study is to provide an objective summary of visualization technology studies related to Architectural Engineering and Construction. The most important points will be summarized by reviewing the literature studies. Studies will be analysed by grouping them according to their subjects. In this way, researchers who are interested in this subject can be found the right area to investigate. This study will contribute to determining the current position of the use of virtual reality technologies in construction projects.

Keywords: *augmented reality, BIM, communication, construction 4.0, construction planning, education, mixed reality, virtual reality, visualization technology.*

Introduction

The construction industry is one of the cornerstones of the world economy, with an annual income of 10 trillion dollars and employment of approximately %7 of the working population worldwide (Gerbert et al., 2016; Barbosa et al., 2017).

However, the construction industry loses value due to low labour productivity. While the labour productivity in the manufacturing industry and other industries has increased regularly in the last 20 years, the amount of labour productivity in the construction industry has remained almost the same. The labour productivity gap between the other industries and the construction industry is increasing every year (Japan Federation Industry Handbook, 2020).

Low labour productivity not only reduces the profitability and earnings of the construction industry, but also negatively affects the world economy. Low labour productivity leads to more labour employment than needed in the construction industry.

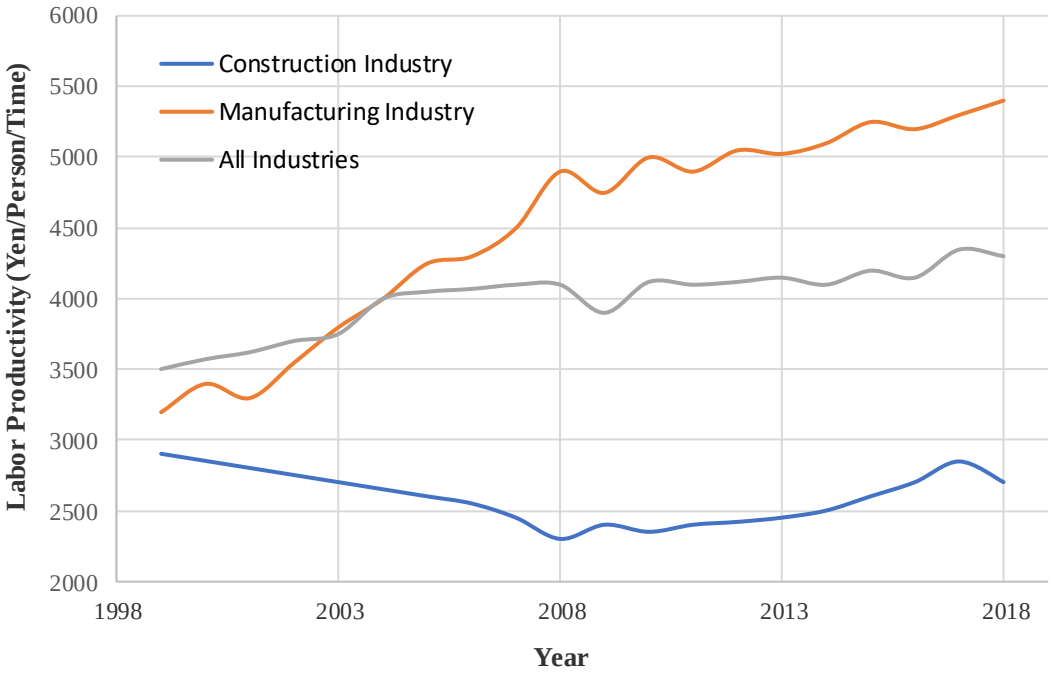


Figure 1: Labour productivity comparison between industries (Japan Federation Industry Handbook, 2020).

Employees employed in the construction industry without adding additional value are prevented from adding value to the world economy by being employed in another sector. As seen in Figure 2, the labour force that cannot be employed in other sectors will be prevented from adding new value between 1.6 trillion dollars and 2.3 trillion dollars to the world economy every year. (McKinsey Global Institute Report, 2017).

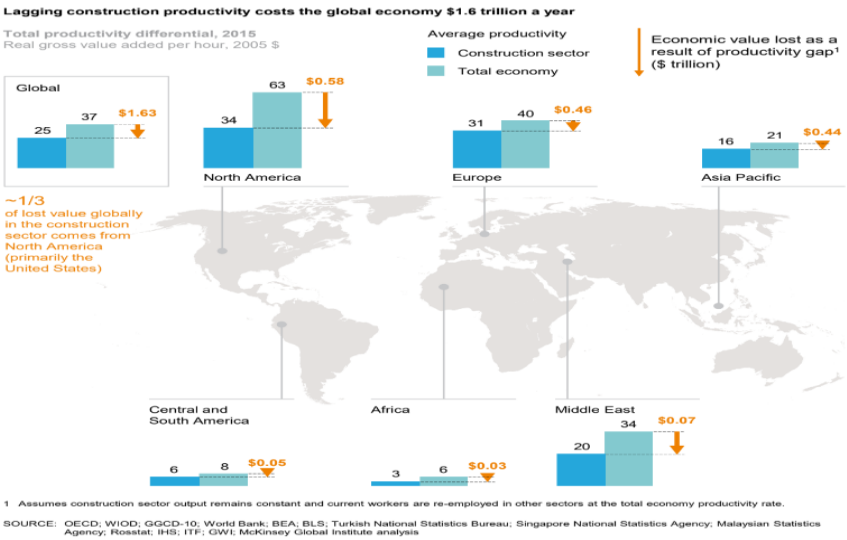


Figure 2: Delayed construction labour productivity costs the global economy 1.6 trillion dollar a year (McKinsey Global Institute Report, 2017).

One of the most important factors that affect the labour productivity of the construction industry and negatively affect the world economy is the low digitalization rate of the construction industry. As seen in Figure 3, there is a strong correlation between the labour productivity of the industries and the digitalization index. Both of digitalization index and labour productivity is lowest value in the construction industry among the other industries. (McKinsey Global Institute Report, 2017).

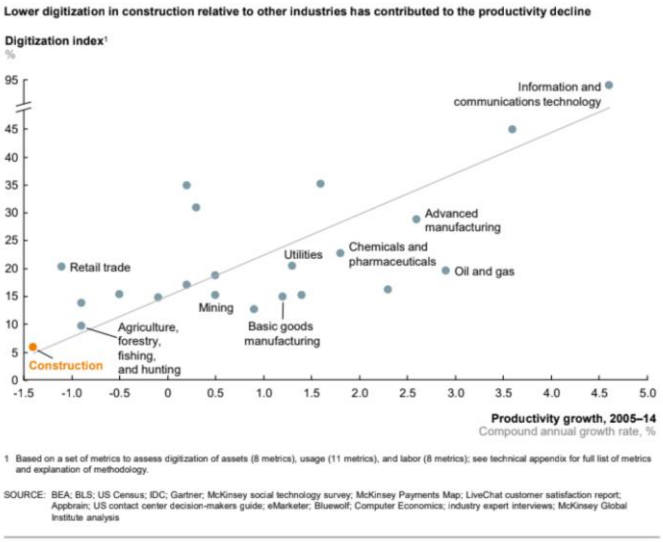


Figure 3: Digitalization index – labour productivity relationship between industries (McKinsey Global Institute Report, 2017).

Bock and Linner (2015) say that the problem of the construction industry with digitalization is that the products used by the industry do not complete the development stage. These two scientists applied Fuster's (1986) S curve plot of a product to the construction industry as seen at the Figure 4. According to this curve, a product initiative is developed in 3 periods. These are innovation, growth and maturity. At the innovation phase, products show lower performance than traditional methods. During this period, developers deal with technical and organizational problems and the challenges of the uncommercialized trial product. It cannot contribute to the performance as much as the traditional method. During the growth phase, performance increases and in the maturity period, it provides superiority to the classical application in terms of performance. Many technological products developed in the construction industry have not been able to contribute to the digitalization of the industry by putting them into practice because they have not yet overcome the technical and organizational problems.

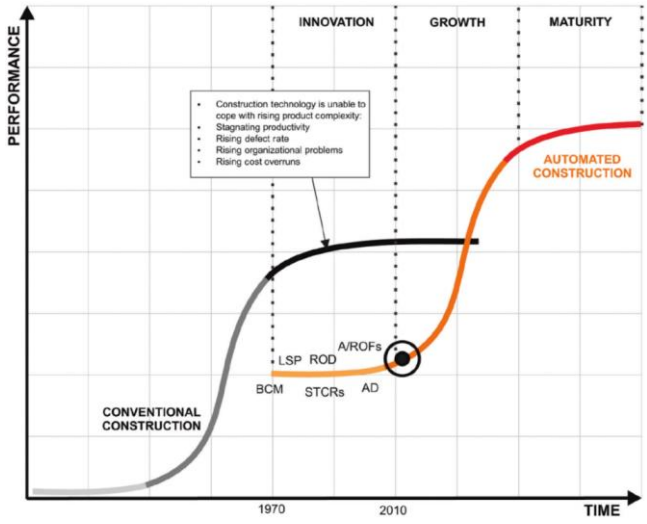


Figure 4: S curve applied to construction technology products (Bock & Linner, 2015).

German scientist Berger schematized the development stages of products in the construction industry and other industries that contribute to digitalization. As seen in the Figure 4, there is no product that has completed its development phase in the construction industry. According to Berger, the only way to increase labour productivity is digitalization. And Berger defined the works for the digitalization of the construction industry as Construction 4.0, inspired by Industry 4.0 (Berger, 2016).

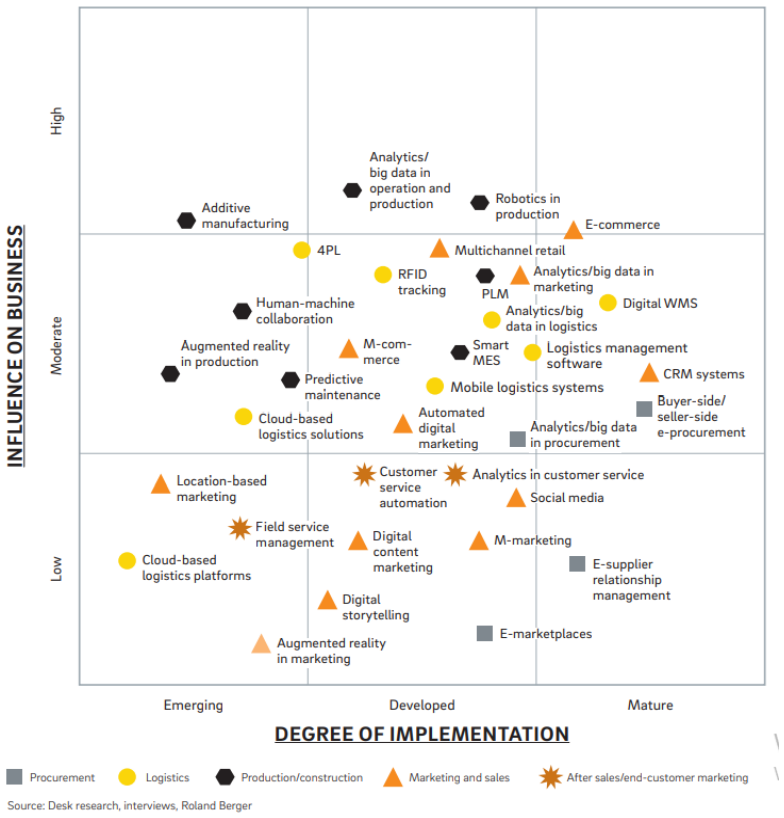


Figure 4: Development status of technology products in different industries (Berger, 2016).

Scientists work in 7 different fields of knowledge about Construction 4.0 to increase digitalization in the construction industry. These 7 knowledge areas are listed below as items.

- Robotic machines
- Artificial intelligence
- Data storage and cloud system
- Building information modelling
- Prefabrication
- Monitoring system (laser scanning, drone and cameras)
- Virtual, augmented and mixed reality.

As seen in Figure 4, virtual and augmented reality technologies have the lowest level of development among the digital products in the construction industry. However, virtual and augmented reality technologies are in the centre of attention of today's biggest technology companies. Facebook claims that virtual reality technology will create a new virtual universe called metaverse. The company attaches so much importance to this technology that it changed its name to "Meta". Meta also announced that they will invest 10 billion dollars in this technology and employ 10.000 highly skilled personnel to develop this technology. (Clegg & Olivan, 2021). Google and Microsoft are other big technology companies that focus on virtual and augmented reality technology.

In A Foster Total Economic Impact Study Commissioned (2019), Microsoft summarizes the benefits that a company will gain when investing in its own product, HoloLens glasses, with following items.

- Enhanced training efficiency
- Increased task efficiency for field workers and onsite workers
- Improved productivity for the project leader
- Improved productivity and avoided travel for specialized experts
- Reduced operational cost
- Protected and grew revenue.

These topics are improvements that will increase labour productivity in the construction industry. Studies that will expand the use of this technology in the construction industry will bring the development level of this product to the maturity level. In addition, the works to be carried out will contribute greatly to the digitalization of the industry, the increase in the labour productivity of the construction industry and the positive impact of the construction industry on the world economy. For this reason, the attention of scientists who works on Construction 4.0 should be get on augmented and virtual reality technologies.

Aim of the Study

Scientists have done a limited number of studies for the adaptation of augmented reality technology to the construction industry. The breakthrough of virtual reality and augmented reality products in recent years has added extra importance to the work done.

In order to augmented reality technology to reach maturity development level in the construction industry, the number and quality of the studies should be increased. For this reason, studies on augmented and virtual reality in construction industry should be reviewed and their deficiencies should be determined.

The aim of this study is to review the studies about augmented and virtual reality in construction industry and determined the deficiencies of these studies.

Methodology

For defining the main borders of studies about augmented and virtual reality in construction industry, eight scientific journal was reviewed. These journals are the most popular journals about digitalization of construction industry. The name of this journals is Automation in Construction, Advanced Engineering Informatics, Journal of Information Technologies in Construction, Journal of Computing in Civil Engineering, Buildings, Engineering Construction and Architectural Management, Journal of Construction Engineering and Management and Computer Aided Civil and Infrastructure Engineering. The searching was made by using augmented reality keyword. 238 article was found at these journals. Keyword relation analyse was made with these articles by using VOSViewer. Analyse report is showed as Figure 5.

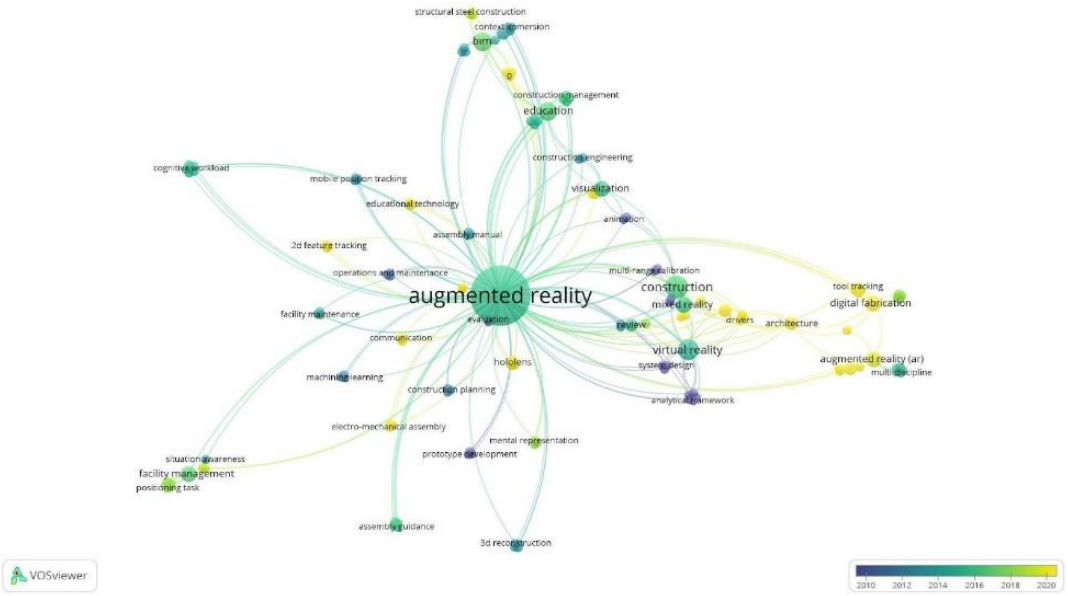


Figure 5: Keyword relation analyse between articles.

It can be seen that researchers generally had focused 4 main subjects at this articles. These are communication, construction planning, education and BIM. According to keyword relation analyse, these 4-research subject were specified as keyword of this research. Also 5 valuable words for this research was added to keywords list such as Augmented Reality, Construction 4.0, Mixed Reality, Virtual Reality and Visualization Technology.

By using these keywords, 50 articles were reviewed in detail. The aims, methods and outputs of each of the articles were determined and noted. The articles were divided into groups according to their area of interests. The aims and outputs of the grouped articles were converted into text to represent all the work done. Also, the pros and deficiencies of literature were specified.

Results

Looking at the writing dates of 238 articles, it is seen that research on augmented reality has increased in recent year. Figure 6 show the count of articles year by year for last 5 years. In 2021 the number of studies doubled compared to 2020.

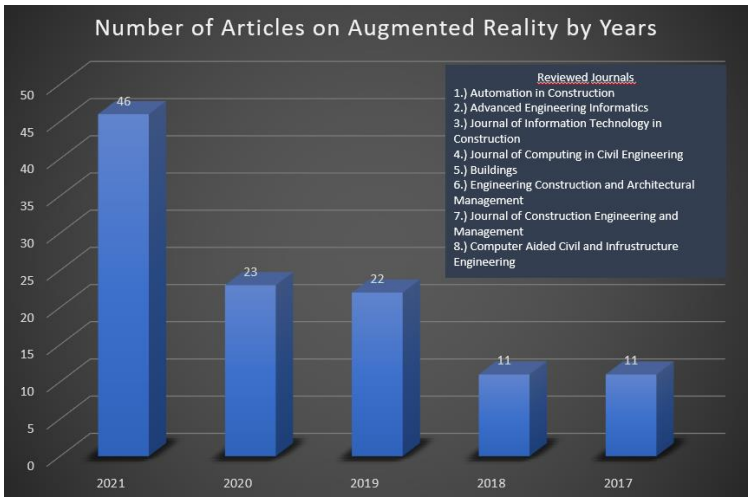


Figure 6: Number of studies in the last 5 years.

50 articles which represent literature was reviewed in detail. Studies on virtual and augmented reality are divided into 4 different groups according to their purposes. These groups are use of augmented and virtual reality in;

- Project Modelling
- Education
- Safety and risk determining
- Inspections.

The classification of these 50 articles according to subjects and years is shown in Figure 7.

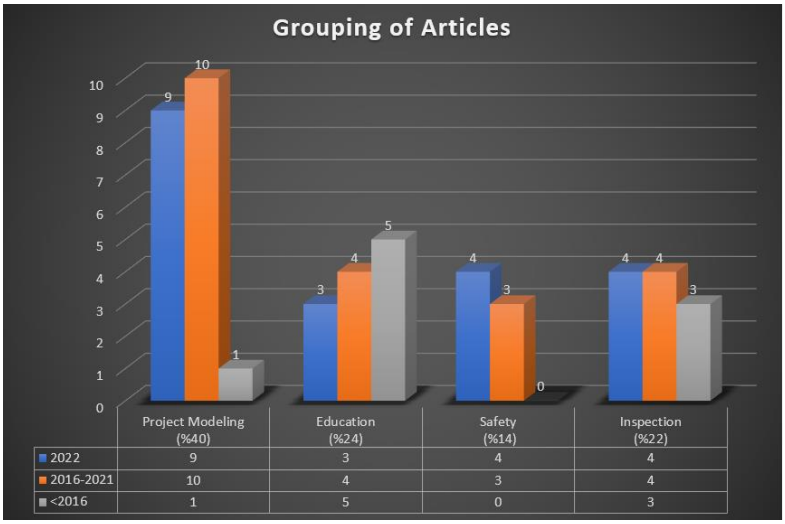


Figure 7: Classification of 50 articles according to subjects and years.

In this section, each group work will be given an overview with a few articles.

In Project Modelling Use of Augmented Reality and Virtual Reality

Scientists thought that people understood the project from the 2D project too late. By using augmented reality technology instead of 2D projects, they tried to make it easier for people to understand the project.

Carrasco and Chen (2021) modelled an office project with mixed reality and traditional 2D project. 42 participants were included in the study. 21 of them viewed the 2D traditional and other 21 of the viewed mixed reality model. After the review, the participants were asked question about the project. Reviewers with mixed reality answered 85% of the questions correctly. Reviewers with 2D traditional model answered 70% of the questions correctly. The difference between the correct answers shows the positive contribution of the mixed reality model to understanding the project.

Chalhoub and Ayer (2018) designed an electrical channel assembly project with traditional 2D project and augmented reality project model. Participants were divided into two groups. One of them made an installation by using a traditional 2D project and other group made an installation by using augmented reality project model. The time that both groups of users watched the project to understand the project was recorded. It was determined that the group using the augmented reality model understood the project in a shorter time. In addition, total project implementation times were recorded. It was determined that the group using augmented reality model, implemented project in a shorter time.

Shi et al. (2020) worked on the piping project. 120 participants were involved in the study. They prepared 2 D traditional simple content project, 2 D traditional detail content project, 3D projects and virtual reality model. Participants were divided into 4 groups. Every group installed pipe project by using different project type. The implementation times were recorded. The group which uses augmented reality project model finished their targets in shortest time.

Hartless et al. (2020) investigated whether the deficiencies in the project model could be better identified with the virtual model. A small building was modelled using virtual reality technology, ignoring the needs of the disabled. Participants tried to find deficiencies with virtual reality model. All of the participants could find all deficiencies.

Ewart and Johnson (2021) say that one of the biggest problems in the project is finding direction. They modelled the university building with virtual reality technology. They asked the participant to find a room. Some participants found room at real world and other participants found at virtual world. The participants which use virtual model found target room in a shorter time.

Du et al. (2018) enabled participants to interact in a virtual reality model. 71 participants were involved in the study. Participants using a virtual reality model detected errors in the project more easily.

In Education Use of Augmented Reality and Virtual Reality

Scientists have conducted research on whether the use of augmented reality technology as an educational tool will be beneficial. Especially, AEC industry students need to see what they have learned in the field. It is not always possible to see the field in the real world with all students because of cost and safety risks. But in the virtual world, it is possible.

Sampaio and Martins (2014) modelled the implementation stages of a bridge with a virtual reality model and used it as a training document. Students say that they understood better when they saw the implementation phases of bridge in the virtual model.

Vasilevski and Birt (2020) created a model where students can communicate with their avatars within the model. After the students' experiences, they took the students comments. Students said that learning with a virtual model is more fun.

Spesgozar (2020) developed a virtual reality model for students to learn how the tunnel boring machine works. 10 people can participate in the model at the same time and can be connected to the model via the internet. Students were able to discuss the subject in virtual environment. Students commented positively on the model as they learned in a risk-free and immersive environment.

In Safety and Risk Determining Use of Augmented Reality and Virtual Reality

In a construction project, risk assessment reports are prepared at the beginning of the project. However, it is not easy to imagine the risks that may occur in all phases of the project without seeing. Scientists have studied on the fact that it may be easier to detect safety risks in the virtual environment model.

Azhar (2017) created virtual reality models of 3 different projects in practice. He has given safety trainings and created safety plans based on these models. A survey was conducted with the project stakeholders about conducting the occupational safety communication with the virtual model. According to the project stakeholders, the communication channel in the explanation of the safety plan to the workers has been strengthened. Also, project safety communication network has been strengthened. And security related logistic materials were addressed in the pre-project phase.

Olurunfemi et al. (2021) worked on the office worker's transmission of safety directives to the site. Telephone communication and mixed reality model communication were compared. The question is that in which communication channel, site workers better understand the directives? After the applications, the participants were surveyed. 58% of the participants said that MR contributed positively to risk communication. 8% of participants said that it contributed negatively. 34% of participants remained neutral.

In Inspections Use of Augmented Reality and Virtual Reality

In many site applications, the construction industry is not digitalized. While many productions are made with machines in the production industry, even the most basic tasks in the construction industry depend on manpower. Site applications as well as site inspections affect labour

productivity. Often workers cannot work because the inspector cannot come for inspection due to busy. Scientists have worked on using virtual reality technology to automate inspections.

Kwon et al. (2014) designed a photo processing system. First, they designed a virtual project model and a mock-up model. They built a cloud system. The system matched photos and virtual model. They took a photo from mock-up model which its location was defined before. Photo was uploaded to the system. The system detected measurement errors.

Zhou et al. (2017) used augmented reality technology to control the segments of tunnel construction. Normally segment checks are done with meters. They modelled segments by using augmented reality technology. They checked whether the segment in the augmented reality glasses and the real segment overlapped. The segment control took less time than the traditional method.

Omer et al. (2021) created a virtual model of a bridge. The bridge was scanned with the laser scanner and compared with the virtual model. As a result of the comparison, cracks and other structural defects in the bridge appeared in different colours.

Conclusion

Studies on the adaptation of augmented reality and virtual reality technologies to the construction sector were reviewed in 8 journals, which include the most article about the augmented reality in construction. Looking at the years of publishing article, it was seen that the studies about augmented and virtual reality increase year by year.

To research in detail, 50 article which represent all literature were specified. These articles grouped according to their subject. It was seen that, the research about augmented and virtual reality in construction industry can be divide to 4 different research area. These are project modelling, education, safety and inspection.

All the articles at all research group show that augmented reality and virtual reality effect positively construction process. They make easier managers, inspectors or employers works compares to traditional methods and they give extra management qualifications to users. This means that augmented and virtual reality technologies need less labour for longer works in construction industry and increase the labour productivity.

The articles about visualisation technologies for construction process show that, users understand construction projects easily by using augmented and virtual project models compared to traditional 2D project. But the target users of these articles are generally construction managers instead of workers. But for the real adaptation this technology should be used at construction application sites. Employees should use visualisation technologies during the application and should take on site educations. These are the missing sides of research and these subjects are open to development.

This research show that, visualization technology contributes new properties to construction industry and these technologies will take more effective location at the sector at near future. In a limited number of studies show the contribution of visualisation technologies to labour productivity of construction industry. In order to eliminate the deficiencies of literature research

and increase the adaptation of visualization technologies to construction industry, researchers should increase studies about adaptation of visualization technologies to construction industry.

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Use of Industry 4.0 Technologies in Stakeholder Management

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Abstract

Industrial revolutions have caused significant changes to the industries of their times. Industry 4.0 has made production systems more responsive, more agile, and leaner, reduced the need for human-workforce, and has increased connectivity. However, in the construction industry, the adoption of Industry 4.0 has not been as smooth as in other industries. There seems to be still quite a bit of resistance to new Industry 4.0 tools, especially in stakeholder management. This study aims to investigate and measure industry 4.0 awareness in stakeholder management in the construction industry. In order to do so, a survey is conducted both with professionals from Turkey and abroad. By analyzing the results of this survey, it is aimed to offer suggestions for better integration of Industry 4.0 into Stakeholder Management in the construction industry. Since understanding the stakeholders and meeting their expectations would determine the overall project success, integration of industry 4.0 tools for stakeholder management would benefit all construction projects.

Keywords: *big data, industry 4.0, integration, stakeholder management, text mining.*

Introduction

Industrial revolutions have caused significant changes in the industries of their time. Since the first industrial revolution, these revolutions have changed production systems and working methods to increase efficiency. The rapid development in digital technology has started a new industrial revolution called Industry 4.0. This revolution defines all modern technologies that strengthen the communication of all elements within the system and cause them to work more harmoniously together. Although the technologies used in Industry 4.0 vary, it aims to connect the components within the related industry to create an inclusive and sustainable production system (Hidayatno et al., 2019). Industry 4.0 refers to "a game-changing set of digital and physical technologies that deliver new values and services to customers and organizations." (Pacchini et al., 2019). Industry 4.0 has made production systems more responsive, more lean and agile, reduced the need for manpower, and aims to increase connectivity.

In the globalizing world, the ways of doing business are changing. Due to the increasing demands of the customers and the growth and complexity of the project scales, the current ways of doing business are insufficient. In this case, the use of industry 4.0 technologies in production systems creates the potential to meet these demands. In our constantly digitalizing world, all sectors are affected by these changes. Industry 4.0 is changing not only the manufacturing industry, but all other sectors, but also the construction industry and associated supply chains.

(Dallasega et al., 2018). The use of Industry 4.0 technologies not only increases the efficiency of the projects but also ensures that more agile, lean, and sustainable projects are produced.

Although it is indisputable that industry 4.0 can be used for and is beneficial to all aspects of the construction industry, this paper's research will be focusing on the use of industry 4.0 technologies in the field of stakeholder management since previous research proves that this is one of the least researched areas. Stakeholders make up all the actors in a construction project. Stakeholders are people who are involved in a project who have an interest in or a conflict with the process or the outcome of the project (Zidane et al., 2015). The involvement of stakeholders throughout the building lifecycle contributes to overall project success. However, simply discussing stakeholder involvement is not enough, it needs to be implemented. When there is more than one stakeholder involved in a construction project, their relationships must be managed carefully. Since the backgrounds of project stakeholders are very different, good stakeholder management is essential for clear communication between parties. If stakeholders are not managed carefully and successfully, their relationships can be harmful to project outcomes. A project's overall success depends on clearly defining and then satisfying the stakeholder expectations (Serrador & Turner, 2015).

Construction projects are usually very complicated and unpredictable, which makes Stakeholder Management challenging. However, "stakeholder involvement is important to project outcomes, and recognition of the concept of stakeholder management is growing" (Yang et a., 2011). Although project managers have tried various ways to engage some of the main stakeholders, the gaps in stakeholder management can cause unsuccessful projects (Oppong et al., 2017). Unsuccessful projects are often defined as projects that can't meet the predefined schedule, projects that are over budget, and projects with unsatisfied participants. Unfortunately, although very important, the shortage of research in this area and the lack of systematic methods for stakeholder management cause the adoption of inadequate methods (Yang et al., 2011; Oppong et al., 2017). During the literature research done for this study, it was realized that there is very fragmented and limited research in the field of Stakeholder Management. Also, it was realized that most methods are left at a theoretical level, do not involve all stakeholders, and do not include the benefits of modern technology.

Since stakeholder management is central to project success, there should be a constant effort to improve it. It is believed that just like other aspects of project management the use of industry 4.0 technologies can be very beneficial to stakeholder management. However, before suggesting ways to utilize industry 4.0 technologies for stakeholder management, first, the current situation should be assessed both in Turkey and internationally. In order to do so, a survey was conducted to see the current situation regarding the use of industry 4.0 technologies for stakeholder management.

Methodology

To observe the awareness of Industry 4.0 use in Stakeholder Management in the Turkish and international construction industries, a 22-question survey was designed and shared with real estate and construction professionals all over the world. The survey was distributed by online platforms, such as email groups regarding the construction industry and academia, LinkedIn connections working in the real estate/construction industry, and personal connections of the authors through the construction sector.

The questionnaire attempted to measure the general awareness of stakeholder management methods as well as the use of industry 4.0 technologies in this area both in the Turkish and international construction / real estate communities. A total of 67 participants responded to the questionnaire of which 31 was international participants and 37 were local from Turkey. Since the survey focuses on both local and international participants and aims to compare practices in Turkey vs. internationally.

The survey was composed of three sections. The first section included introductory questions to determine the suitability of the candidate by asking about which industry they work in, information about their company, and how experienced they personally are. The second portion of the survey measures the current situation of stakeholder management in the construction/real estate industry. It measures the connectivity of all stakeholders during different phases of the building life cycle by dividing it up into pre-construction, during construction, and post-construction phases. The survey also measures the barriers faced in stakeholder management as well as the frequency of use of the stakeholder management models. The third and final portion of the survey measures digital competency, the knowledge and use of industry 4.0 technologies for stakeholder management.

Analysis of Findings

In the first section of the survey, questions were aimed to better know the participants and make sure they are competent. All 67 of the respondents were university graduates, and 52 out of 67 had a graduate or post-graduate degree. All 67 of the respondents were actively working in the industry, and 60 out of 76 had more than 5 years of experience.

Figure 1 represents the distribution of participants' professions. By profession, 49% of the participants were architects, 18% were project managers, 12 % were civil engineers, 7% were business developers, and 4% were real estate/construction-related company owners. The remaining 10% were made of real estate sales/marketing professionals, quantity surveyors, BIM managers and safety consultants.

Figure 2 represents the distribution of where participants' countries of employment. By location, 54% of the participants were from Turkey, 12% were from Germany, 7 % were from the UK, 4% were from South Africa, 4% were from Belgium, 3% were from the USA, 3% were from Uzbekistan. The remaining 13% of the participants were from the Netherlands, Ireland, Sweden, Switzerland, Nigeria, Sri Lanka, and UAE. 36 out of 67 participants were from Turkey and 31 out of 67 participants were working internationally. The international nature of the participants also gives us the opportunity to compare the current situation in Turkey to the rest of the world.

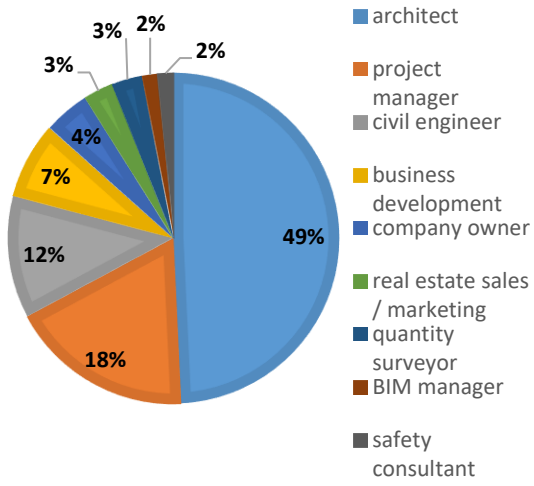


Figure 1: Participants by profession.

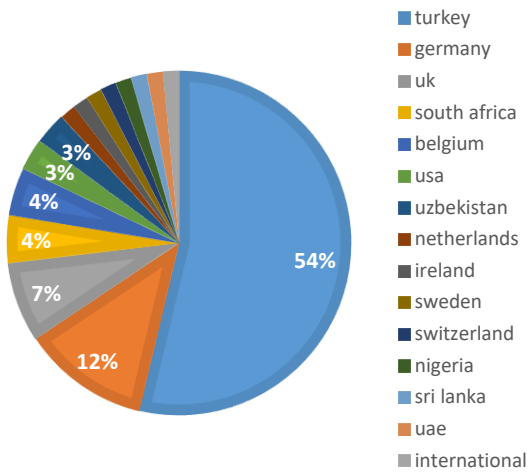


Figure 2: Participants' countries of employment.

Table 1 shows the size of the company in which participants currently work (or last worked). As can be seen, there is roughly an even distribution of small (1-49 people) and big (50-250+ people) companies. Table 2 shows the experience of the company in which participants currently work (or last worked). Only 25% of the companies had less than 10 years of experience. The companies that the participants work in provide the following services: Project management, engineering, contractor / sub-contractor, architectural, real estate development, real estate sales / rental, construction materials production/supply, retail services.

Table 1. Size of company.

Size of company	Number of answers	Percentage
1-9 people	15	22%
10-49 people	16	24%
50-250 people	13	19%
250+ people	23	34%

Table 2. Experience of company.

Experience of company	Number of answers	Percentage
1-10 years	17	25%
11-20 years	13	19%
21-50 years	21	31%
50+ years	16	24%

In the second portion of the survey, a 5-point Likert Scale (frequency scale) was used to measure the connectivity of 15 different stakeholder types during different phases of the building life cycle. The participants were asked, "How often do you communicate with your stakeholders?" The lifecycle of the project was divided up into pre-construction, construction, and post-construction. The list of stakeholders to be surveyed about was a combination of all stakeholders mentioned in previous literature research.

The results of this portion of the survey can be seen in Figures 3, 4, and 5. Although the level of connection with different stakeholders during different phases of the project with changed constantly, it can be easily seen that most answered "never" and "rarely" when asked about external (secondary) stakeholders such as end-users/customers, government authorities, community and public, non-government organizations, unions, and the media.

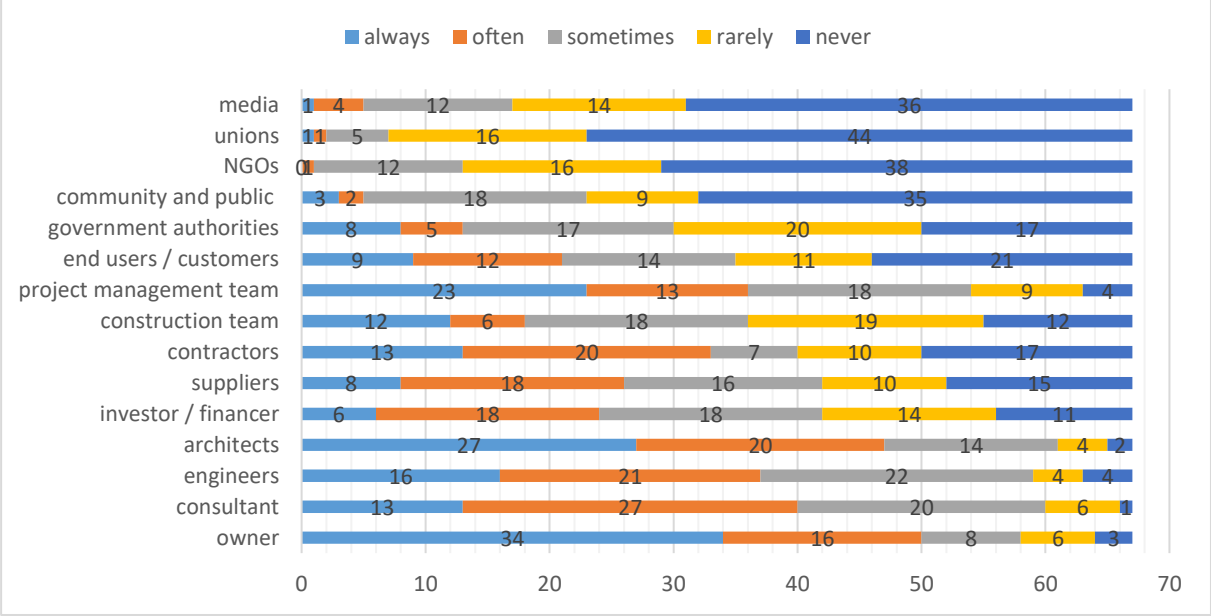


Figure 3: Connectivity amongst stakeholders during the PRE-CONSTRUCTION phase.

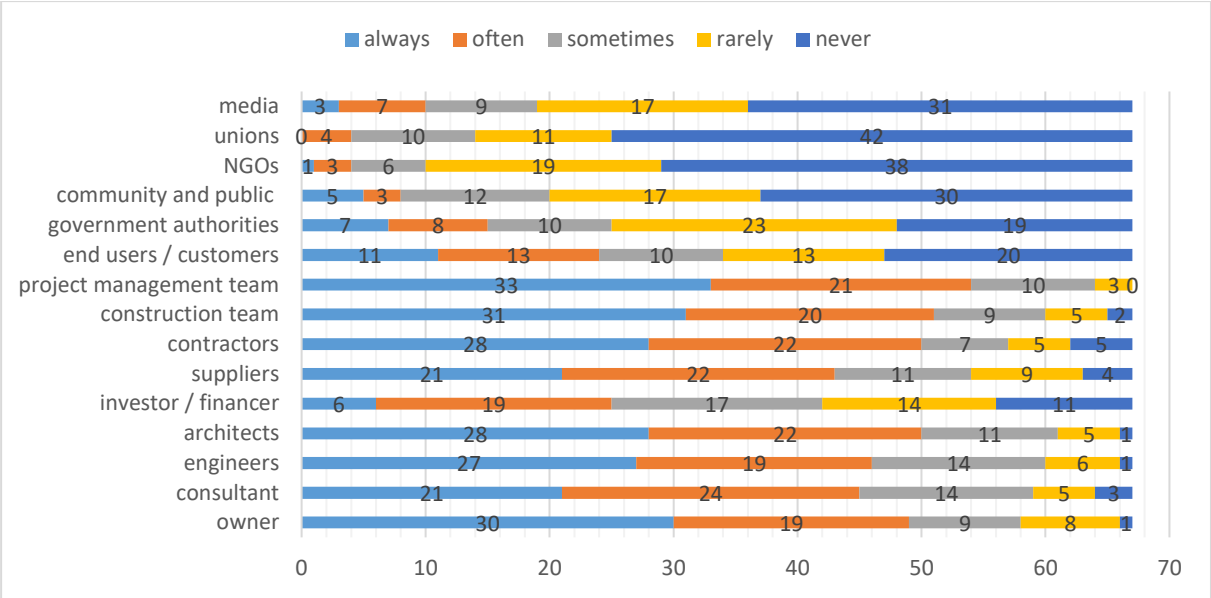


Figure 4: Connectivity amongst stakeholders during the CONSTRUCTION phase.

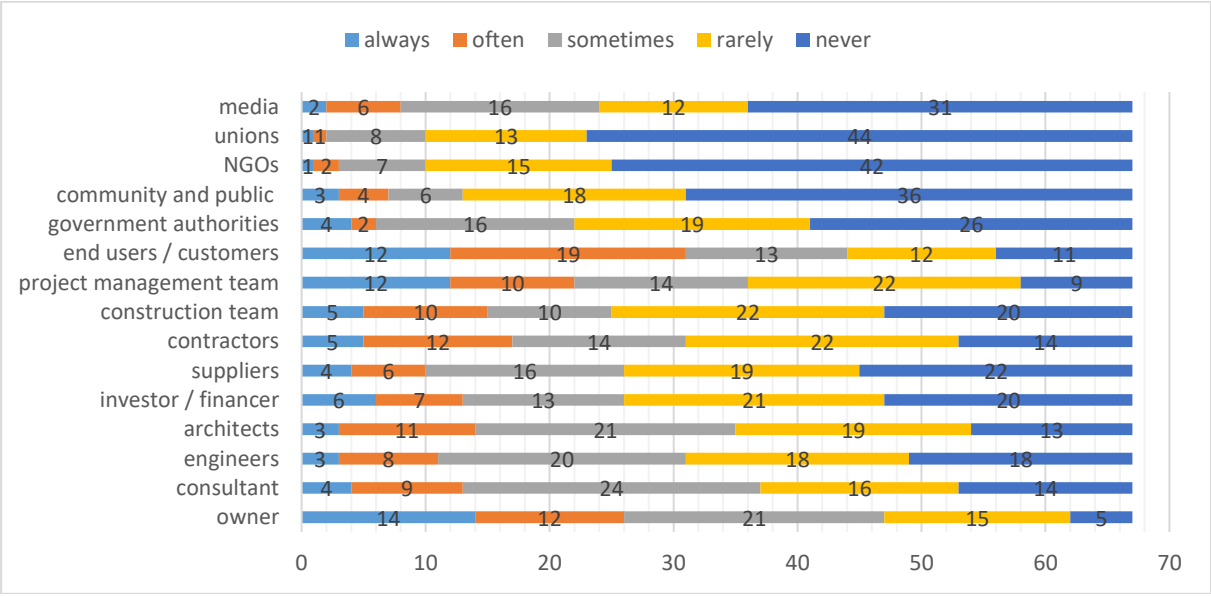


Figure 5: Connectivity amongst stakeholders during the POST-CONSTRUCTION phase.

Figure 6 shows the responses to the question “Is there someone specifically responsible for stakeholder management in your organization?” 57% replied “no” and 7% replied “no need”, totaling negative responses up to 64%. 31% replied “yes” and 3% said they outsource it, totaling positive responses up to 34%. The number of companies that do not have a Stakeholder Management responsible is double the ones that have. In the meantime when looked at geographically, Turkish and international responses were almost the same as can be seen in Table 3. From the 21 participants that answered “yes”, 10 were from Turkey, and 11 were international. Similarly, from the 38 participants that answered “no”, 19 were from Turkey and 19 were international.

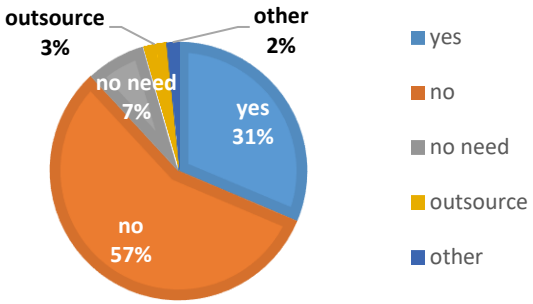


Figure 6: Presence of an employee-specific to stakeholder management.

Table 3. Distribution of responses according to country.

	Turkey	International	Total
Yes	10	11	21
No	19	19	38
No Need	4	1	5
Outsource	2		2
Other	1		1

As seen in Figure 7, when asked about barriers faced in stakeholder management the most common answers were that “the ideas/expectations of stakeholders are different”, “the ideas/expectations of the stakeholders change during the project”, and “the power imbalances amongst stakeholders”.

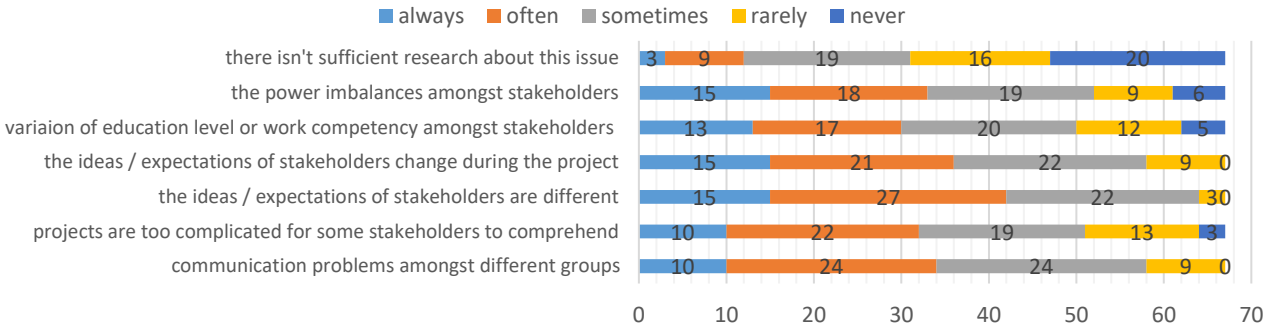


Figure 7: Challenges of stakeholder management.

Finally this portion of the survey wanted to measure the frequency of use for different stakeholder management methods/tools. As seen in Figure 8, when asked about which stakeholder management models are most commonly used the participants replied Building Information Modeling followed by Integrated Project Delivery. These methods are not stakeholder management specific but have a wholesome project management approach. This can be why they were most commonly picked.

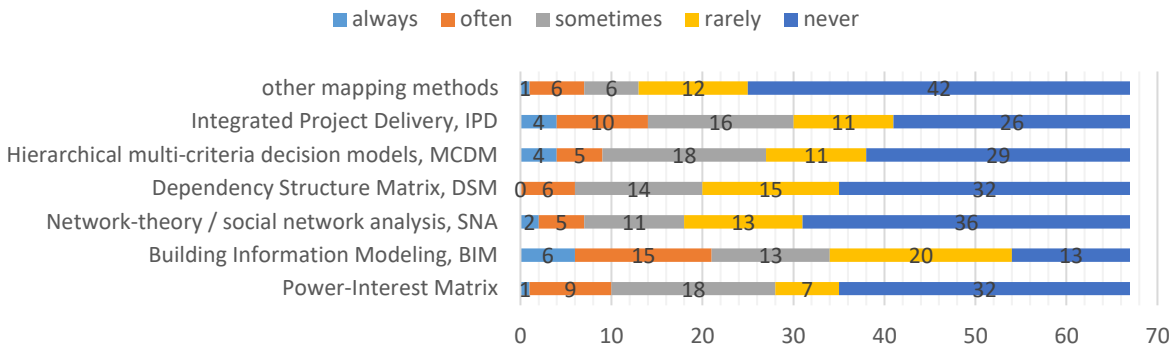


Figure 8: Frequency of use for different stakeholder management methods/tools.

The third and final portion of the survey was aimed to measure the level of digitalization in companies and the frequency of use of industry 4.0 technologies for stakeholder management. Figure 9 shows the responses to the question "Does your company have a staff member responsible for digitalization?" 33% replied "no" and 9% replied "no need", totaling negative responses up to 42%. 45% replied "yes" and 13% said they outsource it, totaling positive responses up to 58%. The number of positive replies is higher than the negative which can indicate a trend toward digitalization in the industry. In the meantime when looked at geographically, international participants were slightly more inclined towards digitalization. As can be seen in Table 4, from the 30 participants that answered "yes", 13 were from Turkey, and 17 were international. Similarly, from the 22 participants that answered "no", 15 were from Turkey and 7 were international.

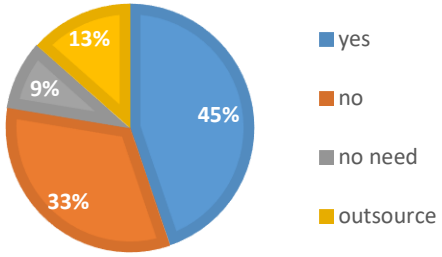


Figure 9: The presence of an employee-specific to digitalization.

Table 4. Distribution of responses according to country.

	Turkey	International	Total
Yes	13	17	30
No	15	7	22
No Need	2	4	6
Outsource	6	3	9

Figure 10 shows the responses of the participants when asked if they use industry 4.0 technologies for stakeholder management. The 15 industry 4.0 technologies that were surveyed about were the most commonly encountered technologies in the previous literature research. The results show that the most commonly used technology is BIM, followed by the cloud. This is understandable considering these technologies provide a wholesome aid to project management overall and therefore are also useful for stakeholder management. The least used technology was robotics followed by blockchain. As can be seen in Figure 11, when the responses were divided into 2 groups who answered as "always-often-sometimes" and "never-rarely", it was seen that more than 60% of the participants responded "never-rarely" to using industry 4.0 technologies except for BIM and the Cloud.

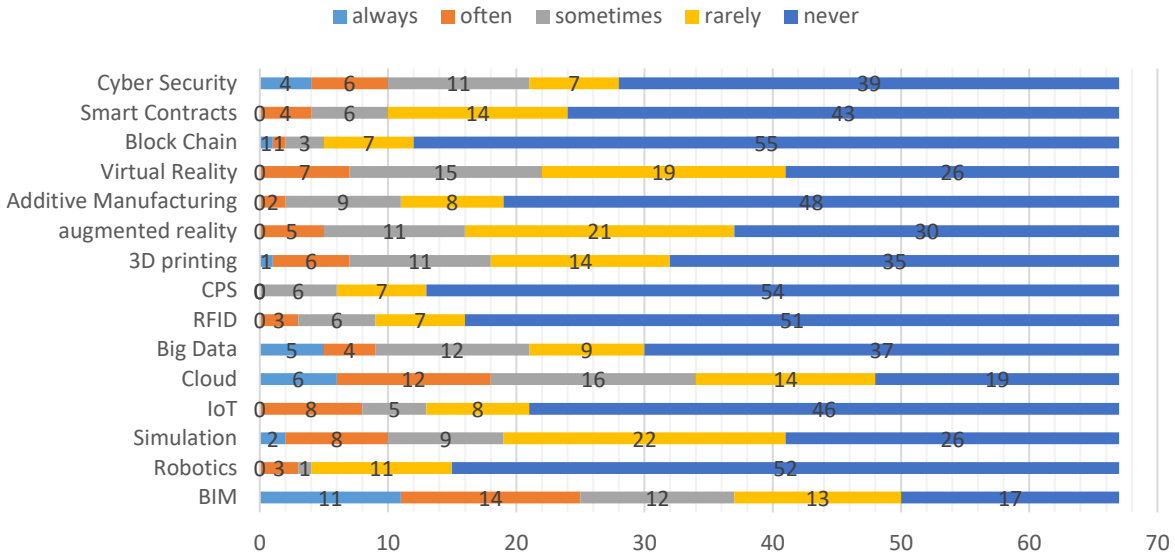


Figure 10: Frequency of use of different industry 4.0 technologies for stakeholder management.

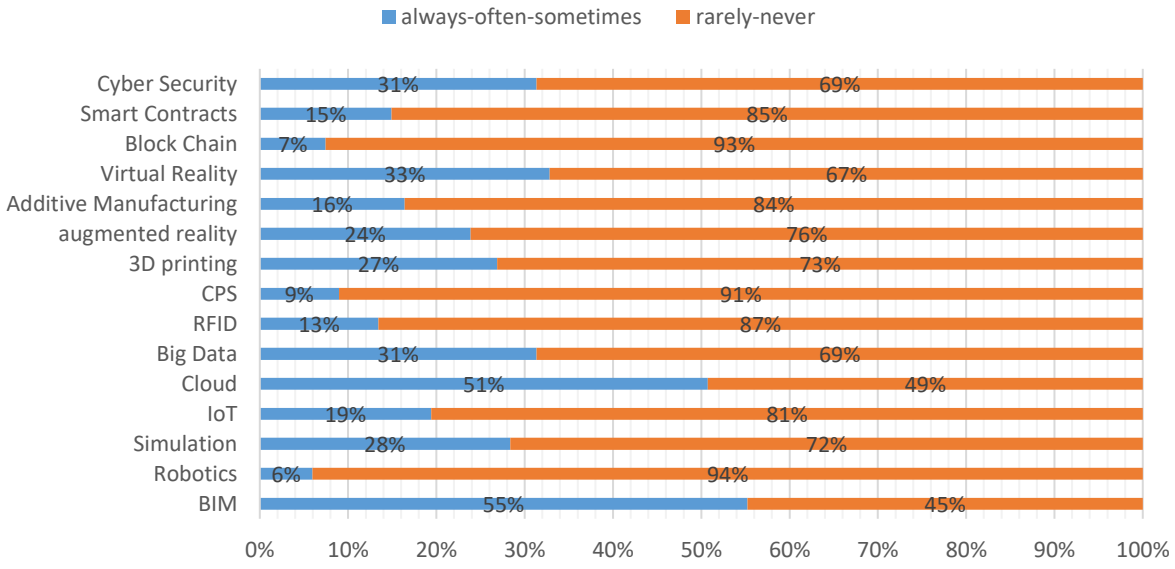


Figure 11: Percentage distribution of "always-often-sometimes" and "rarely-never" answers.

Figure 12 shows the percentage distribution of technologies used for gathering and distributing information amongst stakeholders. When asked "How often would you use the following tools to collect and distribute information among stakeholders?" the most common answer was internet technologies with 54 % answering "always" and 31% answering "often", followed by social media with 18 % answering "always" and 16% answering "often". The least used technologies were sentiment analysis with 72% answering "never" and 16% answering "rarely", followed by data/text mining with 63% answering "never" and 12% answering "rarely". Although participants claimed to use internet technologies and social media, the tools necessary to analyze the information gathered through internet technologies and social media, such as sentiment analysis and data/text mining, were mostly ignored and unused. It was also realized that automated systems, CRM systems, and satisfaction tracking dashboards that

systematize and organize the information flow through stakeholders were also hardly ever used, with more than 60% of participants answering “never” and “rarely”.

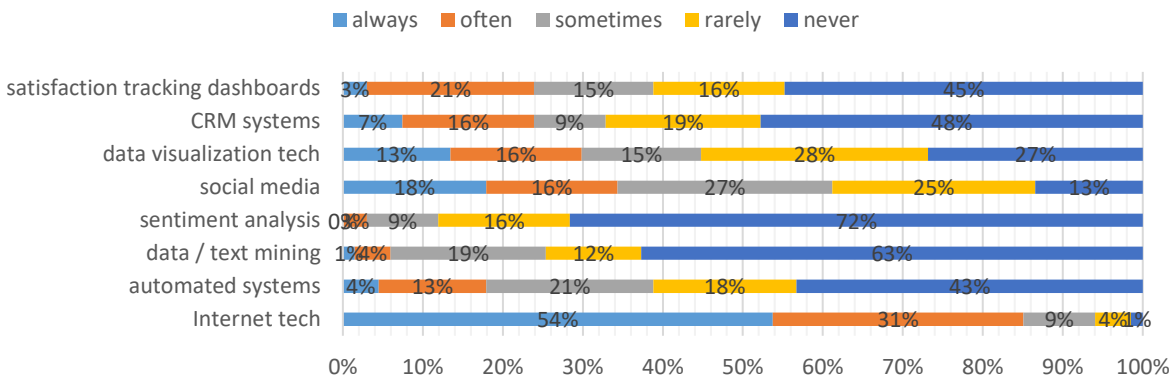


Figure 12: Percentage distribution of technologies used for gathering and distributing information amongst stakeholders.

Figure 13 shows the percentage distribution of ways to improve stakeholder management. The most common answer was that “digitalization should be prioritized and technology should be made more use of”, with 46 % answering “strongly agree” and 45% answering “agree”, followed by “stakeholder needs should be examined in more detail”, with 33% answering “strongly agree” and 58% answering “agree”. The least common answer was “decentralized (multiple) decision-making should be preferred”, with 16 % answering “strongly agree” and 31% answering “agree”.

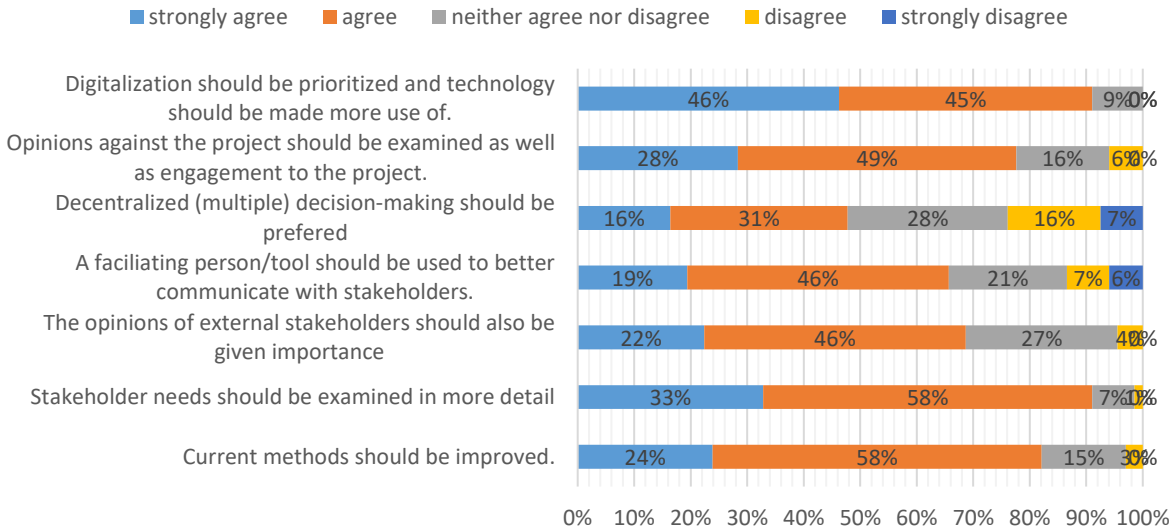


Figure 13: Percentage distribution of ways to improve stakeholder management.

Discussion

Throughout this survey there were two main questions to be answered: “What is the current situation of stakeholder management in the construction industry?” and “Are the industry 4.0

technologies being used to benefit stakeholder management?" Fortunately, answers were found for both queries.

Stakeholder management is mostly done pre-construction and during construction but it was seen through the survey that once the construction is over rarely any opinions of the users are considered post-construction. Throughout the 3 phases, it was realized that stakeholder management is mostly done between/for primary stakeholders but the secondary (external) stakeholders are ignored.

More than 60% of the companies did not have someone specifically responsible for stakeholder management. This didn't vary geographically since answers from Turkey and internationally were similar. The most common methods used for stakeholder management were Building Information Modeling and Integrated Project Delivery. However, these methods are not specifically stakeholder management methods, they facilitate stakeholder management as a part of their wholesome project management structure. When asked about barriers faced in stakeholder management the most common answers were about the constant change in stakeholder demands/needs and the power imbalances amongst them.

Unfortunately, although the participants surveyed hinted that there was an intention of going more digital in their companies it is not to the fullest extent to the benefits of today's technologies. When asked about digitalization, slightly more than half of the responses were positive, with international answers being slightly better than Turkish participants. However, almost none of the most common industry 4.0 technologies were used by the participants for stakeholder management. More than 60% of the participants responded "never-rarely" to using industry 4.0 technologies except for BIM and the Cloud.

When asked about using digital technologies for stakeholder communication such as gathering and distributing information it was realized that although internet technologies and social media were used by many, none of the tools to analyze and utilize the gathered information were used, such as sentiment analysis, big data analysis, etc. This shows that although companies have started to use some of the industry 4.0 technologies to communicate with stakeholders, they do not use (or are aware of) many of them and therefore do not experience the benefits to the full extent.

Finally when asked about solutions to better stakeholder management the most common answer was to make better use of digitalization and technologies, followed by examining stakeholder needs in more detail. Using current technologies of today not only can benefit stakeholder management but also achieve a deeper understanding of stakeholders since by using these new technologies more data from stakeholders can be gathered and analyzed. This idea was also supported by the responses received from the survey.

Throughout the survey, when responses from Turkish and international participants were compared there were no significant differences. It can be said that stakeholder management is lacking in both Turkish and international construction and real estate projects. Similarly, digitalization in stakeholder management in construction and real estate projects is slowly starting both n Turkish and international industries, with international answers being slightly more positive, but not significantly.

Conclusion

The construction industry has to change in order to improve itself. A long-time ignored aspect of project management has been stakeholder management, especially for external stakeholders. Not taking stakeholder needs into consideration has caused project delays and failures. In order to overcome the limitations of current stakeholder management methods, this paper suggests the use of industry 4.0 technologies. In order to do so, the current situation has to be assessed. While doing so it was realized that current methods of stakeholder management focus on a very limited number of stakeholders as well as being too static and not being able to track the changing needs of various stakeholders. Realizing that these problems can be solved by using industry 4.0 technologies, the survey also questioned if these technologies were being used effectively for stakeholder management. It was recognized that although there are a few participants starting to adopt some aspects of the modern technologies they are not used to (or known about) to the full extent. Further studies should focus on which industry 4.0 technologies would be more beneficial to stakeholder management specifically. Frameworks might be developed in the future to facilitate the use of industry 4.0 technologies for stakeholder management.

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Big Data Applications in Construction Industry

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Abstract

There is an exponential increase in the amount of data produced with the development of network and hardware technologies. The inefficient of traditional methods to process a large amount of data and extract useful insight from data has led to the development of big data technology. A wide assortment of industries including construction attempt to use big data technology to derive value and benefit from data. Big data is high-volume, high-variety and high-speed data. Construction data also indicates the characteristic of big data. It is high volume for including samples such as design and financial data and high variety for involving different formats such as dwg, dxf and rvt. As it is also high-speed on account of construction's dynamic structure, it is convenient for implementation of big data technology. This study intends to examine big data and its applications in the context of the construction industry. This technology has a remarkable potential to invent value from data. Moreover, the construction industry can increase its productivity in data management with the implementation of big data technology. Thus, there is a requirement for important research in this area. The study will give an overview of the literature about applications of big data in the construction industry.

Keywords: *applications, big data, big data analytics, construction industry, implementations.*

Introduction

The world is currently overfull with data and, many hardware transfers the data they produce to various applications with the rapidly advancing technology. The amount of data produced, stored and transmitted in this way is constantly increasing. Domo says that in 2021 every minute, 5.7 million searches are conducted Google, 575,000 tweets are posted on Twitter, 694,000 hours are streamed Youtube, and 6 million people shop online. The rising of digital devices such as smartphones and sensors has led to an unprecedented rate of data creation (Gandomi & Haider, 2014). This high speed creates an incredible amount of data. Besides, the generated data can be produced in a wide range of any type and format (jpg, pdf, word, excel etc.). As a result, a high variety of data is created. This increase in the speed, volume and diversity of data reveals the concept of big data. Basically, big data expresses as high-speed, high-variety, and high-volume data. The construction industry is suitable for the application of big data technology as construction data shows the characteristics of big data. Construction data is high volume for including samples such as design and financial data and high variety for involving different formats such as dwg, dxf and rvt. As it is also high-speed on account of

construction's dynamic structure (Bilal et.al, 2016). Big data technology provide efficiency and productivity for organizations; paves the way for developments in its products and services. The construction industry cannot be separated from this development (Madanayake & Egbu, 2019). Therefore, significant research is needed in this area. In this study, researches related to big data and the construction sector were obtained from the Scopus database and analyzed according to their keywords, the lack of studies on big data applications drew attention. This situation is one of the motivation sources for this study. The objective of this study is to carry out a systematic review of the literature dealing with the use of big data in the context of the construction industry. Firstly, related studies were obtained from the Scopus database. Using the Vosviewer application, a big data analytics tool, the most used keywords in related articles were grouped according to their relationships. After the groups were determined, each group was given a headline describing the application area in the construction sector according to the articles in it. As a result, the areas that benefited from big data technology in the construction sector were tried to be thematized five themes were determined as waste management, safety, project management, information management and risk management.

What is Big Data?

Data is raw information obtained from various media. Nowadays, the advancement of network and hardware technologies has led to an increase in the volume, speed and diversity of the data produced, and has brought the concept of big data (Zhang et al., 2015). There are different definitions for big data in the literature. According to Lu and Zhang (2021), this term refers to the storage, management, processing, interpretation and visualization of large amounts of data. Sang et al. (2020) expressed that big data is complex and interconnected volumes of information such as environmental, financial, geographical, social media information. With these definitions, big data is mostly explained through its properties. IT industry research group Gartner, big data; refers to high-volume, high-speed, and high-diversity information resources that require new forms of processing for knowledge discovery (Wessler et al., 2013). Similarly, the National Institute of Standards and Technology expresses that big data is high speed, high-volume and high diversity datasets (Chang & Grady, 2019). As a result, big data differs from simple data with its high volume, speed and variety; moreover, it is a concept about storing and managing datasets and making them meaningful by processing them with various methods and technologies.

Big data and Construction Industry

Construction data is large, heterogeneous and dynamic, so it shows the characteristics of big data (Bilal et. al, 2016). The construction industry has important data from different disciplines over the life cycle of a facility (Yousif et al., 2021). By discovering hidden patterns, trends, and correlations within this data, good management can help gain social, economic, and environmental insights that will support data-driven decision making for competitive advantage (Madanayeke & Ebgu, 2019). This is possible with the use of big data analytical techniques. Although the use of big data in the construction industry is not yet widespread, there are examples, and it is predicted that these examples will increase as technology becomes more involved in our lives (Ram et al., 2019). For example; Lu et al (2016); conducted a study to compare construction waste management performance between public and private projects. They did this using big data in the form of two million waste

records from around 5700 projects undertaken in Hong Kong in 2011-2012. As a result, they found that there is a remarkable construction waste management performance difference between the public and private sectors. Cheng et al. (2012); Taiwan has conducted a study using big data techniques to determine the factors that cause occupational accidents in the construction industry. Among all accident types, the most common cause of injury was fall/ tripping (47%). Collapse of objects (19%), electric shock (13%) and falling objects (5%) were recorded as other important causes. Kim et al. (2007) conducted a study using big data analytics to determine which factors are causing delays in an ongoing construction project. In this study, using the data of a drainage project in the USA, they identified nine important factors that caused the delay. These factors were defined as temperature, material delivery, weekend, faulty site survey, subcontractor delay, incorrect towing, safety, weather, and seasons. Carrillo et al. (2011) also analyzed the pre-project review reports from the two companies using big data methods to find out if there are certain trends that could provide useful information for future construction projects. As a result of the research, the words that are frequently used in the reports for both companies were determined and the relationship of these words was examined, and it was determined where the companies made mistakes in their previous projects and an awareness was created for them to pay attention to these issues in their future projects.

Barbosa et al. (2017); sees big data and analytics methods as a sensible way to alleviate some of the pressures faced by the construction industry. While the use of big data in the construction industry is still in its infancy, numerous studies show that the potential is huge if construction big data is fully utilized (Munavar et. al, 2022).

Research Method

Big data and construction industry related studies were acquired from the Scopus database. In order to see the interests of the researchers, all document types including conference paper, article, conference review, review, book chapter, book and editorial were included. It was only focused on studies written in the English language. The retrieval was conducted using the following code: TITLE-ABS-KEY ("big data") AND TITLE-ABS-KEY ("construction industry" OR "construction sector" OR “construction project” OR “construction projects”) AND (LIMIT-TO (LANGUAGE, "English")). 338 publications were reached as a result of the search. Figure 1 shows the publications by years. According to the Figure 1, big data in the construction industry had more attention in 2012 and onwards. For this reason, it is meaningful to examine the studies on big data applications in the construction sector that is main topic of this article for 2012 and after.

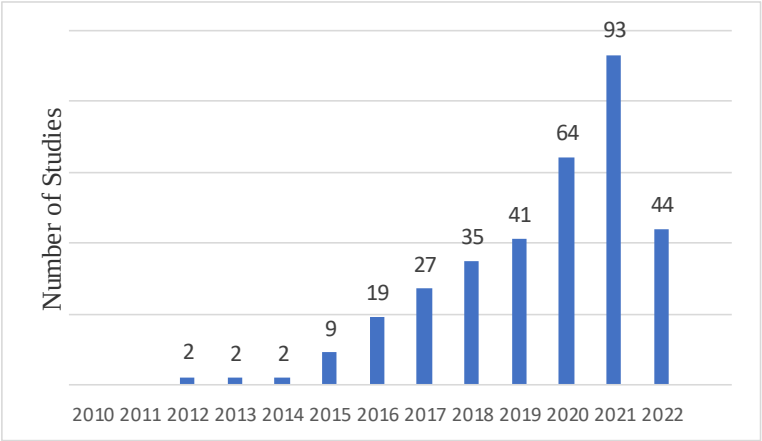


Figure 1: The numbers of studies in Scopus between 2010-2022.

The software VOSviewer that is a tool used to produce meaningful information from big data was used to analyse 338 publications in order to determine the most frequently used keywords in the research. The texts in the title-abs-key section of the publications were analysed according to co-occurrence. 108 keywords were found that repeated at least 2 times out of 908 keywords used in the title-abs-key section of 338 documents. The 103 concepts with the highest relationality are included in the network map. Figure 2 demonstrates network analysis of co-occurring keywords. The total link strength shows the total strength of the connections of an item with other items. Big data and construction industry are keywords having the largest number of total links, 166 and 52 respectively. Other remarkable keywords are BIM (37), industry 4.0 (35), construction (33), blockchain (32), machine learning (31), big data analytics (30). Application keyword has only 4 total link. It shows that there is a lack of studies directly related with big data applications in the construction industry. This encourages the topic of this research. Besides, the “application” item is associated with big data analytics, one of the items with the highest total link strength. Big data analytics contributes to the application of big data. Thus, this keyword was also used for finding articles pertaining to big data applications in the construction industry in the following step.

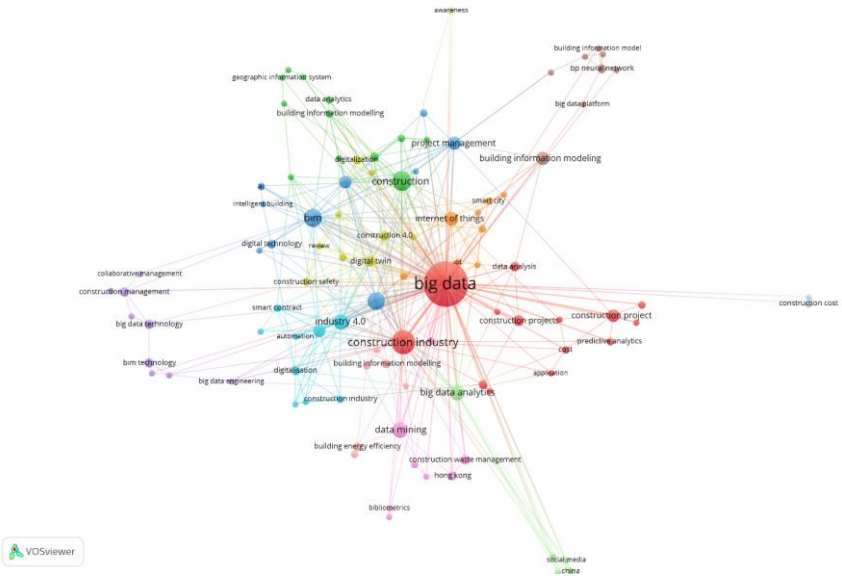


Figure 2: The network analysis.

In the next step, publications pertaining to big data applications in construction industry were acquired from Scopus. The different keyword combinations were developed to reach the most useful and relevant publications and the following code was used for retrieving: TITLE-ABS-KEY ("big data" OR "big data analytics") AND TITLE-ABS-KEY (application OR applications OR implementation OR implementations) AND TITLE-ABS-KEY ("construction industry" OR "construction sector" OR "construction project" OR "construction projects") AND (LIMIT-TO (LANGUAGE , "English")). 152 publications were reached and Vosviewer was used to analyse results. The texts in the title-abs-key section of the publications in the Scopus database were analysed according to co-occurrence. 51 keywords were found that repeated at least 2 times out of 404 words used in the title-abs-key section of 152 documents. Besides, Vosviewer was grouped keywords focused on frequency of together usage and displayed each group with a specific colour. 49 keywords were grouped under 11 clusters. In the continuation of the study, the articles within the clusters were analysed and names were given to these groups in a way to express the big data application areas in the construction industry. Table 1 shows the clusters and cluster names showing areas of the big data applications in the construction industry. Clusters of 'big data and blockchain', 'big data and artificial intelligence', 'big data and BIM', 'big data and internet of things', 'big data and neural network', 'big data and cloud computing' can be associated with the digital technologies pertaining to big data. Therefore, they are out of scope for this study.

Table 1. Clusters on the Vosviewer.

NO	KEYWORD	NUMBER OF LINK	TOTAL LINK STRENGTH	CLUSTER NAME
C01	application	3	3	BIG DATA and WASTE
	big data analytics	13	18	
	building information modelling	6	6	
	construction industry	12	22	
	construction waste management	3	4	
	data analysis	4	4	
	digital transformation	7	7	
	machine learning	9	14	
C02	blockchain	10	16	BIG DATA and BLOCKCHAIN
	blockchain applications	5	10	
	construction 4.0	2	3	
	construction industry	5	10	
	digitalisation	5	10	
	industry 4.0	12	20	
	smart contracts	5	10	
C03	construction site	7	8	BIG DATA and KNOWLEDGE MANAGEMENT
	data analytics	2	2	
	data integration	4	5	

	data mining	1	1	
	digitalization	5	5	
	knowledge management	3	3	
C04	ai	2	2	BIG DATA and PROJECT MANAGEMENT
	BIM	14	19	
	building information modelling	1	1	
	construction engineering	2	2	
	project management	7	7	
C05	big data	33	62	BIG DATA and RISK MANAGEMENT
	construction project	4	7	
	predictive analytics	3	4	
	risk management	2	2	
C06	artificial intelligence	4	5	BIG DATA and ARTIFICIAL INTELLIGENCE
	construction	3	6	
	internet of things	8	9	
	systematic literature review	3	3	
C07	big data engineering	5	6	BIG DATA and BIM
	BIM technology	2	2	
	digital economy	3	3	
	digital technologies	5	5	
C08	big data technology	3	4	BIG DATA and CONSTRUCTION SAFETY
	construction management	4	4	
	construction safety	7	8	
	Thai government	2	3	
C09	building information modelling	4	4	BIG DATA and INTERNET OF THINGS
	digital twin	7	8	
	internet of things (IOT)	7	8	
C10	bp neural network	1	1	BIG DATA and NEURAL NETWORK
	building information modelling	2	2	
C11	cloud computing	3	3	BIG DATA and CLOUD COMPUTING
	construction projects	2	3	

In the next step, the research was restricted only research papers and reached 42 articles. In order to determine how big data is applied in the construction industry, content of the 42 articles was analysed. 20 articles were found eligible. Table 2 shows only the original research papers that uses big data technology as a tool in the construction industry with the

purpose of use. At this stage, it was also determined which of the clusters the articles belonged to in the previous step.

Table 2. Research papers that uses big data technology as a tool.

NO	TITLE OF ARTICLE	AUTHOR	PURPOSE OF USE	CLUSTER
1	Developing a Geospatial Framework for Severe Occupational Injuries Using Moran's I and Getis-Ord Gi* Statistics for South-eastern United States	Fahad et al., 2022	. to analyse the severe injury reports	BIG DATA and SAFETY
2	Applications of Smart Technologies in Construction Project Management	Zhu et al., 2022	. to estimate and schedule in project time management . to estimate and control cost . to predict potential quality issues and trace the root causes of the issues to improve quality assurance	BIG DATA and PROJECT MANAGEMENT
3	Analysing the Freight Characteristics and Carbon Emission of Construction Waste Hauling Trucks: Big Data Analytics of Hong Kong	Wei et al., 2022	. to monitor the effectiveness of policy interventions related to construction waste transportation planning and carbon emission	BIG DATA and WASTE
4	Construction Project Cost Management and Control System Based on Big Data	Chen et al., 2022	. to process large-scale data for construction project cost management	BIG DATA and PROJECT MANAGEMENT
5	Towards sustainability evaluation of urban landscapes using big data: a case study of Israel's architecture, engineering and construction industry	Yoffe et al., 2022	. to enhance sustainability rating systems in landscape development	BIG DATA and KNOWLEDGE MANAGEMENT
6	Handling missing data for construction waste management: machine learning based on aggregated waste generation behaviours	Yang et al., 2021	. to pinpoint the potential of waste big data in portraying project behaviours	BIG DATA and WASTE
7	A BIM and machine learning integration framework for automated property valuation	Su et al., 2021	. to manage information exchange between AEC projects and property valuation and to support automated property valuation	BIG DATA and KNOWLEDGE MANAGEMENT

8	Life Cycle Assessment of Bridges Using Bayesian Networks and Fuzzy Mathematics	Zhou et al., 2021	. to reduce traffic pollution emissions for reducing the impact of the construction industry on the environment	BIG DATA and KNOWLEDGE MANAGEMENT
9	The Impact of Organisational Resilience on Construction Project Success: Evidence From Large-Scale Construction in China	Yang et al., 2020	. to identify organisational resilience factors that affect construction project success	BIG DATA and RISK MANAGEMENT
10	Factor-based big data and predictive analytics capability assessment tool for the construction industry	Ngo et al., 2020	. to develop a capability assessment tool that highlights the strengths and weaknesses of construction organizations and can measure their capabilities in big data and predictive analytics	BIG DATA and RISK MANAGEMENT
11	Social Risk Early Warning of Environmental Damage of Large Scale Construction Projects in China Based on Network Governance and LSTM Model	Fang et al., 2020	. to analyse characteristics of the social risk of environmental damage of large-scale construction projects	BIG DATA and RISK MANAGEMENT
12	Application of remote electron microscope technology in construction management of building engineering	Xu et al., 2020	. to better monitor the quality of the project and ensure the construction safety	BIG DATA and PROJECT MANAGEMENT
13	A Big Data and FMEA-based construction quality risk evaluation model considering project schedule for Shanghai apartment projects	Ma & Wu, 2019	. to predict the relationship between the planned schedule and the project quality risk	BIG DATA and RISK MANAGEMENT
14	Investigating profitability performance of construction projects using big data: A project analytics approach	Bilal et al., 2019	. to create a project analytics approach to understand the profitability distribution of different types of construction projects	BIG DATA and KNOWLEDGE MANAGEMENT
15	A Big Data Analytics Approach for Construction Firms Failure Prediction Models	Alaka et al., 2019	. to reduce the unfavourable waiting time during construction firms failure prediction models	BIG DATA and RISK MANAGEMENT

16	Research on Optimization of Big Data Construction Engineering Quality Management Based on RNN-LSTM	Wang et al., 2018	. to predict the quality problems of steel bars, formworks, concrete, cast-in-place structures, and masonry in the construction project	BIG DATA and RISK MANAGEMENT
17	Mining big building operational data for improving building energy efficiency: A case study	Fan & Xiao, 2018	. to utilize big building operational data effectively	BIG DATA and KNOWLEDGE MANAGEMENT
18	RFID Enabled Knowledge-Based Precast Construction Supply Chain	Wang & Hu, 2017	. to utilize RFID in knowledge-based precast construction supply chains	BIG DATA and KNOWLEDGE MANAGEMENT
19	Big data architecture for construction waste analytics (CWA): A conceptual framework	Oyelede et al., 2016	. to analyse construction waste	BIG DATA and WASTE
20	A Big-Data-based platform of workers' behaviour: Observations from the field	Guo et al., 2015	. to classify, collect and store data about workers' unsafe behaviour in construction site	BIG DATA and SAFETY

Conclusion

The age of big data has begun with the development of network and hardware facilities such as sensors and servers. In order to create an understanding of big data from the perspective of the construction industry, this study examines the applications of big data technology in the construction industry. These studies obtained from the Scopus database were analyzed using the Vosviewer tool. The most frequently used words in related studies were grouped according to their relations and the articles in these groups were analyzed according to their content. As a result, these groups were given titles to express the application area in the construction industry. According to the data obtained, the most common areas of big data applications in the construction industry are waste management, safety, project management, information management and risk management. When only the original research articles are examined, it is seen that the most studies have been done on information management and risk management, followed by waste management and project management. Safety is another area of research. It is obvious that the adoption of big data technology will have positive contributions to the construction industry. Bilal et al. (2016) argue that the optimal use of big data will arguably be the next front of innovation in the construction industry. Yousif et al (2021); the adoption of big data in the construction industry will improve sustainability, become more knowledgeable in decision-making processes, and improve safety and working conditions; It claims that costs and timeouts will be reduced, project delays will be eliminated and risks will be reduced. The broad applications of big data can encompass many perspectives of the construction industry.

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A Brief Summary on Facilities Management Technologies and BIM-FM Integration

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Abstract

Built environments need countless facilities management (FM) services to ensure functionality, comfort, safety, and efficiency for their occupants. Formerly, FM practices have relied on hard copy documents. Following the development of computer-aided systems, the FM industry has started to embrace digital transformation. Nowadays, advanced methods such as building information modeling (BIM) are playing a crucial role in the efficient delivery of FM services. Yet, diverse information needs of different services throughout the operational phase constitute the major hindrance in the BIM and FM integration. This research aims to investigate the widely used FM technologies and identify their synergy with BIM. First, inclusive analysis of scientific literature, as well as industry-specific reports and best practice documents, reveals common FM technologies together with their role in the operational phase of built environments. Then, a questionnaire survey with FM professionals identifies the required building information for efficient FM practices. The final discussion emphasizes the potential of BIM for FM by highlighting the information that BIM can provide for efficient FM practices.

Keywords: *Building Information Modeling (BIM), facility management (FM), BIM-FM integration, digital transformation.*

Introduction

A facility, often used as *facilities*, is something that is built, installed, or established to serve a particular purpose. Architecture, Engineering and Construction (AEC) industry professionals work together to design and construct various facilities to provide a suitable environment for diverse human activities. *Facilities management*, which is synonymously used with workplace management, involves the services to maintain, improve, and adapt the buildings of an organization in order to create an environment that strongly supports the primary objectives of that organization (Barrett & Baldry, 2003). Today, FM refers to an organizational function which integrates people, place and process within the built environment with the purpose of improving the quality of life of people and the productivity of the core business (ISO, 2017). Undoubtedly, FM services differ depending on the needs of organizations. A broad list of those services includes but is not limited to daily operations (i.e., cleaning and catering), administrative services (i.e., security), maintenance and repair works, energy management, occupancy planning and space management, architectural and engineering services (i.e., renovation, refurbishment and retrofitting), financial management, emergency management and

disaster recovery, and FM personnel training (Springer, 2001; Chotipanich, 2004; Atkin & Brooks, 2021).

Until recently, facilities managers have been relying on blueprints, printed manuals, and records to understand the building's history and make future decisions. However, due to the increasing adaptation of technological developments within the AEC industry building projects become more complicated and technology oriented. On top of that, the deepening role of buildings in the climate crisis, cost escalations, human resource limitations, increasing competition and decreasing business profits lead facilities managers to implement innovative technologies to work efficiently. As a result, the FM industry has started to embrace computer-integrated facilities management (CIFM) environments (Yu et al., 2000). A typical list of CIFM environments includes computerized maintenance management system (CMMS), computer-aided facilities management (CAFM), and integrated workplace management system (IWMS). In the early 2010s building information modeling (BIM) concept emerged with the promise of integration and efficiency (Becerik-Gerber et al., 2012; Gao & Pishdad-Bozorgi, 2019). ISO defines BIM as the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions (ISO, 2018). Since its first introduction to the industry, numerous studies have shown that FM can utilize BIM to create digital assets, visualize the exact locations of critical equipment, plan and monitor maintenance work orders, manage workspace, control indoor environmental conditions, monitor building performance, and give training to FM personnel, all in a 3D environment (Becerik-Gerber et al., 2012; Pärn et al., 2017). The literature identifies various reasons that are hindering BIM-FM integration (Korpela et al., 2015; Patacas et al., 2015; Pärn et al., 2017; Durdyev et al., 2022), yet digitization in FM, particularly BIM-based FM, is a globally evolving phenomenon.

The present study investigates the major FM software systems that are frequently used by facilities managers with a special focus on BIM and BIM-FM integration. First, some background information on the key characteristics of CMMS, CAFM, IWMS, and BIM technologies is provided. Then, a survey of FM professionals determines what information is required to efficiently carry out FM tasks. Finally, this study discusses how BIM can respond to FM needs.

FM Technologies and BIM-FM Integration

The list of FM technologies involves numerous software solutions in sophisticated abbreviations, such as CMMS, CAFM, IWMS, building automation system (BAS), energy management system (EMS), enterprise asset management (EAM), enterprise resource planning (ERP), BIM, digital twins, Internet of Things (IoT) and sensors, virtual reality (VR) and augmented reality (AR), and artificial intelligence (AI). Although each of these technologies is notably important for the efficient operations of built environments, they play different roles in the whole FM ecosystem. The previous study by Ebbesen (2016) categorizes these technologies into seven groups and illustrates the relationship among them as seen in Figure 1. Typically, an unexpected issue is detected by an FM staff during inspection or other data capturing systems (i.e., RFID, sensor, IoT, drone, etc.), then it is issued to the facilities manager as a work request, then the facilities manager needs to analyze associated building data located in different platforms (i.e., database, spreadsheet, CAD, BIM, etc.) to make a decision, and issues a work order to the associated personnel through the workflow system (i.e., CMMS, CAFM, or

IWMS). As illustrated in the figure below, there is a continuous data flow among these systems and facilities managers must have the right data at the right time to make the right decisions.

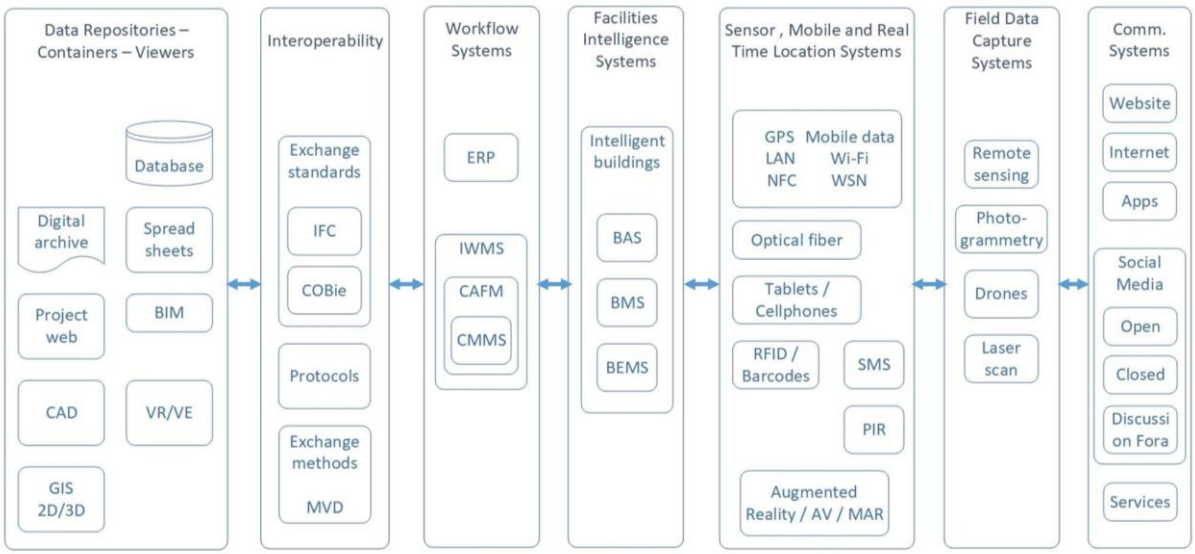


Figure 1: FM technologies.

Among these technologies, the computerized maintenance management system is a software system that supports the maintenance of key equipment and physical assets within buildings. CMMS is essentially a database that stores maintenance operations data such as asset registers (individual records of each asset), work orders, assigned and completed tasks, equipment availability, and inventories. Facilities managers utilize the mentioned data to schedule preventive maintenance, make purchase decisions or generate labor and material use reports. Winker et al. (2016) emphasize the key role of CMMS in lowering the hidden costs of maintenance. Similar to CMMS, computer-aided facilities management is one of the core software solutions for facilities managers. It supports different FM tasks such as space (or workplace) management and asset management. A CAFM system can incorporate CAD or GIS to store floor plans, therefore it is mainly used for planning and allocating space, tracking equipment, physical and technical assets, and monitoring space occupancy (Mohanta & Das, 2016; Zvirbule & Kirikova, 2018). Besides, it enables facilities managers to manage planned, reactive and corrective maintenance works of critical equipment in buildings (Whittaker, 2017; Maslesa, 2019). An integrated workplace management system, as the name suggests, integrates facilities management, real estate management, maintenance management, energy management, and project management functions within a single platform. An IWMS, mostly referred to as a developed version of CAFM, supports facilities managers to make space management decisions, assign and track maintenance work orders, monitor energy metrics and carbon emissions, and design and construct new facilities or remodel existing ones.

Most of the time, facilities managers have to spend extra time and effort to transfer the unstructured data they received at the project completion into the mentioned FM systems (Patacas et al., 2015). This process is tedious and inherently error-prone. However, BIM-based projects store whole building lifecycle data into a repository and interoperability standards enable seamless data exchange between BIM and FM software systems. BIM-FM integration studies and practices are gaining popularity over the last decade (Tezel & Giritli, 2021). Evidence shows how BIM can support maintenance management, indoor environmental quality monitoring, space management, emergency planning, and FM personnel training (Korpela et

al., 2015; Merschbrock et al., 2016; Lavy et al., 2019; Jung et al., 2020; Kula & Ergen, 2021). Diverse FM services utilize different software systems with different information requirements. This prevents a single software solution to respond all types of FM services (Wong et al., 2018). Still, BIM offers great potential to FM professionals as it provides a collaborative platform to create, coordinate and store building information throughout the whole lifecycle of the building.

Research Method

A questionnaire survey was developed to identify the most important information for facilities managers. Respondents were questioned about the necessity of the given 15 items for effective FM practices in buildings, and they were asked to rate their importance. There was an additional open-ended question for the respondents to indicate further items. They were able to select the level of importance for each item among the following three categories: (0) not needed, (1) better to have, and (2) must have. The survey also collected a set of information regarding respondent characteristics, namely, position, years of industry experience, years of experience in the latest company, and their BIM-based FM background.

Table 1. Respondent characteristics.

Characteristics	**Categories**	**Response count**	**Response rate**
Position	Founder/General Manager	16	43%
	Vice General Manager	6	16%
	Director/Leader/Manager	9	24%
	Consultant	2	5%
	Specialist	2	5%
	Other	2	5%
	Total	**37**	**100%**
Experience in the FM profession	< 5 years	4	11%
	6-10 years	11	30%
	11-15 years	10	27%
	16-20 years	5	14%
	21-25 years	4	11%
	> 26 years	3	8%
Years in the current company	< 5 years	14	38%
	6-10 years	11	30%
	11-15 years	5	14%
	16-20 years	6	16%
	21-25 years	1	3%
	> 26 years	-	-

The online questionnaire invitation was shared with the members of three major FM associations in Turkey, as this study adopts an expert sampling (or judgment sampling) strategy. Expert sampling ensures that individuals who are associated with the study subject are present within the targeted sample (Thieart, 2001; Taherdoost, 2016). Even though FM is a relatively new industry in Turkey, it plays a significant role in the O&M of millions of square meters with diverse needs. Within the scope of this study, 90 members of the Turkish Facility Management Association (TRFMA), Professional Facility Managers Association (PTYD), and Urban Facility Management Association (TRKTYD), and local offices of 3 well-known international

FM provider organizations were invited to the questionnaire between February and March 2021. A total of 37 valid responses were received with a response rate of 40%, approximately. Table 1 below shows the general characteristics of the respondents.

The largest group of survey respondents (43%) are Founders or General Managers within the Turkish FM industry, followed by Directors, Leaders or Managers (24%), and Vice General Managers (16%). The remaining groups include Consultants (5%), Specialists (5%), and other experts in different FM service areas (5%). On this account, it is evident that the survey drew the attention of high-ranking FM professionals. The respondents were able to choose their years of experience within the FM industry in general, and within the latest company in particular from the following categories: (1) less than 5 years, (2) 6 to 10 years, (3) 11 to 15 years, (4) 16 to 20 years, (5) 21 to 25 years, and (6) 26 years and more. It is seen that the majority of the respondents (60%) have more than 10 years of experience in the FM industry and again the majority of them (62%) have been working in the same company for at least 5 years. The descriptive findings regarding respondent characteristics imply that the study sample is highly representative of the industry.

Findings

Collected data were analyzed in terms of frequency, mean, rank, and comparison. Figure 2 illustrates the BIM-based FM background of survey respondents. Given the frequencies in Figure 2, it is seen that almost 20% of the respondents (8 out of 37) did previously use or are actively using BIM in at least one project. More importantly, a significant number of the respondents (70%) are willing to work with BIM even though they did not work with it until now. This finding is great evidence of the growing tendency of BIM-based FM services in the country.

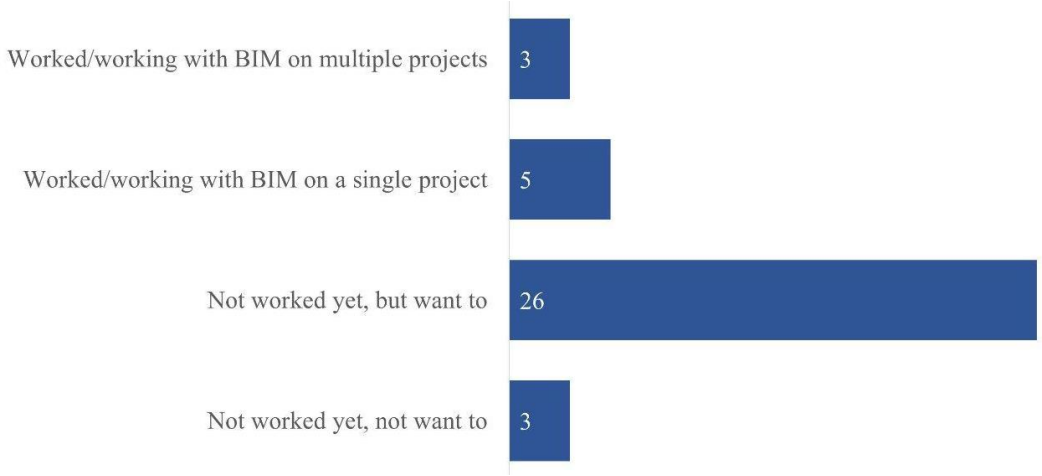


Figure 2: BIM use of the survey respondents.

Table 2 shows the responses given to the question of how necessary it is to have the listed data and information for efficient and effective FM services. Contrary to common expectations, FM professionals prioritize an emergency plan, a document that describes the actions to take during emergency cases, and emergency scenarios at the top. Then, they look for equipment lists, manuals and warranties, equipment logs, maintenance and repair records, and the locations of emergency equipment (i.e., fire extinguisher, first-aid kit, etc.) within the building. It is

interesting to note that, 2D as-built drawings such as floor plans and sections and 3D as-built models that show the exact representation of the buildings do not seem to be as crucial for the facilities managers as the above-mentioned documents. There may be two underlying reasons explaining this outcome. First, the data were collected between February and March 2021, when all industries were still struggling with the COVID-19 pandemic, yet they were continuing business under unstable economic conditions. Therefore, they may ask FM service providers to be prepared for emergencies. Secondly, facilities managers generally receive the major construction drawings, but the inaccurate or outdated floor plans or models do not help them to make further decisions regarding the building. Thus, they may not find these documents as useful as they were expected to be.

Table 2. Data and information requirement rank.

	Responses				
	not needed	**better to have**	**must have**	**Mean**	**Rank**
Emergency plans	-	2	35	1.95	1
Emergency scenarios	-	3	34	1.92	2
Equipment lists and manuals	1	2	34	1.89	3
Equipment logs	1	2	34	1.89	3
Locations of emergency equipment	1	2	34	1.89	3
Regulations and standards	1	3	33	1.86	4
Specifications	-	5	32	1.86	4
Financial information	1	4	32	1.84	5
2D as-built drawings	-	7	30	1.81	6
Occupant information	2	3	32	1.81	6
Policies	2	7	28	1.70	7
Energy consumption logs	-	11	26	1.70	7
Personnel training documents	2	8	27	1.68	8
Certificates (energy, green building)	-	14	23	1.62	9
3D as-built models	-	17	20	1.54	10

In addition to the listed items, open-ended responses emphasize the importance of an adequate FM plan, a clear definition of the FM service scope, and interoperability standards for different FM technologies for better services. Based on the findings, it can be concluded that the FM industry suffers from poorly defined contracts, unavailability of documents regarding critical assets, and technological discrepancies.

Figure 3 compares the answers of the non-BIM-user and BIM-user facilities managers to the question of what the "must have" data is for efficient FM operations. For all BIM users (100%), equipment lists, and regulations and standards are the absolute must documents to have when operating buildings, followed by 2D as-built drawings, equipment logs, emergency plans and scenarios, and financial data (88%). On the other hand, most of the non-BIM users require emergency plans first (97%), followed by equipment logs, emergency equipment locations, and emergency scenarios (93%).

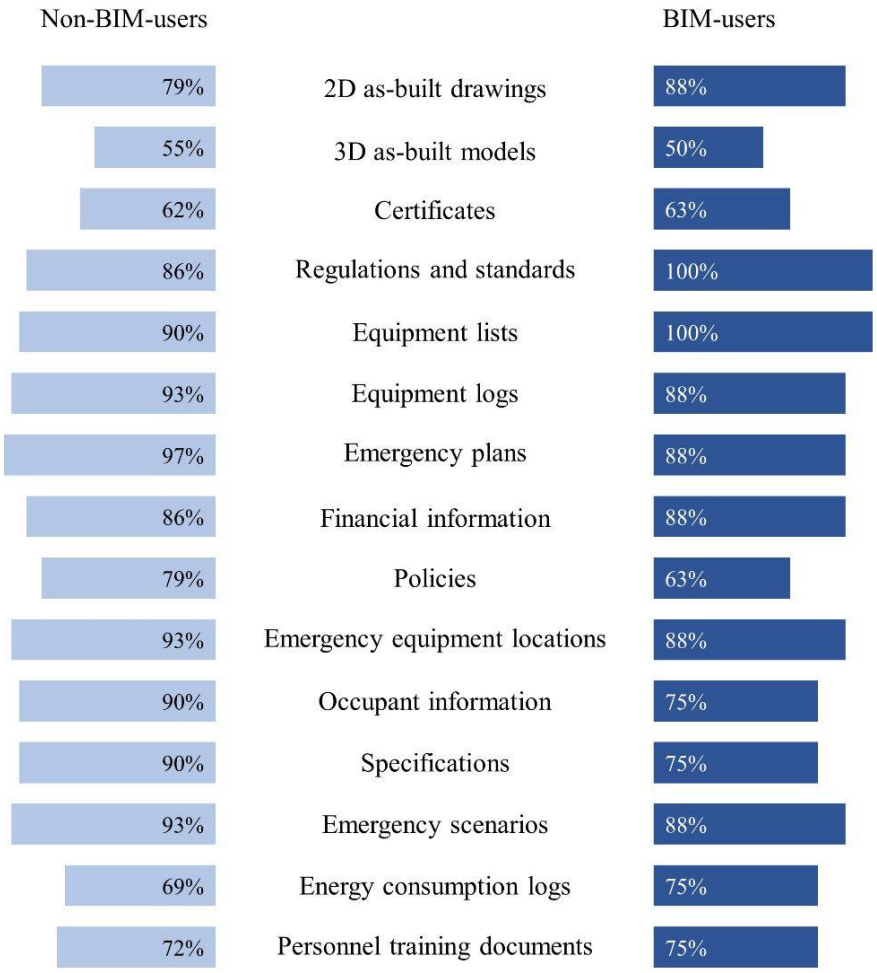


Figure 3: “must have” information for non-BIM-users and BIM-users.

It is interesting to note that none of the two groups look for 3D digital models of the building, in contrast only half of the respondents in each group believe that 3D models are necessary, and the remaining half do not need them at all. This finding may result from the limited BIM understanding of the respondents. According to the National Institute of Building Sciences (NIBS), equipment checks, facility maintenance, and repair activities take half of the time of FM personnel every day (NIBS, 2015). Thus, accurate 3D representation of each component with non-geometric details (i.e., manufacturer, install/replace date, manual, warranty, etc.) will be a time saver, especially in urgent cases. However, in most cases, BIM is accepted as a 3D visual without the associated “information”. Therefore, respondents may not find 3D models as necessary as other documents.

Conclusion

BIM is increasingly diffusing into the AEC practices to improve communication and coordination, reduce errors and rework, and increase efficiency. The more we design and construct buildings with BIM, the more we have BIM-based data to support FM services. Recognizing these developments, countries are taking various steps towards the spread of BIM and promoting BIM-FM integration. On the other hand, the FM industry in Turkey has a great

appetite for BIM, yet BIM diffusion within the industry is still very limited due to numerous reasons.

This study focuses on the most popular FM technologies and their synergy with BIM-based practices. The questionnaire survey with FM industry professionals unexpectedly reveals that documents concerning emergency planning and building equipment are the most required information by facilities managers in place of major construction documents such as as-built drawings and models. Previous studies show that inaccurate and outdated data are a hindrance to healthy decisions about building operations and maintenance. Thus, there may be distrust towards the architectural and construction drawings. However, in all work request facilities managers have to handle different documents at a time, and manually coordinating these documents is tedious and error-prone. BIM-based technologies ensure coordination and synchronization of all building data in a single platform.

BIM has been changing how the AEC industry works, and it changes how the FM industry works as well. ISO has been developing the 19650 series to guide the BIM implementation process for the actors in the entire building lifecycle. ISO 19650 series highlight the influence of industry-specific conditions and suggest associated adaptations on the given documents to ensure a smooth implementation process. The findings of this study support BIM integration within the FM industry in Turkey by identifying the most necessary information for efficient FM services.

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Digital Twin Practices for Enhanced Construction Management: A Literature Review

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Abstract

Effective construction management plays a significant role in overcoming challenges the industry faces including low efficiency and productivity, inability to control processes, low profit, etc. In the digital transformation era, several interrelated aspects such as competition, changing customer demands, new generation employees and stakeholders, presented new instruments which have started to become widespread in construction management. Extensively applied in the automotive and manufacturing industries, Digital Twin (DT) has emerged as a technology-based innovation as one of the advances of the digitalization journey to improve and support construction practices. DT is a virtual system that brings design, construction, and operation together by data-linking to its real and physical assets bidirectionally with combined technologies. To answer key questions -namely "What is the definition of Digital Twin (DT)?", "What are the elements, technologies, and applications of DT in the construction industry?", and "How DT can be used for enhanced construction management?"- a synthesis of the digital twin literature through the lens of construction management will be made and the high potential of DT to improve construction management practices will be demonstrated. Furthermore, the frequency of consideration of DT practices and the level of awareness in the industry will be increased.

Keywords: *construction management, cyber-physical system, digital twin, information technology, literature review, project lifecycle.*

Introduction

On a global scale, the construction industry has a bad reputation for productivity and efficiency. According to the McKinsey Global Institute report, the cost of inefficiency in the construction industry to the global economy is approximately 1.6 trillion dollars, and it is stated that companies and regions that adapt to digital technologies and have an improved management understanding can increase productivity by 50 to 60 percent (Barbosa et al., 2017). In the last few decades, the construction industry has started to look for solution in digital tools such as mass production industries to increase its efficiency and productivity. The acceptance of building information modeling by the entire industry has become a catalyst supporting the digitalization effort in construction processes (Shahzad et al., 2022). Thus, newer and more advanced concepts emerged.

The emergence of the term Digital Twin (DT) is actually not so new. Widely accepted as the first definition of DT, the “digital equivalent to a physical product” was introduced at the University of Michigan in 2003 (Grieves, 2019; Opoku et al., 2021). However, within the scope of the current industrial revolution (industry 4.0), the increasing use of trends such as cloud computing, predictive maintenance, 3d printing, and smart sensors in the manufacturing, defense and space industries accelerated the introduction of the DT concept into our lives. Pan and Zhang (2021) states that a great impact on the rapid growth of interest in digital twins is caused by the work of the National Aeronautics and Space Administration (NASA) aimed at continuously simulating, predicting, and evaluating spacecraft condition, reducing vehicle errors. In general terms, the DT concept is a provision of uninterrupted and bidirectional data flow between a physical entity and its virtual representation. Accordingly, the three main elements that make up the digital twin: the physical entity in the real world, its virtual counterpart in the virtual world, and the data collection that connects both. DT receives the data from the physical entity and applies it to the virtual model. In this manner, a digital twin enables the cyber part of a cyber-physical system to be managed by assisting decision-making and giving functions for real-time prediction, development, monitoring, and control of the physical asset (Camposano et al., 2021). In the literature, presently, it has been revealed that there are DT applications to all life-cycle phases of construction projects except the demolition and recovery phase (Opoku et al., 2021). A variety of data-related, high-fidelity modeling, and simulation technologies are needed for the implementation of DT (Opoku et al., 2021). Building Information Modeling (BIM), Internet of Things (IoT), Artificial Intelligence (AI), Smart Contracts, Blockchain, Augmented Reality (AR), and Virtual Reality (VR) can be cited as examples of these technologies and concepts that support digital twin and offer different advantages from each other. The required data is produced with a series of sources like RFID tags, sensors, gauges, unmanned aerial vehicles and drones, laser scanners, cameras, etc., and in different types of formats.

With this background, the purpose of this paper is to create a guide by examining the literature on the DT concept, and its associated technologies from a construction management perspective for those who will work on digital construction management. Thus, the current applications of DT, the potentials and benefits it offers directly and indirectly have been revealed.

Methodology

A comprehensive literature review was conducted to examine in detail the existing studies on digital twin and its applications. Scopus was chosen as the database because it has a wider scope and provides access to newer publications (Opoku et al., 2021). Title-Abstract-Keywords filtering in Scopus' advanced search engine was used with 2 separate parts. The first and changing part was "digital twin" or its practices such as "artificial intelligence OR ai", “internet of things OR iot" etc., while the second and unchanged part was "construction management" for every search run. The papers obtained in the search results that are not related to the construction industry were eliminated. The remaining relevant papers were read by categorizing them according to DT and its practices. Finally, the current status, potentials, and benefits offered to construction management for each practice were compiled.

Literature Review of Digital Twin Practices from Construction Management Perspective

Building Information Modeling (BIM)

BIM is a methodology of using a digital 3D representation of a structure to simplify construction processes from design to maintenance. BIM, which increases efficiency by managing information in a digital environment and allows more than one discipline to work together, has been frequently studied in the literature in the last 20 years due to the many opportunities it provides. The development of BIM standards, the research of formats in which information will be exchanged, and the continuation of the examination of real projects are constantly improving BIM technology (Jiang, 2021). Working as a dataset of a digital model, the system provides a reliable basis and source of information for decisions to be made throughout its lifecycle. Unlike 2D drawings, the approach to the building takes place as a combination of building components such as walls or windows. Before actually building the structure, it is aimed to prevent conflicts by establishing a simulation environment where different disciplines work together, strengthen communication by keeping project stakeholders on the same page, and enable the development of the project by testing real-life events and conditions. Considering that 3D is only a geometric dimension, BIM models with added data such as time, cost, energy or facility information have dimensions from 4D to 7D according to the data they have. These data determine how much benefit the BIM model can provide in construction management. For example, Agostinelli et al. (2019a) have shown that when the concept of time is treated as the fourth dimension, BIM technology can prevent waste of time, materials, and resources and improve adherence to the schedule by enabling better risk management. The use of a 5D model makes it possible to uncover and analyze costs and alternative scenarios, allowing for more precise material, labor, and resource estimation as well as cost control and planning (Agostinelli et al., 2019a). It has been revealed in the literature that BIM provides efficient processes by providing better information management to the site, project team, and stakeholders in every phase of the project, increases coordination, productivity, quality, safety, and energy efficiency (Goyal et al., 2020; Liu, 2021; Ma et al., 2020; Michalski et al., 2021; Onungwa et al., 2017; Sepasgozar et al., 2021). Many construction management topics such as risk, cost, quality, time, etc. are related to each other and these benefits reveal positive outputs with BIM.

Internet of Things (IoT)

The concept of IoT represents the network in which physical objects (mechanical or digital tools, living beings, or objects etc.) supported by sensors and by technologies such as software and data processing are connected and exchanged data via the internet or other connection/communication types. Administration and examination of multi-source data collecting, automated monitoring, and predictive warning can be given as examples of usage purposes (Han et al., 2020). Gaining importance with the technological possibilities in the 21st century, IoT facilitates processes in many industries, even in our homes and cars, with the uninterrupted communication offered by interconnected objects. The development of Artificial Intelligence (AI) and other technological possibilities has enabled it to be tried as a solution for different purposes and quickly popularized (Liang et al., 2021). As Zhang et al. (2022) have shown us, IoT continues to be studied for many disciplines as well as for construction, to support and facilitate management processes. The fact that IoT resources

provide instant and real data can improve the monitoring of almost every preferred construction element and make it easier to manage. In addition, to enhance it, new positive outcomes may emerge by working together with technological processes such as BIM and GIS (Han et al., 2020; Qian, 2021). With the use of IoT in steel structures, it is possible to monitor the heat, environmental, and health status of the structure, thus making it safer to use, and improving operation and management processes (Liu et al., 2020). With the help of RFID systems, Yu et al. (2019) were able to provide information management of the precast elements to be used in a metro construction through information collection, production management, transportation, and application processes, and provided the necessary data for the quality improvement and maintenance stage. In addition, it has been examined in the literature that working with technologies such as BIM, in which IoT is integrated, contributes to many construction management areas such as maintenance and repair, safety of workers and work-site, inventory management with equipment, material and worker monitoring, and it has been revealed that it increases construction management efficiency by reducing waste generation while increasing productivity (Han et al., 2020; Oke et al., 2020; Qian, 2021; Reinbold et al., 2019).

Artificial Intelligence (AI)

Although its roots date back to the 1940s, AI, which is still one of the most puzzling computer science topics of today, was coined as a term for the first time by John McCarthy at the conference held on the subject in 1956. AI is the ability of a computer or computer-controlled robot to perform and simulate the processes or tasks that human intelligence is related to. The main expected benefit of AI is that it reduces the workload on tasks that require time for a human to think, calculate and control. AI uses a wide range of disciplines applicable to the construction industry such as automation, deep learning, machine learning, robotics, and decision trees (Hooda et al., 2021). Nguyen (2021) defined machine learning as a system that learns from data and mentioned that the quality improvement of the information management system and more precise cost estimation can be made by machine learning in the construction industry. In addition, machine learning and deep learning make it possible to fully automate the processing of data from devices such as robots or UAVs to enhance life-cycle management processes (Jang et al., 2021). If we consider that the main purpose of project management is to maximize quality while minimizing time and cost, for overall improvement (Aziz et al., 2014) developed a smart optimization model named "Smart Critical Path Method System" using AI to support balance between construction time, cost and quality for the decision-makers. Hooda et al. (2021) have compiled the most important applications of AI in the construction industry; (1) Decision making using the parameters of project characteristics, risk, environment and organization, location and workers with artificial neural network (ANN), (2) sticking to the project plan from concrete production to handover with the aid of robotic and machine learning, (3) structural health monitoring with ANN, and (4 and 5) real-time monitoring and smart city opportunities with AI-IoT cooperation. In addition, it has been seen that costs can be controlled more easily with precise looking, more precise forecasts and risk analyzes with ANN (Cao et al., 2021; Nguyen, 2021). Many AI applications have been presented in the literature to increase project quality and productivity, make the construction site safer, and support project managers in decision-making (Alheeti & Aldaiyat, 2021; Wang & Hu, 2022).

Virtual Reality (VR)

VR is a technology that allows users to experience a computer-generated and simulated environment. The virtual environment with realistic scenes and objects, grants users perceptions like vision, hearing, and smell to provide an immersive experience (Xu, 2021). Currently, this environment can be provided with wearable devices called VR Headsets or multi-screen digital rooms. At first, VR became popular in the gaming and entertainment industries, but its entry into the architecture, engineering, and construction (AEC) industry did not take long since the discovery that VR applications allow better visualization and simulation of various scenarios (Pour Rahimian et al., 2020). VR technology, on its own or in combination with model-supporting technologies such as BIM, can act as a guide for better construction management. Allowing users to experience a project that has not yet been built, VR enables the visualization of project design, construction plan, schedules and different activates, thus, helps to spot potential risks, optimize processes, create design prototypes, and facilitate communication between stakeholders (Ozcan-Deniz, 2022; Pour Rahimian et al., 2020). The created virtual environment accelerates material, manpower, and financial resource and time-consuming processes by providing a training field for safety practices or applications such as HVAC and a vision for hard-to-reach areas (Ozcan-Deniz, 2022; Wang, 2021; Xu, 2021). Furthermore, continuing to review the literature from a construction management perspective, Shojaei et al. (2021) state that, this technology improves decision making and productivity while reducing on-site injuries. It has been revealed that VR technology directly contributes to areas such as quality management, cost management, safety management, time management, and logistics management and has a positive effect on Key Performance Indicators (KPIs), which are the outputs of these areas (Bhadaniya et al., 2021; Dallasega et al., 2020; Ghanem, 2022; Zhong & Hao, 2014).

Augmented Reality (AR)

AR refers to an enhanced version of the real physical world through technologies that bring computer-generated objects such as visual elements and sounds, into the user's physical environment. As with VR, smart devices such as mobile apps and headsets are used to support the users' AR experience. Different from VR, to improve the experience, augmented reality overlays virtual data on top of the real and physical world. At its core, AR strengthens understanding by providing detailed visualization of plans or any elements in the construction industry. In the literature, it is stated that there is an increasing interest in AR in the AEC industry and examples of application areas such as education, damage measurement of buildings, risk management, energy control, facility management, synergic site visualization (i.e., tracking or determining the position of the components behind the finished wall), site planning, examining the consistency of what is planned and built and equipment operation are given (Karji et al., 2017; Kim & Irizarry, 2021; Pour Rahimian et al., 2020; Rohani et al., 2014). Improving the visualization, it provides more understandable 3D project data, and sharing this data with stakeholders over the internet creates a more efficient and easier construction management system (Bhadaniya et al., 2021; Kim et al., 2011; Zhong & Hao, 2014). Thus, information such as quality, safety, and process monitoring can be monitored live. In addition, allowing to investigate possible scenarios, these visualization and simulation methods allow AEC professionals to prevent potential conflicts, detect clashes and construction defects in the pre-construction stage, and export quantities from the model (Rohani et al., 2014; Tayeh & Issa, 2020). Thus, a shorter construction time is ensured (Dallasega et al., 2020). AR applications are applied not only in the construction phase, but also in the design, procurement, and maintenance phases (Rankohi & Waugh, 2013). It facilitates decision-making by visualizing care data, enabling faster and more accurate

information sharing, and saving time by accelerating results (Chung et al., 2021). Moreover, Mirshokraei et al. (2019) stated that it offers a better quality management environment by revealing that AR reduces delays, improves quality, provides cost control, and strengthens communication between parties.

Smart Contracts and Blockchain

A smart contract is a computer program that, under specific circumstances, executes the terms of a contract between the parties. Smart contracts execute exactly as they are coded. Working with the if/then concept, SC is coded to follow or execute the next action when a task is completed (Owusu et al., 2020). Smart contracts are connected to a blockchain to keep track of the pertinent data for each user within the network. Users no longer have to rely on a centralized system for their exchanges and transactions, and a decentralized chain is created as a result. Blockchain is a secure distributed file system in which a chain of nodes rather than a single one controls communication between nodes (Darabseh & Martins, 2020). Three characteristics of the Blockchain are summed up by Turk and Klinc (2017): (1) the content is chained across several devices; (2) the chained data cannot be changed and (3) the copies across various sources are identical. And the 6 characteristic features according to (Lin et al., 2021) are: (1) openness; (2) anonymity; (3) safety and reliability; (4) immutability; (5) traceability, and (6) automated information processing. Blockchain technology can advance the digital twin concept by enhancing the transparency of the digital construction industry, data, and communication (Ni et al., 2021). Of course, by enabling a more secure data flow. One of the 7 categories in Li et al. (2019) study, which deals with the built environment applications of blockchain, is construction management. After 2 years, the authors reviewed the literature with 153 sources and listed the construction applications of blockchain and smart contracts as follows: information management, payments, procurement, supply chain management, regulations and compliance, contract management and delivery, dispute resolution, and technological systems (Li & Kassem, 2021). In addition, managerial problems such as data insecurity, delayed payments, poor collaboration, low data quality, and overall project quality can be eliminated with blockchain (Lin et al., 2021; Wahab et al., 2022). When DT applications such as BIM and IoT are integrated with blockchain, it has been shown to have great effects on construction applications such as reduced rework, cost reduction: reliable data monitoring (i.e., air quality), better information sharing, increased trust, strengthened procurement and supply chain activities, automated facility management, traced changes, better data ownership, automated payment (Darabseh & Martins, 2020; Li et al., 2019; Turk & Klinc, 2017).

The Contribution and Use of Digital Twin Practices to Construction Management

In the previous titles of the research, BIM, IoT, AI, AR, VR, and Blockchain practices were examined within the framework of construction management, and their potential, status, and benefits were gathered together by reviewing the existing literature. In the light of the research and the data obtained, in Table 1, the critical problems and main topics of Construction management and the corresponding digital twin applications are brought together. Although the number of proven case studies and DT projects is limited, it has been revealed that DT can be applied in the design, construction, or operation & maintenance

phases of the construction project and provide a variety of benefits, depending on the technology added and the level of data collected.

Table 1. The relevance of digital twin practices to construction management.

Construction Management Related Topics and Technics	DT Practice(s)	References
Alternative Scenarios and Estimations	AI, BIM, VR	(Agostinelli et al., 2019a; Cao et al., 2021; Hooda et al., 2021; Nguyen, 2021; Pour Rahimian et al., 2020)
Automated and Real-Time Monitoring	AI, AR, BIM, Blockchain, IoT	(Agostinelli et al., 2019a; Darabseh & Martins, 2020; Han et al., 2020; Hooda et al., 2021; Jang et al., 2021; Karji et al., 2017; Kim & Irizarry, 2021; Li et al., 2019; Liu et al., 2020; Oke et al., 2020; Pour Rahimian et al., 2020; Qian, 2021; Reinbold et al., 2019; Rohani et al., 2014; Turk & Klinc, 2017)
Contract Management and Payments	BIM, Blockchain	(Darabseh & Martins, 2020; Li et al., 2019; Li & Kassem, 2021; Lin et al., 2021; Turk & Klinc, 2017; Wahab et al., 2022)
Cost Management	AI, AR, BIM, Blockchain	(Agostinelli et al., 2019a; Aziz et al., 2014; Bhadaniya et al., 2021; Cao et al., 2021; Dallasega et al., 2020; Darabseh & Martins, 2020; Ghanem, 2022; Li et al., 2019; Nguyen, 2021; Rankohi & Waugh, 2013; Turk & Klinc, 2017; Zhong & Hao, 2014)
Energy Efficiency	AR, BIM, IoT	(Karji et al., 2017; Kim & Irizarry, 2021; Pour Rahimian et al., 2020; Rohani et al., 2014; Sepasgozar et al., 2021)
Facility Management	AR, BIM, Blockchain, IoT	(Darabseh & Martins, 2020; Karji et al., 2017; Kim & Irizarry, 2021; Pour Rahimian et al., 2020; Rankohi & Waugh, 2013; Rohani et al., 2014; Turk & Klinc, 2017; Yu et al., 2019; Zhang et al., 2022)
Information Management: Communication and Collaboration	AI, BIM, Blockchain, IoT	(Bhadaniya et al., 2021; Goyal et al., 2020; Kim et al., 2011; Li & Kassem, 2021; Ma et al., 2020; Ozcan-Deniz, 2022; Pour Rahimian et al., 2020; Rankohi & Waugh, 2013; Rohani et al., 2014; Tayeh & Issa, 2020; Zhong & Hao, 2014)
Inventory Management	BIM, IoT	(Han et al., 2020; Oke et al., 2020; Qian, 2021; Reinbold et al., 2019)
Logistics and Supply Chain Management	Blockchain, IoT, VR	(Bhadaniya et al., 2021; Dallasega et al., 2020; Ghanem, 2022; Li & Kassem, 2021; Yu et al., 2019; Zhong & Hao, 2014)
Predictive Warning	AR, IoT, VR	(Han et al., 2020; Pour Rahimian et al., 2020; Rohani et al., 2014; Tayeh & Issa, 2020)

Productivity	AI, BIM, IoT, VR	(Alheeti & Aldaiyat, 2021; Michalski et al., 2021; Oke et al., 2020; Onungwa et al., 2017; Reinbold et al., 2019; Shojaei et al., 2021)
Quality Management	AI, AR, BIM, Blockchain, IoT, VR	(Aziz et al., 2014; Bhadaniya et al., 2021; Dallasega et al., 2020; Ghanem, 2022; Lin et al., 2021; Z. Liu et al., 2019; Michalski et al., 2021; Nguyen, 2021; Onungwa et al., 2021; Rankohi & Waugh, 2013; Sepasgozar et al., 2021; Wahab et al., 2022; Yu et al., 2019; Zhong & Hao, 2014)
Risk Management	AI, AR, BIM, VR	(Agostinelli et al., 2019b; Cao et al., 2021; Karji et al., 2017; Kim & Irizarry, 2021; Nguyen, 2021; Ozcan-Deniz, 2022; Pour Rahimian et al., 2020; Rohani et al., 2014)
Safety Management	AI, BIM, IoT, VR	(Alheeti & Aldaiyat, 2021; Liu et al., 2020; Liu, 2021; Michalski et al., 2021; Oke et al., 2020; Onungwa et al., 2017; Qian, 2021; Sepasgozar et al., 2021; Shojaei et al., 2021; Wang & Hu, 2022)
Stakeholder Management: Conflicts and Disputes	AR, BIM, Blockchain, VR	(Bhadaniya et al., 2021; Goyal et al., 2020; Kim et al., 2011; Li et al., 2019; Ma et al., 2020; Ozcan-Deniz, 2022; Pour Rahimian et al., 2020; Rankohi & Waugh, 2013; Rohani et al., 2014; Tayeh & Issa, 2020; Zhong & Hao, 2014)
Time Management	AI, AR, BIM, VR	(Agostinelli et al., 2019b; Aziz et al., 2014; Bhadaniya et al., 2021; Chung et al., 2021; Dallasega et al., 2020; Ghanem, 2022; Ozcan-Deniz, 2022; Pour Rahimian et al., 2020; Zhong & Hao, 2014)
Waste Management and Reworks	BIM, Blockchain, IoT, VR	(Agostinelli et al., 2019a; Agostinelli et al., 2019b; Darabseh & Martins, 2020; Han et al., 2020; Li et al., 2019; Oke et al., 2020; Ozcan-Deniz, 2022; Qian, 2021; Reinbold et al., 2019; Turk & Klinc, 2017; Wang, 2021; Xu, 2021)

As the Digital Twin concept increases and diversifies the data flow with the help of various technologies and practices it offers, it has been seen that it also reveals, diversifies and multiplies the benefits that may correspond to many critical keywords of construction management.

Conclusion

This research reviewed and analyzed the current applications of technologies and concepts that the digital twin will bring to the construction industry. To serve as a guide for those who want to work in the field of digital construction. By examining its practices under separate headings, the benefits that emerged when they worked alone or in pairs were analyzed in the light of current literature. However, when these results are put together, it has been revealed

that DT practices, which have so far been studied singly or in pairs in construction practice and academia, can improve construction management more broadly in response to more problems if they work together and with more data. With an overview, digital twin concept facilitates the decision-making processes, which is the main element of construction management, by offering much faster and more efficient monitoring. Also, a strong positive effect has seen on the project management triangle (cost, time and scope within quality needs) by allowing to simulate and traceability of each desired element in the construction environment enables cooperation and better communication between the parties involved. Thus, it has been demonstrated that it can be a tool for the goal of better construction management that can eliminate the low efficiency and lack of productivity faced by the construction industry.

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Investigation of BIM Perception in Metro Projects

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Abstract

Building Information Modelling (BIM) has led to technological and procedural shift within the construction industry. Since 2015, BIM has been made mandatory in metro projects in Istanbul. BIM adoption and implementation involves key components, including the perceptions of the professionals according to which BIM can either be adopted or rejected. This study aims at presenting professionals' perception on BIM from numerous aspects as revealed in six real-life metro projects based in İstanbul to comprehend in what ways the implementation has affected the work practices, future expectations and barriers. To achieve the aim of the study, two survey studies are conducted among the professionals working in the metro projects in Istanbul. The first study surveyed 279 professionals of all technical staff involved, and the second study surveyed 164 professionals, who are actively using BIM in their day-to-day tasks. This paper presents the similarities and differences of BIM perception between these groups in terms of different profile characteristics of the participants (i.e., age, organization). The study argues that working on BIM-based projects is becoming less challenging and the expectation and understanding of BIM varies from one stakeholder to another.

Keywords: *BIM, BIM adoption, building information modelling, metro projects.*

Introduction

Management of the digital essential aspects of building design and project data has resulted in the emergence of numerous methodologies that rely on certain interacting policies, processes and technologies including Building Information Modelling (Penttia, 2006). Building Information Modelling (BIM) within the Architecture, Engineering, Construction and Operations (AECO) industry is a potential development that has lately gained more attention (Barlish & Sullivan, 2012; Charef et al., 2019). Adoption of BIM is a relatively new area, and it presents its own set of challenges for the AECO industry (Charef et al., 2019). Similar to many other developing countries, BIM implementation remains challenging for the Turkish construction industry.

BIM experience in the construction sector indicates the application of BIM in various domains, and it may be utilised to guide the early phases of BIM growth in the infrastructure field (Shou et al., 2015). Particularly in developed countries, there have been several studies on the use of BIM (Eadie et al., 2015; Chong et al., 2016; Li et al., 2017; Zhang et al., 2020). Likewise, in developing countries, there have been studies conducted regarding the BIM

implementation (Masood et al., 2014; Elyamany, 2016; Hanafi et al., 2018; Al-Ashmori et al., 2020). They emphasize the advantages, disadvantages, critical success factors, and, in particular, the lessons acquired through case studies. As a consequence, all of these research studies enable us to recognize the existence of various levels of adoption around the world.

The applications of BIM are not limited to buildings and are applied within infrastructure projects. The majority of previous BIM studies have mostly focused on buildings, with only a few studies covering the adoption and usage of BIM in infrastructure projects (Chong et al., 2016). Since 2015, BIM has been made mandatory in metro projects in Istanbul. In order for an implementation to be successful and in contrast to the comprehensive application, a thorough understanding of the current state of BIM should be considered (Kim et al., 2016). Despite the fact that BIM has been in use for seven years on several metro lines with various stakeholders, such knowledge has yet to be assessed. Due diligence must be performed on the adoption and execution of completed projects. BIM adoption and implementation involves key components including the perceptions of the professionals according to which BIM can either be adopted or rejected. This study aims at presenting professionals' perception on BIM from numerous aspects as revealed in six real-life metro projects based in İstanbul to comprehend in what ways the implementation has affected the work practices, future expectations and barriers.

Research Methodology

In this study quantitative research method is used. Two survey studies are conducted among the professionals working in the metro projects in Istanbul. The first study surveyed 279 professionals of all technical staff involved, and the second study surveyed 164 professionals, who are actively using BIM in their day-to-day tasks. The metro projects that are covered are Kabataş-Mecidiyeköy-Mahmutbey, Ataköy-İkitelli, Dudullu-Bostancı, Ümraniye-Göztepe-Ataşehir, Çekmeköy-Sultanbeyli, Kaynarca-Pendik-Tuzla metro line projects in İstanbul, Turkey.

A simple random sampling is used for survey 1 to represent the overall population's viewpoint by providing participants equal odds of being picked from the population of metro projects (Kish, 2004). The first survey is administered to professionals who work as technical staff on metro projects and are not among the responders of the second survey. A purposive sampling method is used for survey 2 to obtain the opinions of competent persons that are actively using BIM. The second survey is administered to professionals who are constantly working with BIM to perform one of the following activities; design authoring, design documents creating, design reviews, cost estimation (quantity take-off), record modeling, site utilization planning, digital fabrication, construction system design, 3D coordination, engineering analysis-energy, engineering analysis-structural, phase planning (4D modeling), sustainability evaluation and existing conditions modeling. Surveys were administered over a 3-month period using Google Forms and an online link sent to participants. 757 experts from six metro projects were contacted for survey 1 and 229 professionals were reached out for survey 2. In survey 1, 279 professionals responded, yielding a 37% response rate, while for survey 2, 164 responses were received, yielding a 72% response rate. The response rate for surveys should be at least 35-40%; and as the response rate for both sample techniques is greater than that, the criteria was satisfied (Baruch et al., 2008).

On a five-point Likert scale, survey respondents are required to score their perceived BIM usage, how the adoption has influenced work practices, future expectations, and barriers. In the scale, 1 refers to “Strongly Disagree”, 2 refers to “Disagree”, 3 refers to “Neither agree nor disagree”, 4 refers to “Agree” and 5 refers to “Strongly Agree”. The data collected from the surveys were analyzed and the findings are triangulated.

Data Analysis

The Likert-type data demonstrated within the surveys are analyzed by using the IBM® Statistical Package for Social Sciences (SPSS®) version 27. The normal distribution test was used. In this study the Shapiro-Wilk normality test has become the preferred test because it is a precise test for normality whereas the Kolmogorov-Smirnov Test is more general but less effective (Mendes & Pala, 2003). The Sig. value of the Shapiro-Wilk Test for surveys data is less than 0.05, indicating that the data deviates considerably from a normal distribution. Since the study's data were ordinal and did not have a normal distribution, non-parametric tests were performed (Mircioiu & Atkinson, 2017). These were; 1) the Kruskal-Wallis, 2) the Mann-Whitney U test, 3) the Kendall’s concordance analysis, 4) Spearman's rank correlation test.

Kruskal Wallis H Test is performed to discover inferences within the data since such is judged an adequate statistical mean to compare three or more groups (Kruskal & Wallis, 1952). In other words, it is carried out in order to evaluate the examined phenomenon if it varies according to participant profile parameters. The Kruskal-Wallis H test is a non-parametric variant of ANOVA and it is a modified version of the Mann-Whitney test since it allows for the participation of two or more groups. In this study, the significance threshold is set at 0.05. (Ostertagova et al., 2014). The basic premise is that the null hypothesis (H0) can be rejected if the estimated p-value is less than the allowable significance threshold (e.g., 5%).

Mann-Whitney U test is used to evaluate statistically significant differences or divergences between the median values of the same item between two different respondent groups (Kasuya, 2001). The Mann-Whitney U test is used on the responses in this study, which demonstrates discriminating qualities according to the Kruskal-Wallis H test. The basic premise is that if the computed ρ-value is less than the acceptable significance threshold (e.g., 5%), the null hypothesis (H0), which states that there are no significant variations in the median values of the same item between the two respondent groups, can be rejected (Chan et al., 2010). In the study, the significance level is set at 0.05.

Kendall’s coefficient of concordance test is used to assess respondents' agreement on the examined phenomenon within each respondent group (Legendre, 2005). In this study, consensus among organizations-client, construction manager, designer, contractor-, was investigated. Kendall's coefficient of concordance has a dimension ranging from 0 to 1. The greater the value of the coefficient, the greater the level of agreement among survey respondents within the group (Chan et al., 2010). Because there were more than seven items, the $\chi 2$ test was applied.

Spearman's rank correlation test is used to assess the strength of a relationship between two groups (Chen & Popovic, 2002). In this study it is applied to see if there was a statistically significant association between the age variable and the responses to the research questions. Spearman's rank correlation coefficient (rs) has a dimension ranging from -1 to 1. The greater the coefficient value (positive or negative), the stronger the positive or negative linear

association (Schober et al., 2018). There is no linear association if rs = 0. (Chan et al., 2010). The basic premise is that if the estimated ρ-value is less than the allowable significance threshold (e.g., 5%), the null hypothesis (H0), which states that there are no significant differences in ranks between the two groups, can be rejected (Chen and Popovic, 2002).

Results and Discussion

The survey results are presented at Table 1. This study demonstrates that BIM is being heard more and more, and according to the majority of the professionals in metro projects it is the future's project management system (survey 1;78% (median=4); survey 2;91% (median=5)). The item "The industry is not clear enough on what BIM is yet" had the highest (strongly agree/agree) agreement in Survey 1 with 84% (median=4). On the same item, 90% (median=5) of survey 2 respondents strongly agree/agree. Results from both surveys show that the majority of specialists say that the industry's concept of BIM remains ambiguous.

Survey respondents indicate that with the help of BIM, they face far fewer problems in the field. This benefit was further emphasized among survey 2 respondents. However, the participants state that the design process takes longer due to BIM. This negative effect was emphasized more by survey 2 participants (strongly agree/agree; 56%) than by survey 1 participants (strongly agree/agree; 28%). Professionals who have responsibilities in their daily work related to BIM and therefore use it more, have different evaluations as they experience BIM more in their work. Organizational structure to support BIM within the company is one of the critical success factors for implementation (Morlhon et al., 2014; Tsai et al., 2014; Ozorhon and Karahan, 2017; Chan et al., 2019). Although many studies have noted that one of the most evident advantages of BIM is its ability to accelerate up and simplify the design process (Yan & Damian, 2008; Barlish & Sullivan, 2012), the reason why the design takes longer is that while the project outcomes are delivered by meeting BIM requirements, a new design processes are not developed, and the necessary durations are not allocated for project delivery. Operations continue as in the traditional method although BIM requirements demand a change in how professionals work. Furthermore, the item "Much more difficult to work on BIM-based projects" has the largest (disagree/strongly disagree) disagreement, with 51 percent for survey 1 (median=2) and 73 percent for survey 2 (median=2). Majority of experts believe that working on BIM-based projects is no more difficult. Working on BIM-enabled projects is not perceived as more difficult by professionals than working on non-BIM-enabled projects.

As a result of the Kruskal-Wallis H Test, it can be concluded that the questions with a significance level (Sig.) of less than 0.05 differ based on organizations of the participants (Table 2).

Table 1. Frequency distribution.

n	Statements	Survey 1 Frequency (%)					Median	Mode	Survey 2 Frequency (%)					Median	Mode
		1	2	3	4	5			1	2	3	4	5		
1	You hear more and more about BIM these days	5	9	9	41	35	4	4	3	3	4	37	54	5	5
2	BIM is the future of project information	2	4	16	30	48	4	5	1	3	5	29	63	5	5
3	The industry is not clear enough on what BIM is yet	1	5	9	44	40	4	4	0	4	6	29	61	5	5
4	I think BIM will be used in all projects in the medium term	2	5	25	40	28	4	4	1	6	18	45	31	4	4
5	I think BIM will be mandatory in public projects in the near future	1	5	23	30	41	4	5	1	4	12	38	45	4	5
6	Design process takes longer due to BIM	13	16	43	19	9	3	3	15	13	16	34	22	4	4
7	With the help of BIM, we face far fewer problems in the field	7	8	35	33	18	4	3	5	7	23	36	30	4	4
8	BIM-used projects are more difficult to manage	28	18	36	12	6	3	3	38	32	9	15	5	2	1
9	Much more difficult to work on BIM-based projects	32	18	32	12	6	2	1	41	31	12	9	6	2	1
	Number of Respondents (N Total)	279							164						

Table 2. Kruskal-Wallis H test results.

n	Statements	Survey 1	Survey 2
1	You hear more and more about BIM these days	0.000*	0.656
2	BIM is the future of project information	0.028*	0.23
3	The industry is not clear enough on what BIM is yet	0.902	0.000*
4	I think BIM will be used in all projects in the medium term	0.312	0.298
5	I think BIM will be mandatory in public projects in the near future	0.062	0.000*
6	Design process takes longer due to BIM	0.000*	0.021*
7	With the help of BIM, we face far fewer problems in the field	0.000*	0.647
8	BIM-used projects are more difficult to manage	0.001*	0.000*
9	Much more difficult to work on BIM-based projects	0.000*	0.000*

The Kruskal-Wallis H test determines which questions have a significant difference based on profile characteristics, but it does not determine which groups vary from the others. The Mann-Whitney U test was used to assess whether groups had differences in the questions for which a significant difference was identified based on the participants' organizations (Table 3 and Table 4). The client's acceptance of the use of BIM in their projects is among the three most significant critical success factors in the implementation of BIM (Tsai et al., 2014; Chan et al., 2019). Working on BIM-based projects is more challenging for the client group than for the construction manager group. This result reveals the need for more competent professionals about BIM for client in the projects. Because the implementation process is still new and there is a great need for client guidance, standardization, establishment of procedures and identification of needs (Abubakar et al., 2014; Rogers et al., 2015).

Construction managers and contractor group experts placed a greater emphasis on "BIM will be necessary in public projects in the near future" than client groups. The reason for this is because the client group professionals, who are IMM specialists in this project, believe that the industry is not yet ready for this. Public bodies are reluctant to accept BIM and resistant to change. Similarly, construction managers and contractors place higher emphasis on the statement "The industry is not clear enough on what BIM is yet" than the client group.

When compared to client and construction manager group professionals, designers claim that the design process takes longer owing to BIM. Designers naturally perform more modeling than that of in the prior procedure. This increases their workload and results in longer design timelines in the short term, however, it saves them more time in the long run (Barlis & Sullivian, 2012; Charef et al., 2019). However, it appears that they are still getting adjusted to this circumstance. On the other hand, the employers and construction managers can spot problems more readily and present alternate designs from the designer in less time.

Project management with BIM is more challenging for the designer than for the client, construction manager, and contractor groups. Project management using BIM is more challenging for the contractor than for the construction manager group. The reason for this is because BIM procedures in projects are not yet developed. It is expected that the designer will handle all aspects of BIM in the projects. On the other hand, unclarified demands from the client and construction manager in terms of contractual and project BIM procedures put more pressure on the designer and contractor than that of in the prior system. Furthermore, in order to meet the needs of the clients and the construction managers, they must train specialists and resolve challenges.

Working on BIM-based projects is more challenging for the designer group than for the construction manager and client groups. Designers are allocated more throughout the project's design phase, and they are the team that creates the model in the first place, as opposed to other groups. More than construction managers and contractors, designers believe BIM is the project management system of the future. Designers that are increasingly involved with BIM implementation want to use it in their new projects as well.

According to client group professionals, they meet considerably less challenges in the field with the use of BIM than construction managers and contractor group professionals. This demonstrates that, according to the client, the last stakeholder to whom the outcomes of the BIM process are conveyed, the adoption of BIM has resulted in fewer difficulties in the field.

Table 3. Mann-Whitney U test results, survey 1 (organization vs organization).

n	Item		Organization group pairs	N (gr.1/gr.2)	Mean Rank (gr.1/gr.2)	Mann-Whitney U	Z-value	p-value	Conclusion to Ho
1	You hear more about BIM	1	Client/Contractor	23/91	69.43/54.48	772	-2.032	0.042*	Reject
		2	Construction manager/Contractor	112/91	110.81/91.15	4.109.0	-2.501	0.012*	Reject
		3	Construction manager/Designer	112/53	76.6/96.52	2.251.5	-2.698	0.007*	Reject
		4	Contractor/Designer	91/53	61.49/91.41	1.409.5	-4.39	0.000*	Reject
2	BIM is the future of project management	1	Construction manager/Designer	112/53	77.81/93.97	2.386.5	-2.23	0.026*	Reject
		2	Contractor/Designer	91/53	65.3/84.86	1.756.5	-2.943	0.003*	Reject
6	Design process takes longer due to BIM	1	Client/Designer	23/53	29.87/42.25	411	-2.306	0.021*	Reject
		2	Construction manager/Contractor	112/91	89.67/117.17	3.715.5	-3.562	0.000*	Reject
		3	Construction manager/Designer	112/53	72.04/106.16	1.740.5	-4.445	0.000*	Reject
7	With the help of BIM, we face far fewer problems in the field	1	Client/Construction manager	23/112	83.2/64.88	938.5	-2.138	0.033*	Reject
		2	Client/Contractor	23/91	69.33/54.51	774.5	-2.022	0.043*	Reject
		3	Construction manager/Designer	112/53	72.32/105.58	1.771.5	-4.348	0.000*	Reject
		4	Contractor/Designer	91/53	61.66/91.11	1.425.0	-4.297	0.000*	Reject
8	BIM-used projects are more difficult to manage	1	Construction manager/Contractor	112/91	90.74/115.86	3.834.5	-3.176	0.001*	Reject
		2	Construction manager/Designer	112/53	74.75/100.42	2.044.5	-3.337	0.001*	Reject
9	Much more difficult to work on BIM-based projects	1	Client/Designer	23/53	30.7/41.89	430	-2.08	0.038*	Reject
		2	Construction manager/Contractor	112/91	89.2/117.76	3.662.0	-3.611	0.000*	Reject
		3	Construction manager/Designer	112/53	72.67/104.82	1.811.5	-4.204	0.000*	Reject

Table 4. Mann-Whitney U test results, survey 2 (organization vs organization).

n	Item		Organization group pairs	N (gr.1/gr.2)	Mean Rank (gr.1/gr.2)	Mann-Whitney U	Z-value	p-value	Conclusion to Ho
5	I think BIM will be mandatory in public projects in the near future	1	Client/Construction manager	41/37	29.09/51.04	331.5	-4.547	0,000*	Reject
		2	Client/Contractor	41/43	33.84/50.76	526.5	-3.369	0,001*	Reject
3	The industry is not clear enough on what BIM is yet	1	Client/Construction manager	41/37	31.05/48.86	412	-3.89	0,000*	Reject
		2	Client/Contractor	41/43	34.93/49.72	571	-3.064	0,002*	Reject
6	Design process takes longer due to BIM	1	Client/Designer	41/43	35.46/49.21	593	-2.669	0,008*	Reject
		2	Construction manager/Designer	37/43	33.24/46.74	527	-2.681	0,007*	Reject
8	BIM-used projects are more difficult to manage	1	Client/Designer	41/43	34.91/49.763	570.5	-2.882	0,004*	Reject
		2	Construction manager/Contractor	37/43	33.81/46.26	548	-2.58	0,010*	Reject
		3	Construction manager/Designer	37/43	28.03/51.23	334	-4.666	0,000*	Reject
		4	Contractor/Designer	43/43	37.29/49.71	657.5	-2.375	0,018*	Reject
9	Much more difficult to work on BIM-based projects	1	Client/Construction manager	41/37	46.34/31.92	478	-3.075	0,002*	Reject

Designer group professionals also report less issues in the field when using BIM than construction manager and contractor group professionals.

The value of Kendall's coefficient of concordance (W) for all respondents, according to organizations, is shown in Table 5. The null hypothesis should be rejected since the levels of significance for all of the groups are less than the acceptable significance level (5%). The findings give adequate evidence to indicate that the respondent's sets of question rankings are interdependent, with a significant degree of agreement within each group.

Age variable's normality distribution is examined and no normal distribution is detected since the Shapiro-Wilk p-value is $p=0.000<0.05$. There was no statistically significant difference between the age variable and responses in survey 1 ($p>0.05$). On the other hand, for survey 2, the age variable has a statistically significant relation with items 3 and 4. Item 3 and 4 had significance levels of 0.034 and 0.045, respectively, which are lower than the permitted threshold of significance (0.05). As a result, the null hypothesis must be rejected. There is a statistically significant, negative relation between 3 and 4 items and the age variable at a weak level ($r3=-0,165<0.2$; $r4=-0,157<0.2$; $p<0.05$). According to younger respondents, who are more hopeful than older respondents, BIM will be employed in all projects and will become essential in the near future.

Table 5. Kendall's coefficient of concordance test results.

	Organizations	N	Kendall's W	Chi-square	df	p-Value	Conclusion to Ho
Survey 1	Client	23	0.475	87.34	8	0.000	Reject
	Construction Manager	112	0.463	414.55	8	0.000	Reject
	Contractor	91	0.24	175.08	8	0.000	Reject
	Designer	53	0.233	98.98	8	0.000	Reject
Survey 2	Client	41	0.394	290.56	18	0.000	Reject
	Construction Manager	37	0.573	381.52	18	0.000	Reject
	Contractor	43	0.419	324.21	18	0.000	Reject
	Designer	43	0.291	224.97	18	0.000	Reject

Conclusions

This study presented professionals' perception on BIM from numerous aspects as revealed in six real-life metro projects based in İstanbul to comprehend in what ways the implementation has affected the work practices, future expectations and barriers. Different perspectives are presented based on professional's organizations. The study argues that working on BIM-based projects is getting less challenging, and stakeholders' expectations and knowledge of BIM varies based on their BIM utilization and changes in their processes.

The study confirms that with the help of BIM, professionals face far fewer problems in the field. However, the designers claim that the design process takes longer due to BIM compared to the clients and construction managers. The reason for this is that while the project outcomes are delivered by meeting BIM requirements, new design processes are not developed, and the required durations are not allocated for project delivery. Operations continue as in the traditional method although BIM requirements demand a change in how professionals work. And also, it is revealed that working on BIM-based projects is more challenging for the designers than for the construction managers and clients since designers

are assigned more detailed BIM-related tasks throughout the project's design phase as opposed to other groups, and they are the team that creates the model in the first place.

Similarly, project management with BIM is more challenging for the designer than for the client, construction manager, and contractor. Also, project management using BIM is more challenging for the contractor than for the construction manager. The reason for this is that operational BIM procedures in projects are not yet fully developed. It is expected that the designer will handle all aspects of BIM in the projects and unclarified demands from the client and construction manager in terms of contractual and project BIM procedures put more pressure on the designer and contractor than that of in the prior system.

Furthermore, the study reveals that working on BIM-based projects is more challenging for the client group compared to the construction manager group which points out the need for more competent professionals about BIM for client in the projects. And the implementation process is still new and there is a great need for client guidance, standardization, establishment of procedures and identification of needs.

Client group professionals meet considerably less challenges in the field with the use of BIM than construction managers and contractor group professionals. This demonstrates that, according to the client, the last stakeholder to whom the outcomes of the BIM process are conveyed, the adoption of BIM has resulted in fewer difficulties in the field. Designer group professionals also report less issues in the field when using BIM than construction manager and contractor group professionals.

As per the majority of professionals, the study highlights that the industry's concept of BIM remains ambiguous since it is agreed that the industry is not clear enough on what BIM is yet. However, BIM is becoming increasingly used in the industry, and according to the majority of specialists, it is the project management system of the future.

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Challenges of BIM Implementation in Airport Projects

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Abstract

Digitalization forces the Architecture, Engineering and Construction (AEC) industries to change, and adapt new technologies that intensely affect the traditional way of collaboration in projects. Among these technologies, Building Information Modeling (BIM) is one of the most predominant by enabling project parties to collaborate within a shared environment that includes the entire project data. AEC companies spend massive amounts of resources on BIM implementation and encounter many challenges. Due to their large scale and complexity, BIM implementation in airport projects is critical. The main objective of this paper is to investigate the barriers to the BIM implementation process in airport projects. In this respect, a comprehensive literature review has been conducted and a total of eleven barriers were identified; six at the industry, one at the firm, and four at the project level. Interviews were conducted with the construction professionals to analyze the BIM implementation process in four airport projects. The findings of the study revealed that the top three barriers are; the fragmented nature of the industry, project specific problems, and collaboration problems. This research is expected to facilitate the BIM implementation process in the AEC industries and guide the industry professionals on the most significant barriers to focus on.

Keywords: *airport projects, building information modeling, challenges, construction industry.*

Introduction

In the recent years, construction projects have become more complicated and demanding. This situation puts an emphasis on the new technologies regarding the project management approach and the tools to be utilized. Building Information modeling (BIM) is one of the most fascinating technologies in the Architecture, Engineering, and Construction (AEC) industries. AEC companies are in a transition process to keep pace with the digitalization of the industries and seek to develop BIM capabilities for competitive advantage (Eastman et al., 2011).

BIM represents not only the physical components of the building but also the construction process with the cost and time aspects and the facility management process with sustainability and maintenance aspects (Ozorhon & Karacigan, 2019). BIM is proven to be an effective tool that strengthens knowledge, and communication and advances information sharing within the risk management processes (Kaya et al., 2020). BIM has been defined as a crucial technology for the project lifecycle that may substantially influence a project's lifecycle (Kaewunruen & Lian, 2019). In the literature, it has been stated that improved quality, reduced duration and

costs, and increased collaboration are among the benefits of BIM implementation in the AEC industries (Olawumi & Chan, 2019).

Consequently, BIM implementation has reached a new level across the globe. NBS (2021) reported that the BIM adoption rate in 2021 was 71% globally. During the BIM adoption process, AEC companies spend massive amounts of resources and encounter various challenges. These challenges cause slowness in the adoption of innovation and prohibit BIM to be fully functional (Ozorhon & Karahan, 2016). In order to enjoy the full benefits of BIM, the barriers in front of the implementation should be identified and eliminated.

Mega projects in construction are naturally complex, large scaled, and involve multiple parties which increase the chance of failure (Akcay, 2022). Hence, implementing new technologies such as BIM in mega projects is much more important than a regular construction project. Airport projects are a good representation of mega construction projects since they involve complex systems that require innovative solutions.

In order to ensure a seamless BIM implementation in airport projects, challenging factors need to be identified. This study aims to investigate the barriers to the BIM implementation process in airport projects at three different levels including the project, company, and industry levels. In this respect, a systematic literature analysis has been conducted to identify the challenging factors. A total of eleven barriers were identified; six at the industry, one at the firm, and four at the project level. The identified barriers have been examined on four different airport projects and evaluated via the interviews that were held with professionals from these projects. Distinguishing the barriers based on their influence levels will help the professionals to identify the parties that are responsible for certain barriers and take remedial actions.

Research Background

BIM implementation has been investigated extensively within the literature. Various research focuses on different aspects of the BIM implementation process such as drivers, inputs, and enablers. However, there is also a vast of research on the challenging factors also called barriers.

A group of studies in the literature focus on the barriers against the BIM implementation process in a more general aspect. Based on a research study that analyzed four case projects, there are many barriers that keep project parties from using the most advanced technology including the risk of failure, high initial investment costs, the learning curve for the software, and lack of support (Migilinskas et al., 2013). In another study conducted by Dawood et al. (2012) to investigate the barriers and drivers of BIM, “time and cost”, “resistance to change” and “lack of experience” have been identified to be the biggest barriers to a successful process of BIM implementation.

Barriers to BIM implementation in South Australia have been examined in a study conducted by Newton and Chileshe (2012). The researchers argued that lack of understanding and awareness acts as a challenging factor for BIM implementation. Accordingly, Gerrard et al. (2010) reveal that lack of BIM knowledge and expertise is the greatest barrier. In business organizations, decisions are made with financial concerns by focusing on profits. It would be

hard to convince investors to implement BIM unless there is case study evidence about the financial benefits of BIM (Yan & Damian, 2008).

On the other hand, some research in the literature investigated the BIM implementation process for special cases such as the project's type, company's size, or the country where the project is being built. Olanrewaju et al. (2022) conducted a research study to investigate the barriers to BIM implementation in developing countries and collected data from 90 experts. The findings of the study showed that cost and standards, process and economy, technology and business, and training and people are the most critical barriers. In another study, researchers gathered perceptions of 228 companies (small and medium-sized enterprises (SMEs) and large firms) regarding the challenges of BIM implementation. The results showed that there is a general digital divide as regards to BIM implementation between SMEs and large firms (Saka & Chan, 2021). Akcay (2022) investigated the challenges of BIM implementation in mega construction projects and argued that lack of skilled staff and lack of knowledge were the major barriers.

Although numerous studies have investigated the barriers to BIM implementation, more research is required to clearly identify the challenging factors. In addition, there is no research that specifically focused on airport projects. Based on the research background provided, the current study aims to investigate barriers against BIM implementation in airport projects. To this end, an extensive literature review has been conducted and 38 research papers have been examined in detail. The barriers that are mentioned in the literature are noted and have been re-assessed and merged according to their similarities. In addition, barriers are grouped together according to their level of influence as; industry, firm, and project levels. The importance of the identified barriers is determined by examining four different airport projects. Interviews were held with industry experts, and they are asked to evaluate the factors based on a 1-5 Likert Scale. In addition, experts' opinions are gathered based on their own experiences.

Methodology

Barriers to BIM implementation are defined as the main challenges encountered during the implementation process which make the BIM implementation process complicated and risk its success. Based on this definition, a comprehensive literature review has been conducted to identify the barriers that are mentioned in the literature. A total of 38 research papers have been examined in detail and the factors that are matched with the previously determined definition are noted.

An initial list that consists of 35 barriers was created based on the literature review. The frequency of the identified barriers was counted to find how many papers have referred to each barrier. Following this, similar factors are merged or redefined under a more general name and irrelevant factors are deleted in order to refine the initial list of factors. As a result, the final list of barriers consisted of eleven factors which are defined as; "unavailability of knowledge based on experience", "unclear benefits", "lack of best practices", "high costs", "technology related problems", "change process problems", "legal & protocol problems", "fragmented nature of the industry", "collaboration problems among different parties", "project specific problems" and "lack of government support".

One of the objectives of this study was to distinguish the roles/responsibilities of the industry, companies, and project teams. For this purpose, different influence levels are defined as; industry level, firm level, and project level. The influence level of each barrier is determined, and the barriers are divided into three groups. The influence levels of the barriers are aimed to be logical and consistent with the literature. Table 1 elaborates the final list of barriers to BIM implementation in this study.

Table 1. The final list of barriers to BIM implementation.

No	Barriers to BIM Implementation	Influence Level	Source Number
1	Unclear benefits	Project	12, 14, 16, 17, 23, 24, 25, 27, 40
2	High costs	Project	4, 6, 7, 9, 10, 11, 12, 13, 14, 16, 17, 20, 23, 24, 25, 26, 27, 28, 30, 32, 40, 41, 42, 43, 44, 45, 46, 47
3	Collaboration problems among different parties	Project	3, 5, 7, 8, 9, 12, 14, 16, 17, 22, 24, 28, 30, 32, 38, 39, 43
4	Project specific problems	Project	3, 4, 5, 7, 8, 9, 10, 11, 12, 16, 17, 21, 22, 23, 24, 25, 28, 32, 41, 42, 43, 44, 45, 46, 47
5	Unavailability of knowledge based on experience	Firm	3, 6, 7, 8, 9, 10, 11, 12, 14, 16, 17, 20, 23, 24, 25, 26, 27, 28, 30, 32, 42, 43, 44, 45, 46
6	Lack of best practices	Industry	6, 10, 11, 12, 13, 14, 17, 21, 23, 24, 25, 26, 27, 30, 32, 36, 43, 44, 45, 46, 47
7	Technology related problems	Industry	3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 32, 38, 39, 41, 42, 43, 44, 45, 46
8	Change process problems	Industry	1, 3, 4, 7, 8, 9, 10, 12, 13, 14, 17, 20, 21, 22, 23, 24, 25, 26, 28, 29, 30, 32, 38, 40, 41, 42, 43, 44, 45, 46, 47
9	Legal & protocol problems	Industry	3, 7, 9, 10, 11, 12, 14, 17, 23, 24, 26, 28, 29, 30, 32, 36, 38, 40, 41, 42, 43, 44, 45, 46
10	Fragmented nature of the industry	Industry	7, 10, 12, 16, 22, 23, 30, 32, 41, 42, 46
11	Lack of government support	Industry	16, 23, 24, 43

Four airport projects have been selected as case studies to investigate the effect of challenging factors on airport construction projects in reality. The projects were chosen by considering some project specific factors such as location, size, budget, ownership, and purpose of BIM utilization. In addition to that, the interviewed companies were also chosen by considering the companies' role in the project, size, and BIM experience. The case projects were expected to represent a mixture of the mentioned project and company specific factors.

The first project had a total construction area of 12 Million sqm. The scheduled construction duration of the project was 24 months, and the general contractor was sole ownership. The project utilized BIM in both design and construction phases and employed various software such as Revit, Dynamo, Bentley, Navisworks, Tekla, Synchro, 3DS Max, Sap2000, X Steel, AutoCAD, and BIM360. The total BIM investment is stated as less than 1% of the project budget and the size of the BIM team was 30 people. The interviewed company's role was the architectural consultant for the project. The company had more than 30 employees and 6 years

of BIM experience. The interviewed industry expert was the company's partner and had 18 years of construction experience.

The second project had a total construction area of 76 Million sqm and the project's budget was more than 35 Billion Liras. The total duration of the project was scheduled as 42 months only for the first phase. The general contractor was a consortium and they utilized BIM in both the design and construction phases. The software that has been utilized are; Revit, Dynamo, Bentley, Navisworks, Tekla, AutoCAD, Primavera, and BIM360. The interviewed company was the general contractor of the project and was responsible for architecture, engineering, and construction work. The company had more than 5 years of BIM experience. The interviewed industry experts were the company's BIM team leaders and had 6 to 8 years of construction experience.

The third project was an additional terminal building for an existing airport and had a total construction area of 700,000 sqm. The project's budget was more than 2 Billion U.S. Dollars, and the duration was 60 months. The general contractor was a joint venture. The project utilized BIM only in the construction phase and had a BIM team of 40 people. Bentley, Synchro, and Micro Station were used as BIM software. The interviewed company was the general contractor for the project and had 8 years of BIM experience. The interviewed industry expert was the company's director of engineering & design and had more than 20 years of experience.

The fourth project was also built by the same company as the third project. It had a total construction area of 60,000 sqm and a budget of more than 200 Million Euros. The duration of the project was 24 months. The general contractor was a joint venture and had a BIM team of 15 people. They utilized BIM only in the construction phase and used; Revit, Dynamo, Navisworks, Synchro, Primavera, and Aconex.

Face to face interviews were held with the industry professionals working on the selected case projects. During the interviews, the interviewees were expected to rate the level of significance for listed barriers on a 1-5 Likert scale (1: very low, 5: very high) based on their experiences in that case project. The average values for each of the challenging factors were calculated and compared with the previously counted frequency in the literature. Moreover, interviewees were also asked to share their own experiences during the BIM implementation process for that particular project.

Findings and Discussion

Within the scope of this research study, challenges of BIM implementation for airport projects have been identified via an extensive literature review including 38 research papers. Identified barriers were divided into three groups based on their influence levels to distinguish the responsibilities of the industry, companies, and project teams. The significance of the barriers was evaluated via the interviews that were held with the industry experts working on four different airport projects. The experts also shared their own experiences with the particular project. Table 2 shows the identified factors with a brief description, their frequency in the literature, and the average significance score based on the interviews.

Table 2. Findings for the Barriers to BIM Implementation.

No	Barriers to BIM Implementation	Description	Literature Frequency	Case Study Rating (Avg.)
1	Project specific problems	Delivery method, contract type, unique requirements	25/38	4.25/5.00
2	Fragmented nature of the industry	Number of parties getting involved to the process	11/38	4.25/5.00
3	Collaboration problems among different parties	Low collaboration, lack of coordination	17/38	4.00/5.00
4	Unavailability of knowledge based on experience	Lack of experience, awareness within the company	25/38	3.50/5.00
5	Unclear benefits	Lack of tangible benefits	9/38	3.50/5.00
6	Change process problems	Resistance to change, company culture, fear of failure	31/38	3.25/5.00
7	Lack of best practices	Lack of cases, benchmarks, universal use	21/38	3.25/5.00
8	High costs	Time, HR, software & hardware investment	28/38	2.50/5.00
9	Technology related problems	Licensing, interoperability, reliability	30/38	2.25/5.00
10	Legal & protocol problems	Lack of legal protocols, ownership, responsibilities	24/38	2.00/5.00
11	Lack of government support	Lack of incentives, initiatives	4/38	1.50/5.00

Based on 38 studies that have been reviewed, “unclear benefits” has a very low frequency of 9 out of 38. In contrast, the industry experts evaluated the barrier to have a mid-high level of significance with an average score of 3.5 out of 5. The factor comprises two initial barriers “lack of tangible/measurable benefits” and “BIM deliverables are not clear”. Jin et al. (2017) stated that clearly defined BIM deliverables will enhance the returns from BIM implementation. It is hard to measure the benefits of BIM and people do not know what to expect. Since it is identified as a project level barrier, the project team should clearly identify their expectations from the BIM implementation.

Although high costs are one of the top three mentioned barriers within the literature with a frequency of 28/38, industry professionals evaluated it as 2.25/5. This is an expected finding for airport projects where the project budgets are very high compared to regular construction projects. It should be noted that high costs include “cost of time”, “cost of human resources”, and “cost of software & hardware” as the initially identified barriers. The interviewee from the second case project stated that “there was a specific budget allocated for BIM implementation in that particular project.”

“Collaboration problems among different parties” is one of the most important barriers to BIM implementation in airport projects with a ranking of 4 out of 5 while having a low-mid level literature frequency (17/38). This factor is mostly related to the lack of coordination and collaboration and BIM itself is a catalyst for collaboration. Thus, this barrier can be eliminated with increased coordination among the project parties.

One of the two most important barriers turns out to be project specific problems. It has a literature frequency of 25/38 and consists of four initial barriers; “contract type/delivery method is not suitable”, “unique project requirements make it harder”, “BIM implementation

is not suitable" and "lack of initially integrated models (for construction phase)". Since airport projects are unique, project specific problems are crucial for them. The average ranking of industry experts for this barrier is 4.25 out of 5.

As the one and only firm level barrier, "unavailability of knowledge based on experience" has a mid-high level of frequency (25/38) in the literature which is in parallel with the rating of industry experts (3.50/5). The factor has been generated by merging two initial barriers; "lack of knowledge (awareness) of benefits/rewards" and "lack of experience and skilled personnel". Regarding this particular barrier, interviewee for the second case study project stated that "This was not an important barrier for the core BIM team, however, in an airport project, it was hard to adapt people from too many different disciplines to the BIM process who have no BIM experience." In order to overcome this barrier, companies should hire experienced BIM experts to learn from their experiences and create an awareness within the company.

The "lack of best practices" has been generated by combining four initial barriers; "lack of case study evidence/benchmarking", "lack of universal use", "lack of demand" and "rapidly growing technology/innovations". The frequency among the literature was counted as 21/38 and industry experts rated 3.25/5 on average based on case projects. Arayici et al. (2011) stated that there has been a lack of consistent benchmarking for BIM implementation, and it was critical to review new processes. This barrier will be dismissed by itself as the BIM adoption among the AEC industries increase.

Software compatibility restricts the use of BIM and is required to be solved to maximize the benefits that BIM offers (Stanley & Thurnell, 2014). Based on the literature analysis, "technology related problems" is the second most mentioned barrier with a frequency of 30/38. It has been determined as an industry level barrier and generated by merging five initial challenging factors; "incompatible software", "safety and reliability of the information/cyber security", "user friendliness", "software adoption rates" and "license compliances". On the contrary, industry professionals rated the barrier among the least three important factors with an average ranking of 2.25 out of 5. The interviewee from the third and fourth case projects stated that "technology related problems can be overcome when you are a part of a huge airport project and working with information management experts."

The most frequently mentioned barrier in the literature is the change process problems with a score of 31/38. Change process problems are mostly related to the project people and human nature. It consists of six different initial barriers as "resistance to change", "belief that the current technology is enough", "company culture/business model", "lack of will", "fear of failure" and "training process". Accordingly, it has a relatively high ranking of 3.25/5 for industry experts. Independent of the project type, whether an airport project or a residential building project, people resist changes, and it is hard to interfere with someone's way of doing business.

"Legal and protocol problems" has been identified as an industry level barrier. It has a medium literature frequency, mentioned 24 times out of 38 in the literature. It was determined by merging three initial barriers; "lack of standards/protocols", "legal issues" and "uncertainty of level of responsibility and data ownership". On the other hand, industry experts evaluated the legal and protocol problems as the second least significant with a ranking of 2 out of 5. Incorrect use of BIM models may cause significant and complicated claims due to blurred

responsibility and ownership (Sun et al., 2017). Developing industry wise protocols for the BIM implementation process could eliminate this barrier.

Although the fragmented nature of the industry has the least frequency within the literature (11/38), industry experts evaluated it as one of the two most significant barriers (4.25/5). This was an expected finding because of the multidisciplinary nature of the airport projects. Keskin et al. (2021) stated that "airport projects encompass a higher variety of stakeholder work processes that require more strategic efforts in diffusing BIM in comparison to regular building projects". Similarly, the interviewee working for the first case project stated that "in airport projects, there is a different designer and consultant for each special part such as runway construction or apron lighting." Findings show that more research is needed regarding the fragmented nature of the industry for the airport projects.

Lack of government support is the least mentioned barrier within the literature and also ranked as the least significant barrier by the industry experts. This finding was also expected since airport projects are generally public projects and there is continuous support for BIM implementation. BIM usage for airport projects is even stated as a clause in the contracts. However, interviewees also argued that offering incentives such as tax reduction, etc. may boost the BIM adoption rate in the construction markets.

Conclusion

Airports are large scale infrastructure projects that require the adoption of the most recent innovations regarding digital construction. BIM is the most adopted tool which will become an industry standard in the near future. However, certain barriers hinder the BIM implementation process and cause companies to spend massive amounts of effort and money. This study revealed the challenging factors based on an extensive literature review and showed their perceived significance based on experiences from four different airport projects. In addition, the responsibilities of the industry, firms, and project teams are distinguished to eliminate the barriers.

At the project level, project specific problems can be eliminated during the contract phase by choosing the most suitable delivery type. In addition, collaboration and coordination are the keys to eliminate the other project level barriers and this can be assured via strong communication among project parties. At the industry level, when the fragmented nature of the airport construction industry is considered, it is recommended to increase BIM awareness with industry-wise events. Last but not the least, the only firm level barrier is identified as the unavailability of knowledge based on experience and this can be achieved by hiring experienced staff or external consultancy.

Interview responses showed that the fragmented nature of the industry, project specific problems, and collaboration problems among different parties are crucial barriers to BIM implementation in airport projects. All the top-rated barriers are common characteristics of problems faced in mega construction projects. Hence, it is clear that the BIM implementation process for mega projects is tough and the identified challenging factors need to be eliminated to fully enjoy the benefits of BIM.

This study shed a light on the BIM implementation process in airport projects that have different sizes and locations. Based on the comparison of results for the case projects, it is

observed that the crucial barriers to the BIM implementation are the same regardless of the size and location of a project.

Consequently, the findings of this study will guide the companies willing to implement BIM for airport construction. However, the number of cases within the scope of this study was limited and there are certainly other factors to be considered. Further studies might analyze the identified factors on different types of projects and make comparisons.

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Potential Contributions of the Blockhain Technology to the Construction Industry and its Stakeholders

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Abstract

Blockchain technology (BT) has started to be used in many areas, industries, and geographies. It is relatively not widely used nor researched in the construction industry. Based on the literature review, this paper aims to examine potential contribution(s) of the BT to the construction industry and to its stakeholders. Furthermore, within the scope of this paper, the potential benefits and contributions of the use of the BT in other industries will be examined to enable construction industry professionals and managers to consider how to and why to use the BT benchmarking from other industries. All stakeholders of the construction industry, supply chain and construction project management are expected to get benefit from this paper.

Keywords: *blockchain, construction industry, construction project management, stakeholders.*

Introduction

The construction industry (CI) is known to face many difficulties, such as low productivity. One of the challenges preventing the modernization of CI is its inability to embrace digital developments compared to the successes in some other sectors (logistics, automotive and mechanical engineering, etc.) (Cardeira, 2015). Use of innovative technologies by construction stakeholders can increase process efficiency, support synergetic effect, and development of the entire industry through network interaction between stakeholders and the use of digital platforms/payment systems (Ablyazov & Petrov, 2019).

Blockchain technology (BT), which was initially conceptualized by Nakamoto (2008) as an electronic payment system, became famous with the cryptocurrency bitcoin (Beck & Muller-Bloch, 2017). The first venture capital (Willett, 2012) turned into a development and funding instrument for entrepreneurs, thanks to Buterin (2013)'s Ethereum initiative and smart contracts considering its possible contributions to the solution to many problems encountered in CI with autonomous, decentralized and distributed database applications. For this reason, in-depth research should be carried out on where the BT can be used in the construction

project life cycle, its adaptation and its effects. This paper examines potential contribution(s) of the BT to CI and to its stakeholders.

Blockchain Technology and Applications

Blockchain (BC) refers to the decentralized system technology that allows transfers of digital values without relying on trust and conducts transactions with transparent records in distributed databases (Nakamoto, 2008). In Mattila (2016)'s study, which deals with blockchains in three layers: application, protocol and network communication, value-oriented transactions. In some researches, blockchains are handled at 3 levels, namely: cryptocurrencies (i.e., Bitcoin, Ethereum, Ripple etc.), smart contracts and industrial applications (Hoy, 2017). Dresher (2017) mentioned the application areas for blockchain value transfer as cryptocurrencies, digital assets, payment rails, digital identity, compliance, micropayments, and notary services.

Networks used in the network communication layer of blockchains are considered in 3 types (Nanayakkara et al., 2019);

1. public networks with limited personal data (e.g., Bitcoin, Ethereum), where participants are open to unauthorized participation and data access (Lewis et al., 2017);
2. private networks, where participation is permission-based and enterprise-level secure applications and authorized participants can be included (Martinovic et al., 2017);
3. consortium networks, which does not have a single owner, and which are suitable for the development of partial private blockchain solutions at the enterprise level (Nanayakkara et al., 2019).

Blockchains, which were initially a platform where crypto financial products were developed, have become a tool that develops different solutions in many industries, especially with smart contracts (Cardeira, 2015). Smart contracts are defined by Gronbaek (2016) as "computer protocols in which contract terms are converted into computer codes running on a network". Rudolf (2017), on the other hand, defined smart contracts as a set of self-executing contracts or rules in a distributed, decentralized blockchain network on which the terms of the agreement among the parties are transformed into the codes. Many of the modern or new generation blockchain networks support smart contract and enable development of decentralized applications (DApps) on blockchain networks with the help of these contracts (Nanayakkara et al., 2019). There are studies on some potential application areas in the literature such as digital rights (Ma et al., 2018), increasing flexibility in supply chain management (SCM) (Min, 2018) and fraud prevention (Khan, 2015). Nanayakkara et al. (2019) stated that smart contracts provide many positive effects such as effectiveness, integrity, accuracy, uniformity.

Blockchain in Construction Industry

Thanks to smart contracts, the way of doing business in the financial sector is changing and it is considered to have a potential impact on many sectors, including CI. (San et al., 2019). The studies of some researchers on the possible impacts of BT on construction business processes were reviewed by Yang et al. (2020). These studies are reviewed under the titles of blockchain-enabled contract management (Wang et al., 2017) also SCM (Luo et al., 2019),

autonomous payment systems (Shojaei, 2019) and construction information management (Liu et al., 2019).

Considering construction project's lifecycle, construction project stakeholders make temporary cooperation for project delivery processes, but this causes complexity in the project supply and management processes data, trust issues among stakeholders, and conflicts (Lamb, 2018). According to Hijazi et al. (2019), a digital twin of the physical building can be created with BIM model to eliminate these problems through integration of blockchain-based decentralized data management systems. Thus, all data can be stored in this model and transparent property/facility management can be achieved (Hijazi et al., 2019). In the literature, there are studies on blockchain integration into BIM-based applications. These are the studies on the applicability of the ethereum protocol (Salmon, 2017) and blockchains in BIM management in BIM transactions (Turk & Klinc, 2017), real estate investments (Trofimov et al., 2016). There are also studies such as the one of Barnett (2016), which focuses on many topics, on blockchains for BIM, property rights management, dispute resolution and its applicability in smart city models. On the other hand, studies on use of BT in CI focus on research areas such as payment/prepayment systems (Yang et al., 2020), funding management (San et al., 2019), and facility management (Shojaei, 2019).

Blockchain for Construction Stakeholders

Researches in the literature concentrated on the final product, production process, management model and stakeholders in the CI (e.g., Nanayakkara et al., 2019). In addition, the adaptation of blockchain to construction processes is investigated in research areas such as supply chain and/or project management processes/models/approaches/systems (e.g., Yang et al., 2020).

Complex and dynamic features of the CI may adversely affect supply chain stakeholders such as contractors, subcontractors, suppliers and customers in CI projects (Nanayakkara et al., 2019). Danuri et al. (2015) stated that the negativities arising from payment inefficiencies in the supply chain; is the most fundamental of the disagreements between the stakeholders. In the design of construction contracts, while determining the terms of payment, additional payment, prepayment and partial payment, non-payments and delayed payments are ignored and the resulting disputes can affect financing, reduce efficiency and delay project deliveries (Danuri et al. 2015). For this reason, the effects of blockchain applications should not be ignored to regulate the relations between stakeholders in the SCM and to eliminate the negativities (Danuri et al. 2015). On the other hand, according to Gouin (2018), even in the most basic construction project management model, at least 5 different contracts must be prepared and executed among project developer, project manager, contractor, architect, engineer and other stakeholders (Gouin, 2018). Furthermore, many aggreements or contracts are executed in procurement and delivery processes, relationships between supply chain stakeholders, vendors and/or suppliers and procurement teams (Yang et al., 2020) and logistics (Lanko et al., 2018), contractor subcontractor relations. Also many contracts are used in relations between investors and crowdfunding stakeholders, possible maintenance processes in project life cycle (Giuda et al., 2020), inter-stakeholder relations from design to ending of project life cycle.

How to Use and Applications Areas

In studies dealing with blockchain applications in the CI, their applicability is mainly investigated (i.e., Nanayakkara et al., 2019). These studies focus on how blockchain tools can be used to regulate stakeholder relations (i.e., Yang et al., 2020). San et al. (2019) discussed potentials in construction contracts (Design, Bid, Construction, Life cycle [Giuda et al., 2020]), electronic document management (EDM), BIM, property management, SCM, and funding management. Besides the official stakeholders of the projects, if each participant who may have an impact on/contribution to or relationship with the project is considered as a stakeholder, each of them will be a contracting or agreement party with the help of smart contracts (San et al., 2019). Therefore, smart contract applications in all management areas will be the most important field of study (San et al., 2019). With the help of these autonomous contracts embedded in digital codes, relations and workflows between stakeholders such as investor/investors, project developer and manager, design planning/management and implementation teams, contractor/subcontractors and suppliers, consultants and auditors able to have opportunities for cooperating on a fair, decentralised autonomous platform (Yang et al., 2020). The smart contracts on which the duties, responsibilities and interactions of each of these stakeholders/team are determined taking into account many possible scenarios (Gouin, 2018).

Blockchain-based platforms are handled in 3 different groups (Nanayakkara et al., 2019). Among these platforms, platforms that can support smart contracts and enable the DApps are important in solutions (Nanayakkara et. al., 2019) to be developed for the CI. In determining the platforms and tools to be used for these purposes, it is important to specify which problem of CI is aimed to be solved (Cardeira, 2015). Ethereum protocols (ERC20, ERC75) or public or consortium platforms such as EOS.IO or consortium platforms such as R3 Corda may be beneficial for solutions to be developed in venture capital and funding (Nanayakkara et al., 2019). On the other hand, private platforms such as Hyperledger Fabric may be useful for information management/sharing in SC issues such as inter-stakeholder payment / prepayment (Abrishami and Elghaish, 2019).

Why to Use BT and Its Potential Benefits/Contributions

According to Gouin (2018), blockchain-based solutions have the potential to contribute to the execution of financial transactions and processes in the CI, invoicing and fast payments, and implementation of contract rules and agreements. In this context, especially in terms of transparency and trust, time and cost efficiency, data/information security and international investability, suggestions, which are mostly at the conceptual level, need to be developed with field applications (San et al., 2019).

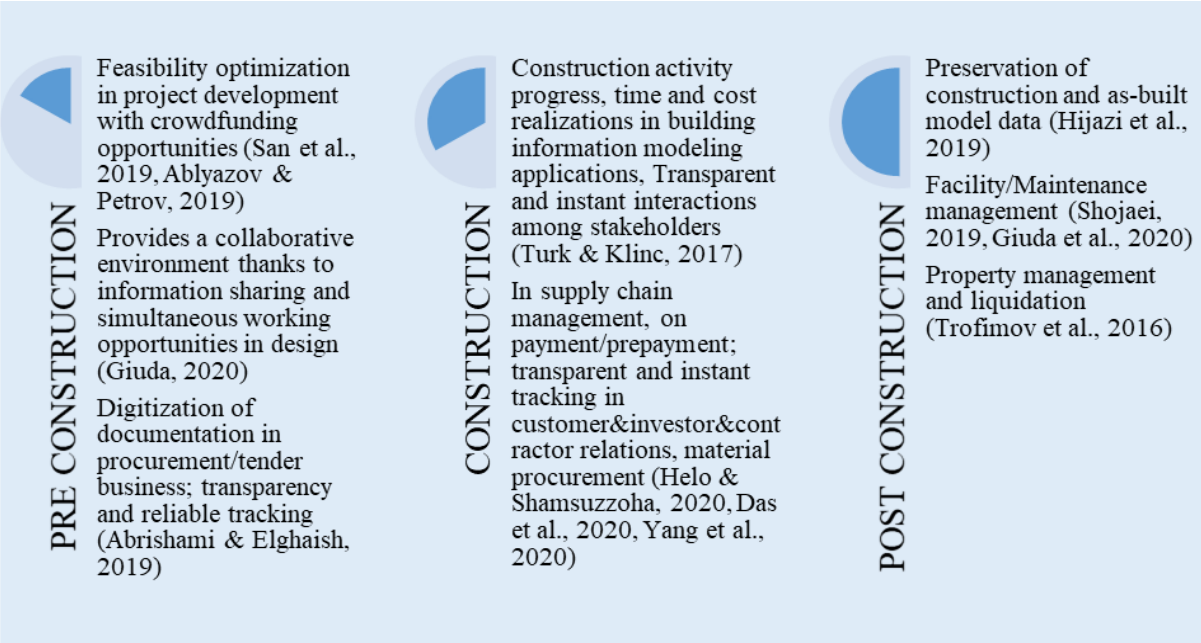


Figure 1: Potential contribution of BC to construction processes.

Nanayakkara et al. (2019) examined perceptions of stakeholders on blockchain adoption to the CI. As a result of their research, the most charming factors for the execution of blockchain in the CI were determined as efficiency, trust, fairness, security and transparency, respectively (Nanayakkara et al., 2019).

In studies (e.g., San et al., 2019; Turk and Klinc, 2017; Hijazi et al., 2019) on the adaptation of blockchains to the CI, it is emphasized by researchers and project stakeholders that this adaptation has important opportunities. For this reason, this issue should be investigated and discussed in depth.

Discussion

BT is applied to CI with limited tools, even though BT can offer opportunities in resolving financial, legal and governance issues to avoid wasted time and money, and quality depreciation/defects Yang et al. (2020). Benefits of this new technology can provide to the construction project life cycle and its stakeholders need to be explored.

The unique nature of construction projects and project-based collaborations of construction project stakeholders; causes confusion, trust problems and conflicts in the construction project life cycle and project delivery processes (Lamb, 2018). In this context, especially in the construction supply chain, the complexity encountered in data management will be solved by securing data on decentralized platforms with blockchain-based BIM applications, and the processes will be carried out transparently (Hijazi et al, 2019). In addition, it is necessary to focus on different solutions for agreements and contracts executed at every stage from design to the end of the project life cycle. San et al. (2019) discussed potentials of BT in construction contracts (Design, Bid, Construction, Life cycle [Giuda et al., 2020]), EDM, BIM, property management, SCM, and funding management. Besides these; Subject-specific researches focuses on; relationships between supply chain stakeholders, vendors and/or suppliers and procurement teams (Yang et al., 2020), contractor-subcontractor relations; investors-

crowdfunding stakeholder relations; maintenance processes (Giuda et al., 2020). Smart contract solutions can be developed for construction project life cycle phases, in which the project/supply chain stakeholders participate.

The negativities experienced in the interactions between the stakeholders in the CI can affect the quality of the product and process, and as a result, cause inadequacies in meeting customer expectations. On the other hand, according to stakeholders, through use of blockchain and smart contract in CI; positive results can be obtained in factors such as efficiency, trust, fairness, security and transparency (Nanayakkara et al., 2019).

As adaptation of BT to the CI has important tools/components that can contribute to the effective and efficient execution of digital platforms/applications/systems and to reduce disputes/conflicts, how and with what applications this adaptation can take place, as well as the potential benefits/contributions it may provide need to be studied. Within the scope of this study, at which stages in the construction project life cycle, blockchains can be used and the contributions they can provide in terms of processes and stakeholders at these stages were determined (Figure 2).

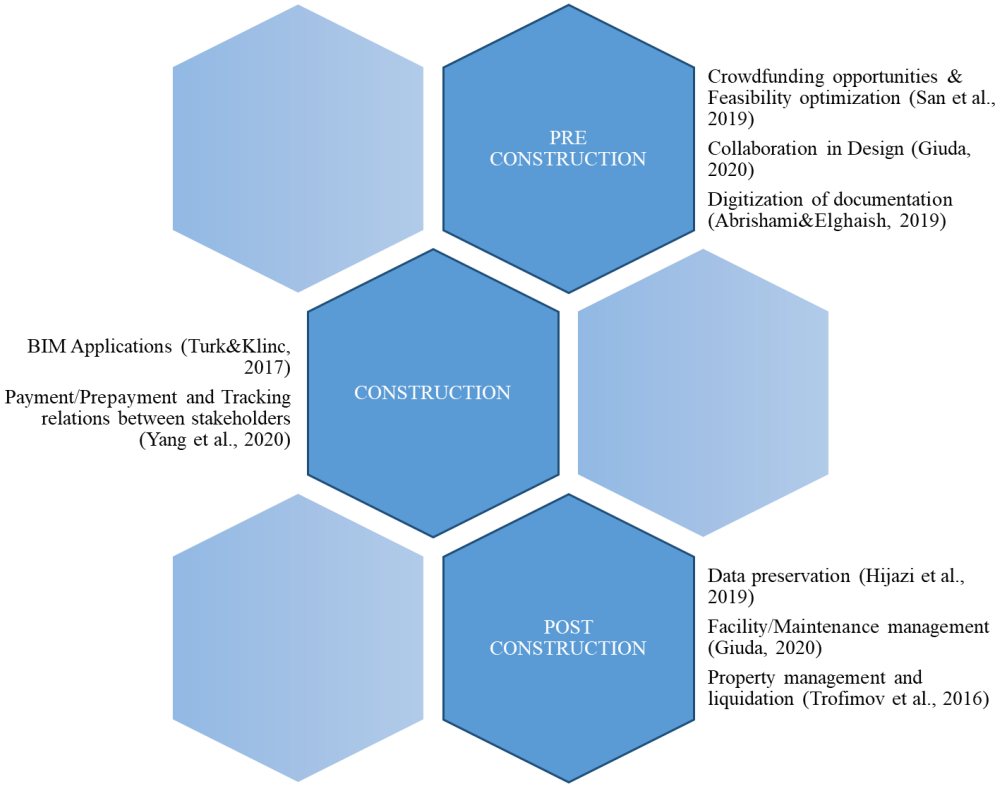


Figure 2: Contribution areas of BC in Construction processes.

The contributions of BT adaptation to the construction project life cycle, specified as follows;

- in the pre-construction phase; funding benefits, collaboration in design and digitization in documentation;
- in the construction stage; time/cost optimization and instant/traceable interactions between stakeholders with blockchain-based BIM applications;

- in the post-construction phase; data preservation of projects, property management and liquidation

Conclusion

The project and supply chain relations of the construction industry, which is negatively affected due to its project-based nature, complex and dynamic features; can be regulated by blockchain platforms, tools, system components and algorithms (Nanayakkara et al., 2019). In this context, Based on literature review, this study investigated properties of blockchain, its possible implementation areas, its effects/contributions to construction project management and supply chain stakeholders, how and why it should be adapted to the CI.

As a result of the study, it was seen that there are researches on blockchain solutions for different issues at different stages in the construction project life cycle (Figure 2). When these studies are examined, it is understood that there are different concentration areas from funding problems to collaboration in design, from Bim applications to payment/prepayment issues, from data security to asset management. The studies on the applicability and adaptation of BT in CI are largely based on literature research or conceptual models. Since real case applications are very limited, more applications and in-depth studies are needed.

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Smart Megaprojects' Requirements Affecting Construction Project Management

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Abstract

Smart megaprojects are constructed and accomplished increasingly affecting all construction project management processes. This paper examines the concepts of megaprojects and smart megaprojects, need for and drivers for smart mega projects. Based on literature review, the objective of this study is identification of smart megaprojects affecting construction project management. This paper underlines and examines different aspects of megaproject and smart megaprojects with respect to the construction project management. This research is expected to be beneficial to the Architecture-Engineering-Construction industry professionals and academics especially with respect to smart megaprojects' and their construction project management.

Keywords: *construction project management, megaprojects, smart city, smart megaproject*.

Introduction

In accordance with a report released by PwC (PricewaterhouseCoopers) in 2018, the market for smart cities worldwide is anticipated to increase by roughly 16% yearly (Kim, 2022). The Architecture-Engineering-Construction industry plays a significant role in establishment of new smart cities and development of existing smart cities by providing input to infrastructure and superstructure development (e.g., roads, skyscrapers) for the smart cities (Brad, 2020). Sarkheyli and Sarkheyli (2019) also mention that many projects such as infrastructure, commercial buildings, city centres, transportation structures are required for smart cities. Based on this, each of these infrastructure or superstructure projects can be considered as megaprojects by the definition of megaprojects. Considering the needs of megaprojects developed for smart cities such as data collection and transfer, real-time data, communication and information management, these projects can be defined as smart megaprojects. (Sarkheyli & Sarkheyli, 2019). This research aims to determine smart megaprojects' requirements affecting construction project management.

Megaprojects

There are several definitions about the concept of megaprojects. Megaprojects are large scaled, and complex, have high-budget (minimum of $1 billion), take long-term with multiple stakeholders, and are transformational (Flyvbjerg, 2014). Jia et al. (2022), similarly, consider megaprojects on the basis of their multi-stakeholder nature, high political sensitivity, long-term duration, technical challenges, important external influences, complex design and high stability requirement. Zhai et al. (2009), on the other hand, discuss megaprojects emphasising their complexity and challenging nature, long-duration, impact on the community, technology, region and even on the entire country (Zhai et al., 2009). In the literature, different authors have approached the definition of megaprojects from different angles.

Due to the complex nature of megaprojects, the activities related to the management are more challenging and difficult compared to small scale projects (Jia et al., 2022). He et al. (2021) emphasise that megaprojects have a reputation for disappointing performance in their management. Most megaprojects are over-budget due to lack of realism in initial cost estimates, ignoring changes in currency exchange rates, price changes and expropriation costs (Marrewijk et al., 2008). Average cost overrun rate of highway projects varies between 20% and 96% depending on the type of project such as bridge, tunnel, railway and dam (He et al., 2021). On the other hand, delays in the schedule are a separate issue for megaprojects, causing both cost overruns and benefit shortfalls (Marrewijk et al., 2008, as cited in Flyvbjerg, 2017). Reasons behind delays include uncertainities, poor consideration of project specifications and designs, security and environmental requests (Marrewijk et al., 2008, as cited in Flyvbjerg, 2017). Kipp et al. (2008) also argue that technological challenge is accepted as an important issue in megaprojects. For instance, Taib et al. (2014) note that ICT (Information and Communication Technology) contractors in megaprojects can face the problem of the inability for ICT work to be delivered as part of construction project in a systematic, efficient and effective manner. Therefore, analyzing megaprojects according to their characteristics, establishing project management systems in accordance with these characteristics and encouraging these management systems aim to increase the success of the project (He et al., 2021).

Smart Megaprojects

The variety of initiatives such as roads, highways, intersections, airports and other transportation systems, skyscrapers, multi-purpose complexes, shopping malls, renewal of city centers are required for the development of smart cities (Sarkheyli & Sarkheyli, 2019). These projects can be considered as megaprojects by definition due to time and budget consumed (Zhai et al., 2009; Flyvbjerg, 2014; Jia et al., 2022). Based on this definition, it can be considered that it is required to comprehend relationship among megaprojects and smart cities to understand smart megaprojects.

Sarkheyli and Sarkheyli (2019) define megaprojects as urban catalysts that can increase sustainable development and ultimately enable smart city visions to be realized. Although megaprojects constitute this input for smart cities, it is deficient because smart city construction is a complex infrastructure development initiative where various stakeholders of the smart city offer integrated city services with advanced technology. (Kwak & Lee, 2021). Considering the data, information and technologies underlying smart cities, smart mega-projects can be suggested as a means of achieving the goals of smart cities (Sarkheyli & Sarkheyli, 2019). Kwak and Lee (2021) referring to the incorporation of ICT with a building

and becoming a smart building, claim that smart megaprojects can be formed with the inclusion of ICT.

Smart megaprojects are essential for smart cities. It is proposed as mediators of smart cities to achieve their objectives (Sarkheyli & Sarkheyli, 2019) such as providing energy efficiency and carbon reduction, providing high quality of life for citizens, developing green areas and accessible infrastructure in the city, ensuring social equality among citizens and economic growth (Ojo et al., 2015). Apanaviciene et al. (2020) emphasize that smart buildings not only improve the concept of smart city but also urban development, national economy, use of resources and quality of life of citizens. Serteser et al. (2020) also mention that smart structures are the components of smart city which aims to minimize pollution and waste, improve user comfort and safety, save energy and improve air quality. Based on the statements of Ojo et al. (2015), Apanaviciene et al. (2020) and Serteser et al. (2020) it can be considered that smart megaprojects are an important need for smart cities, recognizing that smart mega-projects are smart building and smart construction on a larger scale.

Research Method

This study aims to identify smart megaprojects requirements affecting construction project management. An extensive evaluation of the literature on the subject of this study was conducted using the Science Direct and Google Scholar databases for researches published between 2010 and 2022. Megaprojects, smart city projects, smart construction projects, sustainable construction projects and urban projects have been chosen as keywords, considering that they have similarities with smart megaprojects. The requirements of smart megaprojects and their effects on construction project management were determined by using the selected keywords.

Results

Tables 1, 2, 3, 4 and 5 show requirements of megaprojects, urban projects, smart city projects, smart construction projects and sustainable projects that can affect construction project management. The description of the requirements found in the literature are provided in the middle columns of Tables 1, 2, 3, 4, and 5, and the requirements are classified according to their description in the left columns. The right columns of Tables 1, 2, 3, 4 and 5 provide the relationship among the project knowledge areas in PMBOK (Project Management Institute, 2017) and the requirements identified in the literature.

The requirements of megaprojects are presented in Table 1. These requirements are classified in the literature as: resources (Aiyetan & Das, 2022); internal and external stakeholders (Aiyetan & Das, 2022; Damayanti et al., 2021; Flyvbjerg, 2014); technology and expertise (He et al., 2021; Locatelli et al., 2017; Aiyetan & Das, 2022); planning (Flyvbjerg, 2014); government (Ahmadabadi & Heravi, 2019); rules and regulations (Flyvbjerg, 2014; Mišić & Radujković, 2015). Aiyetan and Das (2022) focused on the necessity of a certain number of resources such as people, money, equipment and machinery, time and materials for a very long time for megaprojects. This affects planning, estimating, acquiring and controlling resources (Aiyetan & Das, 2022). External and internal stakeholders can affect megaprojects (Aiyetan & Das, 2022; Damayanti et al., 2021; Flyvbjerg, 2014). Aiyetan and Das (2022) mention that it is very important for all stakeholders of a megaproject to pursue synchronized

project goals and objectives. Moreover, an effective communication, transparency between stakeholders, strong cooperation and coordination can directly affect project success (Damayanti et al., 2022; Aiyetan & Das, 2022). On the other hand, lack of cooperation between stakeholders having different interests can result in complexity (Kardes et al., 2013).

New technologies and operation improvements can affect monitoring and controlling the project work (He et al., 2021). Locatelli et al. (2017) also mention that there is a relationship between technological characteristics of megaprojects, and delay and cost overruns. On the other hand, sufficient and competent workforce, technical personnel, equipment and machinery can also affect megaproject through the application of new technologies (Aiyetan & Das, 2022). Ahmadabadi and Heravi (2019) have emphasized government intervention and government commitment is important for megaprojects. Moreover, Flyvbjerg (2014) and Mišić and Radujković (2015) state awareness of and compliance with rules and regulation affect project success.

Table 1. Megaprojects' requirements affecting construction project management.

Requirements	Description of Requirements	PMI (2017)'s Relevant Knowledge Areas
Resource	Needs huge quantities of resource for a long period of time (Aiyetan & Das, 2022)	Resource Management
External/ Internal Stakeholders	Stakeholder engagement (Aiyetan & Das, 2022)	Stakeholder Management
	Communication (Aiyetan & Das, 2022), cooperation and coordination (Damayanti et al., 2021) Effective partnering among project participants (Flyvbjerg, 2014)	Stakeholder Management
Technology & Expertise	New technologies and operation improvements (He et al., 2021; Locatelli et al., 2017)	Integration Management
	Sufficient and competent workforce, technical personnel, equipment and machinery (Aiyetan & Das, 2022)	Resource Management
Planning	Pre-project planning (Flyvbjerg, 2014)	Project Integration Management
Government, rules & regulations	Awareness of and compliance with rules and regulation (Flyvbjerg, 2014; Mišić & Radujković, 2015)	Scope Management
	Government intervention in operation (Ahmadabadi & Heravi, 2019)	Integration Management/ Cost Management
	Government commitment (Ahmadabadi & Heravi, 2019)	

Table 2 presents the requirements of urban projects affecting construction project management processes found in the literature. They are stakeholders, technology & expertise, organizational structure, government, rules and regulations (Curran & Spillane, 2016; Curran et al., 2018; Kroh, 2021; Yu & Kwon, 2011; Zhang et al., 2011). Identifying and early involvement of key stakeholders from the very beginning of the process is important for project success (Kroh, 2021). Besides, stakeholder engagement, stakeholders' cooperation and communication is another requirement of urban projects (Curran & Spillane, 2016; Curran et

al., 2018; Kroh, 2021; Yu & Kwon, 2011) On the other hand, it is necessary to establish an appropriate organizational structure as different key players are required at each stage throughout the project life cycle (Yu & Kwon, 2011). Besides, Zhang et al. (2011) argued that the competence and experience of customers is another requirement affecting the design. Moreover, appropriate organizational structure (Yu & Kwon, 2011) and team composition (Kroh, 2021) can contribute to the project integration management, creating organizational chart in the project charter. Government commitment is also required for urban projects (Kroh, 2021).

Table 2. Urban projects' requirements affecting construction project management.

Requirements	Description of Requirements	PMI (2017)'s Relevant Knowledge Areas
Stakeholders	Stakeholder engagement (Curran & Spillane, 2016; Curran et al., 2018)	Stakeholder Management
	Early involvement of stakeholders (Kroh, 2021)	Stakeholder Management
	Stakeholders' cooperation and communication (Yu & Kwon, 2011)	Stakeholder Management
Technology & Expertise	Client's qualification (Zhang et al., 2021)	Integration Management
	Qualification of project team (Kroh, 2021)	Stakeholder Management
Organizational Structure	Appropriate organizational structure (Yu & Kwon, 2011)	Integration Management
	Team composition (Kroh, 2021)	Integration Management
Government, rules & regulations	Government commitment (Kroh, 2021)	Stakeholder Management

Table 3 shows requirements of smart city projects affecting construction project management. Alshahadeh and Marsap (2018) state that ICT system knowledge and the privacy and security of the system are technology-related requirements that affect the project management of smart city projects. Furthermore, project stakeholders are another requirement (Alshahadeh & Marsap, 2018; Woods et al., 2016; Kogan & Lee, 2014; Ojo et al., 2014). Monitoring the behavior and movements of citizens in smart cities (Woods et al., 2016; Kogan & Lee, 2014; Ojo et al., 2014), enabling citizens to make decisions on city-related issues, and producing real solutions for citizens' needs can affect design management (Woods et al., 2016; Kogan & Lee, 2014; Ojo et al., 2014; Cardullo & Kitchin, 2019). Developing a common perspective from the aims, opportunities and challenges facing all stakeholders involved in the smart city project may be essential (Woods et al., 2016).

The importance of financing for smart city projects was emphasized by Pétercsák et al. (2016) and Jayasena et al. (2019). He et al. (2021) support this by proposing partnership of a strong local government as key stakeholder and a private partner with expertise in technology and finance. Moreover, Pétercsák et al. (2016) indicate that proposing creative financial instruments that can support the effective and timely implementation of projects is another

requirement. Jayasena et al. (2019) also mention that government support and funds are crucial for the development of smart city projects.

Table 3. Smart city projects' requirements affecting construction project management.

Requirements	Description of Requirements	PMI (2017)'s Relevant Knowledge Areas
Technology & Expertise	ICT system knowledge (Alshahadeh & Marsap, 2018)	Integration Management
	Security and privacy (Alshahadeh & Marsap, 2018)	Stakeholder Management
Stakeholders	Citizens' behaviors and movements in the city (Woods et al., 2016; Kogan & Lee, 2014; Ojo et al., 2014)	Integration Management
	Citizens' decisions about city (Woods et al., 2016; Kogan & Lee, 2014; Ojo et al., 2014; Cardullo & Kitchin, 2019)	
	Citizen needs (Pétercsák et al., 2016)	Scope Management
	Common aim and objectives (Alshahadeh & Marsap, 2018).	Scope Management
	Collaboration between private and public industry (Alshahadeh & Marsap, 2018).	Stakeholder Management
	Partnership local government and a private partner (He et al., 2021)	
	Early involvement of project team (Olawumi & Chan, 2020)	Integration Management
Financing	Creative financial instruments (Pétercsák et al., 2016)	Cost Management
	Partnership with funding from subsidies (Jayasena et al., 2019)	Cost Management
Government, rules & regulations	Support from municipalities (Jayasena et al., 2019)	Cost Management

Table 4 demonstrates requirements of smart construction projects affecting the construction project management. Technology and expertise, stakeholders, financing, government, rules and regulations are requirements found in the literature for smart construction projects (Carlander & Thollander, 2022; Opoku et al., 2022; Reddy & Kone, 2019; Gbadamosi et al., 2019; Olawumi & Chan, 2020). Stakeholders' cooperation (Carlander & Thollander, 2022) and stakeholders' commitment (Opoku et al., 2022) can be crucial for stakeholder management. It can provide information and knowledge sharing between teams (Olawumi & Chan, 2020). Besides, early involvement of stakeholders in the project can affect project management success (Carlander & Thollander, 2022). Moreover, stakeholders' clear targets and client's willingness and requirements are important (Carlander & Thollander, 2022; Opoku et al., 2022).

In terms of technology and expertise, implementation of IoT (Internet of Things) tools and sensors can be quite critical (Reddy & Kone, 2019; Gbadamosi et al., 2019; Olawumi &

Chan, 2020). Technology and expertise can help at increasing work productivity, allocating resources, providing a safety working environment in the site, improving the site supervision, tracking the materials, reducing and controlling project cost, operation and maintenance cost (Reddy & Kone, 2019). On the other hand, Gbadamosi et al. (2019) highlight data ownership, security of data and privacy of users as requirements that should be considered during the management of smart construction projects. Moreover, service availability and power consumption requirements are other requirements that can effect project management of smart construction projects (Gbadamosi et al., 2019).

Table 4. Smart construction projects' requirements on construction project management.

Requirements	Description of Requirements	PMI (2017)'s Relevant Knowledge Areas
Stakeholders	Stakeholders' cooperation and cross functional teams (Carlander & Thollander, 2022)	Stakeholder Management
	Early involvement in the project (Carlander & Thollander, 2022)	Integration Management
	Clear targets of stakeholders (Carlander & Thollander, 2022)	Scope Management
	Stakeholders' commitment, demand (Opoku et al., 2022)	Stakeholder Management
	Client's willingness, requirements (Opoku et al., 2022)	Scope Management
Technology & Expertise	Implementation of IoT tools and sensors (Reddy & Kone, 2019).	Integration Management
	Privacy and security (Gbadamosi et al., 2019)	Stakeholder Management
	Service availability, connectivity, power consumption requirements (Gbadamosi et al., 2019)	Integration Management
	Data ownership (Gbadamosi et al., 2019)	Stakeholder Management
	Technical competence of staff (Olawumi & Chan, 2020)	Stakeholder Management/ Integration Management
	Information & knowledge sharing (Olawumi & Chan, 2020)	Stakeholder Management/
Organizational Structure	Supportive organizational culture and effective leadership (Olawumi & Chan, 2020)	Stakeholder Management/

Table 5 shows requirements of sustainable construction projects affecting the construction project management. As in other project types, stakeholder is also a crucial requirement for sustainable construction projects (Lia et al., 2019; Sang & Yao, 2019; Opoku et al., 2022). Firstly, owner's commitment about sustainability is crucial for the implementation of sustainable construction projects (Opoku et al., 2022). Moreover, effective communication and cooperation between various participants improve the success in sustainable construction projects (Lia et al., 2019). Furthermore, Lia et al. (2019) argue that owner's active involvement in the project can encourage cooperation among the project stakeholders.

Moreover, definition of clear goal and objectives for stakeholders can help to reduce the chance of design changes or change orders (Lia et al., 2019; Sang & Yao, 2019).

Adoption of technology is required for project management of sustainable construction projects (Olawumi & Chan, 2022). Olawumi and Chan (2020) highlight implementation of BIM in project management process can contribute to design analysis, evaluation of energy performance, carbon emissions, daylight analysis, sustainable material selection in the design phase. On the other hand, Lia et al. (2019) mention sustainability implementation plan as a requirement which helps to reduce risks and provides smoother implementation plan.

Table 5. Sustainable construction projects' requirements affecting construction project management.

Requirements	Description of Requirements	PMI (2017)'s Relevant Knowledge Areas
Stakeholder	Clarity in requirements and measures for achieving (Olawumi & Chan, 2020)	Scope Management
	Communication and cooperation between stakeholders (Lia et al., 2019)	Stakeholder management
	Clear goals and well-defined goals by stakeholders (Lia et al., 2019; Sang & Yao, 2019)	Stakeholder management / Design management
	Owner's involvement (Lia et al., 2019)	Stakeholder management
	Owner's commitment about sustainability (Opoku et al., 2022)	Stakeholder management
Planning	Effective project planning and control (Lia et al., 2019)	Integration management/
Technology& Expertise	BIM integration (Olawumi & Chan, 2020)	Integration management/

Discussion

Smart megaprojects are megaprojects and urban projects in terms of scale, budget, time, complexity (Flyvbjerg, 2014; Jia et al., 2022). The characteristics of megaprojects and urban projects can be considered also for smart megaprojects. On the other hand, the smartness and green requirements of smart megaproject also reveal the need to evaluate these projects from a different perspective. Therefore, within the scope of this research, besides megaproject and urban projects; smart city projects, smart construction projects and sustainable construction projects were also evaluated. Figure 1 shows the relationship of smart megaproject with these project types. Besides, it also demonstrates these projects' requirements affecting construction project management.

Technology is one of the most critical requirements, as smart megaprojects involve the integration of smart city technologies, both smart buildings and smart construction projects (He et al., 2021; Locatelli et al., 2017; Aiyetan & Das, 2022; Zhang et al., 2021; Kroh, 2021; Alshahadeh & Marsap, 2018; Reddy & Kone, 2019; Gbadamosi et al., 2019; Olawumi &

Chan, 2020). Smart megaprojects aim to collect data from environment, city through various services and systems and use this data in the construction management process (Sarkheyli & Sarkheyli, 2019). According to Reddy and Kone (2019) and Alshahadeh and Marsap (2018) IoT tools and sensors will directly affect the project management of smart city projects and smart construction projects. Based on these findings, technology and expertise can have an impact on the project management of smart megaprojects. Technology requirement of smart megaprojects can affect integration management and stakeholder management of their construction project management (He et al., 2021; Locatelli et al., 2017; Aiyetan & Das, 2022; Zhang et al., 2021; Kroh, 2021; Alshahadeh & Marsap, 2018; Reddy & Kone, 2019; Gbadamosi et al., 2019; Olawumi & Chan, 2020). Gbadamosi et al. (2019) also argue that technology contributes to design decision making, monitoring and controlling activities, improving the work schedule, thus helping to increase project performance by improving resource management and schedule management. Moreover, use of technology and data require data ownership, privacy and security (Gbadamosi et al., 2019). Therefore, data and information security is crucial to achieving smart management's optimum results. (Sarkheyli & Sarkheyli, 2019). On the other hand, the installation of these systems can create the need for a competent and experienced workforce (Olawumi & Chan, 2020; Aiyetan & Das, 2022).

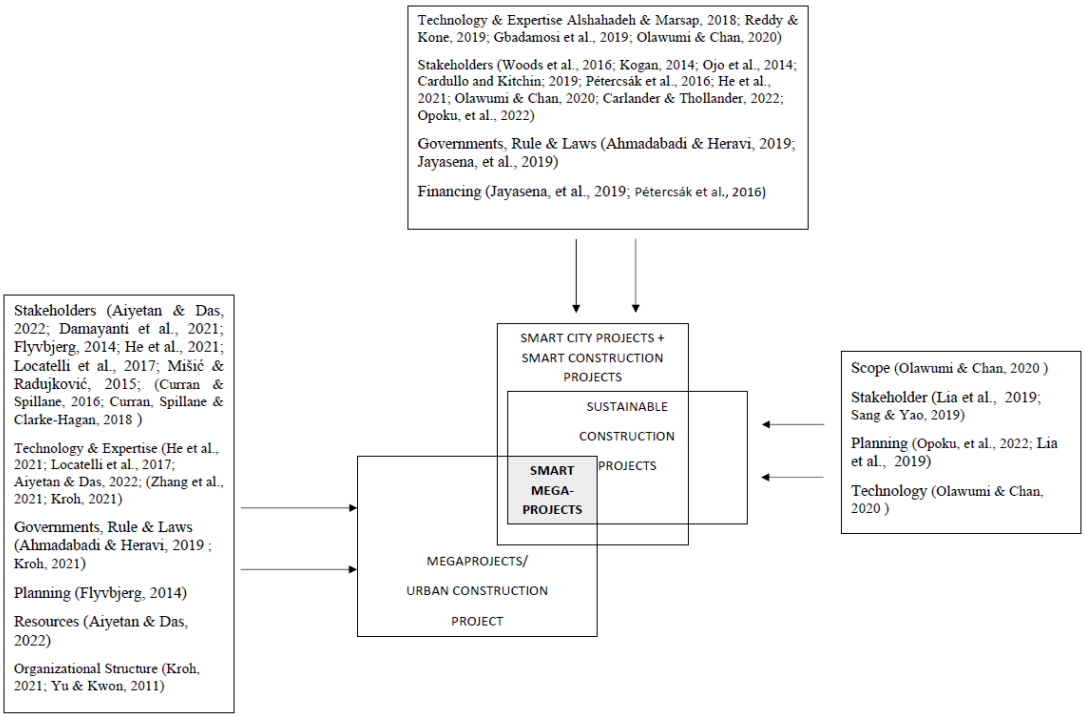


Figure 1: Requirements of smart megaprojects affecting construction project management.

Stakeholders are emerged as a common requirement affecting construction project management of megaprojects, urban projects, smart city projects, smart construction projects and sustainable projects (Lia et al., 2019; Sang & Yao, 2019; Opoku et al., 2022; Carlander & Thollander, 2022; Curran et al., 2018; Yu & Kwon, 2011; Kroh, 2021). From this point of view, it is revealed that it is an important requirement for smart megaprojects. Stakeholder engagement, collaboration and communication among project stakeholders, clear purpose and target definition for all stakeholders are some of the stakeholder requirements (Lia et al., 2019; Sang & Yao, 2019; Opoku et al., 2022; Carlander & Thollander, 2022; Curran et al., 2018; Yu & Kwon, 2011; Kroh, 2021). These requirements affect directly stakeholder management. Clear purpose and target definition of the stakeholders (Carlander & Thollander,

2022) is expected to contribute to scope management of smart megaprojects. Furthermore, as the data collected from the citizens and the citizens' footprints in city (Woods et al., 2016; Kogan & Lee, 2014; Ojo et al., 2014; Cardullo & Kitchin, 2019; Pétercsák et al., 2016) citizens become an internal stakeholder in smart megaprojects. In this case, this should be evaluated within the integration management since it may indirectly affect design decisions. Other requirements found in the literature such as organizational structure, planning, resource, financing and government, rules & regulations can affect the construction project management of smart megaprojects (Ahmadabadi & Heravi, 2019; Flyvbjerg, 2014; Aiyetan & Das, 2022; Yu & Kwon, 2011; Kroh, 2021; Lia et al., 2019; Opoku et al., 2022). The effects of these requirements focus on knowledge areas such as scope management, integration management and stakeholder management.

Conclusion and Recommendations

This study identified the preliminary requirements of smart megaproject affecting construction project management. The definition of megaprojects and smart megaproject were explained highlighting the similarities and differences between them. Requirements of megaproject, smart city project, urban project, smart construction project and sustainable construction projects on project management were investigated (Tables 1, 2, 3, 4 and 5). These highlighted requirements may have an impact on Project Management Institute's knowledge areas like scope management, integration management, and stakeholder management. (Tables 1, 2, 3, 4 and 5). As smart megaprojects are similar to megaprojects and urban projects, the requirements of these projects can also be valid for smart megaprojects. However, since smartness becomes important, it can have similar features with smart city projects and smart construction projects. Furthermore, smart megaprojects must comply with sustainability requirements. Figure 1 shows the requirements of smart megaproject. This paper can be useful for AEC industry professionals, municipalities, governments and academics in the construction project management processes of smart megaprojects. As this study identifies the requirements of smart megaprojects that affect the construction project management, it has a potential to provide input to put forward construction project management models for smart megaprojects. This input can be considered as a future work direction.

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Potentials of VR and AR in Pre-Construction Phases

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Abstract

VR and AR technologies are among the digital tools and techniques of Construction 4.0 which is a new term reflecting the effect of Industry 4.0 digitalization transformation in the construction industry. VR is identified as a digital-driven experience on which the user is transferred into a simulated virtual environment while AR is an interactive experience of a real-world environment whereas AR involves superimposing computer-generated images and information on real-world environment. By increasing complexity and high requirements of buildings, the construction management actions of pre-construction phases play a crucial role on the efficiency and the effectiveness of the building projects. Since the pre-construction phase is mainly associated with its uncertainty; the decisions to be made at this stage brings high risks. This study aims to evaluate the potentials of VR-AR technologies in order to show how VR-AR can be used in various management areas of pre-construction such as feasibility, programming, cost-budget, scheduling, constructability review, communication and coordination. By employing a through literature review, it is also targeted to provide the applicability areas of VR-AR technologies in pre-construction phases.

Keywords: *AR, augmented reality, pre-construction, vr, virtual reality, construction management.*

Introduction

Pre-construction phase plays a crucial role in the whole building project process. Efficiency of the construction phase is related to the accuracy of pre-construction decisions. Pre-construction is the phase of uncertainty involving main services as design review, constructability review, scheduling, cost estimation & budgeting, coordination. Due to the uncertainty and complexity of construction projects, proper planning of each stage is a necessity to deliver the building successfully. A comprehensive and accurate pre-construction process is significantly important to secure the project goes as planned and all project outcomes successfully delivered. In order to prevent delays, cost over-runs, errors in design decisions, wrong detailing, improper material choices, this study aims to investigate the potentials of Virtual Reality (VR) and Augmented Reality (AR) technologies in pre-construction phases. VR is identified as a digital-driven experience on which the user is transferred into a simulated virtual environment while AR is an interactive experience of a real-world environment whereas AR involves superimposing computer-generated images and information on real-world environment.

Research Gap

Previous studies mainly focused on VR-AR applications in the construction phase, however there is a gap to examine the stages of the pre-construction process in this manner. This study targets to respond to this gap. On the other hand, there are some studies, such as Biocca et al. (2013), Noghabaei et al. (2020), and Park et al. (2013), indicating the general advantages of VR-AR technologies such as providing improvement in communication and visualization. However, there is a need of necessity of specifying these advantages connected to the stages of the pre-construction phase. Ultimately, the purpose of this paper is to investigate solutions by utilizing VR-AR technologies in relation to the pre-construction phase problems. As these technologies create immersive environments, in this study it is focused on the potentials of providing improved perception of the project requirements to be able to reach sufficient decisions and planning steps before the construction start. Thus, this study aims to contribute to the whole project life cycle by overcoming the problems arising from the pre-construction process which will impact the construction process negatively in time and the building as a final product.

VR-AR Technologies in the Construction Industry

VR-AR technologies are becoming widespread, and every industry will be affected by the rapid adoption of them (Delgado et al., 2022). Due to the rising popularity of mobile learning and distant working in the last years, usage of AR has drastically increased (Emiroğlu & Kurt, 2018). Moreover, Covid-19 Pandemic has brought new normal conditions which required professionals adopts these technologies widely.

VR-AR technologies are among the digital tools and techniques of Construction 4.0 which is a new term reflecting the effect of Industry 4.0 digital transformation in the construction industry. These technologies identified as one of the top 10 Gartner strategic technology trends for 2019 (Panneta, 2018). According to American Institute of Architects' (AIA) Firm Survey Report (2018), more than 25% of firm leaders surveyed state that VR- AR are having an important impact on the AEC (Architecture Engineering Construction) industry today, and 66% believe that the technology will have a significant impact within the next five years. Noghabaei et al. (2020) indicate that the AEC industry experts foresee strong growth in the use of VR-AR technologies over the next 5–10 years.

The Pre-Construction Phase Problems in The Literature

The pre-construction phase services cause some problems which could affect the overall project outcomes dramatically. Based on a study by Olanrewaju et. al (2017), more than 95% of construction professional had faced communication problems in the construction organization (Abd Rahman et al., 2019). Besides, in pre-construction of a project, people are likely to communicate through paper documents if they are using traditional method. However, misunderstandings can be occurred frequently.

The traditional methods are limited for visualization, understanding, and collaboration within a complex project (Abd Rahman et al., 2019). The lack of coordination results in losses construction phase which was indicated by Peniel Ang, 2013. According to Nassereddine et al. (2019), between $17-36 billion are lost each year because of the omitted information while

transforming design documents into construction documents. Also, some studies about construction efficiency indicate the waste of 25-50% in coordinating labor and management (Modular Building Institute, 2010). According to a report by the US Government Accountability Office (2013), the time overruns faced in construction projects resulted in approximately 35 months per project. The report compiled by Indian Ministry of Statistics and Programme Implementation (2016) declares that the completion delays in construction projects differ from 1 to 261 months.

VR-AR Usage Potentials in the Pre-construction Phase

This study investigates the potentials of VR-AR in the pre-construction phase considering the previous studies. As Table 1 illustrates, the pre-construction phase main services defined as design review, constructability reviews, cost estimation & budgeting, scheduling, and coordination.

Table 1. VR-AR in the pre-construction stages according to literature review.

	References
Design review	El Jazzar et al. (2020); Park and Kim (2013); Alizadehsalehi et al. (2019); Alsafouri and Ayer (2019); Hajirasouli et al. (2022); Foroughi Sabzevar et al. (2021); Williams et al. (2015); Shakil (2019); Bouchlaghem et al. (2005); Rahimian et al. (2011), Index AR Solutions (2018); Gheisari et al. (2016); Wanget al. (2014); Shanbari et al. (2016); Dunston and Wang (2005); Wang et al. (2014)
Constructability Review	Du et al. (2018); Alsafouri and Ayer (2019); Hajirasouli et al. (2022); Foroughi Sabzevar et al. (2021); Rajaratnam et al. (2021); Carneiro et al. (2019)
Cost Estimation and Budgeting	Wong et al. (2014); Balali et al. (2018); Alizadehsalehia et al. (2020); Bryde et al. (2013); Smith (2014); Xu (2017).
Scheduling	Crowther and Ajayi (2019); Hadavi and Tavakolan (2018); Wang et al. (2019); Charlesraj and Dinesh (2020); Ikerd (2013); Shakil (2019); Wang et al. (2014)
Coordination	Du et al. (2018); Issa (2000); Alizadehsalehia et al. (2020); Bille et al. (2014); Romano et al., (2019); Sutcliffe et al., (2019); Shen et al. (2013); Gunarathna et al. (2018); Norouzi et al. (2015)

Design Review

The early usages of VR mostly refer to visualization as Bouchlaghem et al. (2005) defined VR as a collaborative visualization tool for improving the design process. Another VR application in the pre-construction phase related to the design stage is a VR 3D sketching interface for the conceptual architectural design process to increase design creativity in the early stages (Rahimian et al., 2011). VR technologies provide environments for better collaboration among participants, enable a better understanding of complex designs, identify design issues, depict building geometry so that users can make sense of a project and reach a better design decision and aid collaborative decision-making (Alizadehsalehi et al., 2019). According to the research of El Jazzar et al. (2020), VR and AR can be suitable to improve processes and deliverables in planning and design phases. The results showed that VR-AR adaptations are effective in obtaining user feedback which improves the end-user satisfaction rate and performance in design (Shakil, 2019). In a study conducted by Alsafouri and Ayer (2019), the efficiency of AR usage in constructability and design review sessions was compared with the use of BIM, VR and physical mock-ups during these sessions (Hajirasouli et al., 2022). AR extends the opportunity to evaluate different design alternatives. Researchers developed a mobile AR application that can augment BIM models on top of the real-world

building, which helps technicians to optimize and visualize the data and the model (Williams et al., 2015). The proposal of Park and Kim (2013) for visualization system integrates AR, BIM and gaming.

360-degree visualization and AR model rendering features (Index AR Solutions 2018; Gheisari et al. 2016). It can provide project participants with an integrated view of the components in real scale and real time (Wanget al. 2014; Shanbari et al., 2016) while permitting access to the information in an augmented workspace (Wang, 2009; Lin et al., 2015). AR 'popup' models link AR models with physical 2D drawings to help clients and professionals to understand the drawings comprehensively (Dunston & Wang, 2005). Wang et al. (2014) mentioned that the synergy of BIM and AR opens new possibilities in the field of architectural visualisation, navigation, and interaction with a real time modelling facility. Furthermore, it provides early identification of design clarification.

Constructability Review

According to the previous studies, constructability review activities have a significant role in detecting and identifying errors, conflicts and inconsistencies (Abrishami et al., 2015; Carneiro et al., 2019; Foroughi Sabzevar et al., 2021; Rajaratnam et al., 2021; Hajirasouli et al., 2022). Additionally, by walking through the 4D-BIM model in VR, constructability analysis contributes to productive and efficient planning of a project (Du et al., 2018). Alsafouri and Ayer (2019) ran constructability and design review sessions with industry partners and practitioners to analyse their actions during these sessions while using AR as a means of communication (Hajirasouli et al., 2022).

Scheduling

VR-AR scheduling activities are interrelated with 4D BIM which provides environments to communicate and collaborate visually while scheduling sequences of work items by linking the BIM model (Crowther & Ajayi, 2019), Shakil (2019), Wang et al. (2019), and Charlesraj and Dinesh (2020) mentioned that AR integrated 4D BIM is useful in project scheduling. Wong et al. (2014) stated that both time and cost-saving opportunities are available to the project managers by using AR technologies. There are wide range of software for scheduling such as Navisworks, Synchro, Bexel, Fuzor and Visual 5D. Even though their interfaces are differentiated, aim of these tools are to eliminate rework, protect the budget by finding problems in advance, save time & resources by optimizations. Ikerd (2013) developed a framework to integrate 4D BIM with VR applications.

Cost and Budget

In pre-construction phases, VR-AR is beneficial for cost estimation in management for construction projects (Alizadehsalehia et al., 2020). In the study of Balali et al. (2018), a framework for cost estimation in construction using VR technology was developed which used a real-time VR model that provides the ability to change the building materials with the real-time price impact. VR-AR technologies in cost estimation extend its usage thanks to 5D BIM which involves cost planning and budgeting through linkage with BIM model. Davidson (2009) and Aouad et al. (2007), focused on cost and BIM relation in early phases. Xu (2017), Wong et al. (2014) and Smith (2014) emphasized VR-AR and 5D BIM interactions which result in accurate estimations.

Coordination

As VR-AR technologies create a virtual environment and enhance real world, they increase the perception and understanding of the project both for the professionals and the clients. Issa (2000) mentioned VR technologies are not limited to only a presentation tool but could also act as the main interface used to facilitate communication of construction information and cooperation among project participants. According to Shen et al. (2013), if design requirements are not sufficiently managed and client viewpoints are not fully understood, conflicts often arise among the designers and clients, especially in the pre-contract stage (Gunarathna et al., 2018). Thus, design knowledge acquisition (knowledge and experience of the designer and client) and knowledge negotiation (design understanding among the stakeholders) must be well-coordinated (Norouzi et al. 2015). Moreover, Alizadehsalehia et al., 2020; Bille et al., 2014; Romano et al., 2019; Sutcliffe et al., 2019. Du et al. (2018) proposed a BIM-related VR system to achieve collaborative decision-making, which enables users to revise modifications in BIM models concurrently from VR headsets. Additionally, to improve communication among participants, researchers introduced a cloud-based VR system called CoVR by integrating a multiuser interactive virtual environment with BIM data (Du et al., 2018). Besides these technologies provide virtual walk-through tours for clients while in the office before construction started.

Table 2: Potentials of VR-AR for the activities of the pre-construction phase (by authors)

	Problems caused in the Pre-construction phase	**Problem Area**	**Potentials of VR-AR**	**Tools**	**Software**
Design review	Errors in design documents Low performance in design End-user dissatisfaction Overloaded revision requirements	Quality	• Proper design deliverables • Providing real time experience in early stages • Increased perception of drawings • Better performance in design • End-user satisfaction • Less revisions in the upcoming stages of the project	Headsets, Handsets, Desktop Mode Mobile	Unreal Engine, Unity, Sim Lab
Constructability Review	Unproductive and inefficient planning Errors, conflicts and inconsistencies Mischoice of systems/detailings Rework	Quality Time Cost	• Productive and efficient planning • Detect and identify errors, conflicts and inconsistencies • Proper detailing and system selections	Headsets, Hand Sets, Desktop Mode Mobile	Unreal Engine, Unity, Sim Lab, Bexel Manager
Cost Estimation and Budgeting	Mistakes in cost estimation Cost overruns	Cost	• Accuracy in cost estimation • Better cost- budget control • Compatibility with 5D-BIM	Desktop Mode Mobile	Synchro Primavera BIM 360 Bexel Manager
Scheduling	Errors in schedule Need of extra resources Delays	Time	• On time delivery • Better resource assignments • Time efficiency	Desktop Mode Mobile	Synchro Primavera Bexel Manager
Coordination	Conflicts among participants Clashes in drawings Misunderstandings Limited communication with clients	Quality Time Cost	• Better communication • Better cooperation among participants • Better visualization and presentation options for clients • Elimination of misunderstandings	Headsets, Handsets, Desktop Mode Mobile	Unreal Engine, Unity, Sim Lab Revit BIM 360 Bexel Manager

Table 2 represents the problems, problem areas, VR-AR potentials, tools and software. The problems were defined according to the literature review. Problems were categorized in three areas as; quality, time and cost. Potentials of VR-AR were composed and interrelated with each problem. Additionally, the most common tools and software were listed in Table 2 for each activity of the preconstruction phase.

Discussion and Conclusion

This study discussed the current problems of the pre-construction phase in terms of design review, constructability review, cost estimation & budgeting, scheduling and coordination. Accordingly, the potentials of VR-AR technologies were investigated based on a comprehensive literature review, to provide an insight for researchers and the AEC professionals. Pre-construction problems affects the quality, time and cost of the whole project lifecycle and this study evaluated the adoption of VR-AR technologies before construction starts.

VR and AR technologies are not only visualization tools but also, they are increasing design abilities by creating a virtual environment or a virtual object. This augmentation real environments results in increased creativity and accurate choice among design alternatives. Additionally, these technologies can help to handle uncertainties of the pre-construction phases. Budgeting and scheduling of can be more precise to minimize the cost and time overruns during construction phases. On the other hand, according to client's point of view, can give some advantages in communication of design with the professionals, moreover they can virtually experience the design which increases their perception and understanding.

But the potentials of VR/AR in early stages of building projects can further be explored. Especially activation of 5G technology is expected to enhance the performance of VR and AR usage in near future. Also, companies such as Microsoft, Google, Apple and Facebook are investigating on these technologies as well as many start-up companies are focusing on them recently. In this regard, participants of AEC industry need to emphasize on technology solutions and establish research development departments. Integrating these technologies in construction industries can be reconsidered as a new career path for architects and/or engineers. In order to reach success in construction projects, the pre-construction phase should be empowered with these recent technologies.

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A Simulation of Tunnel Operation Model Using Stroboscope

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Abstract

Construction simulations are helpful in analyzing construction steps, designing construction processes and related steps in the most effective way which increases the productivity to the maximum level possible. These simulations can be used for all repetitive processes of construction. As a repetitive work subject, a tunneling operation in which precast pipe sections are used is chosen. Tunneling operations are frequently used repetitive works in construction industry and a study for productivity may be useful in prospective works. In this paper, an EZStrobe simulation is modeled for a tunneling operation with the help of the data obtained from site. Also, productivity and effectiveness, ways of increasing productivity, and solutions to possible problems are discussed. Outputs of this study can be used to estimate and increase productivity in tunneling as well as different kinds of repetitive construction works.

Keywords: *construction simulations, simulations, Stroboscope, tunneling.*

Introduction

The simulation tool has been used for more than 50 years in the design and development of technical processes, as well as in the analysis and optimization of the processes. Resources such as workers, equipment, and management included in the simulation are important for the simulation to work. Simulation models provides an understanding of the logic of the works and the specific processes. Analyzing model results is important to understand factors such as efficiency (Thanh, 2017). One of the main purposes of creating a simulation is to compare alternative situations (construction methods, etc.) by modeling (Ioannou & Martinez, 1995).

Simulations are also extensively used in construction work. With the use of simulations, some situations in construction works are compared and the decision-making process is carried out in a sufficient way. The processes in the construction are repeated both in terms of the works (formwork manufacturing, etc.) and in terms of fields (construction of high-rise buildings, etc.). It is seen that they are repetitive within the scope of the foundations on which the construction operates. For this reason, simulations created for construction work need to be cyclical and scalable. (Martinez, 1996).

It can be difficult to create simulations about the complex construction operations. There seem to be three major obstacles in the way of modeling construction works in a simulation. One of these obstacles is that the language created by the simulations is shaped according to production needs, and not construction processes. CYCLONE, RESQUE, COOPS, etc., the emergence of simulation types as such has helped to overcome this problem. These simulations are similar to CPM in that they are based on their scans of activity in construction works. The fact that these simulations are not a language makes it incomplete for modeling complex construction processes. With the advent of STROBOSCOPE, this problem has been largely resolved (Ioannou & Martinez, 1996).

One of the processes applied in construction works is the process of opening micro-tunnels with micro-tunnel tunneling machines. It has been seen that more than a thousand sales of microtunneling machines have been made in the last 20 years. The usage of microtunneling methods is increasing day by day. Microtunneling is carried out with MTBM. The efficiency of the MTBM is affected by factors and components such as weather, equipment adequacy, design changes, rework status, space flexibility (Thanh, 2017).

Microtunneling is a complex process involving personal experience and the interaction of various equipment. Regulating this complex process can help to understand the factors affecting productivity (Dang et al., 2013).

The aim of this study is to model a pipe jacking operation and discuss results for the possibility of increasing the efficiency of the operation.

Pipe Jacking Operation

The history of pipeline jacking goes back almost more than a hundred years. Pipe jacking was first used in the United States in 1896 to place a concrete culvert beneath the Northern Pacific Railroad, but it did not become widespread in the United States until the 1950s. (Sterling, 2020). It was 30 years later where microtunneling technology, which is a type of pipe jacking, first entered the market. The first microtunneling machine was developed in Japan in 1972 by Komatsu and the first job was completed in 1974. Microtunneling spread slowly but gained popularity in Europe specifically in Germany and the United Kingdom starting in 1981 and 1984, respectively (Hafez et al., 2022).

Microtunneling is a tunnel construction technique used to construct an auxiliary tunnel with a diameter of approximately 0.5–4 m. Because of their small diameter, it is not possible for an operator to operate the tunnel boring machine, so they must be operated remotely.

Micro-tunnel boring machines (MTBM) are similar to larger tunnel boring machines (TBMs). The methodology starts with the installation of MTBM and hydraulic thrust frame on a shaft at the required depth. The operator monitors the position, orientation and hydraulic devices of the MTBM via a computer console, a CCTV camera or a Gyro unit. Gyro Control has often replaced cameras for location and digital feedback.

The pipes, which are lowered into the shaft with the help of a crane, are driven into the tunnel by the pushing force performed by hydraulic pistons in the microtunneling method. The control of the system is made from the control cabinet on the surface.

The microtunneling machine needs to excavate the tunnel and the hydraulic rams in the jacking frames simultaneously pushes the pipes in the excavated part. While the cutter head is pushed forward with the hydraulic pushing system, a new pipe is connected to the system when there is enough space for a new pipe to be driven, and the pushing process continues this way.

After the micro-tunnel machine excavates the soil with cutters and hammers, pressurized water is used to remove the excavation from the system in the form of a slurry. This slurry is sucked by the existing discharge pipes in the system and taken to the discharge tank on the surface or inside the shaft.

Measurement processes in the micro-tunnel method takes place with the help of continuous data exchange between the machine and the control panel in the control cabinet on the surface. These received data are evaluated instantly by the operator who manages the control panel on the surface, and the machine is prevented from going beyond the prescribed deviation limits.

The data is evaluated on the computer in the control cabinet, and the horizontal and vertical position of the machine is displayed numerically and graphically on the control panel. In the graphic display, the position of the main body of the machine, the position of the cutter head and the fixed position of the machine are displayed in different colors on the screen on the control panel. Control system, operates with +/- 0.01% sensitivity with immediate intervention.

Equipment Used in Microtunneling

There are various equipment and tools used in the operation of microtunneling. The ones that are explained are the main procedures that effects the microtunneling simulation.

- Pipes and Concrete Segments: Concrete pipes and segments used for tunnels must be of high quality without surface defects. The stock should be ready next to the shaft.
- Transport of Segments: With the help of a crane, the segment stones are carefully placed on the guide rail.
- Cutter Head: It is a steerable mini drilling machine equipped with a suitable cutter head at the front for excavating small diameter tunnels. It uses a laser guidance system to transmit instant feedback. The blades of the cutter head can be changed according to the floor type and usage time. Different types of cutter heads can be seen at Figure 1.

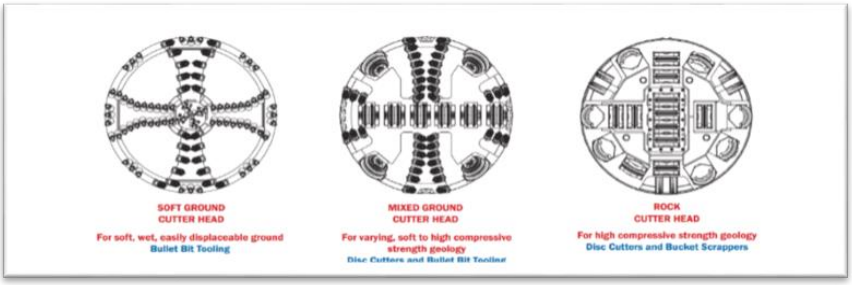


Figure 1: Cutter heads for different soil conditions (Akkerman, n.d.).

- Lubricant Bentonite Mixture: Automatic Bentonite Injection System – Remotely controlled delivers oil directly to the pipe ring at predetermined pressures and intervals to reduce friction forces.
- Slurry: A mixture is created by injecting a mixture of water or bentonite clay into the crushing cone of the MTBM. This sludge-like mixture is carried to the return lines and passes through the sludge transmission pipes so that it can be removed from the system. The weight can be sent directly out of the shaft with the help of the pump, it can also be filled into the carrier feet inside the tunnel.

Stroboscope and EZStrobe

Models were created using EZStrobe. Stroboscope is a programming language used to simulate repetitive and common processes in construction works (Martinez & Ioannou, 1994). Stroboscope is a discrete event simulation system for creating simulations of complex construction works (Ioannou & Martinez, 1996). The processes to be simulated consist of complex structures containing different resource types (Martinez & Ioannou, 1994). Models of this programming language, which are similar to activity loop diagrams, consist of node and connection networks (Ioannou & Martinez, 1996). Efficient and effective results are obtained by analyzing the simulation outputs (Martinez & Ioannou, 1994). It can be said that Stroboscope is a scalable monitoring system that complements existing tools (Tilmans et al., 2018).

Accessing the resources and the appearances of these resources in the construction processes is the main basis of the simulation. Elements in the modeling are assigned properties that define how they should behave. There are characters that represent situations such as the duration of an activity, the amount and direction of flow of resources and the order of activities. The simulation considers the order of the elements and how they should follow each other. Examples of these situations are: until the crews leave the field or until the cables are examined (Martinez & Ioannoui, 1994).

Ioannou and Martinez (1998) demonstrate by modeling the link and correlation between the activity durations of STROBOSCOPE. In addition, a sample highway project is modeled using an additional program with CPM planning. Martinez and Ioannou (1994) created an aircraft service center simulation model to demonstrate the programming language of STROBOSCOPE. Ioannou and Martinez (1996) gave examples of simulations created with STROBOSCOPE in complex construction processes. Tilmans et al. (2018) created a declarative network monitoring on a budget with the help of STROBOSCOPE.

EZStrobe is a straightforward yet powerful general-purpose simulation system created for modeling construction activities, although it is domain independent and hence applicable to a wide range of systems in any discipline. EZStrobe works with Microsoft Visio, hence it is based on visual modelling and easier to use. The Three-Phase Activity Scanning paradigm is used by EZStrobe, which is based on Activity Cycle Diagrams. (Martinez, 1998) As a result, it's well-suited to complicated systems with several resources working together to complete tasks, such as those found in construction. The paper also explains the fundamental concepts of the system.

To express the essentials of a model, these systems make use of a network based on Activity Cycle Diagrams. These systems are intended for both simple (e.g., CYCLONE) and

complicated (e.g., STROBOSCOPE) modelling programs. EZStrobe is intended to bridge this gap in currently available simulation tools and to ease the transfer to more complex tools as the system matures. Also, other programs that do not meet the demand for a tool that is simple to learn and capable of modeling somewhat complex situations with little effort. (Martinez, 1998).

Following are the basic modeling elements for EZStrobe shown in Figure 2, as well as the precedence rules that govern them and their explanation:

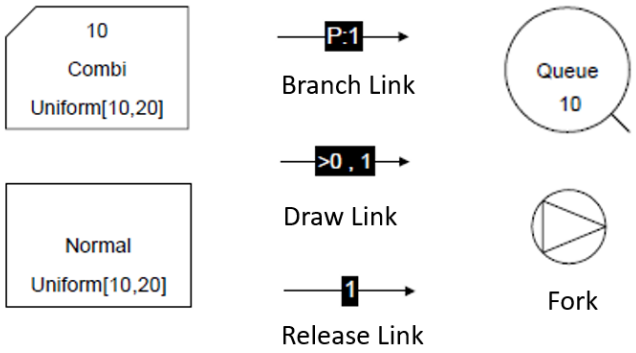


Figure 2: EZStrobe modeling elements.

- *Queues* are named elements that contain idle resources. The Queue's name is displayed in the center. Queues have a limited quantity of resources at the start of a simulation.
- *A Conditional Activity (Combi)* is a named element that specifies tasks that can begin whenever the resources in the queues preceding it are sufficient to support the task.
- *A Bound Activity (Normal)* is a named element that represents tasks that begin when any previous activity instance expires. The Bound Activity's name is displayed in the center.
- *A Fork* is a component of probabilistic routing. It usually follows an activity, but it can also be followed by another Fork.
- *A Draw Link* is a link that connects a queue to a conditional activity.
- Except for conditional activities, a *Release Link* connects an activity to any other node.
- On the other hand, except for a conditional activity, a *Branch Link* connects a fork to any other node (Martinez, 1998).

Project and Modelling

In this paper a simulation model of the microtunneling operation is conducted based on EZStrobe methodology for modeling and simulation. The specific operation discussed in this paper was taken from the book ‘Planning and Analysis of Construction Operations’, in which CYCLONE was used to create a model of this tunneling work. A visual explanation of the operation was shown on Figure 3.

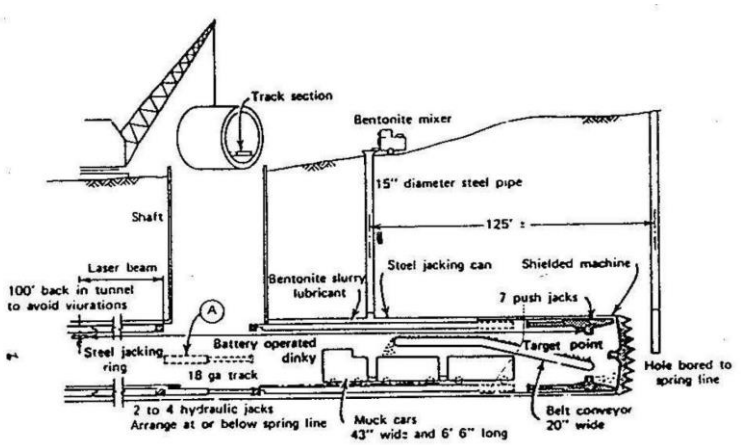


Figure 3: Microtunneling operation shown in Planning and Analysis of Construction Operations (Halpin & Riggs, 1992).

The operation that is simulated includes the previously discussed equipment and procedure. For this operation, instead of removing the excavated soil by pressurised water, 6 ft. long muck cars are used with the help of 20 in. wide conveyor bands. There is a 15 in. diameter steel pipe to pour the bentonite lubricant for a 125 ft. long microtunneling operation. The concrete pipes are pushed by 4 hydraulic jacks.

For modeling the process, duration data gathered from the book "Planning and Analysis of Construction Operations", various articles and a real site in Istanbul, Turkey. The simulation outline was taken from the book, and additions were made according the engineers from the site. Duration of activities were obtained from different articles and from the site. Then model was created and possible efficiency improvements were discussed with the engineers.

An EZStrobe simulation in Figure 4 was created and results were discussed using Stroboscope. EZStrobe was used for modeling for modeling this pipe jacking process. Simulation was made for only 2 pipes cycle because EZStrobe was unable to reach the total duration of this model. To reach the total duration, SimTime of the simulation will be multiplied with a number, thus this model can be used for projects at different lengths.

Activities (cornered elements) throughout the process are;
1) Lowering the Pipe (LowerPipe)
2) Positioning the Pipe (PstnPipe)
3) Replacing Jacks and Collar (RplcJackscollar)
4) Jacking 6 ft Forward (Jack6ftFwd)
5) Emptying the Muck (Empty)
6) Removing Jacking Collar (RmvJckngCollar)
7) Reset Jack Rams (ResetJackRams)

For lowering the pipe,

a) Crane must be in idle position (CrnIdle=1)
b) There must be a pipe in stockpile (PipeStckp>0)
c) Crew 1 must be in idle position (Crew1Idle=1)
d) After the first cycle, jack rams must be in reset position and thus, NewSctnRqrd, which is a messenger element, must be 1.

Positioning will start directly after lowering the pipe is completed.

For replacing jacks and collar to start,

a) Pipe must be in position (PipeinPstn=1)
b) Collar must be removed after the first cycle (CollarRemoved=1)

For jacking to start,

a) Jacks must be in position (JackinPstn=1)
b) Muck cars must be empty (MuckCarsEmpty=1)

For emptying the muck cars to start

a) Muck cars must be full (MuckCarsFull=1)

For removing jacking collars,

a) Jacking must be completed, so CollarMustRmvd must be 1
b) Crew 1 must be in idle position

Resetting jack rams will start directly after jacking 6 feet forward.

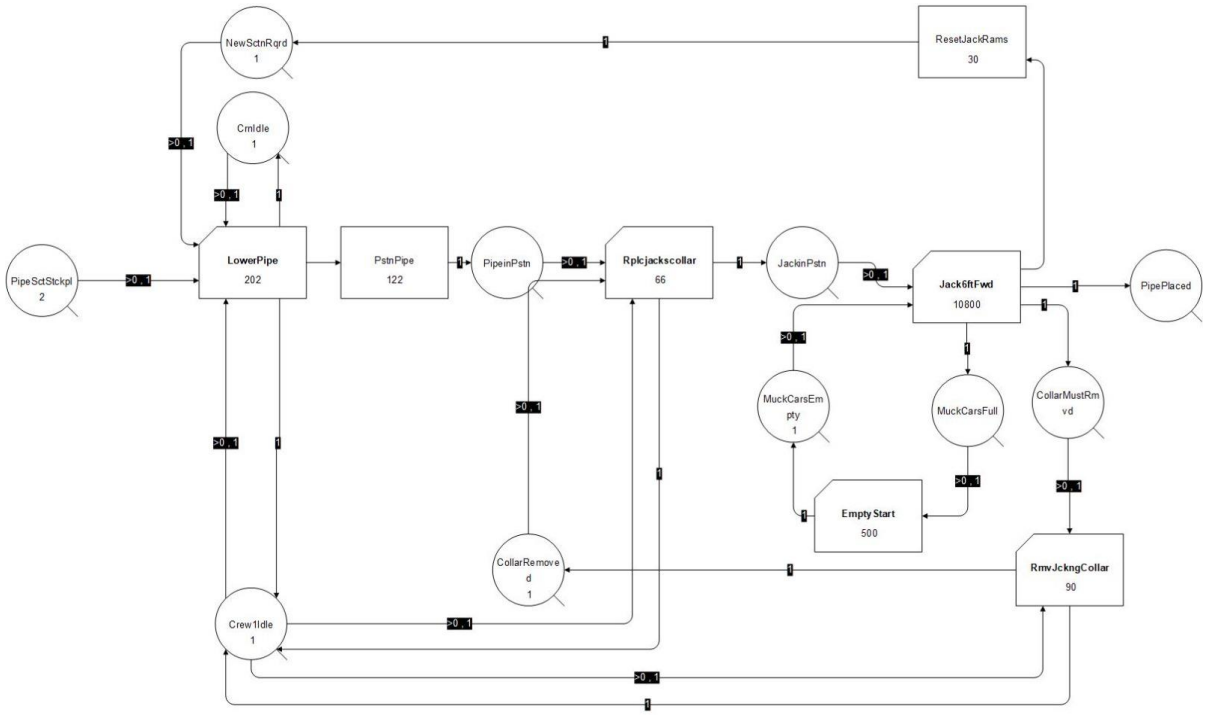


Figure 4: EZStrobe model for pipe jacking operation.

Results

Simulation time was calculated as 22990 seconds for 2 pipe cycles. In this project, there are 19 pipes, so total time required is 3640 minutes. Results are given in Figure 5.

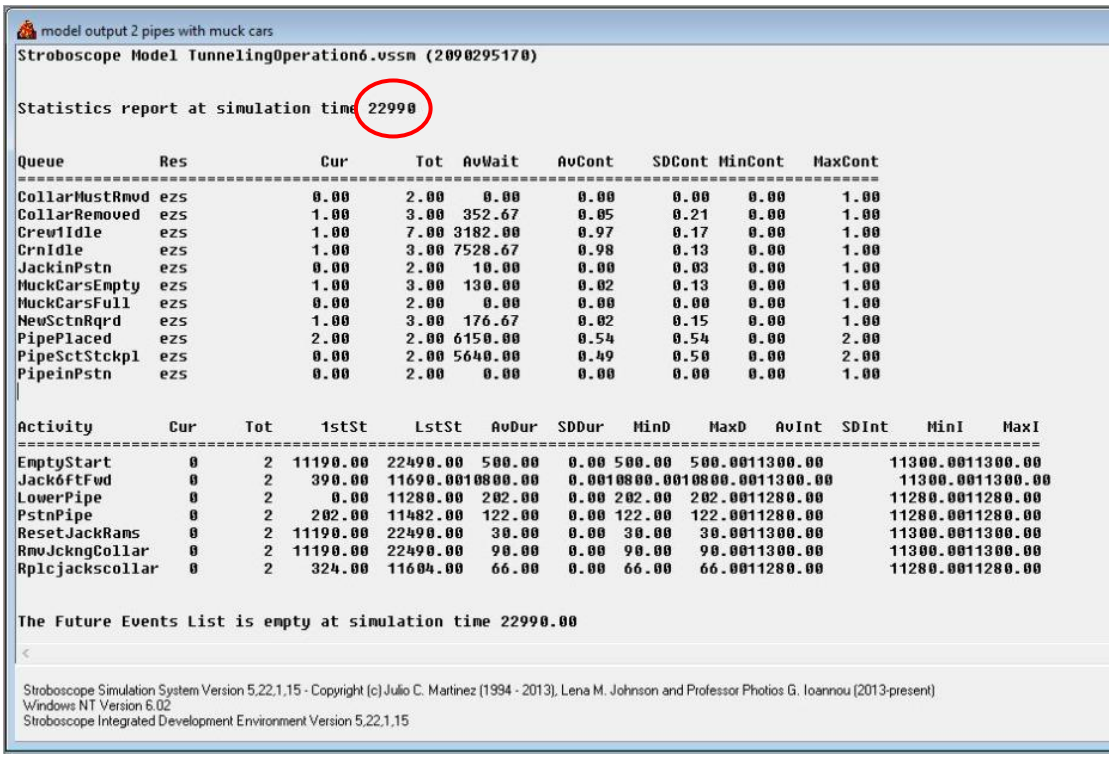


Figure 5: EZStrobe simulation results.

As a result of the simulation, it was seen that 94% of the duration is due to jacking activity, and none of the other activities can take place at the same time with this activity. However, it is not possible and efficient to reduce the duration of this activity, because one of the factors affecting the duration is the soil type, which cannot be changed. The other reason is spread rate of bentonite. Bentonite should be evenly and deeply spread and reach far points of the pipeline to jack the pipes properly. Even in soils have less density, jacking must be done at a certain speed for spreading the bentonite. Different possible improvements are explained in the Discussion section.

Discussion

Numerous factors influence the productivity of microtunneling operations. The productivity of microtunneling is primarily influenced by the underground circumstances, operator experience, pipe conditions, obstructions, use of lubricant, and main jack capacity. Geotechnical challenges, soil conditions, and impediments are some examples of underground circumstances, which is not possible to change. On the other hand, experience of crew and operators can play a significant role in productivity enhancement. Pipe conditions include alignment and diameter of the pipe and the cutter head. Main jack capacity includes the torque of the machine, shape and diameter of the cutter head. Based on computer simulations, the significance of the elements was explored in this paper. These elements should be taken into account by owners, engineers, and contractors who are aiming to increase project productivity.

Conclusion

In this paper, pipe jacking operation and modeling this operation using EZStrobe was discussed. In research, activities and durations were taken from different studies and also an actual pipe jacking project in Istanbul, Turkey. After running the simulation, possible restorations for efficiency were discussed. 94% of the duration of a cycle is caused by Jacking activity, which cannot be affected unless some parameters hard to change such as pipe diameter, torque of the machine or fluidity of bentonite used changes. Various improvements can be done for the other 6%, such as adding crew members or using a better crane operator.

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Using Blockchain Concept in Smart Home

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Abstract

The growing population has created new challenges, although expanding technology has provided numerous benefits over the previous two decades. Some of those; excessive and rapid consumption in line with their needs and new rational areas that we need to create for these consumptions. Buildings utilize up to 40% of global energy and are predicted to reach 50% by 2030. Energy consumption in buildings has led to an increased interest in smart home technologies. As they used automation systems that can become passive at certain times by adapting to environmental factors, reducing energy consumption throughout the life of the building. These systems provide monitoring energy requirements and consumptions so facilitating the controllability of energy. However, there is a need for a transparent, decentralized and constant system in order to monitor the energy needs throughout the life cycle of the building. Blockchain technology (BTC) is seen as a solution to the question marks such as how to follow all these processes, data storage, and transparency in data. The study aims to discuss how smart homes (SH) can be managed with blockchain and how to cycle using devices from the preliminary design stage to the end of their lifecycle.

Keywords: *blockchain, energy management, life cycle, smart home.*

Introduction

Since the beginning of the universe, the world has undergone regular changes. However, in the last half-century, humanity faced crucial problems with a rapidly growing population. It was triggered by fast consumption and require new places for shelter. Thus, with the global warming caused by climate change emerged another problem like agricultural land declining as glaciers melted, the resulting food supply problems, loss of biodiversity, pollution of the air, water and ground (Cilingir, 2020; FAO, 2019). Besides, starting with industrial revolution period, human had transferred to the city center from town and village. Today, world populations live in cities approximately 50% (IPCC, 2014). This causes trouble decreasing raw material production and increasing of energy consumption. These are totally domino effects for world. Because of this, the construction industry has the most crucial point in energy consumption. According to the statistics, it consumes %30 of energy in global energy consumption, and also more than %50 of electric in the worldwide (Santamouris & Vasilakopoulou, 2021). Approximately, it has one-third of carbon emissions (Santamouris & Vasilakopoulou, 2021). When we look at water consumption, the construction sector is consuming one-fourth of the total water consumption. Another important statistic is about waste, %25 of solid waste and %20 of liquid waste has produced in the buildings (Kabakçı, 2019).

With all these adverse effects seen, concepts such as sustainability and renewability began to be discussed (United Nation, 1987). As a result of developing technology, that is, digitalization, building businesses that are out of human management started to be used. These building systems are also called smart home (SH) or smart buildings. Smart homes (SH) are different from green buildings. Although green buildings have entered our lives as a concept which is environment, economy and social sustainability as an ideology, with the developing technologies have been integrated into the building sector. In other words, the smart homes (SH) can be considered as the integrated version of the developing technologies in the building field. Even though this system has many positive aspects, some problems have emerged regarding the operation of the system and the storage of data in process of time (Türkyılmaz & Altındag, 2022).

With studies in recent years, our perspective has changed about the data and data warehousing. Blockchain technology (BTC) is novel in this fields. First definition or ideas came in 1990s by a group of researchers. However, first real definition is come from Satoshi Nakamoto in 2008 (Kandiye, 2020). He adapted the old version for himself.

Consumption is advancing in many sectors which are occurred food industry, clothing meaning the fashion sector (Castagna et al., 2022), technological inventions and also construction. Humanity needs to control their consumption. In the study, it will be discussed how smart homes (SH) can be operated with blockchain technology (BTC) and how to energy cycle used items from the preliminary design stage to the end of their lifecycle.

Blockchain Background

The system that allows tracking of all assets and transactions in a business network is called the blockchain. Another definition is a decentralized distributed ledger technology that faultlessly creates, confirms and records encrypted processes of digital assets (Owens, 2017).
System is working in this way;

- Each process saves as a data block
- Each data block has a connection with before and after
- Any operation can't be undone, and it has saved into a chain in a blockchain, which is a chain (Nakamoto, 2009).

In the traditional system, databases have used, and it works on a server, and other channels connect with host server. However, blockchain technology (BTC) means decentralized systems. It can also define that this network occurs on many computers, although in a way that the data cannot shifted without the unanimity of the whole network. Each block has a hash and connect with previous block or hash (Owens, 2017). So, blockchain has proof of work for recording all steps in detail.

When examining the chronology of blockchain, there are three plunge points.

1. Blockchain 1.0: Decentralization of money and payment
2. Blockchain 2.0: Decentralization of markets
3. Blockchain 3.0: Decentralization of government, science, health, art, culture. Meaning is that applications beyond money and market (Kandiye, 2020).

There are 3 main elements for working: block, chain and network. Block is where places of transactions are recorded. Chain is that connection of the creation blocks each other. Network namely the whole system (Kandiye, 2020).

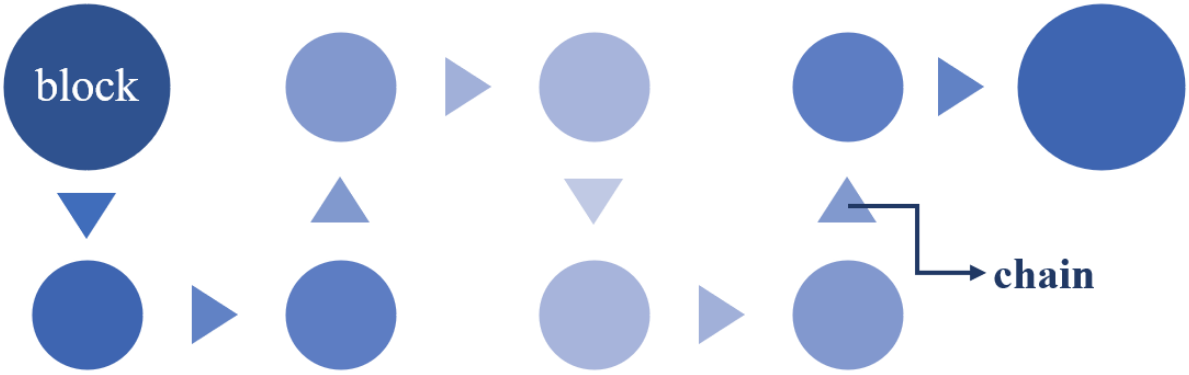


Figure 1: Blockchain main elements diagram.

Although blockchain technology (BTC) is a solution to many problems, its main subjects are 3 topics which are scalability, reliability and decentralization. In order to create a good system, these 3 main issues should work together (Kandiye, 2020).

A survey has done which conducted asking about the main supporting elements of blockchain technology (BTC) that is being used by businesses in which more than 50 companies participated. The survey participants answer that 61.5% of the respondents said transparency, 58.5% immutability, 40.8% trust, 33.7% of them answered decentralized and 20.1% of them as cost reduction, intermediation, and automation, which are described as other (Sebastian, 2019).

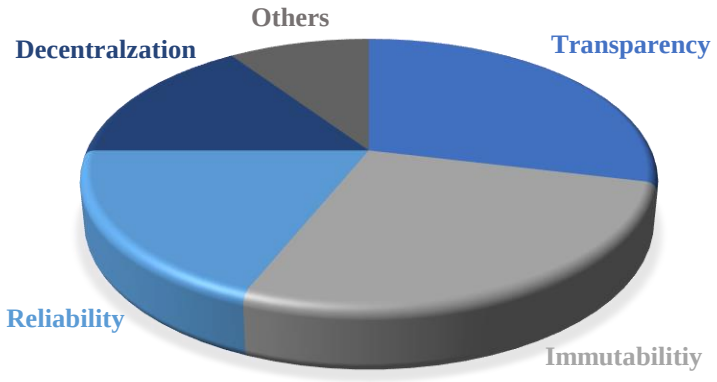


Figure 2: Main supporting elements of blockchain technology.

Types of Blockchain

a) Public Blockchain

This type of the blockchain is a network that anyone can join without restrictions. Most types of cryptocurrencies operate on a permission-less blockchain governed by consensus or rules algorithms (Solomon, 2019). In construction sector, public contract applications can be suitable for this type of blockchain technology (BTC), inasmuch as, public blockchain is transparent (Kandiye, 2020).

b) Permissioned or Private Blockchain

In the Permissioned blockchain, only authorized participants can join the network. However, participation is just by invitation. Transactions can only take place on approved participants, not on every participant (Solomon, 2019).

c) Federated or Consortium Blockchain

The consortium blockchain does not have a single owner, so it is somewhat similar to a private blockchain. This blockchain network is closely controlled by a preselected set of nodes or a preselected number of stakeholders in which the mining process (Solomon, 2019).

One of the sectors that the developing blockchain technology (BTC) can adapt to is the construction sector. With this technology, we can determine how we will use the accumulated data from the preliminary design stage to the end of the building's life cycle. Blockchain technology (BTC) is a very important innovation, especially in order to follow the energy efficiency issue, which is one of the biggest problems of today. Blockchain technology (BTC) will be a very important technology in matters such as the monitoring of the energy produced by the buildings, the list of needs, and if there is unnecessary energy production, its supply to the necessary places.

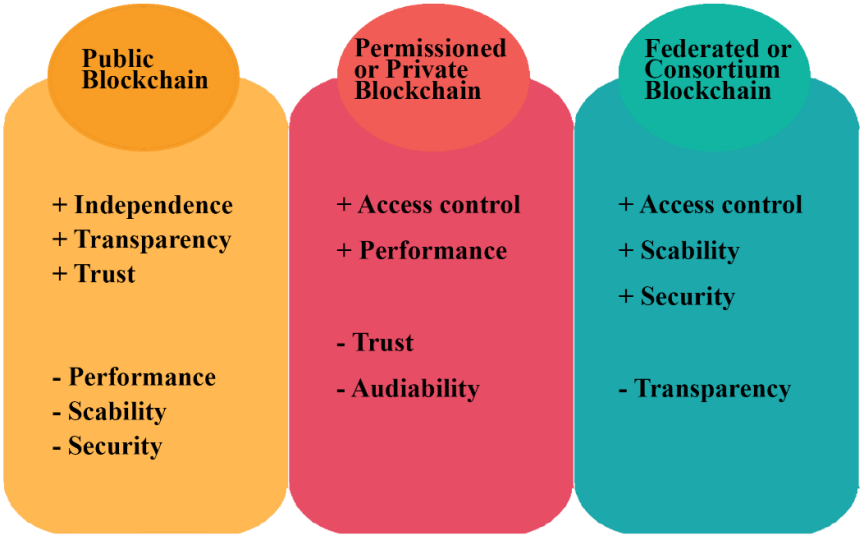


Figure 3: Types of blockchain and pros and cons.

Smart Home Background

Smart homes (SH) can be expressed that automatically controllable buildings distantly. Devices or appliances need a connection network which can be managed via mobile phone or monitoring vehicle. Internet technology is the most important invention for this. All home vehicles can be added control plugs and connected with smart phone. Distances are not important for most duties, user can open or close electrical vehicles or can control times or issues can command working time. Control capacities can list like security accessing, lighting, temperature, vehicle control and home theater (Smart Home, n.d.).

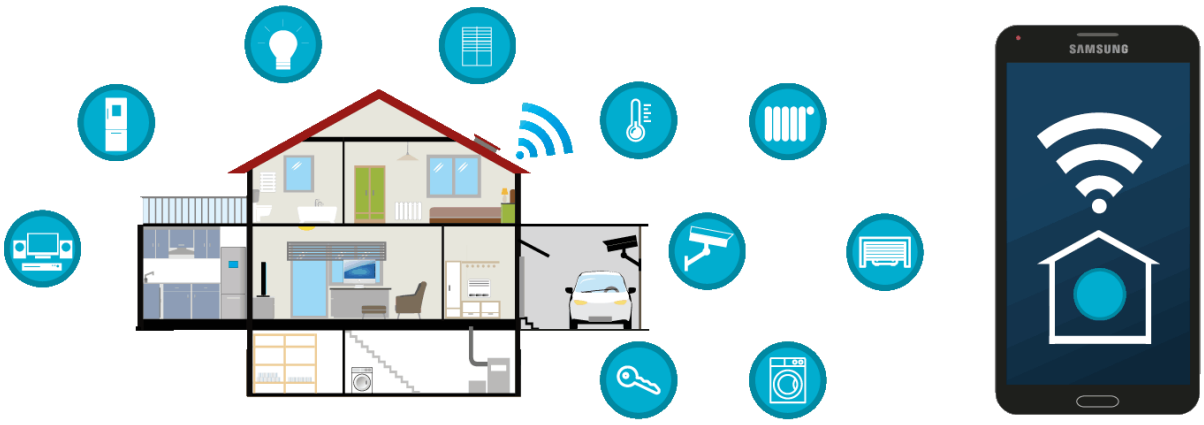


Figure 4: Smart home systems (Blog de Trisacor, 2017)

Another definition;

"Smart homes are, in their simplest definition, the computerization of housing. They gather data on inhabitants and their habits with a range of sensors; by analyzing these collected data, they respond to these actions and events by controlling certain mechanisms built into the housing." (Emekci, 2022).

These systems, which can be self-supporting, have to use some sources. These are energy and network connection with the outside world and between each other. So, after the energy, the most important requirement in using smart home systems is internet infrastructure. The theoretical name of this is Internet of Things (IoT). What is the IoT?

Internet of Things (IoT)

IoT is the most significant technology in this century. It can describe in this way; the network of a material object. IoT is using a vast amount of fields nowadays. Since, new technology brings us new requirements and humanity needs to connect and swap data with other gadgets and systems via the internet (Oracle, n.d.).

Nowadays, IoT has lots of benefits these are access to low-cost and power sensor technology, connectivity, cloud computing platform, machine learning, analytics and conservations artificial intelligence (AI) in these matters.

The studies on the use of the IoT system in the smart home were examined in 3 groups (Sepasgozar et al., 2020).

1. The energy management processing, provide today's smart home applications from the point of energy efficiency and energy consumption following
2. Applications of artificial intelligence in smart homes, such as deep learning algorithms and machine learning can be applied in divergent contexts
3. Aged care systems can be adapted in different places and can be learned from these practices.

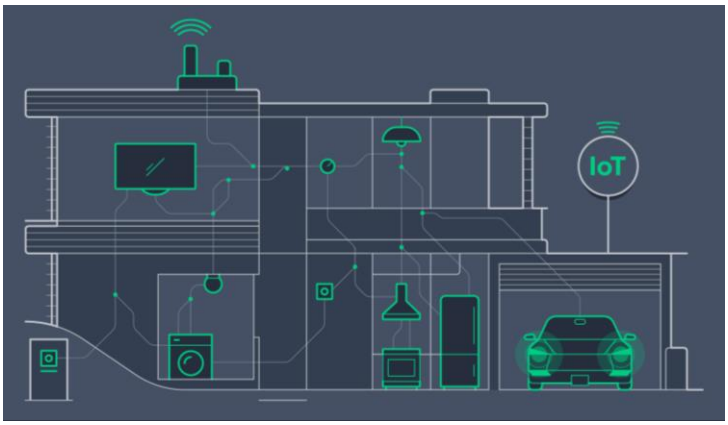


Figure 5: IoT in the smart home (SH) (Mundle, 2020).

The reason for the need for the computerization of houses is the global climate problems. The climate crisis and the rapid increase in population have pushed people to use their resources more efficiently. It would be more explanatory to consider these resources as production waste rather than evaluating them only based on raw materials. The carbon that comes out while processing any raw material used, the water used and the energy we burn are buried energy that no one thinks of. When a construction evaluation after construction terms is just looking but it's totally wrong energy efficiency has to start from scratch. Inasmuch as, carbon emission starts with the first step and continues until the end of the life of the building and its demolition.

Blockchain Technology (BTC) in Smart Home (SH) Life Cycle

The cradle-to-grave concept, which is frequently used in sustainability, has been the best technology that can define and follow the life cycle. Starting from the very beginning of the process, that is, the agreement of the parties, design, construction, delivery, placement of the users and the active use of the building, etc. It has become mandatory today to record the list one by one and follow up on the needs of the users in light of these data.

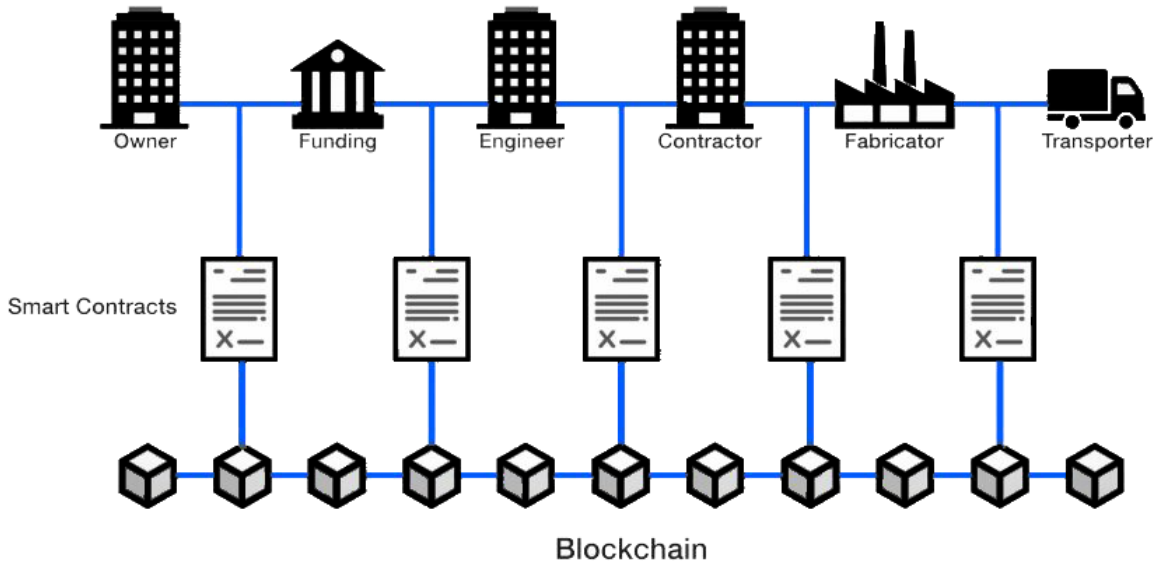


Figure 6: Blockchain network.

In smart home systems, if we start from the user's location, innovations such as the maintenance of the devices used, the monitoring of the energy they consume, the easy monitoring of the safety of the individuals in the house, the automatic provision of appropriate temperature and lighting will be appropriate for this era.

There are some timed intervals used in the structure. These are dishwashers, cloth washers, plug-in hybrid electric vehicles (PHEV). The promptitude of these tools plays an important role in saving electricity usage, that is, in bills (Sethi et al., 2020). At the same time, all vehicles have vital importance for managing energy consumption automatically. The user can see vehicles working conditions and how much time can be taken or how much energy will consume. Thus, of vehicles can be changed or renewable some problematic parts.

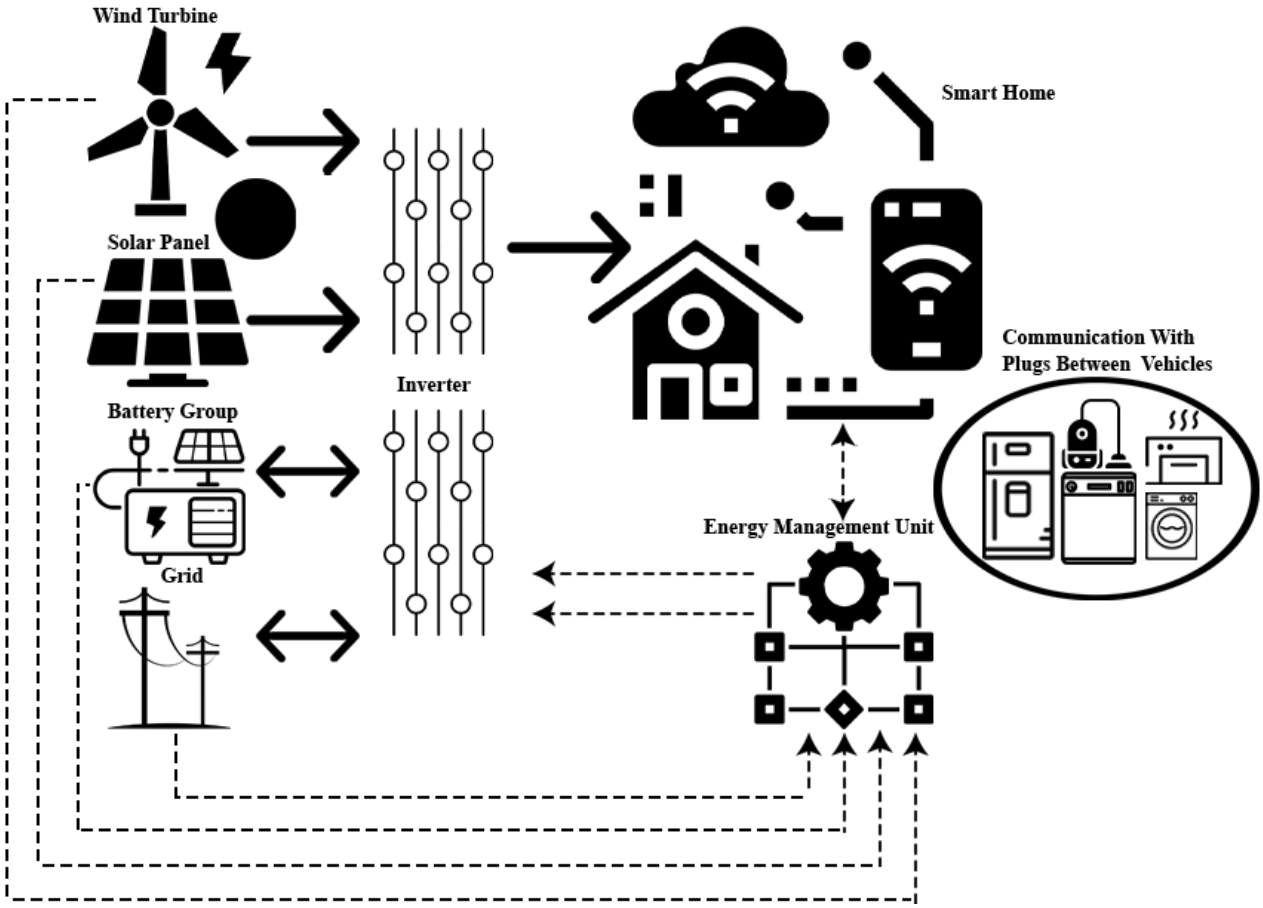


Figure 7: Energy management systems in smart homes (SH).

Building life cycle can be divided 3 main parts. Design and construction phase, user phase and completing its life. These all phases are consumed energy and they can be monitories via blockchain interface.

The use of blockchain technology (BTC) in the building life cycle begins at the stage of deciding on the construction of the building. During the construction phase, it creates a safe and systematic organization between the parties. The reason is that the system is transparent, and everyone can participate in the blockchain network at equal distance. When accessibilities and control panels are easily, energy consumptions can be organized easily. This is mutualist relationship between consumer and system.

In the using phase, it continues in parts such as the control and maintenance of smart home systems, automatic provision of material-based needs, resource and waste management. The energy needs registered in the system or the transfer of wastes to the relevant places will be carried out automatically, thanks to an open contract. The electricity produced by the building itself is directed to the needs as a priority. If there is excess electricity storage, it is sold to the relevant units and the building is ensured to sustain itself economically. Another way is If-This-Then-That (IFTTT). This method, which stands for "if-this-then-that", is the algorithm-generated version of the system known as a "smart contract". It can be argued that this system should be used in the construction industry.

In blocks in the blockchain, codes can be generated that automatically arrange the necessary messages and payments using the “if-this-then-that” logic. It is an undeniable fact that the use

of smart home devices will be more efficient thanks to the created algorithm. The reason is that the maintenance in Decentralized Autonomous Organization (DAO) smart home systems can automatically set the repair order. In this way, issues such as the maintenance of the vehicles in the building, equipment needs, and waste management can be carried out automatically.

If-This-Then-That (IFTTT) can also be defined as the adaptation of smart contracts to blockchain technology (BTC). However, it is certain that transparency will be ensured in the contracts. Therefore, it is argued that the adoption of If-This-Then-That (IFTTT) in the construction sector will increase the trust environment between the parties. If-This-Then-That (IFTTT) will increase efficiency in many fields, from vehicle and equipment rental to waste management.

The most important features that make this system powerful are; efficiency, automation, privacy, transparency, decentralization and auditability. On the other hand, their weak features are; scalability, low performance, high energy consumption over time, having a complex structure. Although these technologies, which have been in our lives for the last two decades, have many positive and negative features, the most crucial feature is to control energy management and thus reduce it. Nevertheless, it will take time to eliminate all negative features and maximize efficiency.

At the last stage, it can be easily determined that the productive life of the building has been completed. All processes in the building are recorded and it is automatically known which systems are efficient and at what level. If the building's general life is over, and there are still usable vehicles, these are determined and transferred to the centers where they can be used. The same applies to the materials used in the construction of the building. Therefore, energy management is possible to make a complete follow-up from the cradle to the grave by using blockchain technology in smart homes.

Discussion and Conclusion

System Requirements

Some minimum conditions are required for the use of blockchain technology (BTC) in smart home systems. The most basic of these is the internet infrastructure. Smart home (SH) and blockchain technology (BTC) work on totally electric and internet infrastructure. Therefore, in cities, the internet and electric infrastructure have to strengthen. On the other hand, these requirements provide preparation for smart city grounds. Inasmuch as, smart home devices can access each other, and they have to connect their relation units and services.

In this era, thanks to the technological invention, human life has been both easier and harder. Although machine learning or smart technologies make human life easier, it is possible for all systems to fail and shut down in the smallest infrastructure problems. This shows that these systems require very clever and reliable design. Considering the smart systems to be used only as simple machines in residential buildings is due to the insufficient perception of the scope of these systems. Although the use of smart technologies in the field of health aims to minimize human error, it can be predicted that system failures caused by infrastructure problems may lead to greater losses.

To sum up, smart home technologies can be applied easily and can adapt lots of place but it requires hard infrastructural technology. If there are any basic insufficient, smart technologies will be unmeaningness.

Management of Energy, Material and Time

Blockchain technology (BTC), which started in the 1990s and has gone through many leaps to the present, has become inevitable to be used in the building sector and construction. The energy and material management in the building's design phase, starting from time management and in the advancing processes, is very valuable and has become very easily controllable thanks to blockchain technology (BTC). The use of blockchain technology can make all processes fast, transparent, reliable and effective. Choosing a blockchain at a scale suitable for the area to be used and using it can be said to be the only condition necessary to ensure the flow of work.

In a globalized world for any project managed, there is no chance of progress accidentally. The carbon, water and energy emissions that occur in every project consume the natural resources of the world. In order to prevent these, highly controlled and reliable methods should be used. The first condition to reduce the effects of increasing population and climate change problems should be to minimize the margin of error in the selected methods. It is seen that the real purpose can only be achieved by the continuity of the positive features of the methods used and the development of the negative features in the positive direction.

In this study, the positive and negative features of the use of blockchain technology (BTC) in smart homes (SH) were investigated. In line with the results obtained from the research, it was concluded that the positive features are efficiency, time, energy and material management. It is foreseen that the system will be able to operate with full efficiency as a result of the elimination of negative features such as the need for internet infrastructure and the need for permanent energy.

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Major Research Areas in Smart Factory Research

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Abstract

The rapid and continuous development in Information Technologies (IT) has led to the 4th industrial revolution which triggers the Construction 4.0 approach in the Architecture, Engineering, Construction, and Operation (AECO) industry. Digitalization, as the major step for technology adoption, increases in the AECO industry as in all other industries throughout the world with the help of improvements in computer and data sciences. This revolution may be defined as the transformation of production systems from automated to digitalized smart production. Smart production may increase the quality, cost, sustainability, and efficiency via the new revolutionized production environment, tools, techniques, and methods within the Smart Factory concept. This article focuses on Smart Factory research in the literature. Bibliometric research and scientometric analysis were conducted to figure out the research areas in the Smart Factory concept. The research areas in the Smart Factory subject were clustered under six main headings. In the light of the findings, the Smart Factory subject is the focus of scholars since it triggers efficiency in production and facility management.

Keywords: *cognitive systems, Construction 4.0, data management, digitalization, Industry 4.0, smart facility management, smart factory*.

Introduction

Digital production has begun to evolve into smart manufacturing with the rapid development of information technologies (Chen et al., 2017). Industry 4.0 is based on smart production and aims to transform into smart factory (SF) that make resource management more efficient than traditional factories. This goal integrates factories with the product lifecycle and activities (Fernandez-Carames & Fraga-Lamas, 2019; Kang et al., 2016). SF covers networked manufacturing systems for smart manufacturing. To implement SF, smart objects must be combined with big data analytics. Smart objects may be configured dynamically, while big data analytics can provide feedback and coordination to achieve high throughput. Thus, SF can produce products efficiently, profitably, and in a short time (Wang et al., 2016). In addition, production processes can be physically monitored in these facilities and a digital twin of the physical world can be created. In this way, SF can make smart decisions through real-time communication and collaboration (Zhong et al., 2017). This innovation has emerged thanks to developments in artificial intelligence (AI) and automation and new digital technologies connected to the Internet of Things (IoT) (Sjödin et al., 2018). IoT refers to objects that communicate with each other to create a dynamic network (Borgia, 2014).

The most relevant term for SF is Cyber-Physical Systems (CPS) (Xu & Duan, 2019). Computing and networking may be integrated with physical processes, dynamics can be controlled and managed, and more efficient and reliable next-generation Information and Communication Technologies (ICT) systems can be achieved via CPS (Mittal et al., 2019). Better data collection and faster communication networks can be established with CPS, thereby increasing the formation of interconnected physical facilities to generate large amounts of data. Such big data in CPS of SF have great potential for better supply chain management, reducing failure rate, improving production speed and quality (Xu & Duan, 2019). In recent years, the cheapening of sensors and ICT, the success of machine learning (ML) and AI plays an important role in the implementation and development of SF. AI is important in smart production because of features such as learning, smart execution (Zhong et al., 2017). The success of these technologies has also triggered the dawn of the digital twin concept. A digital twin (DT) is the creation of a virtual representation. It aims to improve the operations of the product throughout its lifecycle and provides real-time inspection of the product (Rasheed et al., 2020). Representing the conceptual ideal for product lifecycle management, the DT allows for virtual representation with data bidirectionally integrating the physical asset at any time (Ozturk, 2021).

Data in SF flows over the internet. As a result, threats to security and privacy have increased. It is important to ensure security and confidentiality, especially apart from issues such as data integrity and data redundancy. This challenge can be overcome with blockchain technology, which can eliminate the need for the central authority to perform various transactions (Bodkhe et al., 2020). Blockchain can keep a permanent and tamper-proof record of transaction data. Each node of a blockchain maintains a copy of the ledger to prevent a single point of failure. All copies can be updated and verified simultaneously (Hammi et al., 2018). Blockchain helps automate industrial processes involving multiple companies. Therefore, the concept of smart contracts is important. The smart contract relies on data connected to external services that receive real-world data and store it on blockchains (Fernandez-Carames & Fraga-Lamas, 2019).

This paper aims to classify the mainstream research areas in SF research to capture the gaps and current research tendencies and to make projections for prospective research areas in the field. Thereby, scholars, industry experts, managers, and the SF research society would profit from the results by creating an understanding of the future to shape and clarify the research and development path of implementing SF tools, techniques, technologies, and philosophies.

Methodology

This research utilized bibliometric search, scientometric mapping, and scientometric analysis to provide an overview of current Smart Factory research areas. (Represents articles published up to October 2021). Bibliometric data was acquired from the SCOPUS database, which contains more information than any other database due to the ever-growing resource (Aghaei Chadegani et al., 2013). The SCOPUS search API uses a system called Boolean Syntax to combine search results for sensitive data (Cobo et al., 2011). Since the data collection is a one-time snapshot of the literature, it only includes research patterns, gaps, and trends for that period. Providing a dynamic data graph can be more effective for the presentation of the research. Language limitations, including only articles, are other limitations for the study. Scientometric Mapping analyzes bibliometric data to show the relationship between research areas through keyword co-occurrences. VOSviewer software was used to analyze the data

collected from the Scopus database. This research involves clustering keyword combinations to visualize, analyze and explore the research areas of Smart Factory. However, future research can reveal more insight about Smart Factory by further analyzing publication sources, citation, co-citation, co-authorship, and bibliographic matching of articles, authors, organizations, and countries.

Scientometric Analysis and Results

Bibliometric Search

The Boolean search was used to consolidate search output and to find results related to the research area. A summary of the bibliometric search entry showing other limitations of the keywords is shown in Figure 1. This research resulted in 9038 articles. Additional limitations such as language, document type, document source, and subject area were applied. Then, 3229 articles that were highly relevant to the research topic remained.

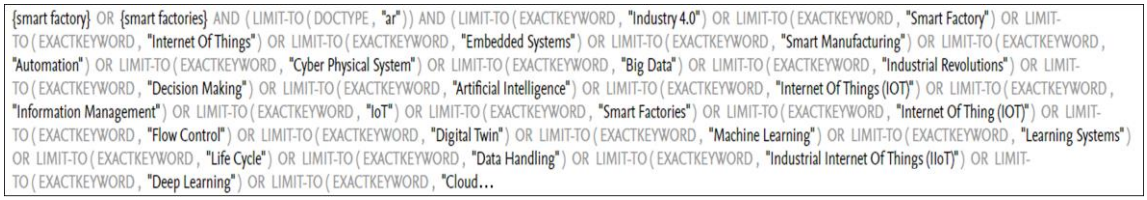


Figure 1: Summary of bibliometric search input.

Scientometric Analysis and Mapping of Keywords

Keywords play a key role in identifying important points in research (He et al., 2017). Using Vosviewer enabled natural language processing and text mining methods application. A network visualization map was established to show the relationship between keywords and cluster main research areas (Eck & Waltman, 2014). In this research, the keywords that were overlooked were prevented by using index keywords other than the keywords used by the authors. Filtering Figure 2 shows the network visualization map of keywords co-occurrence analysis results. The keyword list is shown in Table 1.

Related keywords were clustered with VOSviewer, thus allowing comments on sub-areas of the research field. Each color in the image given in Figure 2 belongs to a separate cluster. The clusters were given names after the keyword sets' related research areas. Accordingly, the clusters are named Information Management (red-coded), Data Utilization (green-coded), Cognitive Smart Systems (blue-coded), Smart Facility Management (yellow-coded), Information and Communication Technologies (purple-coded), and Information Security (turquoise-coded).

The red-coded cluster called "Information management" is related to collecting, processing, and managing data for a predictive decision-making process in order to enhance efficiency throughout the product life cycle. In the Smart Factory implementation, all systems and products are equipped with sensors to acquire and update information. The management of consists of ensuring the quality and accessibility of the acquired information to share it with all stakeholders. IoT sensors and actuators are among the most widely used technologies for

collecting data. The collected ‘big data’ is handled such as categorization, analyze, and evaluation to manage data to information cycle in order to establish a robust decision-making process. This cluster consists of the basic elements necessary for the formation of a Smart Factory and smart manufacturing.

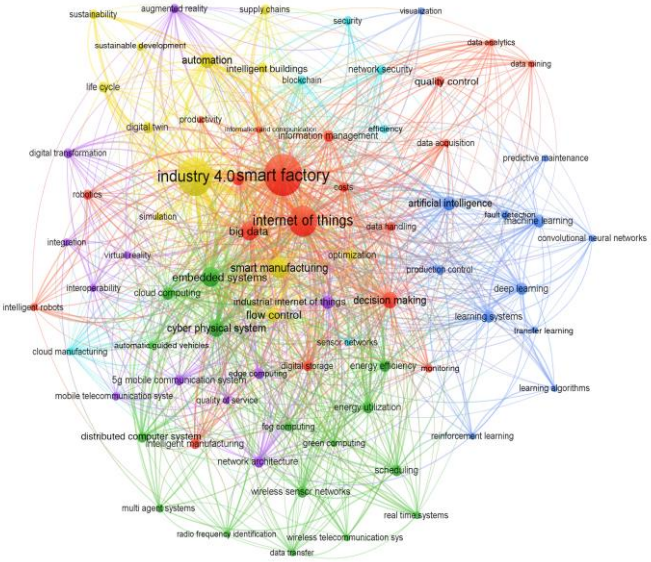


Figure 2: Network visualization map of keyword co-occurrence analysis of Smart Factory.

The green-coded cluster called “Data Utilization” is related to how the collected data will be used. It is possible to reduce error rates in production, produce with less cost and higher efficiency with the use of data collected and managed by sensors. Better data can be collected; production speed and quality can be increased with CPS. Thus, energy efficiency is ensured to a great extent.

The blue-coded cluster called “Cognitive Smart Systems” is related to systems that can learn by themselves and produce what they learn. These systems are developed using AI technologies. Sub-fields of AI such as deep learning and machine learning in this cluster show that intelligent systems are being used.

The yellow-coded cluster called “Smart Facility Management” is related to the smart product at each AI level. With the implementation of AI technologies in SF, the idea of real-time monitoring of production emerged. This has triggered intelligent facility management. Smart facility management (SFM) ensures the integration of systems, processes, technologies, and people to improve management in facilities. Providing SFM increases productivity by reducing costs and manpower. In order to achieve this, DT technology is used.

The purple-coded cluster called “Information Communication Technologies” is related to collaborative and integrated systems. ICT can realize the connection in production systems at any time and place. ICT was used in order to communicate systems with each other and therefore, increase interoperability between the systems used in SF.

The turquoise-coded cluster called “Information Security” is related to emerging cyber security limitations against rapidly revolutionizing technology. Information security is the protection of the integrity and confidentiality of data during the storage and transfer of

information. The flow of data over the internet in systems used in SF has made the issue of data security important. Blockchain technology aims to reduce threats to data security.

Table 1. Keyword co-occurrence analysis results for Smart Factory.

Clusters	Keyword Group	Link	Total Link Strength	Occur-rences	Average Citation	Average Normalized Citation	Average Published Year
Information Management (red-coded)	*Big data*	59	244	65	55,14	1,81	2018,65
	Decision making	63	214	51	28,24	1,18	2019,16
	Internet of things	74	548	174	26,53	1,16	2019,10
	Smart Factory	73	763	305	22,88	1,16	2019,05
Data Utilization (green-coded)	*Cyber physical system*	52	251	52	51,62	1,81	2018,65
	Embedded systems	62	355	72	57,76	1,75	2018,29
	Energy utilization	48	133	28	23,46	1,30	2019,04
Cognitive Smart Systems (blue-coded)	*Artificial intelligence*	46	127	38	13,26	1,00	2019,58
	Learning systems	48	118	27	13,33	0,76	2019,30
	Visualization	19	34	10	17,10	0,82	2019,80
Smart Facility Management (yellow-coded)	*Digital twin*	31	59	26	15,19	1,70	2019,92
	Industry 4.0	74	646	258	30,91	1,44	2019,19
	Smart manufacturing	64	308	81	31,56	1,21	2019,21
	Sustainability	23	51	17	35,53	0,76	2019,47
ICT (purple-coded)	*Industrial internet of things*	49	106	36	15,22	1,99	2020,25
	Interoperability	28	50	13	7,46	0,75	2019,38
	Network architecture	48	119	25	37,92	1,45	2019,20
Information Security (turquoise-coded)	*Blockchain*	33	65	16	45,25	4,20	2019,18
	Network security	36	72	20	31,50	2,37	2019,55
	Security	19	39	17	15,06	1,12	2019,55

Discussion

Through the triggering of the Industry 4.0 concept in recent years, smart production has become the focus of attention of the business world and academics. Smart systems have attracted great interest in many sectors with the new information technologies offered by Industry 4.0. The AECO industry has also benefited from these developments. The fact that the AECO industry plays an important role in the economies of countries and consumes raw materials very quickly is an indication that digitalization plays a key role in the sector. Using smart production technologies in the sector, the optimization of time, cost and quality parameters in project management can be achieved. Materials and resources are correct; labor

and machinery can be used efficiently via smart production technologies. In addition, by providing integration between stakeholders, delivery times can be reduced, quality and cost can be increased.

The collection and processing of data necessary for the development of the SF has been the primary focus of the research area. For this reason, technologies that enable data collection with sensors such as IoT are attracting more and more attention. Data collection alone is not enough to build a SF. The correct processing and management of this data has been achieved with the development of ICT. After collecting and managing the data, the next step is to set up a learning system on its own and produce it more efficiently. With AI technologies, human participation in production can be minimized in order to provide a more sustainable and efficient product life cycle. Exchange of information over the network in SF jeopardizes data security. This is one of the biggest challenges in implementing the SF. In recent years, the number of researches in the direction of blockchain and network security has increased. Collecting and processing data, developing self-learning systems, ensuring inter-system communication and ensuring data security will ensure the full realization of the SF. Thus, with the smart production provided by the SF, energy efficiency and a sustainable product life cycle can be achieved.

Conclusion

This study aims to reveal the scientific trends of research on SF in the literature. For this purpose, bibliometric research and scientometric analysis were performed. As a result of the research, it has been revealed that SF can provide sustainability and energy efficiency in production. According to the Scientometric mapping results; research on SF seems to focus on collecting and managing data and ensuring security. Research has shown that there is a trend towards integrating SF with AI technologies, which minimize errors in production and may increase productivity. In addition, a virtual representation of the product can be obtained and the product life cycle can be followed in real-time. ICT can be used to enable systems used to communicate among themselves. Thus, inter-system integration and interoperability can be achieved. Ensuring information security management in SF is a challenging task. By ensuring information security management and interoperability of systems, the difficulties in implementing SF can be overcome. Thus, future studies may be aimed at increasing the contribution of SF to sustainability and energy efficiency.

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Distributed Ledger Technologies for Building Knowledge Management in AECO-FM Industry

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Abstract

Digital age of the architectural, engineering, operation, and facility management (AECO- FM) industry fosters knowledge management with the extensive and inclusive data acquisition and information transformation for better management throughout the building life-cycle. The transformation of data into knowledge enhanced via the data acquisition, data retrieval, data store, information share, knowledge generation, knowledge utilization. Information management is the creating, sharing, using and managing the information from concept creation to demolition of a building. However, the diverse nature of the building information complicates the management of building knowledge in terms of interoperability, transparency, time, accountability, customization, size, linguistics, and diverging needs. The chaotic environment triggers safety, transparency, speed, accessibility needs throughout all information sharing processes. Therefore, distributed ledger technologies become prominent for building information management, to provide security of data. Our objective in this paper is to show different distributed ledger types and their usage in the AECO-FM industry.

Keywords*: construction industry, data security, digital twins (DTs), distributed ledger technology (DLT), internet of things (IoT).*

Introduction

The AECO-FM industry has been modified through technological developments within the last decades that results in the AECO-FM industry managing building assets throughout their lifecycle, automating facilities management activities to increase business potency.

Industry 4.0 emerged as a set of systems consisting of three stages: the Internet of Things, Internet services and cyber-physical systems. In general, the traditional construction industry was beginning to be integrated into industry 4.0 and its components. The information sharing structure in project management, which was applied in the traditional method, contained deficiencies in terms of security, integrity and applicability. With Industry 5.0, there were also new developments to eliminate these shortcomings. Industry 5.0, which stands out with its unmanned technologies, virtual realities and sustainability solutions, started to work rapidly on

solution proposals that were aimed to be applied to the construction sector as well.

The digital twin is one of the most prominent issues in the construction industry. Digital twin technology, which aims to minimize error, loss of time and danger by working on virtual structures before starting real construction, is seen as a groundbreaking progress. However, although it solves many problems, this technology has its own shortcomings. The biggest handicap is the lack of security in sharing information.

This study examines the distributed ledger approach to develop DT technologies and synthesize the findings from these cases to propose an abstract implementation framework that might be used as a catalyst for raising the potency of AECO-FM.

Distributed Ledger Technology

Digital systems that provide decentralized databases are called Distributed Ledger Technology (DLT). These digital systems eliminate the central authority hence it spreads digital data across multiple places at the same time. DLT controls against manipulation of the network and allows for record keeping of all information in the system safe and secure with cryptographic algorithms. Every record keeping part of the network is called node. These nodes replicate, share and synchronize digital data through the network. To ensure replication across nodes is undertaken, distributed ledgers require a peer-to-peer network and a consensus algorithm.

Classification of DLTs

It is crucial to choose the right DLT type for an application. Most of the cryptocurrency and virtual applications couldn't succeed in the area just because they don't understand the importance of the right DLT type. DLT classification depends on its information sharing structure. In Figure 1 whole database types are shown with their examples. For DLT there are 3 main types:

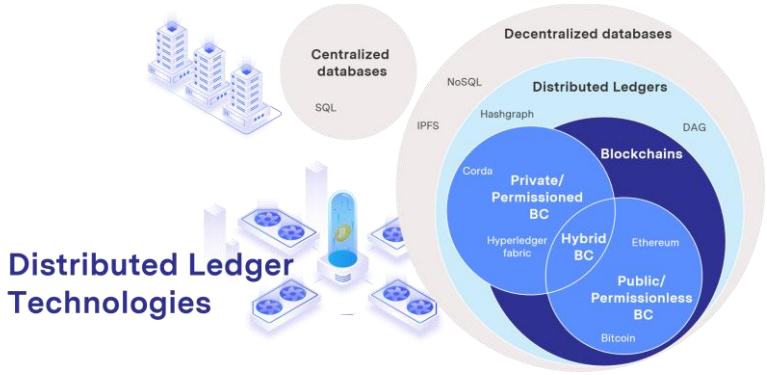


Figure 1: Taxonomy of distributed ledger technologies. Graph from Raphael Iten and Severin Kranz, Different Types of Blockchain, (mm1 consulting, Jun 26, 2019).

Public, Permissionless distributed ledger systems do not require any permission from an authority. All nodes in the network are able to maintain and operate public distributed ledgers. Public DLTs are, due to their structure, available to anyone who wants to get access to it.

Most well-known public ledger is Bitcoin. It was originally designed with public parameters, however lots of the on-ramps and off-ramps for Bitcoin are increasingly permission-based recently.

Private, Permissioned distributed ledger systems, on the contrary, require permissions. Authorized nodes are mandatory for validation of blocks. Hence authorized nodes maintain the ledger, determining restriction, like read and write access, is also possible in private distributed ledgers. It is feasible to identify users whitelisted or blacklisted through KYB (know your business) or KYC (know your customer) procedure which is a common method in traditional finance. Transaction costs and data redundancies are less than public ledgers. On the other hand, it needs a manager for determination of authorized nodes.

Hybrid distributed ledger systems are the combination of public and private DLTs. With the privacy utility of private ledger and with the security and transparency utilities of the public ledger, hybrid ledger gains significant flexibility for businesses.

Features of DLTs

Following features are common in all kinds of DLTs:

A. Distributed: makes possible multiple parties collectively enabling multiple parties to collectively generate, edit and operate a shared set of records (the ledger).
B. Multi-party consensus: enable all parties to come to agreement on a shared set of records
C. Independent validation: verification of transactions and integrity of the system is enabled by each participant.
D. Tamper evidence: non-consensual changes applied in the records are detected by each participant.
E. Immutable: make it hard for a single party to unilaterally change past records (i.e. transaction history).

DLT Criteria

A. Consensus Algorithm

In the network some rules and processes are needed to add, validate new assets to that network. This set of rules, to reach an agreement in the network, are called consensus. The most well-known consensus algorithm is PoW, depending on complex computational problems. Based on the consensus, the faster participant in the network solving the problem first gets the creation right for the next block. Since this consensus depends on computation power, energy consumption of it is very high. Alternative consensus mechanisms have been launched according to created DLTs need and usage area. They affect transaction time, security level, scalability and many properties of DLTs.

B. Protocol

In the network some rules are needed for communication between participants. This set of rules determine how systems work together and how they understand each other. Protocols affect integrity, security, robustness and many properties of DLTs.

C. Data structure

Very basically data structures declare the aim of DLTs. The specific kinds of information and data structures that are held by a node, are always specific to the DLT system. Data structures affect durability, transparency, standardization, tamper resistance and many crucial properties of DLTs.

D. Cryptography

In the network, secure communication and data exchange is provided by different cryptographic algorithms, encryption methods and key types. The method used in a DLT depends on system requirements and field of study. Cryptography is also involved in some of the consensus protocols and is the primary vehicle in achieving consensus. Also, encryption is possible in different layers of the system as shown in Figure 3. Cryptography affects security, integrity, confidentiality, authority and many properties of DLTs.

E. Mining

Process of generation of new blocks is called mining. New transactions' sender, receiver and data values are sent in encrypted form. Miners, also referred to as validator nodes, go through some processes to add the transaction to the block which vary depending on DLTs mining protocol. For example, in Bitcoin, miners have to solve complex algorithmic problems to get the writing turn of the block. Miners are also rewarded for encouraging the mining process in some DLTs.

F. Transactions per second

The number of transactions in one second, as a measuring concept, is called transactions per second (TPS). It is used for all kinds of actions in the computational field as TPS. In this paper it is used to measure the duration of between two transactions of DLTs. TPS affects speed, energy consumption of DLTs.

G. Validation of transactions

The action of checking or proving the validity or accuracy of transactions. Verification is done in the network if transactions and records are valid, consistent and conform to the set of rules in the system. Some DLT types rule that validated transactions can never be reversed. Validation of transactions can affect immutability of DLTs.

H. Energy Efficiency

Concept of decreasing energy bills, and increasing sustainability by getting the same result with less energy consumption is called energy efficiency. Although power is a must for DLT systems infrastructure it is possible to reduce waste of energy by choosing better options for DLTs.

I. Security

It is stated as being free from danger or threat. Cryptography, hashing algorithms and public/private keypairs are used to provide security in DLTs. It signs and encrypts messages (transaction) with public/private keypair. When the message is sent to the network, the encrypted version can be seen by other nodes. This is called asymmetric cryptography and DLTs' security depends on it. Based on ledger implementation scale key size varies.

J. Scalability

The capacity to be changed in size or scale in a system is called scalability. If a DLT don't structured on the correct requirement, the need to store all data pertaining to that DLT, may grow to be unmanageable in size for individual end-users.

K. Platforms

Technologies or groups that are using DLTs for their applications, processes.

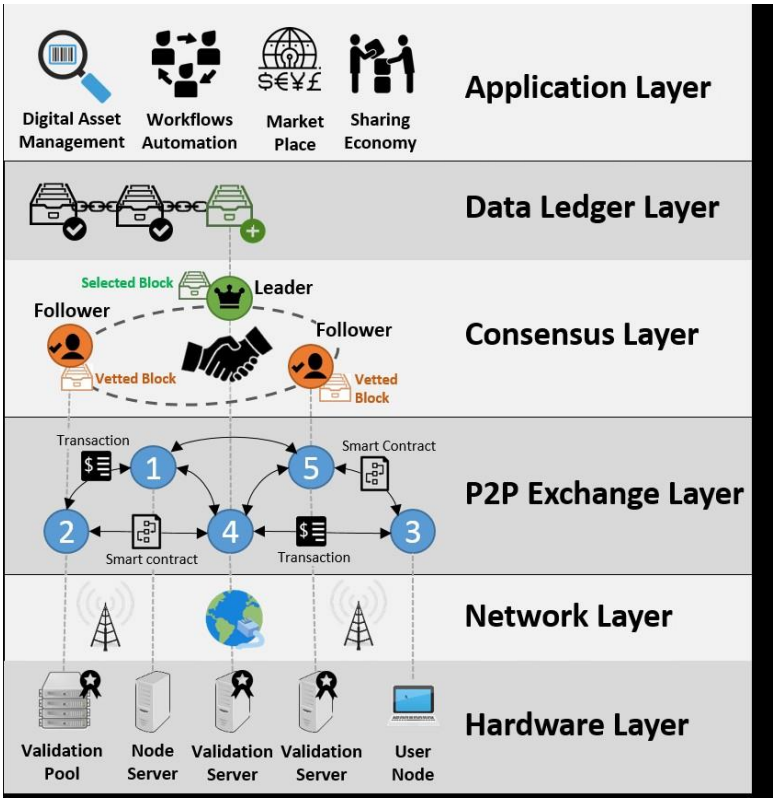


Figure 2: Blockchain high level architecture (graph from: Omar Dib et al, Consortium Blockchains: Overview, Applications and Challenges, iariajournals, Sept 2018).

Types of DLT

Blockchain Features

- Immutability: Since validation of transaction is irreversible and one valid chain exists, that ledger cannot be changed. This makes the system immutable.
- Enhanced security: Due to its infrastructure and cryptographic methods used it's very hard to interfere with this DLT type.
- Consensus: First blockchain application launched with PoW consensus. However, the consumption of energy led producers to use alternative consensuses. Currently it supports a wide range of consensus algorithms that help the nodes to make the right decision.
- Mining: Similarly, it started with Bitcoins mining algorithm. Nowadays participants have the ability to mint new tokens via different consensus algorithms.
- Transactions per second: Highly limited in terms of scalability and TPS
- Data Structure: Hash of current and previous block, time-stamp and data is the basic elements of a block. These blocks added to each other and created blockchain after validation by miners.
- Validation of Transactions: A transaction can be validated or canceled by miners in the network.
- Time of launch: Despite the first known blockchain proposal being launched in 1982 by

cryptographer David Chaum, popular usage and common knowledge of real-world application blockchain was Bitcoin in 2008.

- Speed: Slow to medium speed
- Platforms: ethereum, corda, hyperledger fabric

Directed Acyclic Graph(DAG)Features

Connection directed in one-way and with none cycles is called directed acyclic graph generally. This means irreversibility of blockchain provided by benefits in transaction rules, is coming from the data structure of DAG itself. All nodes in the network can commence transactions in DAG, however benefits in transactions is only probable if the nodes confirm at least two prior transactions on the ledger. Validation of recent nodes is formed by a process which arbitrarily selects the two transactions of interviewee nodes and checks them with valid node's transaction records. However, a process randomly selects the prior two transactions for each participant to validate. Due to measurability facilities, this DLT type is appropriate for large volume transactions including systems.

- Scalability: Validation time reduces as the number of nodes in the network increases. In theory it can reach an infinite extent of scalability for this reason.
- Micro-Nano Transaction: Every transaction in the network is confirmed by the nodes without any size restriction. Thus, even micro and nano transactions are confirmed directly.
- Quantum-resistance: Conjointly DAG uses one-time signature (OTS) that is difficult to break in even using quantum-computers.
- Parallelly lined transactions: Another feature increasing speed of the transaction. Validated transactions are aligned parallel with alternative transactions. To prevent maintenance problems there are some regulations in the structure.
- Mining: All nodes in the network act like miners and verify transactions to attain consensus. This provides high speed.
- Transactions per second: Unique data structure via directed acyclic graph guarantees that scalability and TPS are high.
- Data Structure: Each transaction is independent owing to directed acyclic graph structure.
- Validation of Transactions: The efficiency of a present transaction depends on its capability to validate two prior transactions.
- Everything as a Service: Any device with a chip can work as a service. Conjointly computational power, PC storage, Wi-Fi bandwidth, etc. can also be leased.
- Time of launch: IN 2013 NXT is launched as a DAG-based payment network.
- No Transaction Fees: It does not charge any transaction fees from their users.
- Platforms: NXT, Iota, byteball

Hashgraph Features

Hashgraph was invented in 2010 by a computer scientist Dr. Leemon Baird, also founder of Swirlds. Hashgraph is patented technology for an authorized ledger which is called Hedera Hashgraph. It was aimed to propose a solution for the scalability issue in the blockchain. DAG's structure for speed and PoS's voting mechanism for security are used in hashgraph. Addition to them, time-stamping is shared to the nodes in the unpredictable order which makes the system 'fair'.

- Enhanced Fairness: Compared to other DLTs, hashgraph has the most reliable consensus algorithm. Time-stamping architecture makes it so special. Each transaction is distributed to the nodes in a random order. Hence, any adversarial attempt to

manipulate transactions is not possible. To verify the transactions, all time-stamps in each node are going through a process and calculated with an algorithm.

- Gossip about gossip: History of the ledger is meant as gossip here. Therefore, nodes exchange what they tell to whom in the past. It makes the exchanged information very small, not more than a few bytes, which provides speed. Same as the gossip algorithm, gossip about gossip is made randomly. Gossip spreads binary, so as the network grows, the time required for a transaction decrease. Nodes randomly gossip about what they know with the other nodes to spread to information until every node knows the information.
- Virtual Voting: Prediction of what other nodes would have been voted for is what virtual voting is. Very basic and efficient way of verification. When the transactions reach a specific number, determined in the structure, each node checks its data, which is collected from gossip about gossip protocol. Since all nodes have the history of other nodes, it is possible for that node to predict what the other nodes are kept in their ledger. If a malicious node tries to interfere it is detected by other valid nodes during voting. Vote of majority is accepted as valid in the ledger. With virtual voting also zero bandwidth is used.
- Mining: Energy consumption free mining is possible with DAG structure.
- Transactions per second: Contrary to blockchain, as the number of nodes increases, TPS decrease in the network.
- Data Structure: Virtual Voting and Gossip about Gossip ensures that transactions are validated by the majority. The ledger logs down every gossip sequence on the network in an orderly fashion.
- Validation of Transactions: Validation of transactions is as per consensus.
- Time of launch: Available for public use as of August 24 2018.
- aBFT (asynchronous Byzantine Fault Tolerance) = the highest degree of security a consensus algorithm can provide.
- Energy efficiency: Hashgraph is more than hundreds of thousands of times more energy efficient than blockchain. Due to its consensus algorithm, transactions can be done constantly with 100% efficiency.
- Speed: Very fast up to 500.000 transactions per second.
- Security: Asynchronous byzantine fault tolerance (aBFT) is claimed as the best security measure. All participants, none of whom trust each other, have to come to an agreement for validation of a transaction. When a participant reaches a decision, it's irreversible. Then all participants have to do a mathematical calculation to ensure all participants reach the same agreement in their computer without using any bandwidth. Eventually they decide if that transaction is valid or not. Decision of majority accepted as correct.
- Platforms: Hedera, noia, minga

Holochain Features

Holochain is a technology that is totally different from all other DLTs, and offers improved transfer and data storage. There is no consensus algorithm in this DLT because every node has its own chain locally. It's inspired by nature and it has no consensus in self. Just two parties involved in that transaction keep the record of that transaction in their local chain. All of the records are cryptographically signed by two sides to provide security.

- Agent-centric: Agents mean nodes and they can run their ledger in their local computer without any consensus forced.
- Energy Efficient: Energy consumption of DLTs comes from running complex consensus algorithms, spreading data to other nodes and so holochain doesn't have none

of these, it's much more energy efficient.

- True Distributed Ledger: Each ledger is kept and maintained in local computers so this is only true distributed ledger launched.
- Configurability: Since participants control their own data in this DLT, user empowerment is provided. It is possible for each app to have its protocols, standards, and choice of the consensus algorithm. This means that every dApp created on the chain can maintain a customizable interoperable network.
- Microservices: Every node, which keeps its own chain, also serves for a bigger purpose of the system. As a server, bridge, edge for a network they all work voluntarily. When it's considered there's a big network, there is no big burden for nodes and the network can even work when the nodes are offline.
- Mining: Nodes run on individual chains hence miners are not needed to validate transactions.
- Transactions per second: Each node processes its own ledger hence limitless scalability and TPS. Only limit is the local computer's capacity.
- Data Structure: Data is not distributed through nodes. They are stored in local chains and one public center of holochain
- Validation of Transactions: Validation is not a process since every transaction is kept in local chains.
- Time of launch: Alpha1 product released on May 26, 2018.
- Platforms: holochain

Tempo Features

- Sharding: Every node on the network keeps a shard (smaller section of the global ledger) with a unique ID.
- Gossip Protocol: Nodes send out all their information to synchronize their own shards.
- Logical Clocks: Rather than time-stamping the transactions, this DLT remembers the sequence of the transactions to reach consensus.
- Platforms: radix

SWOT Analysis of DLT Types

Blockchain is the first invented and developed distributed ledger type in all. There are many commercial decentralized applications (DApp) based on blockchain. For the beginners and last users, blockchain could be the best DLT type since there are plenty of sources and examples of it. Yet, it is the slowest and most expensive one.

Dag is a good option for industrial usage of DLT. Since it doesn't have mining there are no transaction fees. It provides quantum-resistance since it has one time used signatures. The possible problem with DAG is scalability. Quite the contrary of blockchain DAG scalability improves when the network grows. So, for small projects it might be a problem to use this type. And even though transaction per second is better than blockchain, it's the second slowest DLT type.

Hashgraph reduces computational burden through its unique consensus mechanism. It's also the second fastest DLT type. However, it's created by a professor and now controls this DLT type in one company and this can cause some trust issues in the future work.

DLT TYPE / PROPERTIES	Blockchain	DAG	Hashgraph	Holochain	Tempo
Mining	Participants have the ability to mint new tokens via different consensus algorithms	The previous transaction validates the succeeding to achieve consensus. No new tokens to discover	Nodes create energy-intensive mining	Nodes process their own ledger hence there is no need for miners	Developer Royalty System
Transactions per second	Highly limited in terms of scalability and TPS 4 to 7 TPS	Unique data structure via directed acyclic graph ensures that scalability and TPS are high 500 to 800 TPS	Unique consensus mechanisms reduce computational burden hence high scalability and high TPS. >200.000 TPS	Each node processes its own ledger hence limitless scalability and TPS. infinite scalability	More nodes increase the number. 20.000 TPS
Data Structure	Data structured in blocks in order of transactions which are validated by miners in the ecosystem.	Data structure follows the directed acyclic graph mechanism where each transaction is independent.	Virtual Voting and Gossip about Gossip ensures that transactions are validated by the majority.	Data is distributed among various nodes on the platform hence there is no problem of network congestion.	Every node on the network keeps a shard (smaller section of the global ledger) with a unique ID.
Validation of Transactions	Miners have the power to postpone a transaction or cancel it entirely.	The success of a present transaction relies on its ability to validate two previous transactions.	Nodes do not have to validate the transactions. Validation of transactions is as per consensus.	Distributed hash table (DHT) sends transactions to random neighbours for validation.	The system only processes transaction if, for every input object with a validated owner , the owner validates the transaction.
Speed	Slow comparing to other DLTs	Faster than blockchain	Very fast, more than BC, DAG and Tempo	Very fast since ledgers are locally process and validation is random	Faster than BC and DAG
Energy Efficiency	High energy consumption comparing other DLT's	More energy efficient than BCT	As there is no consensus algorithm for mining, you don't have to waste powers	The different nature of the ledger makes the system much more energy efficient than others.	Energy efficient
Consensus	PoW, PoS, etc.	Pow, GoF(Grades of finality)	aBFT(asynchronized Byzantine Fault Tolerance)	Agent-centric instead of data-centric	Cerberus(aBFT, PBFT)
Security	Hacking this DLT is nearly impossible due to its decentralized nature and cryptographic encryption.	One time used signatures make structure quantum-resistant	aBFT makes it robust against the cyber-attacks	Every node on the network maintains their own ledger, which creates a true distributed system.	Message authentication codes, digital signatures, or threshold signatures
Accessibility	Private, public, hybrid	Public or Private	Public or Private	Private	Public
Protocol	Bitcoin, Corda, Ethereum	Gossip protocol	Gossip about Gossip & Virtual Voting	Hydro Protocol	Multi-shard transaction processing protocol variants using the original Cerberus protocol
Scalability	Scalability issue with increasing number of nodes. It needed to be downloaded all ledger to become a valid node.	Scalability improves as the network grows.	Only 128 bytes of data need to be downloaded which contains events and signature.	No scaling limit	Unbounded scalability
Expenses	High transaction fees	No transaction fees	USD $0.0001	Almost non-existent	Very low currently
Time of Launch&Platforms	2008 Ethereum, Bitcoin, Corda	9 Nov 2015 Iota, byteball	24 Aug 2018 Hedera, noia, minga	26 May 2018 Holochain	2012 Radix

Figure 3: DLT types and properties.

Holochain offers the best solutions to all imaginable problems with infinite scalability, fast structure by local processing and a true distributed system by every user having their own ledger. Only problem with holochain, because it wants to change the whole internet concept rather than offering an adaptable solution to the existing environment, it doesn't look applicable for commercial use.

Tempo, although better than most of the other options, because it doesn't have enough sources about it, it is hard to be evaluated as an option for industrial use. In theory, it has a different sharing structure which gives high scalability and security to this DLT type.

DLT Type Selection Proposal for Design Team

Distributed ledgers are needed to be chosen carefully depending on usage areas. In the AECO-FM industry there are numerous departments, teams and responsibilities for every phase. There is limitless information in every project for each department and keeping track of these connections is vital for information security. To make the correct decision of DLT type, it is needed to evaluate every information and every project separately depending on the priorities.

Problem of the BIM model is that the data cannot be controlled strictly in project phases by stakeholders, therefore the quality of the BIM model and included documents are limited and disordered. Redefining structure of the BIM, data storage, data update and data transfer, is the solution proposal of this paper. Lack of security and trust in the BIM structure will be improved with this new way of data sharing and storing method. Decentralized decision- making processes and even no administration systems can be possible with this kind of solution.

To sum up, digital twins will be in common use sooner than thought. That's how the dangerous and long processes can be handled more securely and in the short term. One big issue with digital twin technology is the way of information sharing and storing. Distributed ledgers offer many options for different usage purposes. As in other areas of technology, it is critical to determine the needs and priorities in the selection of DLT. Since the project in question is information security, it would be more rational to prefer applicability and security rather than speed. Most prominent type of DLT is DAG with its nano-transaction structure. Also, since there is no mining it's free. With the high level of configurability, DAG can be transparent and private at the same time. Yet, different DLT types can be chosen for one project but different parts of it through its interoperability structure. Even though many practices are required in the field, it would not be wrong to say that it is a groundbreaking development already.

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Development of BIM-Based 3D Visualization and Quantity Take-off Calculation Software

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Abstract

Determination of the material requirement and cost of a construction project is the most important part of the design process. Presently, quantity takeoff and cost estimation can be made much faster than traditional methods by using Building Information Modeling (BIM) software. However, the quantity take-off data obtained by considering only the geometric shapes without determining the intersections of the structural and architectural elements with each other cannot have satisfactory accuracy. The state-of-the-art BIM software cannot detect the dimensions of the intersection exactly. Most of the software implemented through the BIM process have different processing style because of the computational differences occurred in many countries. In addition, the licensing fees of BIM software are quite expensive. Therefore, through the implementation of BIM process, conflicts may arise due to the local legislation. Therefore, in this study, it is aimed to develop a software that helps the BIM process, which calculates the concrete, formwork, formwork scaffolding and reinforcement quantities of a building by taking into account the semantic representation of the elements that make up the structure, and performs the 3D visualization of the structure, using the free and open source python programming language. In this context, a drawing interface is created and the geometric dimensions of the structure are defined by drawing with the mouse. In addition, by creating data entry boxes, the material information and mechanical properties of the building elements are defined. The developed software is tested on a 2-storey reinforced concrete building and the calculated quantity take-off values are checked manually. As a result of the experiment, it is determined that the amounts of concrete, formwork, formwork for the scaffolding and reinforcement are calculated exactly. The analysis results show that cost-effective BIM software that Turkish contractors can safely use through the management of the construction process can be developed if the capabilities of the software is improved.

Keywords: *building information modeling, quantity takeoff, python programming language, 3D visualization.*

Introduction

Project management of construction activities is tiresome because there are significantly many work items to control and manage. In addition to this, every quantity take-off tasks and construction scheduling have to be prepared from the beginning because construction projects and management of them are unique endeavors. BIM is a convenient tool for the construction

firms to execute the construction management related tasks such as quantity take-off and scheduling. BIM software can execute project management endeavors which were executed by much software in the past. Preparation of technical drawings, quantity take-off, and the schedule of the construction tasks can be given as examples that are performed by different software. Execution of project management tasks on sole software has important benefits for the contractors and the engineers as it reduces the risk of malfunctioning data extraction, incompatibilities caused by the version differences, and rework of the prepared documents.

BIM is a developing subject and in the literature there are important contributions to the BIM implementations. BIM is implemented by the academic and practical purposes as well as and certification intentions (Kalfa, 2018). Omaran et al. (2019) performed life cycle cost analysis of a building. The construction of the building is 4D simulated by a game engine. During the construction both the construction and operation costs of the constructed utility are simultaneously computed. Delgado et al. (2020) investigated the implementation of Augmented Reality (AR) and Virtual Reality (VR) by the Architecture, Engineering and Construction (AEC) sectors. Four discussion groups are formed and each group examined the benefits, complexities, difficulties, and the deficiencies of the state-of-the art AR and VR technology. The discussion groups revealed that the AR and VR technologies are not used effectively by the AEC participants. Ozcan-Deniz (2019) interviewed 18 construction firms to identify the possible applications of VR. Sarı and Pekeriçli (2020) investigated and compared the legal issues on the implementation of BIM in Turkey and in USA and UK. Temel and Başağa (2020) analyzed the code compliance checking from the data extracted from Industry Foundation Classes (IFC) file format. The study revealed that BIM models and software is appropriate for the detection of code violations without human endeavor.

Adobe Acrobat Reader version 9 or later enables visualization of 3D drawings. Nadeem et al. (2015) prepared 3D models on Autodesk 3DSMax and embedded them to Adobe Acrobat Reader pdf files. The mentioned file extraction allows rotation as well as zooming in and out on the 3D drawings of a building by Adobe Acrobat Reader software. As a result the 3D visualization of the building can be examined on site by tablets or mobile phones. Sacks and Barak (2007) states that 3D modeling decreases the design and drawing errors. Moreover, 3D drawings provide shorter delivery time, increase the efficiency and reduce the costs.

Millman and Aivazis (2011) state that Python programming language is an opportunity to write codes for the engineering applications. The ability of handling complex numbers, easiness of plotting and graphics are some of the advantages of the programming language. Quraishi and Dhapekar (2021) investigated the difficulty level of programming on Python and stated that instead of using spreadsheets for the necessary computations for the construction site management, the same computations can be programmed on Python language easily by the civil engineers. Sarvade and Pore (2019) developed reinforced concrete beam design software by Python. The study briefly utilizes the NumPy, SciPy, Pandas, and Matplotlib libraries of Pythons programming language.

Bettemir (2018) developed a procedure to decrease the difficulty and workload of quantity take-off computations of excavation, concreting, and formwork tasks. The developed algorithm is executed on spreadsheet. Khosakitchalert et al. (2019) implemented Dynamo software version 1.3.3.4111 to prepare quantity take-off of construction items such as walls and floor coverings. Lee et al. (2014) computed the QTO and construction cost of tiling construction item by automated inference process. Choi et al. (2015) developed a schematic QTO estimation process for the preliminary design stage of the buildings. The data is

extracted from IFC model to Open BIM software. Liu et al. (2016) implemented ontology-based semantic approach for QTO. Entity relationships among the construction items are formed and related materials and workmanship which constitutes the ontology is computed. In addition to geometric and topological relationships host relationships such as a wall can host a lintel or window is defined. Voids of quantity take-off are computed by database queries. The proposed system enabled faster and more accurate QTO.

Benefits of the utilization of BIM software is investigated by Olsen and Taylor (2017). The researchers conducted a survey and the respondents stated the advantages of BIM as fast QTO preparation, and more accurate QTO than manually prepared QTO. The disadvantages of implementation of BIM are stated as complexity of BIM software and possibility of entering outdated data.

Kim et al. (2019) investigated the inconsistencies of the computed QTO values caused by the definition of object models. Compositely modeled object and individually modeled object definitions are investigated and the study concludes that compositely modeled object definitions may cause up to 6% deviation from the exact QTO value. Individually modeled object definition contains more detail and thus provides better results.

Liu et al. (2022) developed a knowledge model based quantity take-off model in order to eliminate the inability of the state-of-the-art BIM software which does not enclose all the necessary data for precise automatic quantity take-off (QTO). The study suggests defining different types of slab-wall; slab-beam; slab-column and slab-wall joint connections. Consequently, better QTO estimations are obtained. Bettemir et al. (2021) prepared a quantity take-off estimation procedure for the volume of the excavation tasks. The literature review illustrates that the construction sector utilizes BIM mainly for the quantity take-off computations and visualization of the state of the construction. This situation motivated the authors to develop BIM software capable of executing the mentioned tasks. In the remaining part of the study, the methodology of quantity take off of concrete, formwork, and support for the scaffolding is described. In the fourth section a case study is performed to implement the developed software. In the final section the results and the findings are concluded.

Methodology

Exact quantity take-off algorithms of concrete, formwork, reinforcement, formwork scaffolding of a reinforced concrete structure is developed. In addition to this, 3D visualization of the 2D structural drawings are established. The developed algorithms are programmed on Python programming language, Sqlite3 database engine and Ursina game engine and software created. The software is tested on one story structure. An overview of the intended method framework is presented in Figure 1.

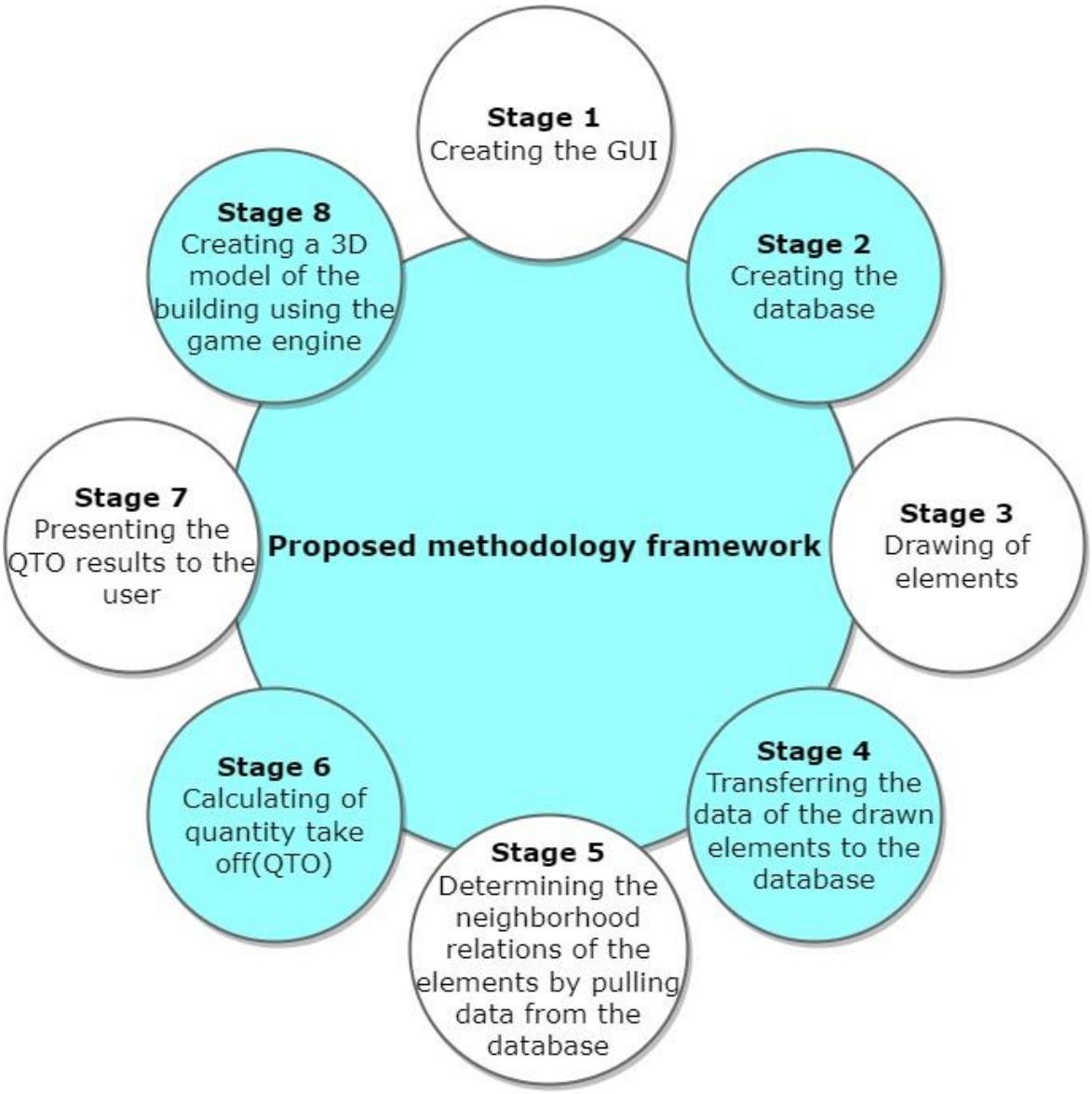


Figure 1: The framework of the developed quantity take-off and visualization software.

Creation of the Graphical User Interface

The Graphical User Interface (GKA) is built by Tkinter library which is the standard GUI development library developed for the python programming language. Using the Tk, Canvas, Frame, Button, Entry and Label classes in the Tkinter library, the GUI window, buttons, panels and drawing area in the window are created. By creating pop-up windows for column, beam and floor elements, the user is able to enter the geometric and material properties of the relevant element.

Creation of the Database

The execution of quantity take-off calculations and material as well as resource requirement computations require a database to manage and retrieve data about the drawn structure. SQLite database development library is used for the developed software. In addition to this,

job definitions of concrete, formwork, and support for the scaffolding are defined and stored in the database. The defined job definition tables are joined by the relevant construction activities for material and resource requirement computations.

Drawing the Structural Elements

Axes of x and y directions are defined in the drawing area to determine the nodal points of the elements as the first task of the drawing process. After this step, the required structural elements are created by pressing the "DRAW" button in the main window. The material and geometric properties of the elements are entered by the pop-up window. The user enters the mechanical and geometrical properties of the structural element by the pop-up window. The software starts the drawing process by mouse when the user completes the data entry process and approves the entered data. The structural elements are represented by two points which are located at the top left and bottom right corners. 2D model of the structural element is drawn by clicking on the aforementioned two nodes one after the other. The drawing of the structural elements completes the data entry process of the element. The drawing process is continued until all of the structural elements are drawn.

Creating the Database

All the features of the drawn elements must be stored permanently which enables editing, retrieving, deleting, and performing any kind of queries and analysis with the data. The entered data related with the structural elements are stored in data tables which includes the data about the unique id, position, dimensions, and properties of the elements. The data tables are formed by the Sqlite3 database engine. The created data tables are identical to each structural element type, because the data type and features are unique for each element type. For example, the data table containing the properties of the column elements is named column.db, while the data table containing the properties of the beam elements is named beam.db. The data stored in the database is used to construct the semantic relationships between the structural elements. The mentioned relationships will be used to calculate the quantity of contact in terms of length, area or volume. With the help of the database, the management of the data is realized in a more organized way. The database is created by the connect() method in the Sqlite3 library. Then, a cursor is created with the cursor() method to interact with the database. After the created cursor, adding, deleting operations or updating the data can be performed with the execute() method. The transaction in the database is committed with the commit() method and the database is closed with the close() method. In Figure 2, the code script of the function that deletes the data of a beam from the beam.db database is presented. By entering the number of the beam as the parameter of the function, the relevant beam is deleted from the database.

```
5  def delete_beam(kirisNo):
6      con_2 = sqlite3.connect("beam.db")
7      cur_2 = con_2.cursor()
8      cur_2.execute("DELETE FROM beam WHERE kirisNo ='" + kirisNo + "'")
9      con_2.commit()
10     con_2.close()
11
```

Figure 2: Execution of delete operation in the created database.

Determination of Semantic Relationships

Determination of the semantic relationships between the structural elements is extremely important to detect the topological relationships. These relationships are used to detect the contacts between the structural elements. The amount of contact in terms of length, area or volume is used to compute the amount of voids in the quantity take-off calculations. This ensures the prevention of repetitive calculation or omitting the quantity of the structural element. The neighborhood relationships of the elements is determined by the *find_overlapping()* method of the Canvas class. The coordinates of the region covering the element are determined by using the coordinate data of the element whose neighbors is to be determined. The mentioned parameters of the elements are entered as the parameter of the *find_overlapping()* method. Then, the neighboring elements are detected. The type of elements is determined by the tag parameter assigned while drawing the element. To illustrate, it is stated that the type of the relevant element is a column by stating "*tag = column"* in the tag of the command. Thus, the types of elements are easily determined while determining the neighborhood relations. Determining the neighborhood relations reduces the error rate, especially in the calculation of formwork quantity.

Quantity Take-off

The geometric properties, material properties and coordinate information of the structural elements are retrieved from the database before the quantity take-off calculations are made. The retrieved data is specific for each construction item whose quantity take-off is to be computed. To illustrate, the volume of the structural element is calculated to determine the amount of concrete necessary to construct the element. The intersection amounts between the columns and the slabs are detected. This data is used to compute and deduct the amount of voids. The unit of concrete is m^3.

The lateral areas of the structural elements are calculated in order to determine the amount of formwork. The obtained quantities are represented as gross area since some of the computed area contains the contact locations of the structural elements where formwork will not be applied. The detection of contact surface involves determination of neighboring beam-slab, column-slab, and beam-column neighborhoods. This task is achieved by logical queries among the structural elements. The contact area is computed by considering the positions and dimensions of the neighboring structural elements. Then, the amount of formwork is calculated by subtracting the lateral area of the surfaces in contact with the neighboring elements from the gross formwork amount.

The volume occupied by the structure is calculated to determine the amount of support for the scaffolding. The concrete quantity of the corresponding floor is subtracted from the volume of the floor. The unit of the support for the scaffolding is m^3.

The number of reinforcements for each structural item is calculated using the data related with the reinforcement quantity (reinforcement area, etc.) which is received from the user. The amount of reinforcement is computed by taking into account the restrictions on the number of reinforcements, reinforcement spacing and reinforcement ratio represented in TS500 and TBDY 2018. The spacing length is used to detect the number of reinforcement bars and

stirrups. The length of the reinforcement bar is computed by considering the neighboring structural elements. To illustrate the longitudinal reinforcement bar placed in a beam should elongate into the neighboring beams. The semantic relationships are used to detect the neighboring beams and their spans. After the detection of the length and the number of the reinforcement its quantity is computed in kg.

3D Visualization

In order to create a 3D model of the structural elements that constitute the building, the geometric properties and coordinate data of each element are retrieved from the database. The 3D model of the element is created using the *Entity()* class in the Ursina game engine. In the *Entity()* class, the position parameter is assigned as the coordinate information of the element, and the scale parameter is assigned as a tuple data type in the form of the element's width, height and height information (x, y, z). A sky object from the *Sky class* and a *camera object* from the *EditorCamera* class are added to the environment after the 3D model of the building is created. The 3D model of the structure can be scrolled, zoomed in and zoomed out, and the model can be viewed from the desired angle by the created sky object and the camera object. The mentioned utilities of the Ursina game engine provide important simplicity for 3D visualization. In addition, a first-person shooter can be created from the *FirstPersonController* class to navigate through the structure.

Case Study

Quantity take-off calculations of the formwork, concrete, reinforcement and support for the scaffolding as well as 3D visualization of a reinforced concrete structure are made in order to test the software's ability of quantity take-off computations. Moreover, construction of neighborhood relations, determination of contact areas and 3D visualization algorithms are also examined. The structural plan of the first floor is given in Figure 3. The formwork plan represented in Figure 3 is drawn by the developed software.

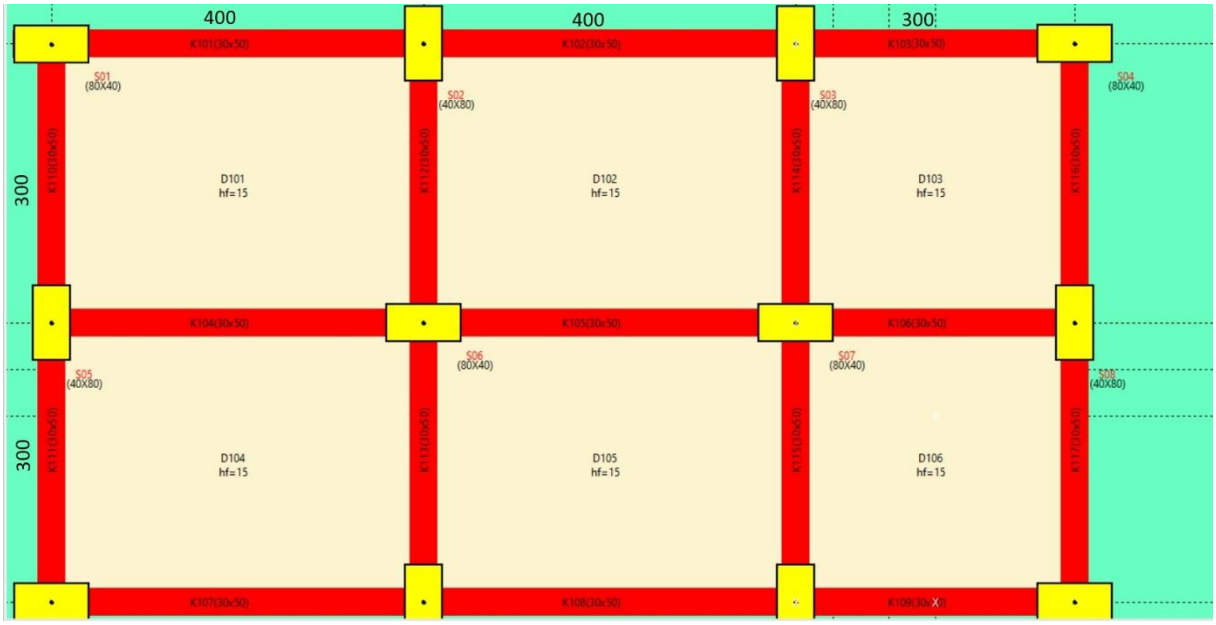


Figure 3: Structural elements of the case study problem which are drawn by the developed software.

Material information such as the concrete type of the structural elements, the yield strength of the steel and the maximum grain diameter of the concrete, as well as the number of floors and story heights are entered in a separate pop-up window opened by clicking the Building Information button. The geometric properties and other material properties such as the preferred rebar diameter are entered through element-specific pop-up windows before the drawing of the each element.

The coordinate data of the elements are detected according to the x and y pixel positions of the clicked points during the drawing process. All properties are transferred to data tables created for the each element type. The relevant quantity take-off algorithms are run and the quantity take-off results in .xls format are presented when the Beam Analysis, Column Analysis, Slab Analysis and Q.Takeoff buttons on the GUI are pressed. The results can be examined by opening the meter scales named .xls with the MS Excel program.

To illustrate the drawing process as shown in Figure 4, the "Beam" button is pressed to draw the beam element. Then, 3D drawn elements models are created automatically and displayed as in Figure 4 when the "3D" button on the GUI is pressed.

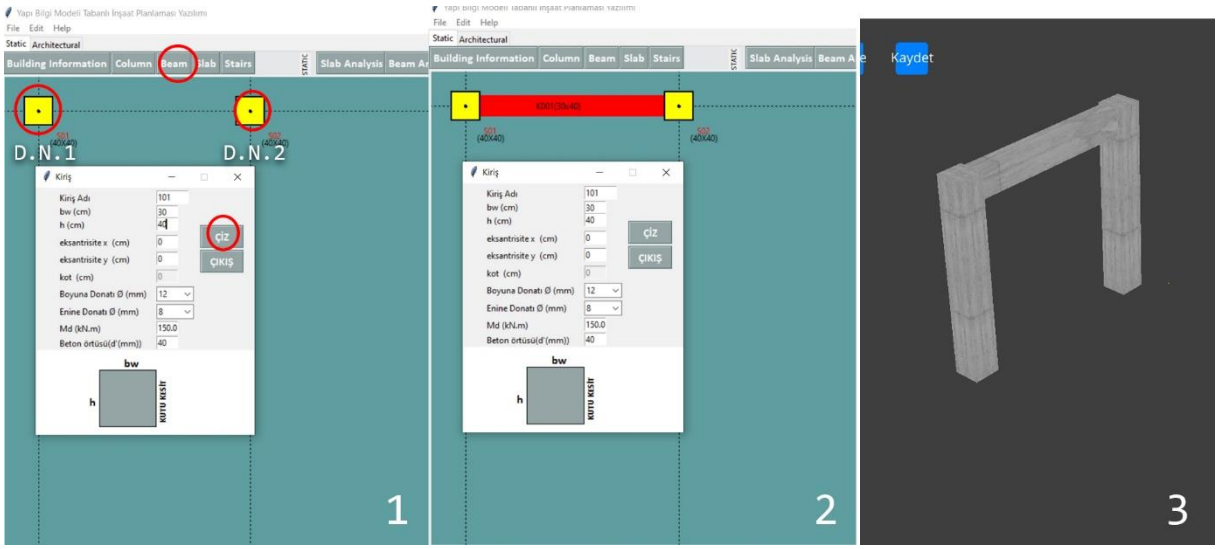


Figure 4: Representation of drawing and 3D visualization of column and beam structural elements.

By pressing the 3D button on the GUI, the 3D model of the structure is automatically created. The created 3D model can be examined and navigated by the user. The 3D model of the structure can be examined by scrolling, zooming in and out on the model in line with the capabilities of the Ursina game engine. The user can walk inside the building and navigate using the keyboard arrow keys and mouse. In Figure 5 and Figure 6, uncoated and concrete patterned 3D models of the structure are displayed. The figures are created after pressing the 3D button. Then the illustrated screenshots presented in Figures 5 and 6 are obtained.

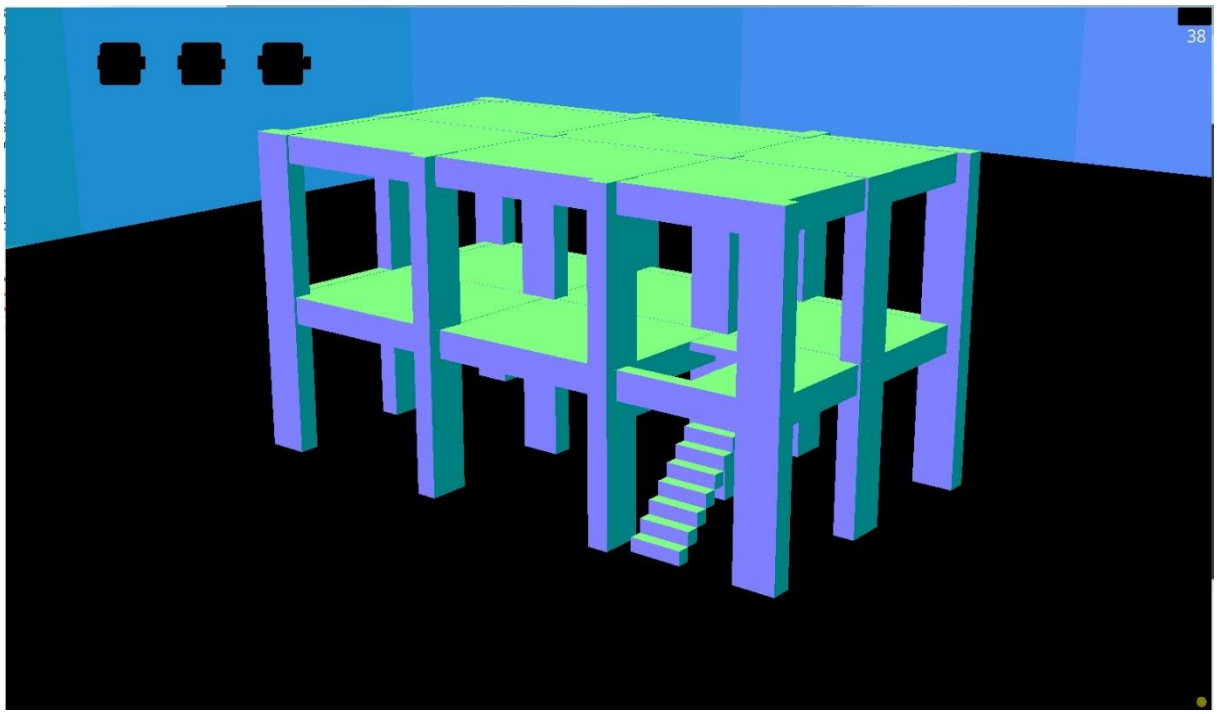


Figure 5: 3D visualization of the structure without concrete pattern.

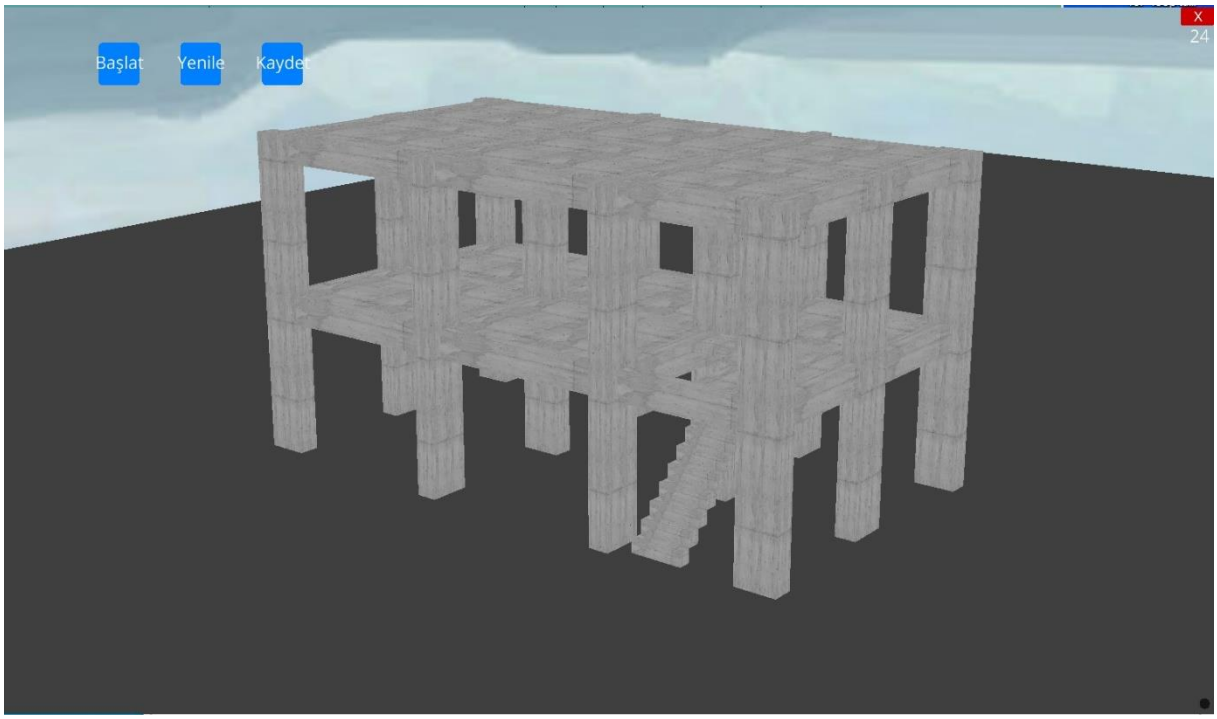


Figure 6: 3D Visualization of the structure with concrete pattern.

The developed software executes the quantity take-off algorithms and computes the quantity take-off of concrete, formwork and support for the scaffolding construction items. The results are presented in Figure 7 as the screenshot of the software. The represented data can also be extracted as excel file.

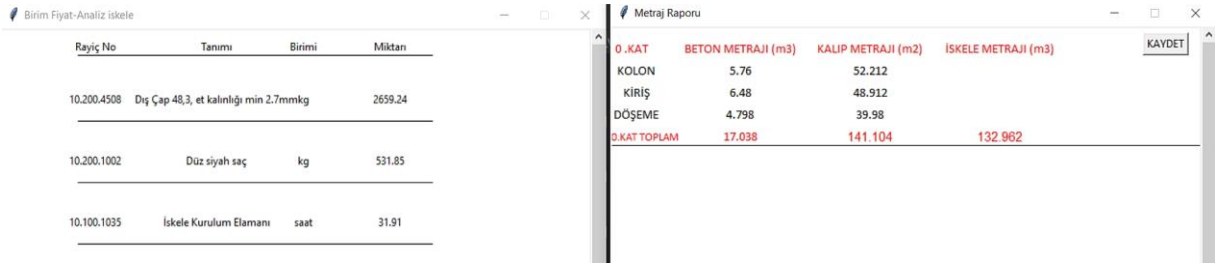


Figure 7: Results of quantity take-off computations and material requirements.

Conclusion

In this study quantity take-off software which can obtain the dimensions of the structural elements by drawing interface is developed. The software can accurately compute the quantity take-off of concrete, formwork, reinforcement and support for the scaffolding construction items. The quantity take-off results of the software is checked by manually computing the mentioned quantities and it is seen that the obtained results are exact. The developed software can perform 3D visualization of the drawn structural elements in 2D. The height or thickness data are adequate for the construction of the 3D model of the structural elements. The user can walk through inside the building by navigating the arrow buttons on the keyboard. The visualization and the quantity take-off computations should be extended to cover other construction items related with buildings as future study.

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Development of a Roadmap for The Systematic Implementation of Artificial Intelligence in Construction Companies

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Abstract

Productivity stagnation and process inefficiency is a pervasive problem in the construction industry. Many processes are manual, resource-intensive and have a high potential for failure. At the same time, in the course of digitalization, new technologies were developed that can mitigate the existing problems.

The aim of the paper is to present a roadmap for the systematic implementation of Artificial Intelligence (AI) in a construction company. The roadmap considers implementation from a procedural, organizational and information technology perspective.

Based on literature research, the use of AI in other business sectors is shown. Additionally, existing approaches of the technologies in the construction industry are identified. The next step is to conduct expert interviews. Based on the interview results, the roadmap is derived. Furthermore, recommendations as minimum standards for the implementation of AI systems in the context of the use of the roadmap are defined.

The roadmap serves as a strategic framework for construction companies for a qualitative implementation of AI systems in the company structures.

The results of the article show the potential of AI in construction companies and the necessity of a uniform procedure plan to support the AI implementation, presented in a roadmap.

Keywords: *artificial intelligence, construction company, roadmap, strategic implementation.*

Introduction

In a direct comparison with other industrial sectors, the construction industry is characterized by poor productivity, inefficiency and a low level of digitalization. However, this dilemma has not just existed recently, but has been prevalent for several decades (Barbosa et al., 2017;

Adwan & Al-Soufi, 2016; Jäkel et al., 2022). In the course of Industry 4.0, artificial intelligence in particular is seen as playing a key role that can contribute to the further optimization and digitization of the global economy. These added values have already become noticeable in other sectors of the economy, for example in the service sector and manufacturing industry, through successful implementation of the technology (Buhgin et al., 2017; Abioye et al., 2021). Even in the conservative construction industry with its hands-on mentality, artificial intelligence has gained importance in recent years (Liu et al., 2019; Akinosho et al., 2020). Current research indicates that the use of AI technology is also constantly increasing in the complete construction industry and that there is a lot of potential (Darko et al., 2020; Pan & Zhang, 2021; Rampini et al., 2022; Sacks et al., 2020).

The potentials, areas of application and added value of AI are therefore known to the construction industry, but a uniform framework for the systematic implementation of AI technology for construction companies in their existing structures has been unavailable until now. This research paper closes precisely this research gap and develops a roadmap for AI implementation based on qualitative expert interviews and defines necessary minimum standards.

Related Works

The development of artificial intelligence has not gone unnoticed in the construction industry. Over the past year, several authors have examined the potential and opportunities that the implementation and use of various artificial intelligence techniques could bring to the construction value chain (Abioye et al., 2021; Hatami et al., 2022; Regona et al., 2022). These studies all come to the same conclusion that the construction industry should harness the benefits of artificial intelligence from the design phase throughout the construction phase till the operation of a structure. There is a wide range of artificial intelligence algorithms which can be categorized into seven subfields of artificial intelligence: Machine Learning (ML), Knowledge-based Systems (KBS), Computer Vision, Robotics, Natural Language Processing (NLP) Automated Planning and Scheduling and Optimization (Russell & Norvig, 2003). Recent literature shows, as Abioye et al. (2021) found, that especially Optimization attracted large interest among the scientific scene, followed by Machine Learning and Knowledge-based Systems. The research has condensed in the last decade, which shows the rapid growth of interest among researchers (Abioye et al., 2021). The adaption of the new technologies is confronted with a few challenges. Regona et. al. (2022) depict high initial costs for the implementation of artificial intelligence, security concerns, project uniqueness and the difficulties in information sharing, to name a few, as challenges inhibiting the industry wide introduction of artificial intelligence (Regona et al., 2022). Throughout the phases of construction projects, artificial intelligence can yield various improvements. In the following, exemplary AI applications are shown for each lifecycle phase of a building. In the planning phase, for example Artificial Neural networks or support vector machines can be used to accurately predict heating and cooling loads of planned buildings. Since the artificial intelligence algorithm only needs seconds for predictions, the energy planning could be implemented in real-time during the planning process, while established simulation tools use the finished design (Chou & Bui, 2014). Also, Artificial Neural Networks are used to increase the accuracy of cost estimations for engineering services of construction projects, which are often done by experts based on their experience (Matel et al., 2022). With the use of building information modeling, the planning data can be accessed in a more structured and uniform way. So, the review of the design in regard of clashes or compliance with regulations show potential

for integration of artificial intelligence (Hsu et al., 2020; Sacks et al., 2019). In addition, intelligent AI algorithms are also being used in construction to promote productivity and efficiency. Especially for safety aspects, artificial intelligence can create a healthier environment on construction sites. Computer Vision algorithms could be used to process data gathered by cameras and sensors which capture 2D and 3D images of a construction site. With the data an object detection and tracking algorithm could identify unsafe areas. (Lin et al., 2021; Oyedele et al., 2021; Seo et al., 2015) Further the use of robotics and automated systems on construction sites is fueled by the implementation of artificial intelligence. This is a huge opportunity to boost productivity of the construction industries. (Balaguer & Abderrahim, 2008; Davila Delgado et al., 2019) After completion and handover of the building, AI systems are used primarily for optimized management and maintenance of the building. Neural Networks can be used to improve decision making in facility management. Marzouk et. al. describes the use of artificial intelligence in facility management, which enables facility managers to maintain buildings in a more proactive manner. So expensive repairs or even sudden failure of the facility could be reduced (Marzouk & Zaher, 2020). Furthermore, Luo et al. (2019) propose a big data platform which uses artificial intelligence methods and sensor data to predict heating and cooling demands throughout a building. This information could then be used to run the building more efficiently.

As shown in the sections above, there is much potential through the use of artificial intelligence for the construction industry in different areas along the life cycle of a built structure. However, there is still no uniform framework for the implementation of AI systems in construction companies. The systematic application of the roadmap will facilitate access to the use of this key technology, minimize entry barriers and thereby enable AI systems to be implemented for all companies of different sizes. This strategic framework will be developed in this scientific article in the following subsections, hence closing the existing research gap.

Research Design

General Methodology

The scientific article consists of a total of three subsections - (i) state of the art, (ii) development of the roadmap, and (iii) derivation of company-wide minimum standards. In the first step, the general state of the art is determined by a literature analysis. This section was already described above. Based on this, the roadmap for the systematic implementation of artificial intelligence in construction companies is developed. The roadmap considers the implementation from a procedural, organizational and information technology perspective and also has a defined implementation timeframe. The basis for the roadmap development is the result of a preceding qualitative investigation in the form of expert interviews. Based on this, company-wide minimum standards for AI implementation are defined. The article ends with a discussion of the artifacts developed, a critical appraisal of the results and an outlook on the resulting research questions.

Structure of the Qualitative Study

To create a sound knowledge base for the development of the roadmap and to derive the minimum standards for the systematic implementation of AI in construction companies, a

qualitative study with semi-structured expert interviews was conducted. The interviews were systematically evaluated and generally valid statements for the roadmap were derived. As part of the semi-structured expert interviews, a total of thirteen experts were interviewed using a guide with semi-open-ended questions. The experts were selected from both academia and industry. The interviewees from industry were experts from the medium and senior management levels of construction companies. The representatives of science were specialists from the domain of computer science and artificial intelligence. This heterogeneous group of experts provides a holistic perspective on the subject matter and serves to generate knowledge at the process, organizational and information technology levels. The interviews were evaluated using content analysis according to Mayring and Fenzl (2019). The insights gained and generalized were used for roadmap development and the derivation of holistic, generally applicable minimum standards for implementation.

Development of the Roadmap

Fundamentals of Roadmap Creation

The development of a roadmap is understood as a creative analysis procedure used to forecast, analyze and visualize the basic steps of a development and implementation of technologies (e.g. products, services, etc.) and innovative methods. The roadmap aims to systematically implement corresponding products and technologies systematically in the future in a certain business area of a company. The basis of the roadmap development are the opinions of experts and involved persons with specific knowledge of the technologies or methods. The result is a future prognosis in which a path to systematic integration is presented in a visualized form. (Specht & Behrens, 2005). The roadmap is developed following the approach of Specht and Behrens (2005). It is defined as a mix model of a science and industry roadmap and comprises an ordinate (object axis) and abscissa (time axis) in the two-dimensional representation form. The ordinate contains a total of four object levels - processes, organization, data and application systems. On the one hand, this subdivision specifies the individual levels that need to be considered in the company, at the same time, clarifying their interdependencies for successful systematic implementation of the technology. The time axis (abscissa) reflects the defined period under consideration, which is derived on the basis of expert opinions. In addition, time dependencies are assigned to the individual object levels and subdevelopment steps. This strengthens the systematic character of a roadmap for its application in practice. The development of the actual roadmap is based on the results gained of the qualitative study, which will be explained in more detail in the next chapter (Zernial, 2008; Specht & Behrens, 2005).

Conducting and Evaluating of The Expert Interviews

The interview guide was differentiated according to the four object levels. These levels were considered individually while conducting in all interviews. A total of 13 experts with different expertise were interviewed. Seven interviewees worked for large construction companies, four for small and medium-sized enterprises, and two for public institutions. The areas of work of the experts interviewed were in the strategic area of the company (e.g., managing director or department head) or linked to the topics of digital transformation. Due to the fact that a presentation of all results of the thirteen interviews would require an excessive amount of space within the scope of the scientific article, a summarized presentation of all key statements per

object level is given below. The findings are determined from the interviews with the help of content analysis according to Mayring and Fenzl (2019) and after the generalization and consolidation, form the knowledge base for the further development of the roadmap. The first step is to describe the generalized core statements at the four object levels processes, organization, application systems and data. This core statements are shown in Table 1.

A general important finding from the expert interviews is the set time horizon for implementation projects. This time horizon should be four years for the first implementation and divided into annual stages. All levels have their own individual requirements, but there is still a direct dependency between all object levels. The core statements form the basis for a qualitative implementation of the AI system and the roadmap development.

Table 1. Core Statements of the expert interview.

Process Level
▪ Creation of a uniform understanding of all the main and secondary processes ▪ Identification of the automation potentials ▪ Creation of a high level of process standardization ▪ Perform a Make-or-buy analysis (Inhouse development or outsourcing)
Organization Level
▪ Creation of central responsibilities in the area of artificial intelligence ▪ Employment of IT experts and programmers with fundamental knowledge in the AI ▪ Knowledge sharing and training of own personal
Application System Level
▪ Creation of a central data base (Cloud system or own physical server) ▪ Establishment of a robust and stable IT infrastructure ▪ Creation of continuous interoperability between the application systems
Data Level
▪ Unified data standards and continuous data maintenance ▪ High level of data quality

Derivation of the Visualized Roadmap

Based on the results of the expert interviews, the roadmap is developed in the form of a two-dimensional reference frame. The roadmap can be categorized as a mix of a science and technology roadmap and has two axes (Kappel, 2001). The ordinate represents the object levels - processes, organization, data and application systems. The abscissa represents the time axis under consideration. The ordinate characterizes the main and sub-processes of the systematic implementation. The time horizon, in turn, considers a four-year time horizon for the implementation phase of an AI system. This duration for an implementation project was derived from the expert opinions and is further specified in sub-periods with a duration of one year in the roadmap. This subdivision allows a precise and systematic approach to be presented in each individual object level and cross-level dependencies in the individual implementation steps. The object levels are marked with different colors in the roadmap for better visualization. The following color scheme is chosen - processes (blue), organization (green), application systems (orange) and data (yellow). The individual implementation years are illustrated below, and the action steps are described.

In the first year, the principles for the complete four-year implementation period are set (see Figure 1). The object levels of the organization, application systems and data are important in this regard. The organizational level focuses on the establishment of a specialized work group and the recruiting and onboarding of suitable specialists. In the first year of implementation, the application systems level focuses on defining requirements for a central data room for the structured storage and management of all necessary data in the company. In addition, all existing interfaces between the AWS in the company are analyzed and measures for company-wide interoperability are defined. At the same time, all data in the company are analyzed and a uniform data quality standard for existing and future new data will be created.

In the second year of implementation (see Figure 2), the process level is also considered in addition to the object levels of the first year. The process-related measures focus on the identification and analysis of main and secondary processes in the company and their interdependencies. In addition, the processes are evaluated for existing automation potential through the use of AI systems and specific use cases are defined for initial pilot projects. In the organization, the knowledge about AI systems is continuously expanded in the working group and the first specialized IT project teams are established. This team subsequently prepares the measure of systematic implementation and development of AI systems. In addition, preparations are made for the data and IT infrastructure level.

Furthermore, the personnel requirements are defined and necessary training for additional employees in the company is planned. Moreover, a market screening of solutions already existing on the market or external service providers for the outsourcing of the development work is carried out. At the level of the application systems, the first implementation measures are taken on the basis of the defined requirements. In this context, the central database (company-owned server or cloud) is implemented, and the data storage structure and the extended infrastructure are developed. Within the context of the data, measures are implemented to maintain the inventory data to improve the quality. This data is then loaded into the company's previously newly established central data room. Another step in the second year of implementation is the selection of training and validation data sets for the AI system development process.

After the successful creation of the foundations on the four object levels, the third year focuses on the first development steps of the AI system for its one or more defined use cases (see Figure 3). At the process-oriented object level, a distinction is made between two possible approaches for the development and implementation step: in-house development or outsourcing. In the case of in-house development, a pretotype is developed in the first implementation stage. This serves as the first simplified version of the system and is used for initial analyses in the context of efficiency and further feasibility. This pretotype is considered a Minimum Viable Product (MVP) and has the minimum characteristics of the final product (Martins Pacheco et al., 2021). After successful creation of the pretotype, further development into a prototype takes place in the second implementation stage. The prototype is a functional but simplified system for its further training and validation in iterative cycles. (Martins Pacheco et al., 2021). Furthermore, the system is optimized until the defined goal of system efficiency is achieved. The outsourcing variant is carried out in cooperation with external companies or service providers. In this case, existing AI solutions are already purchased on the basis of the results of the market screening and further developed for the corresponding use in cooperation with the manufacturer. If no adequate solutions exist on the market yet and the personal resources for the development work are not sufficient, service providers can also be cooperated with for the complete system development if required. For example, this case can occur in small and medium-sized

enterprises, but it is not considered in the roadmap. In the context of the organizational level, a strong IT unit for the development, implementation and use of the AI systems is formed in the first two implementation years. In the third implementation year, the focus is on continuous knowledge transfer of the AI topic with other internal staff. This transfer will be accomplished by conducting internal employee training on how to use the future AI systems. If the development work is outsourced, the IT department with its AI knowledge serves as a coaching and control function for the company vis-à-vis external partners.

At the application system level, the permanent functionality of the IT infrastructure and the server play a central role. A frictionless infrastructure is the only way to ensure the quality of development and training of the system. Furthermore, the further identification and parallel development of additional API is required. On the object level "data", the corresponding inventory data is divided into a training data set and validation data set and used for prototyping and further development. Simultaneously, it requires compliance with enterprise-wide data management with constant monitoring of the defined data quality in the enterprise as well as the correct storage. In addition, company-wide data security standards and guidelines must be defined and established for the subsequent use of the AI system. If the company works with an external provider or service provider, it is essential to establish a contractual agreement for the AI development and use of sensitive company data. After completion of the third year of implementation, the first fully functional version of the AI system is available.

Following successful development in the third year, implementation in the existing process structures takes place at process level in the final year. This involves realigning the process structures and increasing the degree of automation. In addition, the focus is on evaluating the pilot project. Furthermore, the AI system will be continuously developed, and further AI projects will be planned and implemented in the company based on the experience gained from the systematic implementation. In the case of cooperation with third parties, it must be evaluated whether extreme services are still required for the follow-up projects or whether further development can be implemented independently. At the organizational level, an initial cost-benefit analysis of the AI development and the mid-term use of the system is performed. Furthermore, the experiences of the implementation project are processed and compiled in a company-wide lessons-learned documentation. This expands the company's knowledge base in the context of AI development and use. A further important aspect is the constant transfer of knowledge, the further training of employees in AI topics and the recruiting of suitable personnel for the subsequent projects. Depending on the planning of further developments of AI systems in the company, accurate planning of the expansion and scalability of the IT infrastructure is required. In the same way, the size of the data growth through the use of the AI system should be evaluated and, if necessary, the memory of the storage should be increased. Furthermore, the functionality under ongoing operation of the AI system should be evaluated and possible optimization measures implemented in the short term. In addition to the data room and the IT infrastructure, a demand-oriented and user-friendly control of the AI system for the employees must also be ensured. In addition, all interfaces along the process chain are constantly monitored during normal operation and optimized if necessary to ensure lasting interoperability between the various application systems. At the data level, continuous data maintenance, compliance with data protection, qualitative data management and structured data storage continue to play an important role under the aspect of the increasing number through the use of the AI system in daily operational business. In addition, the evaluation of the acquisition of additional metadata for the further optimization of the system is required. Furthermore, building on the standards set in the context of data management in the company, a uniform governance for dealing with artificial intelligence systems will be set up and

implemented in the company. This will ensure safe and responsible use of modern technologies in the long term.

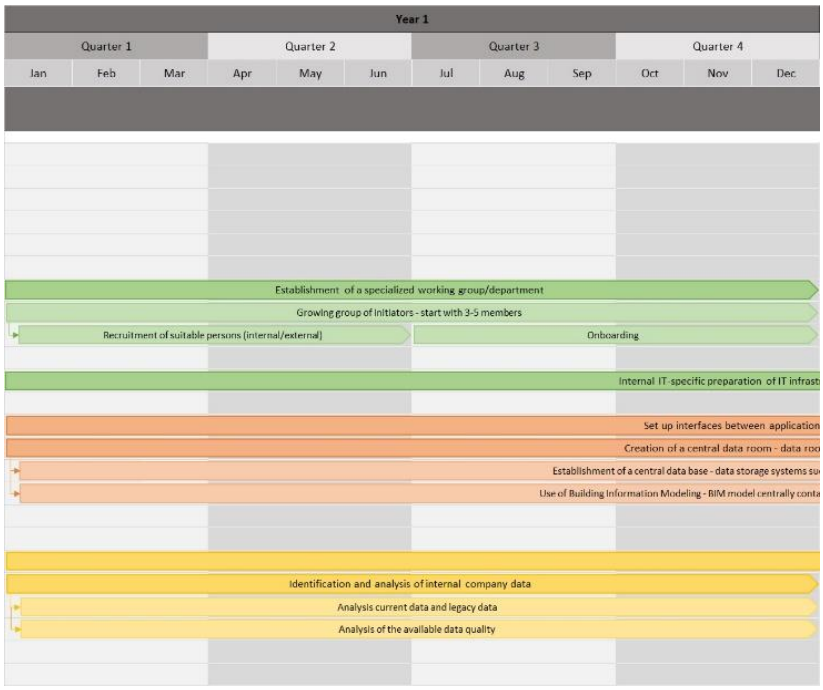


Figure 1: Roadmap in the 1st year of implementation.

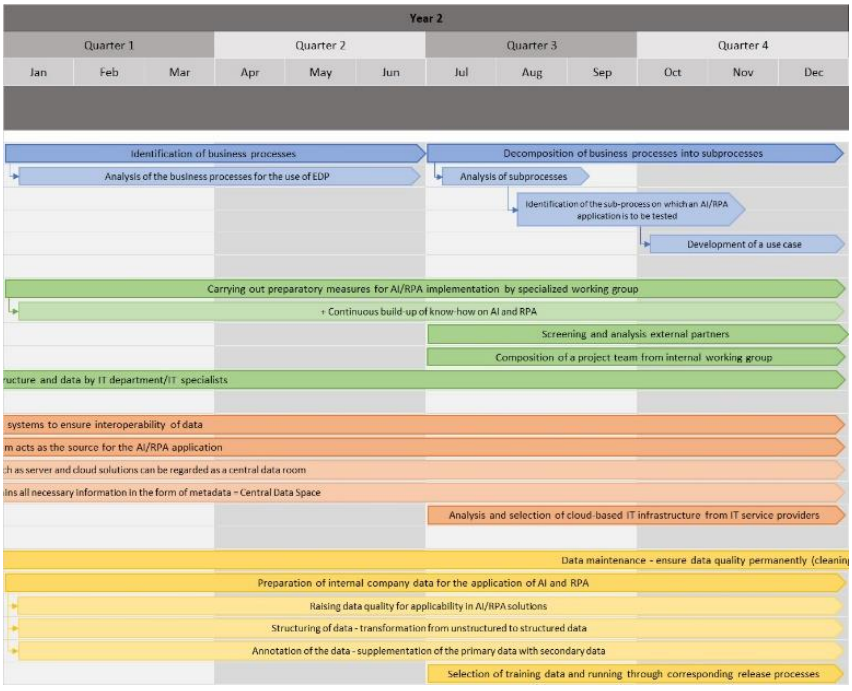


Figure 2: Roadmap in the 2nd year of implementation.

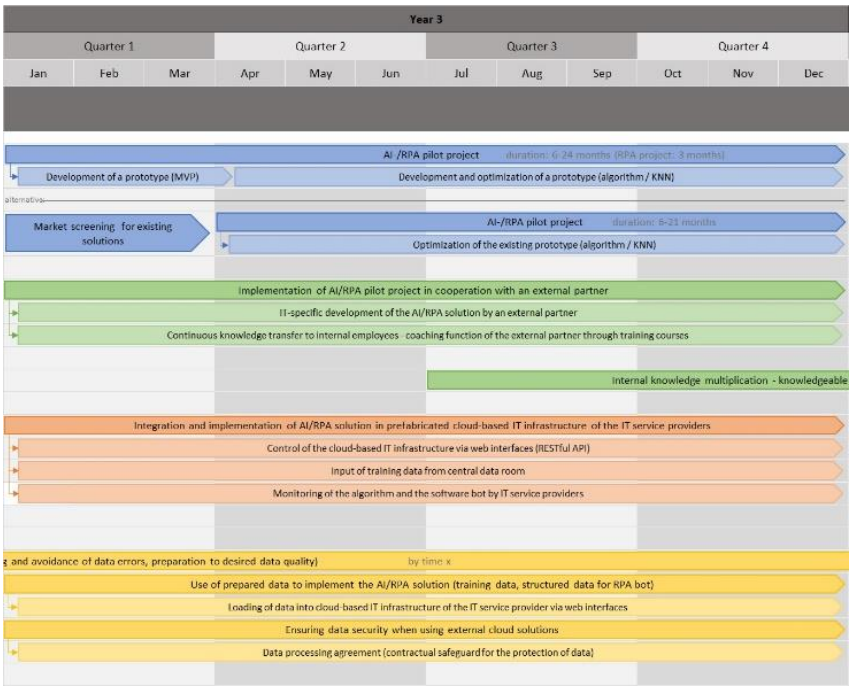


Figure 3: Roadmap in the 3rd year of implementation.

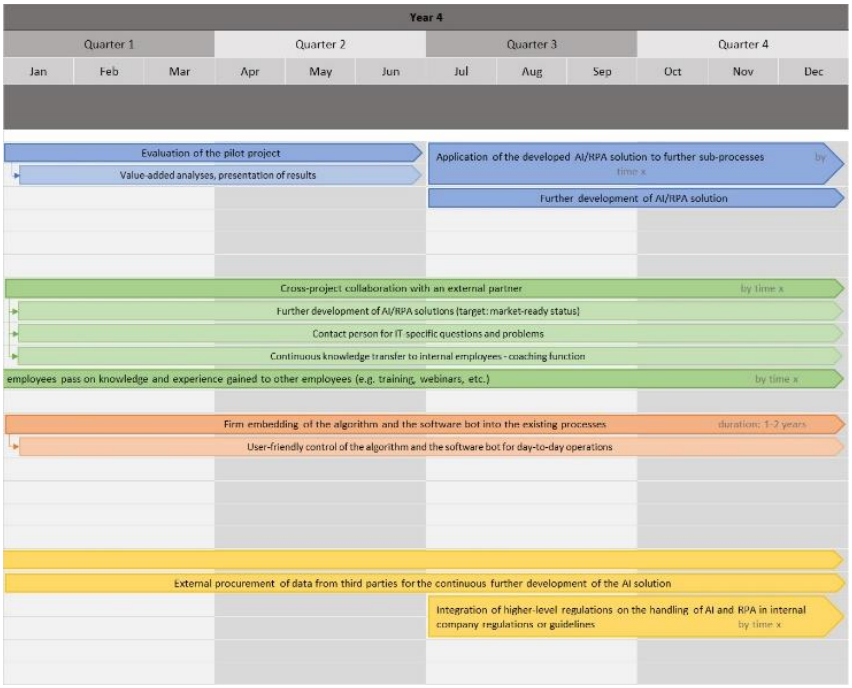


Figure 4: Roadmap in the 4th year of implementation.

Definition of company-wide minimum standards

Table 2. Minimum standards for AI implementation.

Minimum standards: Processes	**Minimum standards: Organization**
▪ Identification and recording of the overall business processes ▪ Standardization of business processes ▪ Identification of sub-processes ▪ Existence of continuous digital processes ▪ Identification of repetitive processes for pilot projects without risk	▪ Establishment of a specialized working group ▪ Involvement of an IT department or IT specialists (internal/external) ▪ Establishment of a central responsibility ▪ Cooperation of external specialists ▪ Build-up of know-how and continuous knowledge transfer ▪ Early recruiting of knowledgeable specialists (internal/external) ▪ Training of own employees ▪ Close cooperation with management ▪ Sensitization of internal employees to modern technologies
Minimum standards: Data	**Minimum standards: Application systems**
▪ Identification and knowledge of all existing data in the company ▪ Setting standards for internal data quality ▪ Creation of uniform data structures ▪ Continuous data maintenance ▪ Guidelines for data protection ▪ Overarching strategy for data governance and data management ▪ Training on secure data handling	▪ Creation and expansion of a high-performance infrastructure ▪ Ensuring a resilient and scalable IT infrastructure ▪ Interoperability between systems ▪ Interface integration ▪ Establishment of a central data room

After the development and description of the roadmap, generally applicable, company-wide minimum standards for the implementation of AI in construction companies are defined. The individual object levels of a company - processes, organization, data and application systems - are considered independently for this purpose. The content builds on the roadmap developed and is derived from the results of the expert interviews. The minimum standards are shown in Table 2.

Concluding, there is a connection and a direct dependence between the minimum standards of the individual object levels of the company. Hence, it is necessary to create the individual minimum standards in the company and to comply with them at the same time. Thus, the systematic implementation process of AI systems can be fully and qualitatively completed.
Non-compliance with the minimum standards at a single object level jeopardizes the qualitative implementation. This results from the level dependency and the chain of effects between the minimal standards. For this reason, the definition and specification of the minimum standards is essential when applying the roadmap for implementation projects.

Discussion

This article provides a roadmap for the systematic implementation of artificial intelligence in construction companies. A structured literature analysis of the current use of artificial intelligence along the life cycle in the construction industry and 13 expert interviews served as the basis for the roadmap development. The derived roadmap considers a time horizon for implementation of four years in total and differs between the four object levels - processes, organization, application systems and data. For a better utilization of the roadmap, company-wide minimum standards for the implementation and use of AI systems were additionally defined. The roadmap bridges an important research gap. It serves as a general framework for construction companies of any size and for any type of AI algorithm. Furthermore, it minimizes existing barriers to entry for future implementation projects and pilot projects with AI in the company, hence making widespread use possible. This increases the digitization of construction companies and consequently the entire construction industry in the medium and long term. In addition, the degree of automation of existing processes and their efficiency will be increased and, in the same way, productivity will be boosted. This creates a basis for the promotion of Construction Industry 4.0. Despite the conclusive development of the roadmap as a holistic and strategic framework for AI implementation, it is still necessary to consider limitations. So far, the knowledge base of the roadmap is an expert interview with 13 participants. Further specification requires the inclusion of additional experts with different expertise at the strategic, process and information technology levels. In addition, the roadmap has so far been a theoretical construct that should be tested for its accuracy and practicability through further validation steps, such as using the roadmap in a real case study in cooperation with an industry partner. Furthermore, the roadmap considers the technology of artificial intelligence very globally. In case of additional specification, it also requires the consideration of different AI models and training variants.

In future research activities, the developed research results, roadmap and minimum standards, will be further specified and validated with the involvement of further experts and practice partners. The specification will consider different implementation scenarios depending on the type of AI model, its characteristic intended use, and individual development and training. The validation of the artifact is aimed at using practical case studies.

Conclusion

The article centers on the development of a roadmap for the systematic implementation of artificial intelligence in construction companies and the definition of necessary minimum standards. In the first part, a literature analysis is conducted to identify existing AI use in the construction industry along the life cycle. Subsequently, thirteen qualitative expert interviews are realized and evaluated. The acquired findings serve as a foundation for the roadmap development in the next step. In addition, minimum standards for companies to implement and use the roadmap are derived. The roadmap and the minimum standards differentiate between the four object levels of a company: processes, organization, application systems and data. The roadmap serves as a generic model on a strategic level and describes relevant steps for a qualitative and successful development of AI systems and its implementation in existing structures of construction companies. Although the roadmap and minimum standards were developed based on a substantiated methodological approach, further research is needed by specifying and considering other aspects of managing AI in construction companies. In this way, the existing barriers to AI use will be further lowered and the attractiveness and

comprehensibility of the technology will be increased. As a result, in the medium and long-term horizon, the construction industry will experience an increase in the level of automation and digitization based on the successful development, implementation and use of AI.

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WEB Based Waste Management System

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Abstract

In Turkey, recycling process is executed by collecting different types of wastes in waste bins located mainly at the institutions, organizations and public corporations. The wastes are collected from the mentioned recycle bins and they are transported to a recycling center. The amount of waste collected from waste bins in many public areas is unknown since the amount of waste collected from the recycling bins is not measured. It is necessary to know the amount of collected waste in order to execute the recycling process effectively and efficiently. In this study, it is recommended to implement a web-based waste management system in order to solve the stated problems. In the specified system, first, distance measuring sensors is placed at all waste bins and the occupancy rate of the boxes and thus the amount of waste in the box will be measured by means of the placed sensors. The measured data are transferred to a web-based system. All the transferred is stored and monitored. Benefits of this system to institutions and organizations will be the possibility of determination of whether the size of the waste bin is sufficient or not. Moreover, how often the box should be emptied can be determined by analyzing the long-term measurements, and it will be ensured that recycling can be carried out efficiently with the ideal number of personnel. The system has potential of improvement with the use of artificial intelligence techniques. The developed system ensures effective and efficient recycling.

Keywords: *deneyap card, recycling, remote access, sustainability, waste management.*

Introduction

In the last century, the world population has tripled and there has been mass displacement from rural to urban areas. Approximately 50% of the world's population lives in cities and it is estimated that this figure will reach 70% by 2050 (Raina et al., 2017). The rapid growth of urbanization resulted in the production of large amounts of waste. Over the past decade, urban people consistently produced enormous amounts of waste that has a detrimental impact on human health and the environment. It is estimated that the world produces approximately 1.3 billion tons of solid waste per year and the amount of waste produced will increase to 2.2 billion tons per year by 2025. On average, each person produces about 0.11 to 4.54 kilograms of solid waste per day. It is estimated that 33% of solid wastes produced in cities are not managed in an environmentally friendly and safer way (Kaza et al., 2018; Bocquier, 2005). Improper management of wastes pollutes the oceans, spreads diseases and harms animals that eat waste unintentionally. Currently, recycling and waste management systems have become the focus of many cities and municipalities due to urbanization and climate problems. The

solid waste management system is the backbone of a smart and sustainable city and should include the functions of collecting, sorting and recycling the waste.

The basic processes of waste collection have remained the same for decades. Solid waste problems resulting from human activities have been tried to be solved by means of wild storage, landfill and incineration (Yılmaz & Bozkurt, 2010). Wild landfill is a method in which solid wastes are arbitrarily transferred and stored (Gökçe & Hasanoğlu, 2015). Landfill is a system in which garbage is disposed of by dumping the garbage into an area where the impermeability is provided and a drainage system to collect the leachate from the garbage is built, compacted every day and covered with soil (Aras et al., 2006). Incineration is carried out by burning the municipal solid waste directly without any pre-treatment in order to reduce the volume of the waste. This process is carried out to ensure the stabilization, sterilization of the wastes and to obtain energy from the waste (Aynur, 2011). Storing the wastes by burying or dumping, which is accepted as a wild storage method, increases the environmental problems caused by wastes and reveals the necessity of dealing with these problems in more than one dimension (Solak & Pekküçükşen, 2018).

The collection and storage of solid waste is under the responsibility of local governments, but due to financial and technical deficiencies, this task may not be effectively managed. The findings highlight the necessity of solid waste legislation and a compliant institutional structure. This is because an integrated solid waste management requires a significant financial resource which may be a bigger investment than a municipality can handle alone. The solid waste management policies and strategies are determined with political concerns rather than local needs. In addition to this the policies of the local governments is to prefer workarounds which causes the resources to be spend on waste management be shifted to other items even if there are sufficient resources (Solak & Pekküçükşen, 2018).

The amount of produced solid waste is very high and the management of solid wastes is very difficult. This fact led conducting studies on the recycling or reuse of solid wastes. For this reason, many public institutions, private institutions, and enterprises develop plans for the collection of solid wastes generated at homes and dormitories for recycling or reusing them. Many universities implement waste management actions to collect wastes which are produced inside the campus. On the other hand, managing the solid waste collected in large institutions requires a serious workload.

There are many recycling and waste bins especially in university campuses. Timely collection of wastes accumulated in the waste bins is an important problem for the university administrations. This is because the university administrations carry out the maintenance, cleaning and protection services of the university campus with a limited number of personnel. It is an important problem for university administrations to retain the waste bins, which are not filled in regular time intervals. In general, a single duty staff is appointed for a building and this staff is responsible for the cleaning of classrooms, academicians' rooms, toilets and the maintenance of the building's garden. For this reason, emptying and monitoring of waste bins has the last priority. When the waste bins are ignored, it cannot be noticed that they are full and cannot serve as represented in Figure 1. In this case, the recyclable wastes are thrown into the garbage bins, and both economic and environmental losses are experienced. In addition, wastes waiting for a long time in waste bins can cause hygiene problems. In order to prevent the mentioned problems, the amount of waste accumulated in the waste bins should be measured regularly and the last time the waste bins were emptied should be measured.



Figure 1: The handling difficulties of the recycle bins inside the campus.

Smart home technologies are an important source of inspiration for the automation of solid waste collection, which must be carried out with limited personnel and budget. Pavithra and Balakrishnan (2015) developed a system which carries out continuous monitoring of various household appliances with a smart phone in order to facilitate human life and prevent house fires. After connecting to a web server accessible from a smartphone, computer or tablet, home appliances can be remotely controlled and monitored. A light-dependent resistor (LDR) detects the fire and provides instant response to the fire by sending a message to the smart phone.

Al-Kuwari et al. (2018) developed IoT-based smart home automation detection and monitoring system to facilitate daily life. The system basically consists of sensors, processor, user interface, and data communication circuits. Data from all sensors is continuously uploaded and stored on the EmonCMS platform. EmonCMS is an IoT cloud server for logging data with an option to view it using dashboards. Finally, an automatic solar panel cleaning device is included to the developed system.

Measurement, data transfer and data processing techniques implemented in smart home systems can also be applied in the management of solid wastes collected inside the university campuses. With the help of IoT-based data transfer technologies, cameras and sensors, waste collection processes can be improved and modified.

In this study, a Web-based waste management system is created to prevent the difficulty of monitoring the collected waste and the hygiene problems that may be caused by the waste collection units. With the use of the developed system, efficiency of the waste management will increase, environmental pollution will be reduced, and the sustainability of the urban life will increase. Transparency and openness will be ensured by integrating the system into the blockchain in the future.

Abd Wahab et al. (2014) developed a web-based system for smart waste management. The weight of the waste accumulated in the boxes is automatically measured and the measured data is transferred to the web base. RFID system placed in the boxes tracks the collection of the accumulated waste by the authorized staff.

Ahmad et al. (2021) investigated the benefits of blockchain technology for the management of waste in cities. The utilization of blockchain technology can provide traceability, immutability, transparency and auditing features in a decentralized and reliable way. Real-time monitoring of waste, reliable sewage, compliance with waste treatment laws, efficient waste management, and preservation of waste management documentation are also discussed.

Kurre (2016) developed a system to detect overflow of dust bins with infrared distance measurement units. Rashinkar et al. (2017), Khedikar et al. (2017), Dhaya and Sujithra (2018) and Makde et al. (2019) developed a monitoring system for the waste collection which measures the occupancy ratio of the dust bin by ultrasonic sensors.

The properly management of waste and the efficient collection of waste in public institutions and organizations create a significant workload. Disruptions that may arise in waste management can lead to the neglecting the recycling of the potential wastes. Hygiene problems that may affect human, animal and environmental health, bad odor caused by the gases to be formed in the waste bins, pollution and throwing the wastes into the wrong bins due to the filling of the waste bins are examples of the possible adverse consequences. Data collection and data management has become significantly easier due to the reduced costs of sensors used in smart home technologies and the widespread use of internet of things applications. Consequently, a web-based waste management system that can instantly monitor the amount of solid waste thrown into the solid waste collection bins system is designed. The monitored recycling bins can collect many and different types of waste and the designed system can monitor when the solid waste bins are full, when they are emptied, and can estimate the amount of waste by processing the data collected over a long period of time.

Architecture of Waste Management System

It is aimed that the waste management system should have low initial investment and operating costs. Moreover data collection and data processing should be carried out in a way that requires minimal human intervention. The waste management system is based on the principle of measuring the amount of wastes in the recycling bin by placing an ultrasonic distance measurement sensor in a suitable location inside each recycling bin. Occupancy rate of the recycling bin will be computed by the measured distance data. The computed occupancy rate will be transferred to the central computer at regular time intervals. The flow chart of waste management is presented in Figure 2.

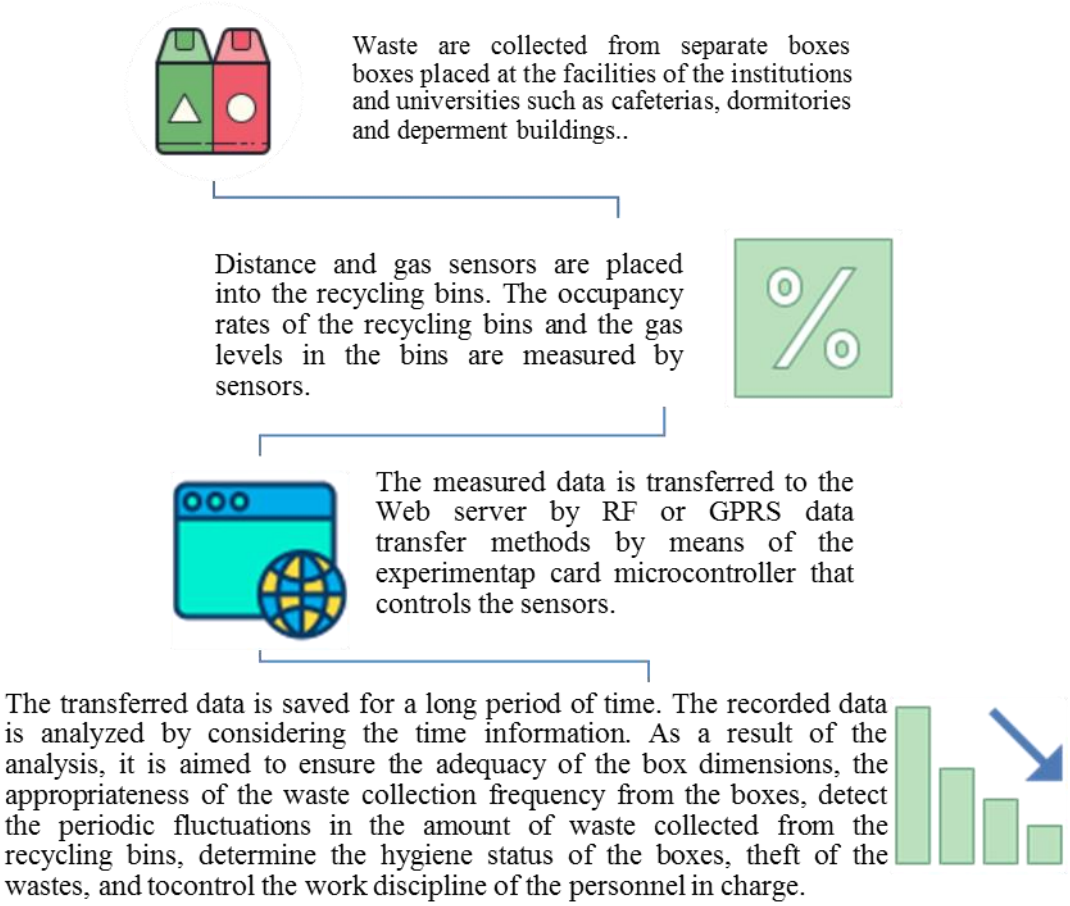


Figure 2: Flowchart of the web based waste management system.

Waste is collected separately in recycling bins of certain dimensions. Waste collection boxes spread over a wide area within the university campus aiming to collect different type of wastes. Sensors are placed inside each waste bin to continuously measure the amount of waste in it. Weight sensors measure the weight of the waste inside the waste bins, but they are expensive. For this reason, monitoring the amount of waste by measuring the volume change inside the box is preferred. The volume measurement is carried out by measuring the distance with an ultrasonic sensor and determining the height of the waste. Since the ultrasonic sensor only measures one point, which may cause erroneous measurement, the ultrasonic sensor will be placed on a 40 cm long thin rod and a servo motor will be placed on the other end of the rod. When the servo motor rotates, the ultrasonic sensor will sweep and measure different positions inside the box. The height of the ultrasonic sensor will remain constant and will only sweep in the plane. The position of the ultrasonic sensor will be calculated by the trigonometric relationship between the position of the servo motor, the rotation angle and the fixed distance between the ultrasonic sensor and the servo motor. The height of the waste material is calculated by considering the location of the ultrasonic sensor and the distance between the ultrasonic sensor and the waste material. The amount of waste in the recycling bin is estimated from the height of the waste material measured from different locations. This process is performed every 1 minute.

Although recyclable wastes are expected to be disposed of in recycling bins, organic wastes can sometimes be thrown into recycling bins. This situation can lead to hygiene problems, especially in the summer season. For this reason, it is aimed to measure the concentrations of

CO_2 and methane gas in the recycling bins by placing a gas sensor inside them. Figure 3 shows the waste bins placed outside. Animals such as cats and birds can enter the boxes outside in search of food or water at night when there is no human activity. Such a situation may cause fatal consequences for animals that may enter the boxes where hazardous wastes such as waste batteries and fluorescents are collected. For this reason, LDR and PIR sensors will be placed inside the waste bins to detect motion.

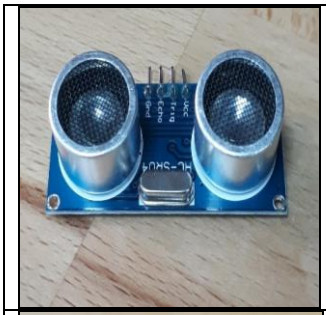
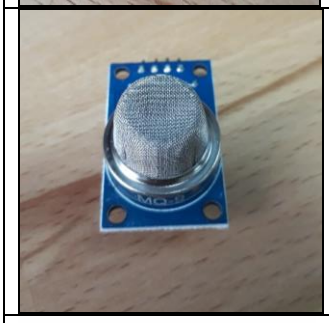
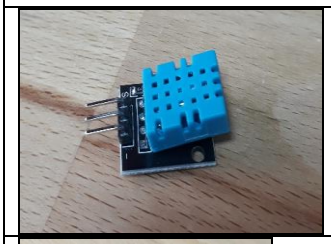
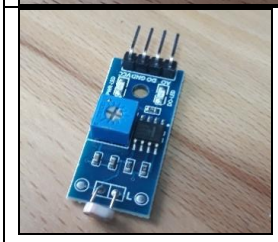


Figure 3: Recycling bins placed outside at the campus.

There are recycling bins in the campus to obtain compost from organic waste. The growth of bacteria accelerates especially with the warming of the air temperature. In order to determine the need for collection of the compost inside the bins, sensors measuring the temperature, humidity, CO_2 and methane density is placed in the bins, as well as measuring the fill rate. The decision to collect the compost material is taken according to the conditions of the environment where the compost material is located. Thus, the collection of compost waste, which is a laborious and costly work item, will be carried out in the most economical way.

When the responsible personnel for the maintenance of the recycling bins empties the bin, the staff will make the RFID reader read his card which is registered to him. The RFID card reader will be placed in a suitable place in the immediate vicinity of the recycling bins, and when the reading process takes place, the information that the waste bins have been collected will be recorded in the system. The collection information of the recycling bins will also be confirmed by comparing the occupancy rate of the waste bin, and the personnel in charge of the waste collection will be supervised.

In order to process the data obtained from the waste bins, the data must be transferred to the central computer in real time with access permission for the academic and administrative personnel responsible for the recycling bins when needed. For this reason, a web-based waste management system is developed, consisting of data collection, data transfer to the central computer, and data processing. During the data collection phase, the data to be collected from the recycling bins will be controlled by the Deneyap Card microcontroller and ultrasonic distance sensor, carbon monoxide and combustible gas sensor, temperature and humidity sensor, motion sensor, LDR sensor, and servo motor placed in each box. The sensors used in the system are explained in Figure 4.

	HC- SR04 Ultrasonic distance sensor measures the distance by sending sound waves from its trig pin in 40 kHz. The ECHO pin measures the received sound wave when the sound wave hits an object and returns. The sensor measures the travel time of the sound wave and computes the distance between the sensor and the object.
	MQ-5 and 9 sensors can measure the CO2 and flammable gases in the medium. The conductivity of the sensor increases as the gas concentration of the medium increases.
	HC-SR501 is an adjustable movement sensor. It detects the movements in the medium. The sensitivity of the sensor can be adjusted up to 5 meter distance.
	DHT11 temperature and humidity sensor contains 8 bit microprocessor and measures the temperatures between 0 and 50°C within 2°C error margin.
	LDR light sensor contains a light dependent resistance. At dark medium it outputs 0 V and outputs 5 V at bright medium.
	MG90S Rc Servo Motor is a small servo motor with 180 degree amplitude. The motor can be directly powered by the microcontroller.

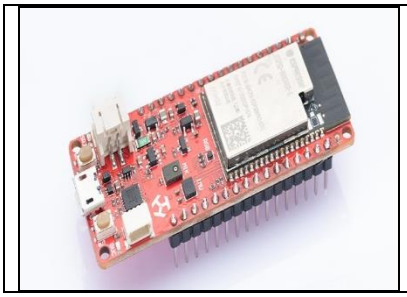
	Deneyap Card contains ESP32-WROVER-E processing unit and internal Wi-Fi and Bluetooth data transfer modules.

Figure 4: Components of the developed system.

The main objectives of the developed system are low cost, flexibility and remote access. If the occupancy rate of the recycling bins is measured by the weight sensor, the cost of the system would increase considerably. For this reason, a weight sensor is not used for the occupancy rate measurement of the recycling bins.

The average of the occupancy rate data is used to increase the accuracy of the measurements. In order to filter out the outliers, the sensors inside the box will measure every second and record for one minute, and the average of 60 collected data will be sent to the central computer. In this way, measurements that may contain random errors caused by the sensor anomalies will be filtered as well as the size of the data to be transferred will be reduced.

Data transfer is carried out with the Deneyap card. Data transfer will be ensured by adding a module that transmits data via radio waves for recycling bins located outside. The data to be collected from the recycling bins to be placed inside the building is transferred to the central computer via the Wi-Fi network in the building. The data to be transferred is the code number and time of the relevant recycling bin unit, labeled occupancy rate, temperature, humidity values, and CO_2 and methane gas densities. When the PIR and LDR receivers placed in the box detect any motion in the box the sensors will output 1 and 0 vice versa. Each dataset will be sent in every 1 minute. In this way, the amount of data transfer will be limited to 150 bytes per minute. Since the data volume is low, it can be transferred by radio frequency data transfer modules. For this reason, it is aimed to send the data to the central computer in the campus with a radio receiver and transmitter with a booster antenna with a range of more than 300 meters in the open area. Different radio modules available to send data will be tried. In case the radio transmitter range is insufficient due to the surrounding trees and buildings, data transmission will be carried out with GPRS, which is a more expensive alternative.

The transmitted data will be stored by a web-based system and the data can be accessed by all authorized personnel. In this way, the occupancy rates of the recycling bins, their temperature, gas concentration and whether there is an entrance into the bin will be displayed on the web platform in near real time. Recycling bins that are full or nearly full will be reported specifically and brought to the attention of authorized personnel.

The purpose of the developed system is to measure the amount of collected material as well as to encourage the recycling. In order to carry out waste management effectively, the amount of collected waste should be measured and the data must be evaluated. Periodic fluctuations can be determined by analyzing the measured data within a certain time interval. The analysis will make it possible to determine whether the size of the waste bin is sufficient or not. In addition, to improve the efficiently of the personnel, the handling periods of the recycling bins will be analyzed and the optimum frequency of handling the recycling bins will be

determined. In addition, as a result of a possible negligence in waste collection, the wastes will be prevented from waiting for a long time in the recycling bins and the emergence of hygiene problems will be prevented.

The collected recycling material from department buildings, dormitories and cafeterias will be regularly measured. The collected material per person of each utility building will be determined. According to the amount of collected recycling material per person, a certificate of appreciation will be given to the administrative supervisor of the facility, and a thank you poster will be hung at the entrance of the building which achieves the highest amount of recycling. If the facility is very low in the ranking, trainings and meetings will be held to encourage recycling at that facility. In this way, the recycling culture and awareness will be spread throughout the campus.

Data collection process will continue for a long time and the data cloud of the collected recycle amounts will be modeled through time series analysis. Accordingly, future projections will be made and data will be provided for economic feasibility analyzes of waste collection and storage investments. In addition, periods during which periodic fluctuations may occur in the amount of collected recycling material will be determined and appropriate measures will be taken.

Conclusion

Many institutions have a duty to implement waste management and protect the environment. The management of solid wastes collected by recycling bins in university campuses which spreads over a wide area requires serious personnel resources. In this study utilization of an IoT supported web-based waste management system is proposed. The proposed system is cost-effective, is flexible and provides remote access, which will be a solution for the institutions having a campus settlement. The system consists of distance, gas, light and temperature sensors, a servo motor, data transfer module with radio frequency and Deneyap Card microprocessor. With the help of sensors, the amount of waste in the recycling bins will be measured, the occupancy rates will be displayed instantly, and the gas levels will be measured. By emptying the waste bins on time, hygiene problems will be prevented and human, animal and environmental health will be ensured. The data received from the sensors is stored on the web platform. The collected large data sets will be processed by time series analysis. The efficiency of the proposed system will increase with the accumulation of the data. In addition, data will be integrated with the blockchain to improve the system, ensuring transparency and openness. It is aimed to ensure a beneficial competition in the waste collection process by sharing the collected data with the people living inside the campus.

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Measurement and Analysis of Haul Routes

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Abstract

Haul routes of a road or a dam construction where earthworks are intense affect the duration and cost of the earthwork to a great extent. Mapping and location applications such as Google Earth, provides location, height, distance and visual information. However most of the construction sites are settled in mountainous regions which are far from urban settlements. Satellite images and maps of these regions do not have enough resolution and accuracy. Therefore, the mentioned services cannot be implemented to determine the route of the haul roads used by the construction machines with reasonable accuracy. In order to help solve the stated problem a GPS measuring device consisting of NEO-6M GPS Module and Arduino Card is produced. The software for obtaining the GPS measurement data obtained by Absolute positioning method is coded by using C programming language. The device is mounted on a vehicle and haul route measurement is carried out with sufficient measurement accuracy and measurement frequency. The measurement data expressing the latitude, longitude and height are transferred to the computer in real time by the serial port. In this study the haul road of a mining facility is measured and recorded by the developed system. 3-dimensional measurement of the road is made by measuring at 640 points of the haul route. The system used in the measurements does not require an additional device other than Arduino card and GPS module. The specified devices can be obtained for approximately $20. Therefore, the designed system has a high price advantage compared to ready to use GPS positioning based devices available in the market. As a result the developed system will assist in the analysis process of determination of the most suitable haul truck which reduces the construction time and cost. The developed system can easily be assembled to a vehicle and can be used as vehicle tracking system.

Keywords: *earthwork, GPS, haul road.*

Introduction

Construction machineries are used to prepare the construction sites, as well as to perform the work items such as excavation, transportation, and compaction, leveling and demolition. Excavator, dump truck, backhoe loader, skid steer loader, bulldozer, scraper and motor grader are mainly used for the earthworks and site improvement tasks. Since the specified construction machines have high initial investment costs, it is very important to choose the right size as well as types and use them with high efficiency. Otherwise, the contractor may lose money or even forfeit the collateral. In order to prevent adverse consequence, the construction machines should be utilized with high efficiency which depends on many factors.

Loader and backhoe bucket volume, weight of the construction machines, engine power, swing angle, height of construction machine, transport distance of loader, soil and site conditions, operator's working efficiency and experience, environment and weather conditions, and haul route effects the job efficiency. Efficiency of the construction equipment affects cost of the earthwork. In order to keep the excavation cost low, construction equipment with appropriate production efficiency should be allocated. The amount of production per unit time that the construction machinery can perform significantly affects the unit cost of aggregate production.

For this reason, it is important to determine the production rate of the construction machines with high accuracy. Caterpillar (1979), Nunnally (2001) as well as Peurifoy and Schexnayder (2002) have published tables that determine how many cycles loaders and excavators can make in an hour, and the amount of soil which the bucket can be filled according to site, environment and job conditions. The table and charts are utilized manually, in order to automate the output estimation of the construction machines software based on regression models are developed. Edwards and Holt (2000) established a regression model using the cycle time of 35 hydraulic excavators and named the model ESTIVATE. The developed model estimates the cycle time of the construction machine based on its parameters. Edwards and Griffiths (2000) fed the artificial neural network with the data of 43 construction machines and established a prediction model according to the technical characteristics of the construction equipment. Edwards et al. (2001) presents a decision tool for selecting the optimum excavator type for job conditions and defined production scenarios by adding the linear programming algorithm to the realized forecasting model. Tam et al. (2002) aimed to increase the accuracy of the model by adding additional construction machines to the established model. Yang et al. (2003) estimated the production quantities of construction equipment with fuzzy logic. Vahdatikhaki and Hammad (2014) used location tracking techniques to simulate near real-time earthwork projects. It improved the simulation model parameters by measuring the differences between the simulation prediction and the actual situation.

Drygin et al. (2017) conducted a study to increase the unit time performance of construction equipment in Kuzbass open pit quarries and determined that reducing the idle times of the construction machines is the most efficiency increasing factor. Holt and Edwards (2015), Manyele (2017) and Balaraaman and Chandrasekaran (2021) examined the efficiency of construction machines in open pits and stated that the availability of maneuvering space of the excavators, the loading position, the size of the excavator, the compatibility of the truck and the excavator size had a great effect on the efficiency. Yoon et al. (2014) investigated the factors affecting the hourly excavation rate of the excavators and found that the truck height is not very important, but the distance between the excavator and the truck and the rotation angle are significant. Bettemir (2009) modeled the uncertainties and risks related to weather, ground conditions and operator productivity with Monte Carlo analysis and examined the effects of these factors on job completion time and equipment requirement. Sağlam and Bettemir (2018) developed software that estimates the excavation time and the number of required trucks by considering different ground and environmental conditions. Chan et al. (1989) developed a database system which focuses on selecting the most suitable construction machine for the earthwork project according to the technical data of the loader-excavators.

For many years, the European construction sector has been in a change process due to different effects such as globalization, legal changes and technical developments. The construction industry faces a challenging environment with very tight time and budget

constraints. At the same time, the lack of real-time information makes it impossible to control the construction projects effectively. Before the tender, accurate computation of the construction times and costs of the construction projects are very important. Tender files with incomplete or incorrect data contain significant risks. If the effects of the uncertainties in the aforementioned data on the construction time and cost are determined, the risk involved in the bid price and the construction time file will be determined more accurately.

The hauling route is one of the important factors affecting the production efficiency and cost of the earthworks. The soil type, road conditions, slope and total length of the route affect the production rate. With the real-time control of the haul routes and the combination of the right construction equipment, it is possible to determine the production rate, the volume of the transported soil and the consumed fuel before the commencement of the earthwork. There are location based applications, which presents the location, height, distance and visual information of the construction sites. However most of the heavy constructions in which the volume of the earthwork are intense, are far from the central settlements in mountainous regions. The visual information and the digital elevation model of the mentioned regions are obtained via satellite images which do not have high resolution and accuracy (Bettemir, 2011). Therefore, determination of the location of the haul routes through which the construction equipment passes with high spatial resolution will help the construction managers to determine the most suitable construction equipment to be used in the project, and to reduce the construction time and cost.

As a result there are important studies in the literature on the control and monitor of earthwork machines. Upon the widespread use of GPS systems and the improvement of positioning accuracy, many systems have been developed to monitor the movements of the construction machines and to monitor the construction quality and speed by placing precise GPS on the construction machine. Baertlein et al. (2000) developed a machine control system for the road construction that monitors the construction machine and directs it by achieving sub-centimeter precision with laser-guided dual-frequency real-time kinematic positioning method. Jonasson et al. (2002) and Lee and Han (2003) stated that the machine control systems created by using precise GPS receivers significantly increase the efficiency of the construction machines and significantly reduce the re-passes of dozers and graders that pass at the wrong height. Han et al. (2005) used Web CYCLONE software to simulate situations where earthworks are performed with and without a GPS-based machine control system. As a result of the simulation, it has been shown that the GPS-based system is 32.48% more efficient than the traditional system. The GPS-based system costs 22.88% less. Shengxiang et al. (2005) increased job tracking and quality control by placing sensitive GPS receivers on to the compactors in the earth fill dam construction. Rausch (2010) developed a system that increases the efficiency of the excavation and road construction by executing performance and cost analysis with the data obtained from GPS receivers placed on construction machines. The system records the position, time, coordinates of an excavator's bucket, and data sets consisting of directions and angles obtained from the GPS receiver. The specified GPS-based systems accurately measure the number of hourly cycles of the construction machines. But these sensors are sold at very high prices due to the use of very sensitive positioning devices and advanced artificial intelligence software. Because of their cost, CORS GPS-based systems are not in high demand in small and medium-sized open-pit mines.

In this study, a GPS measuring device consisting of NEO-6M GPS Module and Ardunio Card are assembled to obtain a cheap positioning device. The device is mounted on a vehicle in order to measure a real haul route cost-effectively with high accuracy and spatial resolution.

Design

Ardunio Card and NEO-6M GPS module are used to perform real-time observation and measurement of the excavation route. Arduino is a microcontroller platform with open source software and hardware. Arduino consists of both a physically programmable circuit board and a piece of software or IDE (Integrated Development Environment) that runs on computer, which is used to write and upload computer code to the physical board.

The Neo-6M module is a standalone GPS receiver module with high performance U-blox 6 chipset. It can monitor up to 22 satellites in 50 channels. It achieves the highest level of sensitivity among GPS modules. Unlike other GPS modules, it can update 5 locations per second with 2.5m horizontal location accuracy. The U-blox 6 positioning engine also offers a Time to First Fix (TTFF) of less than 1 second.

In order to realize a real and on-site application, the haul route of Çevkur mining firm of Zinc - Lead Open Mine located on the Malatya - Kayseri road is measured. The haul route is in the degraded form in which some portions are smooth and some portions are with bumps and pits.

In order to measure the haul route, NEO-6M GPS Module and Ardunio Card is mounted on a vehicle and the measurement of the haul roads is carried out with sufficient measurement accuracy and measurement frequency. The measurement data expressing the latitude, longitude and height of the road are transferred to the computer in real time by using the serial port over the Arduino Card with the software developed with the C programming language. The developed Arduino GPS receiver is shown in Figure 1.



Figure 1a: GPS device. Figure 1b: GPS device mounted on vehicle. Figure 1c: GPS transfer of measurement data.

Analysis of the haul route and the related calculations are carried out by transferring the latitude, longitude and altitude data to the Microsoft Excel software. Table 1 shows some portion of the data transferred to the Excel program.

Table 1. A portion of the measured spatial data.

Measurement	N (phi)	E (lam)	h
1	38.1681219	38.0796797	1173.2
2	38.1681220	38.0796797	1173.2
3	38.1681220	38.0796794	1173.1
4	38.1681208	38.0796769	1173.1
5	38.1681162	38.0796708	1173.1
6	38.1681068	38.0796654	1173.1
7	38.1680954	38.0796654	1173.1
8	38.1680849	38.0796723	1173.2
9	38.1680780	38.0796844	1173.3
10	38.1680763	38.0796979	1173.3
11	38.1680788	38.0797136	1173.3
12	38.1680855	38.0797302	1173.2
13	38.1680939	38.0797444	1173.2
14	38.1681030	38.0797567	1173.2
15	38.1681124	38.0797686	1173.0
16	38.1681214	38.0797791	1172.6
17	38.1681285	38.0797867	1172.5
18	38.1681367	38.0797929	1172.2
19	38.1681492	38.0797960	1171.9
20	38.1681653	38.0797912	1171.6

In order to compute the total length of the haul route, position data are obtained with respect to Earth Centered Earth Fixed (ECEF) Coordinates (Figure 2). The mentioned Earth-Centered Earth-Fixed (ECEF) coordinate system is also known as the "traditional terrestrial" coordinate system. It is a simple Cartesian coordinate system in which the center of the earth forms its origin. The +X axis passes through the intersection of the Equator and the Prime Meridian. ECEF coordinates are defined by the World Geodetic System 1984 (WGS84) standard.

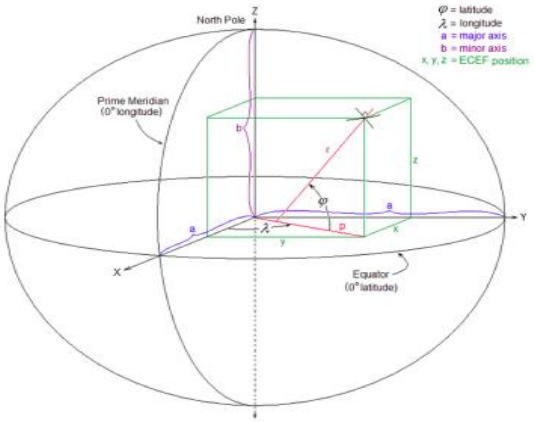


Figure 2: Definition of WGS84 (coordinate transformations by Dr. John Stryjewski).

The shape of the earth is defined by two parameters which are a, semi-major axis, and 1/f, the flattening parameter. The values of the semi-major axis and flattening parameters are a = 6,378,137 meters and 1/f = 298.257223563 (Torge, 2001).

The eccentricity and the normal distance are computed by Eqs. 1 and 2 respectively (Torge, 2001).

$$e = \sqrt{2f - f^2} \tag{1}$$

$$N(\varphi) = \frac{a}{\sqrt{1-(e \cdot \sin(\varphi))^2}} \tag{2}$$

Change in the horizontal coordinates of each point measured with the GPS receiver is determined by the formula presented in Equation 3 to find the total distance of the haul route. The given distance computation is based on the Euclidian distance.

$$\Delta D = \sqrt{(phi_{i+1} - phi_i)^2 + (lam_{i+1} - lam_i)^2} \times \frac{\pi}{180} \times N(\varphi) \tag{3}$$

The distance between the successive measurement points is found by multiplying the difference between the two points, by the normal distance. The total distance of the haul route is determined by adding the distance measurements of all points. In Table 2, a portion of the computed haul route distances by applying Equations 1 to 3 is given.

Table 2. Computed horizontal distance between the measurement points.

Measurement	**N(φ)**	**Δα**	**Distance**
1	6386305.535	0	0
2	6386305.535	0.011	0.011
3	6386305.535	0.033	0.105
4	6386305.535	0.309	0.309
5	6386305.533	0.852	0.852
6	6386305.530	1.208	1.208
7	6386305.525	1.271	1.271
8	6386305.522	1.400	1.404
9	6386305.519	1.553	1.556
10	6386305.518	1.517	1.517
11	6386305.519	1.772	1.772
12	6386305.522	1.995	1.998
13	6386305.525	1.839	1.839
14	6386305.528	1.705	1.705
15	6386305.532	1.690	1.702
16	6386305.535	1.541	1.592
17	6386305.537	1.159	1.164
18	6386305.540	1.146	1.184
19	6386305.545	1.435	1.466
20	6386305.551	1.873	1.896

The measurements conducted on the open mine haul route by the designed GPS receiver, contains measurements of 640 points. The latitude, longitude and height data are graphed as

cross section and longitudinal section. In Figure 3, horizontal graph of the haul road is created to analyze the latitude and longitude coordinate data of the haul route in the Microsoft Excel. The x-axis is the latitude and the y-axis is the longitude.

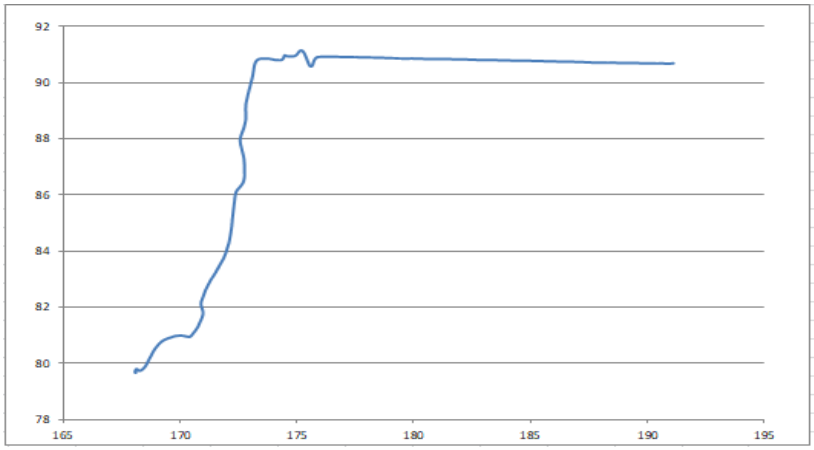


Figure 3. Horizontal graph of the haul route.

The vertical profile of the haul road created in Microsoft Excel is given in Figure 4. In the graph, the x-axis shows the total distance and the y-axis shows the elevation.

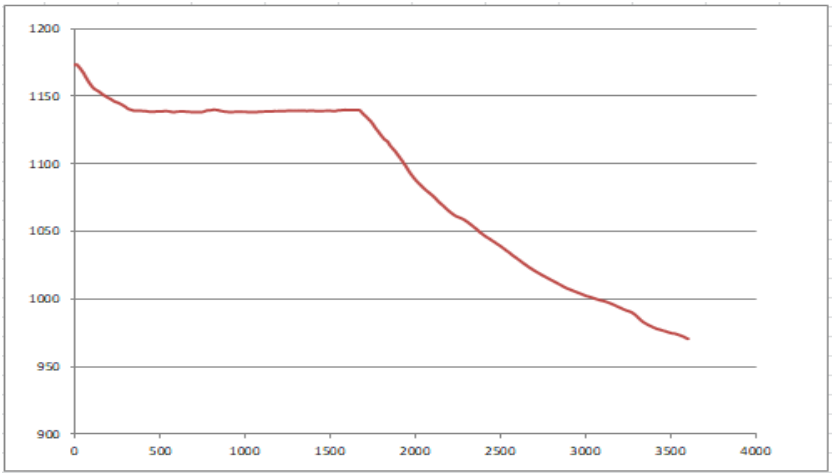


Figure 4. Vertical profile of the haul route.

The total distance of the haul route is calculated as 3602.28 meters based on the distance calculations executed on the position data collected by the GPS receiver. The highest point of the haul route is determined as 1173.2 m and the lowest point as 970.5 m. Thanks to the real-time coordinate measurement performed at the construction site, the haul route is determined with high resolution compared with the satellite image based location data services. In addition to this, the positioning accuracy of the GPS with absolute positioning is better than the free satellite image based location services. Because SRTM DEM is used to provide the elevation data which has lower accuracy than the GPS positioning with absolute positioning technique.

Discussion and Results

The utilized system during the measurements does not require an additional device other than Arduino card and GPS module. The specified devices are available for approximately $20 cost. Therefore, the designed system has a competitive price advantage compared to off-the-shelf GPS receivers. Moreover, the obtained coordinate data and the calculations and analyzes performed on the Microsoft Excel program can be easily stored because it occupies only 50 to 100 KB of storage space depending on the length of the haul route.

The developed system can be protected against falling, being affected by weather conditions and deterioration with a protecting case as future studies. The case can also protect the device from dusty environment. The effects of the construction machine selection, on the project cost and time can be investigated by recording the haul routes with different features such as GPS measurement system to the computer and comparing the different haul route alternatives. The velocities of the haul trucks can be monitored on the haul route by mounting the GPS measurement system and the condition of the haul route can be predicted.

A domestic system with sufficient positional accuracy that can be used instead of high-cost imported GPS measuring devices is developed. The low cost system can be used quickly and easily, and can be easily mounted on the vehicle, and provides real-time measurement. The engineers and contractors will have the opportunity to obtain data with satisfactory accuracy and resolution with reasonable cost. This benefit is important when the economic situation of our country is considered.

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BIM Use in Retrofit Optimization for the Climate Change Mitigations and Adaptations Measures

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Abstract

Sustainability and sustainable development are highly linked to climate change which has a growing interest in the literature. Climate change mitigation and adaptation measures are vital applications in the built environment to overcome the hazardous effects of climate change. However, the BIM integration with sustainability is still immature and rarely conducted. Besides, there is a need to link BIM and climate change in the scope of the climate change mitigation and adaptation measures. In this respect, this study aims to systematically investigate the distinguished studies about BIM use in retrofit optimization for climate change mitigation and adaptation measures. The Scopus and WoS database is used to search the published papers between 2012-2022 related to BIM and retrofit optimization from the climate change perspective. Most related papers to the topic are selected by reviewing their abstracts and chapters after omitting the duplications. As a result, selected papers are examined to identify and classify mitigation and adaptation measures in the scope of BIM use in retrofit optimizations. Niche themes, clusters, thematic evaluations, changes in concepts, the trend topics, applied methods and tools used in the studies are presented.

Keywords: *BIM, optimization, retrofit, climate change.*

Introduction

BIM (Building information modeling) enables the users to embed all information related to building parameters into the model. The information in the model can be used for different sustainable solutions, ranging from carbon emission calculations to energy performance simulations. In this respect, BIM integration with sustainability can be provided as a Green BIM concept (Khahro et al., 2021). However, its integration with sustainability is still immature and rarely conducted. Moreover, the increase in global temperatures (IPCC, n.d.-b) raises the climate change topic. Hence, various governments have set a target of a decrease in carbon emission levels within the scope of international agreements (IPCC, n.d.-a; IPCC WGI, n.d.; United Nations, 1998, 2015). Beyond the climate change mitigation measures to decrease carbon emission levels and energy consumption, climate change adaptation measures are also regarded (Díaz-López et al., 2022; Global ABC, n.d.; IPCC WG III, 2022). Different retrofits related to building components are made to improve building efficiency and decrease carbon emissions. Moreover, more comprehensive retrofits and refurbishments are also made to adapt various buildings to climate change in case of uncontrollable change. In addition, different retrofits as distinct scenarios are conducted to achieve the best results with optimized

building parameters and results (Lim et al., 2021; Seghier et al., 2022). However, BIM integration with even sustainability is considered immature (Khaddaj & Srour, 2016; Lim et al., 2021), whereas its integration with climate change seems challenging.

In this regard, this study aims to examine the studies related to BIM use in retrofit optimization for climate change mitigation and adaptation measures. The science citation indexed articles in Scopus and WoS are primarily used in the study.

Method

The related articles are detected through Scopus and Wos databases and clusters regarding their themes are created in the first step. The information from both databases is downloaded as BibTeX format to merge them in the R environment. 376 publications from Scopus and 134 publications from WoS are merged and detected five duplicates are removed.

The last merged BibTeX file without duplicates are converted to xlsx format to visualize the analysis results through biblioshiny (Biblioshiny, n.d.). The publication numbers, thematic evaluation, niche themes, clusters and most related publications for each cluster are detected through the bibliometric analysis. Niche themes and clusters by documents are overlapped to detect main clusters. Niche themes are generally related to energy efficiency, life cycle, optimization and architectural design with costs (Figure 1).

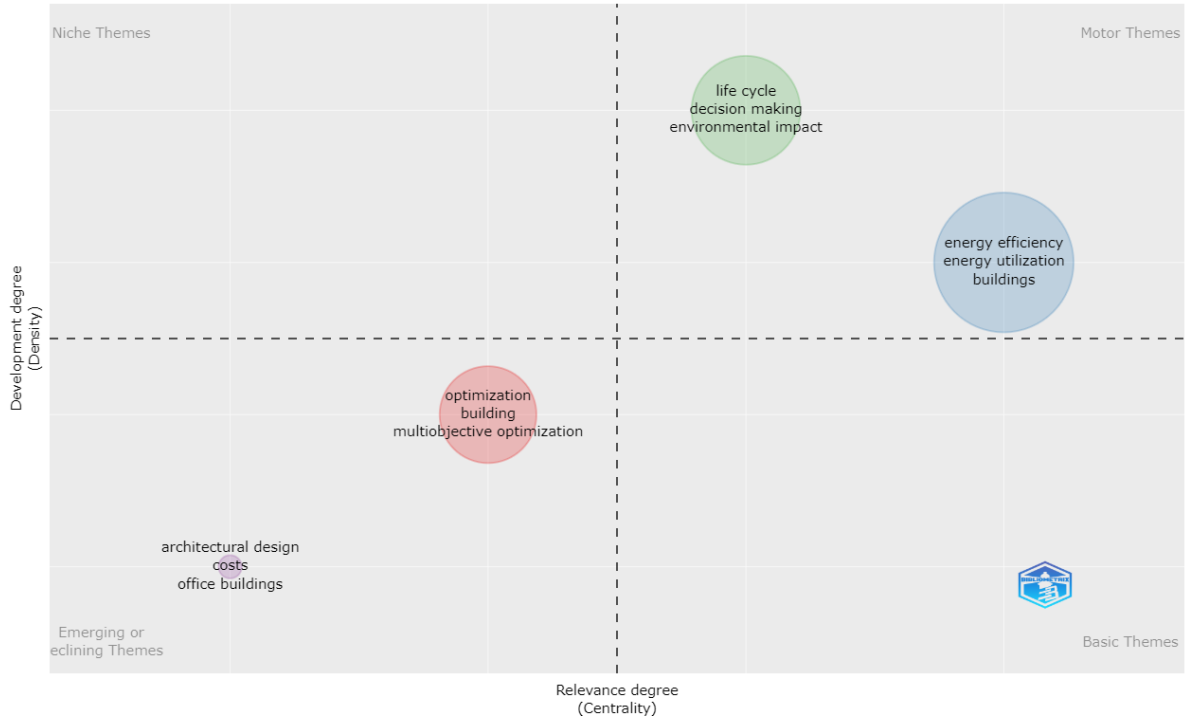


Figure 1: Niche themes.

On the other hand, the cluster about the life cycle, the cluster about energy efficiency and the cluster about optimization are highly studied with high frequencies regarding the clustering map (Figure 2).

label	group	freq	centrality	impact	color
All	All	All	All	All	All
energy efficiency - conf 25.2% buildings - conf 34.8% energy utilization - conf 28.4%	1	45	0.485141071367105	1	#E41A1C80
energy efficiency - conf 15.5% sustainable development - conf 19% retrofitting - conf 24.3%	2	32	0.369792046452276	1	#377EB880
life cycle - conf 53.8% environmental impact - conf 56.5% architectural design - conf 29.5%	3	60	0.393962759486854	1	#4DAF4A80
energy efficiency - conf 22.3% architectural design - conf 20.5% sustainable development - conf 27.6%	4	59	0.333313288498527	1	#984EA380
architectural design - conf 33.3% energy efficiency - conf 24.3% multiobjective optimization - conf 78.3%	5	54	0.426519568729316	1	#FF7F0080

Figure 2: Clusters by document.

In this regard, overlapped three clusters in niche themes and clusters by documents are regarded as three main clusters in this study. These clusters are:

- Cluster 1 – life cycle
- Cluster 2 - energy efficiency
- Cluster 3- optimization / multioptimization

Subsequently, most related documents for each main cluster are detected through network data in coupling map clusters. Most related nine articles are selected to examine them in detail to find related retrofits, climate mitigation and adaptation measures and BIM use from climate change or at least a sustainable perspective. In the selection, documents except review papers are included to see the used methods and measures in the related studies. In the meantime, the publications in the most related and distinguished journals are generally regarded.

Analysis Results of the Studies

The bibliometric analysis of the studies shows that most of the total 505 documents are published after 2018. Therefore, this year can be considered a turning point for examining thematic evaluations (Figure 3).

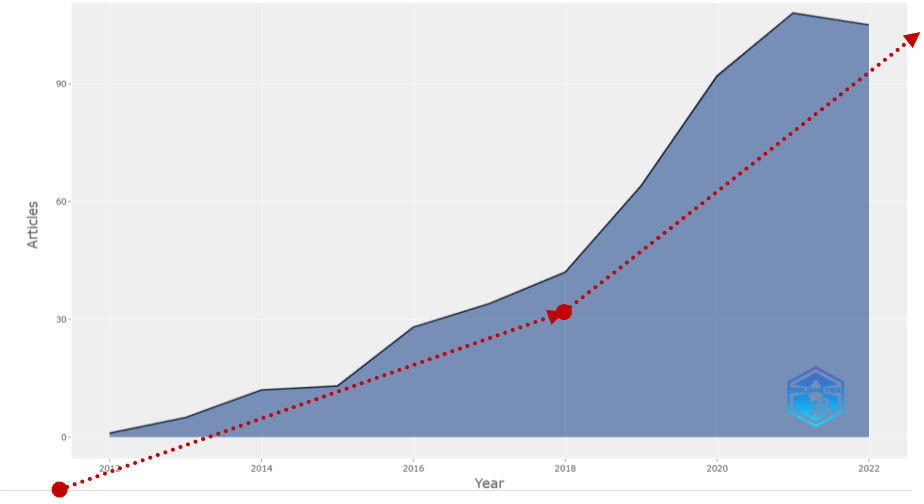


Figure 3: Annual scientific production.

Trend topics are examined regarding the turning point year – 2018. Buildings and optimization are highly examined after BIM and climate change topics in 2018. When energy efficiency was the following trend topic in 2020, sustainable development and decision-making were studied. In addition, it is notable that the life cycle is a trending topic in 2022, whereas carbon emissions after energy consumption are specifically conducted in 2022. Since this study is conducted before the mid of August, studies about carbon emissions might increase until the end of the year and be the top trend. In addition, it is vital that artificial intelligence is integrated into studies in 2022 (Figure 4).

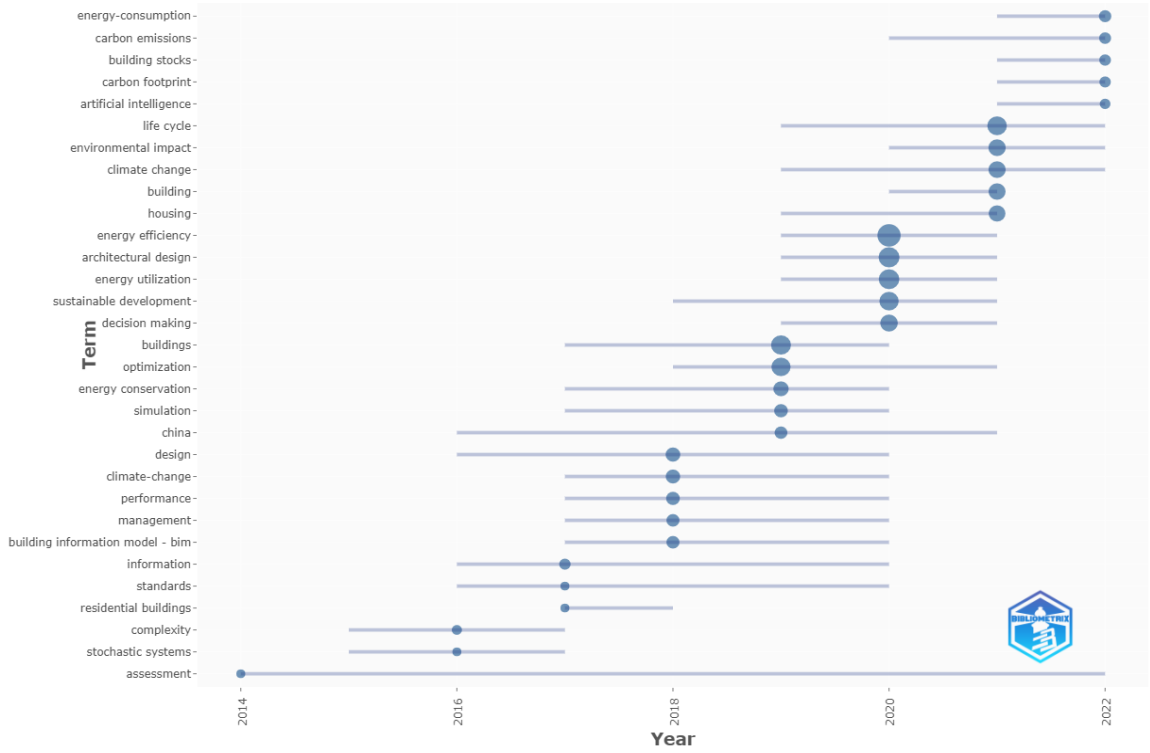


Figure 4: Trend topics.

Thematic evaluation after 2018 is examined regarding the author's keyword. It is clearly seen that multi-objective optimization beyond optimization dominates the field after LCA. On the other hand, climate change and sustainability are more discussed. Since the integration of BIM with LCA and sustainability has been highly discussed recently (Lim et al., 2021; Seghier et al., 2022), it seems logical that the BIM topic evolution to the LCA topic after 2018. It is notable that a literature review is more conducted after 2018. Since the integration of new terms such as climate change, optimization and artificial intelligence might be challenging for BIM, an increase in reviews seems logical. In order to provide more robust and valid integration frameworks and methods in the future, the backgrounds might be specifically examined (Figure 5).

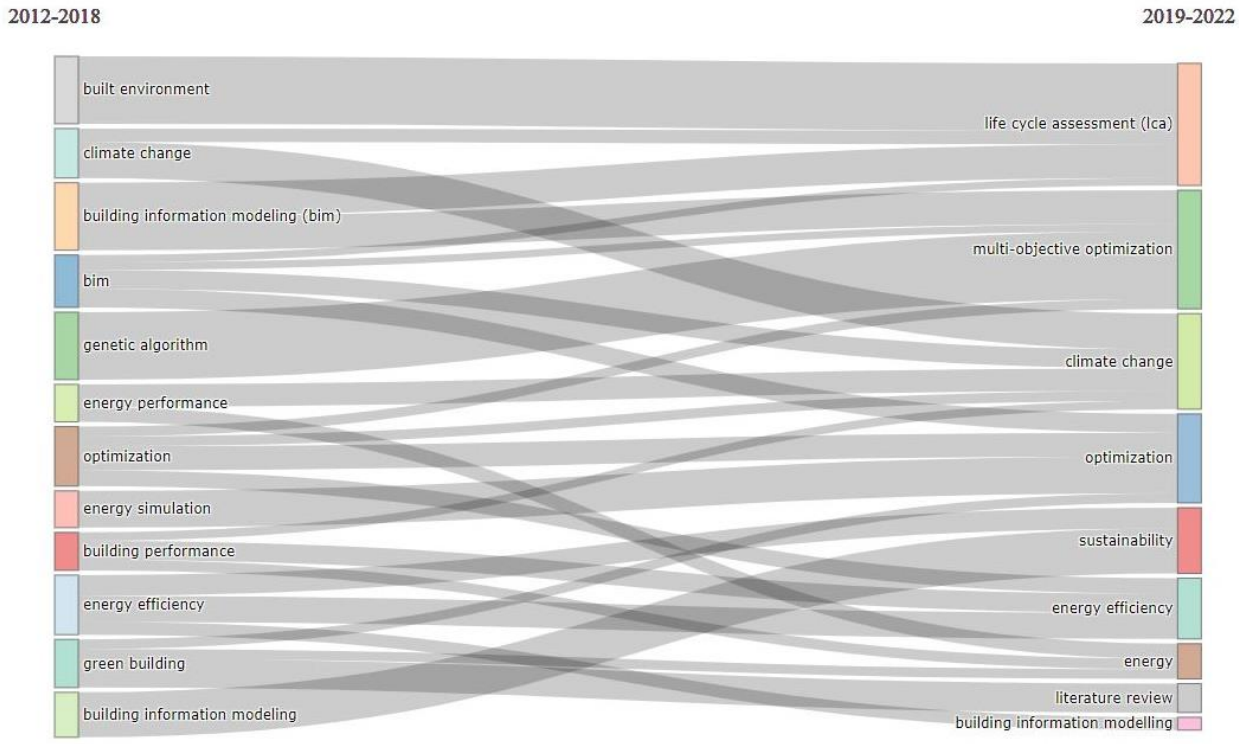


Figure 5: Thematic evolution.

Subsequently, the most related nine papers regarding their frequency in the network data are selected. Beyond the frequency, the publications in the most related sources are generally regarded. These articles are examined in detail to find out BIM use purpose in retrofits and their relations with climate change mitigation and adaptation measures. The information about articles and used tools with their purposes are tabularized. Residential and educational buildings worldwide are generally used in studies as case studies (Table 1). The BIM use in cluster 1 - life cycle is generally about integrating BIM with LCA (Motalebi et al., 2022; Rivera et al., 2021; Tushar et al., 2021). On the other hand, the studies in cluster 2 – energy efficiency integrates BIM with distinct energy tools such as "Autodesk Green Building Studio" (GBS) and "DesignBuilder." (He et al., 2019; Huskinson et al., 2021; Khahro et al., 2021) Moreover, BIM integration with ML methods and optimization tools such as Dynamo - Optimo is provided in the studies of cluster 3 – optimization (Chen et al., 2021; Chen et al., 2020; Ciacci et al., 2022).

Table 1. The information of the selected articles in detail.

Authors	**Year**	**Journal**	**Cluster C1/2/3**	**Building Type**	**Location**	**BIM use purpose**
Motalebi et. al.	2022	Journal of Building Engineering	C1 - Life Cycle	Multi-story residential building	Tehran, Iran	6D-BIM; BIM-LCA integration
Rivera et. al.	2021	Energy & Buildings	C1 - Life Cycle	Three high-rise residential buildings	Toronto, Canada	Modeling and integration with other tools
Tushar et. al.	2021	Journal of Cleaner Production	C1 - Life Cycle	Detached residential dwelling	Melbourne Australia	BIM-based framework for integration of

						LCA and energy rating
Khahro et. al.	2021	Sustainability	C2 - Energy	Hospital building	Hyderabad, India	BIM-GBS (energy tool) integration
Huskinson et. al.	2021	Energies	C2 - Energy	Small primary school	Alicante, south-east of Spain	BIM-Energy tools integration
He et. al.	2019	Sustainability	C2 - Energy	Typical high-density residential building block	Hong Kong, Shanghai, Beijing cities, China	BIM-Energy tools integration
Ciacci et. al.	2022	Energies	C3 - Optimization	Two different school buildings	Florence, Italy	BIM-integration with distinct tools, including DesignBuilder
Chen et. al.	2021	Journal of Cleaner Production	C3 - Optimization	New teaching building for the university	Hubei city, China	BIM integration with ML method for BIM-based framework
Chen et. al.	2020	Buildings	C3 - Optimization	Realistic single-story house	Sydney, Australia,	BIM integration with Insight (energy tool) and Dynamo, Optimo

Then, the type of retrofit measures is detected and their purposes as climate mitigation and/or adaptation are checked. The major retrofits are generally related to building envelopes and walls, roofs, windows and window-to-wall ratios (WWRs) are highly examined. Beyond that, renewable systems, appliances and rarely shadings are also integrated into the studies. The generation of future files is also investigated to see if there is a climate change perspective for future years or not. In this regard, it is detected that there is a need for climate change weather file integration into BIM (Table 2).

Table 2. Primary approaches and climate change measures in the studies.

Authors	Year	Climate Change		Carbon emissions		Energy Consumption				
		Mitigation measure	Adaptation measure	Embodied	Operational	Heating	Cooling	Cost	Optimization	Generated Future Weather File/Files
Motalebi, M. et. al.	2022	✓	✓	✓	✓	✓	✓	✓	✓	X
Rivera et. al.	2021	✓	✓	✓	✓	✓	✓	X	X	X
Tushar et. al.	2021	✓	✓	✓	✓	✓	✓	X	✓	X
Khahro et. al.	2021	✓	✓	X	✓	✓	✓	✓	X	X
Huskinson et. al.	2021	✓	✓	X	✓	✓	✓	X	X	X
He et. al.	2019	✓	✓	X	X	✓	✓	X	X	X
Ciacci et. al.	2022	✓	✓	X	X	✓	✓	✓	✓	X
Chen et. al.	2021	✓	✓	X	X	✓	NA	X	✓	X
Chen et. al.	2020	✓	✓	X	X	✓	✓	X	✓	X

Discussion and Conclusion

The BIM integration with sustainability is tried to advance; however, its integration with climate change, especially conducting future scenarios, is still rare. The LCA tools and energy tools are highly integrated with BIM. Beyond, the optimization tools and ML methods are combined with BIM to provide more comprehensive results or robust frameworks. Without integration of programming and ML methods, carbon emission and energy consumption calculation for optimization seem more challenging. Since different alternatives for each parameter are applied to scenarios for each possible result, various simulations are conducted after any change in a parameter. Hence, it turns into a time-consuming process that needs more effort. However, programming with correlation analysis and ML methods might be more effective in seeing results fast with limited data derived from simulations or real datasets. Therefore, cluster 3 – optimization studies provide comprehensive and less time-consuming approaches and predictions that require fewer input data. In addition, the studies generally include retrofits related to building envelopes such as walls, roofs, windows and window-to-wall ratios. Even if these measures are highly vital as climate change mitigation and adaptation measures, distinct measures should be integrated into retrofits, especially as cooling measures due to the increase in temperatures. Moreover, renewable systems and appliances are conducted in addition to the air leakages problem. However, passive measures should be more integrated since the increase in heat causes outages. Furthermore, only orientation as a building parameter from the general perspective is considered in the studies. Beyond the orientation, distinct general parameters related to buildings such as building form, compactness ratio and area and volume relationship (A/V) can be integrated into BIM-based

retrofits. Moreover, there is a need for climate change scenarios integration with BIM, including the mitigation adaptation retrofits, beyond its sustainability integration.

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Exploring the Current Implementation Status of BIM, Lean Construction and Sustainability Concepts in Construction Industry

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Abstract

With the AEC industry being one of the contributors to climate change, sustainability has become more than a trend in recent years. Building information model (BIM) offers engineers a genuine chance to help create a better world, So most researchers are focusing on building information modeling (BIM), sustainability(S), and lean (LC) fields. This paper aims to search for applying BIM, (S), and (LC) in construction and how those methods can affect the construction industry and enhance performance. The study explored the frameworks that integrate BIM with both LC and S. In especially, the study is expanded by highlighting the gaps. in the body of knowledge on BIM-LC and S in projects to help use lean techniques and BIM functions in sustainable public projects and megaprojects more effectively. It also summarizes what the researchers found of the critical success factors and constraints facing the achievement of the goal, which must be resolved, taking into account the research gaps. A systematic review methodology was employed. The result of a systematic review analysis helps in categorizing studies according to their content. The systematic review analysis showed that there are 11 journal papers only published between 2010 and 2022 (August). The current research also showed the scarcity of research on how it takes advantage of this inclusion in project performance as a real case study.

Keywords: *building information modelling (BIM), framework, lean construction, performance, sustainability*.

Introduction

Construction managers face constant challenges to solve problems within the construction industry, especially since it is the second-largest emitter of CO2 and accounts for one-third of all greenhouse gas (GHG) emissions (Al-Hamrani et al., 2021). In addition, the success of mega-engineering projects is affected by overcoming risks, including those associated with stakeholders (Aladağ & Işık, 2018). According to some experts, the main obstacle the construction sector faces is meeting its obligations and fulfilling its development role in the applications of the ideals of global sustainable development (Isik & Hasan, 2021). Sustainable development is defined as the provision of environmental, economic, and social services to all community members without damaging the durability of the built, natural, economic, and social systems at which the systems are dependent (WCED, 1987). As a sustainable construction, factors like energy efficiency, integrated design, indoor air quality, thermal

comfort, visual comfort, site suitability, acoustic comfort, spatial comfort, and building durability should be taken into account. (Nwokoro et al., 2011). The AEC sector regards as one of the least productive and technologically advanced sectors. So professionals must integrate manufacturing technologies with sustainability standards through all phases of the project's lifecycle like design and construction (Demirdöğen et al., 2021). BIM is a method based on intelligent 3D models that give professionals the tools they need to more effectively plan, design, build, and manage facilities. Additionally, enable more active decision-making (Azhar et al., 2012; Saieg et al., 2018). In contrast to tools or software, BIM is a process (Hardin et al., 2015, Eastman et al., 2011). If the construction processes have been integrated with BIM ideas, BIM technology would be effective in managing projects at any step of the project's lifetime. Implementing BIM technologies in project management might make the process better and unevenly cover all management facets. (Shaqour, 2022). Although the traditional engineering system focused on three-dimensional (3D) from various disciplines like architectural, structural, Mechanical and electrical power (MEP) engineers separately. BIM coordinates those models into one model and adds more "dimensions" of data to the information models, including time 4D, cost 5D, sustainability 6D, Operation & maintenance, Facility Management FM, 7D model (Porwal et al., 2013). After BIM was acknowledged the focus of studies on Lean Construction (LC) switched to an examination of the benefits of BIM usage in LC. LC consider one of the key techniques used to address issues in the AEC sector, where it improves project performance and reduces cost overruns (Demirdöğen et al., 2021). A theory known as "lean Construction" is based on the lean concepts Taiichi established in Toyota (Saieg et al., 2017). LC is a corporate approach whose main goal is to reduce waste (Saieg et al., 2017; Murata et al., 2018). The following five principles of lean theory can be summed up: (value, value stream, flow, pull, and perfection) (Womack et al., 2007). There are studies examining the twinning between BIM-LC, BIM-S, and LC-S in the area of performance enhancement in the design and construction sector, for example, according to Arayici et al. (2011), the application of BIM skills, including constructability analysis, energy, environmental analysis, and structural analysis, can improve project outcomes, particularly for projects striving to be lean and environmentally friendly. the study discovered parallels between green and LC performance metrics. However, according to Bostancı et al. (2022), there are extremely few studies that incorporate all three of these concepts together, Where the number of the results according to three concepts until May 2020 was 10 articles, almost started after 2017 (Mellado et al., 2020; Bostancı et al., 2022). By 2019, there was less interest in examining the relationship between BIM, LC, and S (Bostancı et al., 2022). LC implementation with BIM in the design process greatly improves project efficiency. Using BIM as a tool will assist in implementing LC principles by increasing owner value and eliminating waste (Eldeep et al., 2022). 56 connections were provided by (Sacks et al., 2010) as hypotheses of how lean and BIM interacted, taking into account the genuine difficulties that businesses have while implementing lean and BIM. Both the usage of BIM and LC have brought about significant developments that have led people to consider the sustainability of the world's future (Saieg et al., 2018). Additionally, BIM supports LC technology, where the majority of lean concepts utilized in the construction sector have components in common with BIM like visual analysis and data flows among stakeholders and the reduction of mistakes through guiding the management decision-making process (Saieg et al., 2018). Engineering-based information sharing issues are one of the main factors influencing diminishing construction project performance due to the creation of several types of conflicts (Tommelein et al., 2012). Making decisions during design and construction can result in the generation of a variety of waste (Sacks et al., 2010). As a result, sustainability is directly tied to BIM and LC. According to Lekan et al. (2018), combining LC-BIM ideas will produce a powerful framework that might help nurture characteristics that

support sustainable growth (Lekan et al., 2018). There are studies examining the twinning between BIM-LC, BIM-S, and LC-S in the area of performance enhancement in the design and construction sector. However, according to Bostancı et al. (2022), there are extremely few studies that incorporate all three of these concepts together, Where the number of the results according to three concepts until May 2020 was 10 articles, almost started after 2017 (Mellado et al., 2020; Bostancı et al., 2022). By 2019, there was less interest in examining the integration BIM, LC, and S (Bostancı et al., 2022). The study aims to discover the research gaps by knowing the current level of research on BIM, LC, and S simultaneously. Also, the study reveals if there is a framework that achieves an optimal synergy between BIM, LC, and S by full integration and if can it be applied to mega-projects to obtain maximum efficiency in certain aspects. The political objectives of diverse groups and local governments frequently have an impact on megaprojects (Jia et al., 2011). We hypothesize that the use of BIM, LC, and S must be combined, as it is in the Integrated Project Delivery (IPD) method, to fully realize the potential for the improvement of mega-projects. The following questions provide the main framework for the research:

Q1: What is the current level of research on BIM function with LC and S?
Q2: Is there a framework that integrates the three concepts in public or megaproject, can the framework be deduced through a literature review?
Q3: What is the current knowledge gap in academic research and/or practitioner concerns with the integration of lean construction; BIM technology and sustainability?

The following additional sub-questions were provided to guide the investigative process: What are crucial factors and challenges that will ensure the success of this integration in published research face? So, the research is not only seeking to show the current situation of the construction industry but also seeks the gaps to continue to be studied in future studies. To address the research issues that were presented. The article is divided into sections, and Figure 1 shows the overall review workflow. The findings of this study will further the current body of knowledge in the disciplines of BIM, LC, and S integration research. It reveals the importance and benefits of applying integration in projects and the tools to be used to reach integration in mega projects. It also reveals the main obstacles and challenges that stand on The road to the final adoption of BIM, LC, and S models in projects with a focus on critical success factors that lead to improved synergy and development of BIM, LC, and S goals. In addition, the study reveals the gaps that must be explored in the future to inform key stakeholders in the construction industry of possible solutions.

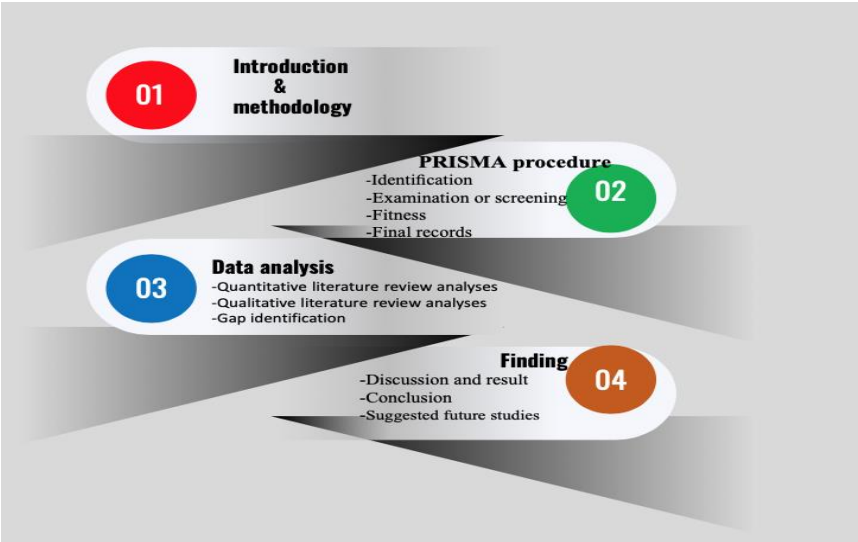


Figure 1: The overall review workflow.

Methodology

Systematic reviews serve as the reference standard for research evidence through assist in the creation of practice guidelines and providing information for decision-making (Moher et al., 2015). The study adopted a quantitative and qualitative research strategy. The systematic literature review (SLR) technique is explained in detail. The search results are discussed then the review of LC-BIM-S connections is provided. The research also proposes a methodology for developing a framework that demonstrates how to achieve the integration of BIM with LC to achieve megaproject sustainability. The study then identifies knowledge gaps to direct academics future research. The study's methodology guarantees an accurate description of the analytical strategy based on the protocols for systematic reviews and meta-analyses (PRISMA-P), following the procedure presented by Moher et al. and Okoli as shown (Moher et al., 2015; Okoli, 2015).

PRISMA Procedure

There are procedures used to gather, choose, and filter pertinent materials namely: Identification, Examination or screening, fitness or eligibility, and final records (Moher et al., 2015; Okoli, 2015; Qiao et al., 2021). It is presented in the diagram in Figure 2.

• Scoping :
The initial phase is scoping, during which research questions and queries are created. An extensive literature search was conducted based on: title, abstract, and keyword. The research was done by databases such as Clarivate analytics-Web of Science database to perform the scientometric analysis addressing BIM, lean, and sustainability. Journal papers in the following databases were screened during the identification phase: Elsevier (www.sciencedirect.com);Emerald(www.emeraldinsigh.com);Springer(https://www.springer.com/gp/);(https://link.springer.com);Taylor&Francis(www.taylorandfrancis.com);Wiley(https://onlinelibrary.wiley.com/action/showPublications ; ASCEE library (https://ascelibrary.org/); MIDPI open access journal (https://www.mdpi.com/) and Google Scholar database.
These databases were chosen because of their effective, simple, advanced search capabilities and their trustworthy and thorough academic content in the subject matter of this study. Mendeley, a reference manager that enables annotations, document-level searching, and simple duplication elimination, was utilized to consolidate, organize, and regulate the data acquired. Since the most relevant and trustworthy sources for literature reviews are peer-reviewed journals and conference proceedings, they were taken into consideration. (Saunders et al., 2012). Using inclusion and exclusion criteria, SLRs' fundamental properties are illustrated (Qiao et al., 2021). Thus, the requirements for inclusion in these SLRs are the Articles about BIM integration about sustainability and lean that were published in journals and conference proceedings articles were included over the previous 12 years (2010 - August 2022) since early studies were suggested using information technology in building. The study includes English-language articles and it was restricted to the following construction-related disciplines: decision sciences, engineering, business management, accounting, social sciences, economics, and finance.
• Identification:

According to Bostancı et al. (2022), the most relevant keywords in the integration of BIM with LC and S studies are (TITLE-ABC-KEY) - (“building information modeling" OR “building information modeling” OR "BIM") AND ("lean" OR “lean construction” OR “lean thinking”) AND ("sustainability" OR "sustainable" OR "green" OR "environmental"). The most popular keywords are “building information modeling, BIM capabilities, lean construction, “BIM” then comes “sustainability”, according to only Quantitative literature review analyses done by (Bostancı et al., 2022). After additional filtering based on the inclusion criteria, in total 12278 articles were found then eliminated the duplicates. After a total of 11009 items were removed, the remaining 1269 articles got further screening.

• Screening

Through title and abstract evaluations in this stage, 1269 articles among the databases were published between August 2010 and August 2022. Additionally, searches without specific keywords in the abstract were disregarded. 1192 items were left out.

• Fitness

The publications were examined to confirm their direct relation to integration between BIM, LC, and S with the effect of this integration on improving performance in the construction industry. According to the PRISMA-P standards, briefly reading an article's title, abstract, and entire text constitutes screening which may also be evaluated if there is a suspicion of ambiguity. So, some articles that focused on each concept separately were segregated. The literature review only covered 11 articles. Then, related articles were stored on a platform for managing references (Mendeley Desktop version).

• Inclusion or final records

The 11 selected research articles were subjected to a more thorough review and inspection. The research approach flowchart of (PRISMA) is shown in Figure 2, the results of the final approach show a large number of studies that were excluded from the analysis because they dealt with merging two concepts or of them. 11 papers were analyzed later to find the gaps as shown in Table1 which shows the phases of a literature review.

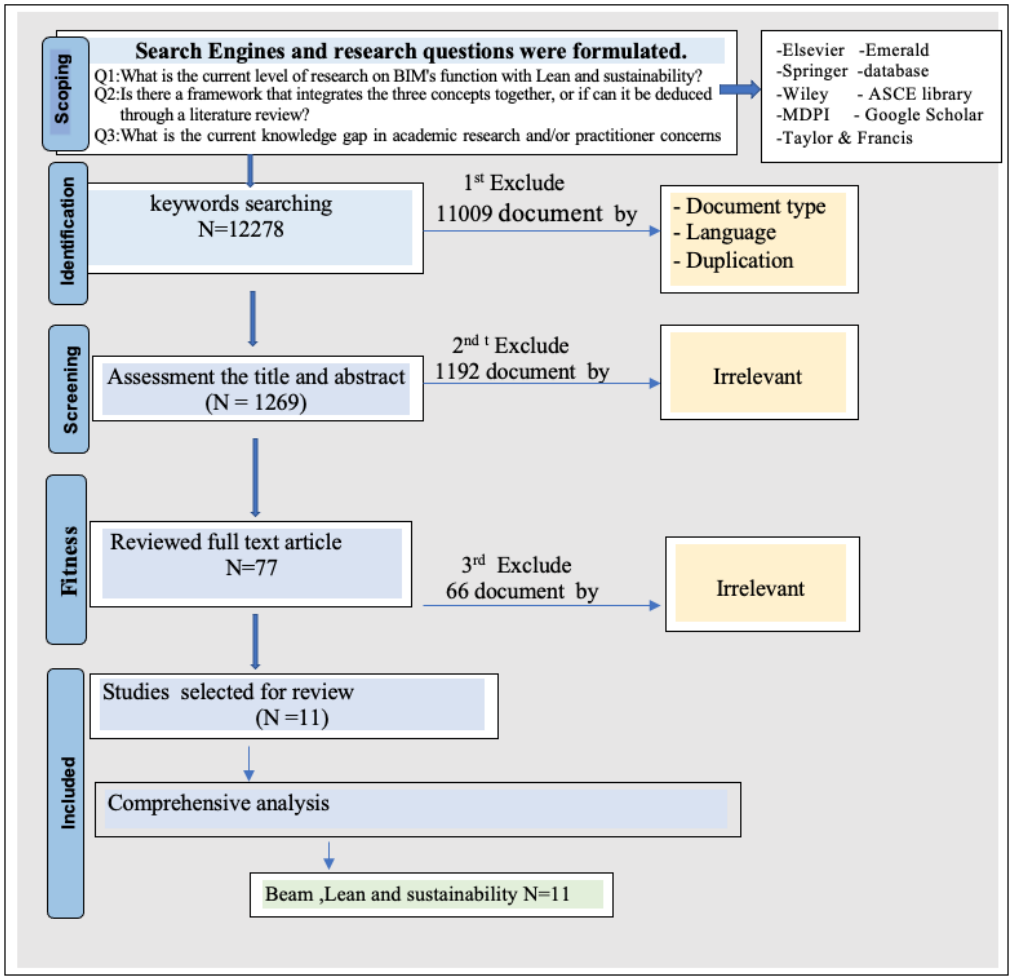


Figure 2: The research approach flowchart (PRISMA).

Table1: Phases of a literature review

Databases	Step review 1	1st Exclude	Step review 2	2nd Exclude	Step review 3	3rd Exclude	Final review
• Elsevier	548	365	183	139	47	44	3
• Emerald	448	424	24	23	1	0	1
• Springer	42	35	7	3	4	3	1
• Taylor & Francis	91	73	18	18	0	-	0
• Wiley	213	208	5	4	1	1	0
• ASCEE library	237	220	17	10	7	6	1
• MDPI Open Access Journals	99	80	19	10	9	8	1
• Google Scholar database	10600	9604	996	985	11	7	4
Total	12278	11009	1269	1192	77	66	11

Data Analysis

To answer question 1 the study combined quantitative and qualitative research methods. Quantitative analysis is the process of combining quantitative data from numerous relevant studies in order to provide a thorough synthesis of empirical knowledge about a given topic (Bronson & Davis, 2011; Andjar-Montoya et al., 2018; Arayici et al., 2018). This technique has been applied in several studies that combine two ideas (BIM-L) or (BIM-S) (Saieg et al., 2018; Bryman,2017; Bryman, 2017). With the use of the research technique of qualitative analysis, data may be categorized to reveal trends (Reale, 2014).

Quantitative Analyses

The analysis concludes the largest number of publications was in 2018 as shown in Figure 3. It's interesting to note that 64% of the research on combining BIM with Lean and sustainability techniques has only recently been published (in the past five years), proving that this field of study is still in its infancy.



Figure 3: The distribution of articles by year.

Database of ScienceDirect and Google Scholar was the most published database for this topic, while publication was absent in each of "Taylor & Francis" and "Wiley" as shown in Figure 4. Through Table 2 and Figure 5. it could see that approximately 60% of articles were published in international journals with high cite score and the rest within scientific conferences. The highest-published journal in terms of cite Score is the "Journal of Cleaner Production" with a cite score of 15.8, then "Sustainable Cities and Society" and "Engineering Construction and Architectural Management" with a cite score of 14.4 and 5.7, 5.2 respectively. Finally, the Journal of "Sustainability" and Journal of "Theoretical and Applied Information Technology" with citing scores of 5 and 1.3 respectively. Table 3 shows Selected article information like authors, article title, citation, and keywords.

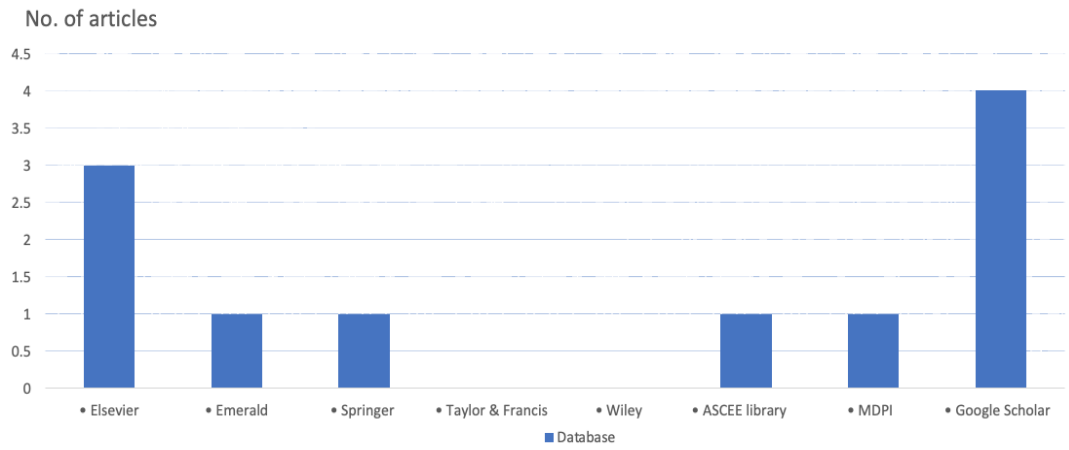


Figure 4: Article distribution based on the database.

Table 2. Publisher information.

	Publisher	Cite Score	Type	Database
1	"Sustainable Cities and Society"	14.4	Journal	ScienceDirect
2	"Journal of Cleaner Production"	15.8	Journal	ScienceDirect
3	"International Journal of Sustainable Built Environment"	5.7	Journal	ScienceDirect
4	"Engineering Construction and Architectural Management"	5.2	Journal	Emerald
5	"Climate Emergency – Managing, Building , and Delivering the Sustainable Development Goals"		Conference	Springer
6	"Sustainability"	5	Journal	MDPI
7	"Construction Research Congress 2010: Innovation for Reshaping Construction Practice"		Conference	ASCE
8	"Proceedings of the 2010 ERACOBUILD Workshop on BIM and Lean"		Conference	Google scholar
9	"21st Annual Conference of the International Group for Lean Construction"		Conference	Google scholar
10	"Journal of Theoretical and Applied Information Technology"	1.3	Journal	Google scholar
11	"Proceedings of the 22nd Conference of the International Group of Lean Construction"		Conference	Google scholar



Figure 5: Publish type.

Table 3. Selected article information.

Authors	Article title	Cited	Keywords
Mellado et al (2020)	"Building information modelling, lean and sustainability: An integration framework to promote performance improvements in the construction industry"	33	"Building Information Modelling (BIM); Lean, Sustainability and the combination of them, framework; model; Lean Production; Green"
Saieg et al.(2018)	"Interactions of building information BIM lean and sustainability on the architectural, engineering and construction industry: a systematic review"	106	"Building information modeling; Lean construction Green construction Synergies; Sustainable development"
Ahuja et al. (2017)	"Driving lean and green project outcomes using BIM: A qualitative comparative analysis"	72	"Building Information Modelling (BIM);Lean Green Crisp set qualitative comparative analysis (csQCA)'BIM capabilities, project outcomes"
Ahuja,et al. (2018)	"Developing organizational capabilities to deliver lean and green project outcomes using BIM"	24	"Building information modelling; AEC sector, BIM capabilities; Lean principles; Green principles"
Bostancı et al.(2022)	"Investigating the Trinity Between Sustainability and BIM-Lean Synergy: A Systematic Review of Existing Studies"	-	"Bibliometrics; Building Information Modeling (BIM);Lean Construction; Sustainability"
Sepasgozar et al.(2020)	"Lean Practices Using Building Information Modeling (BIM) and Digital Twinning for Sustainable Construction"	34	"Digital construction; lean; lean construction; Building Information Modeling (BIM); Internet of Things (IoT); Digital Twin; computer-aided engineering (CAD)"
Enache et al.(2010)	"A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles, and BIM"	48	"A Unified Process Approach to Healthcare Project Delivery: Synergies between Greening Strategies, Lean Principles, and BIM"
Koskela et al. (2010)	"Lean construction, building information modelling and sustainability"	23	"Lean construction; building information modelling; sustainability"
Rahman, et. Al.(2013)	"Exploring the synergies between BIM and lean construction to deliver highly integrated sustainable projects"	10	"BIM, Integration; Lean Construction; Project Delivery; Sustainable Construction"
LEKAN et al. (2018)	"Creating sustainable construction: Building informatics modelling and lean construction approach"	15	"Construction, Sustainability; BIM; Lean; Diffusion; Integration"
Ahuja, et al.(2014)	"BIM based conceptual framework for lean and green integration"	26	"Building Information Modeling (BIM) lean, green, sustainability"

Qualitative Literature Review Analyses

The papers under analysis, which numbered 11 manuscripts, were comprehensively evaluated, including the following: Year; finding; limitation; gaps; research methods; suggested framework (FW); validation of suggested framework (VFW); Industry type; performance assets (PA) and whether the investigation identifies any potential integration or adoption restrictions or challenges. To respond to the following research issues, this review study critically analyzes the existing literature to answer the research questions. Table 4 shows the summary of selected articles.

Table 4. Summary of selected articles.

Ref. / year	Finding	Limitation & Gaps	Research methods.	F. W	V.F W.	Industr y type	PA.
Mellado et al (2020)	The research suggested a framework for integrating the three concepts, as it determined that the important factor for the interaction of BIM and Len is waste reduction, while BIM is positioned towards sustainability by promoting environmental aspects through waste reduction. it identified CSFs and showed that stakeholder integration is the most crucial factor.	It was advised to use it for a small-company strategy. - Lacks framework validation and there are yet no fully developed frameworks that might be compared. - CSF validation is still necessary. - There is no published study on how project performance might improve with integration but performance has been individually studied. - The findings indicated a lack of social integration.	Qualitative analysis 2001-2018	Yes	No.	Small sized construc tion project	No
Saieg et al.(2018)	The integration matrix for BIM, lean, and green was exhibited in the study. The advantages and disadvantages of BIM were merged, Study suggests doing a comprehensive evaluation of the literature pertaining to studies on synergies, BIM interactions, lean, and sustainability.	- On the selected databases, there is a restriction and a time limit. The range is 2006–2015. - It focused on peer-reviewed articles and conference proceedings in English, ignoring books or other - FW. has to be improved in order to seek real-world evidence and gradually verify it. -The paucity of studies that examine all three topics.	systematic reviews of the literature. A conceptual synthesis and quantitative results	No.	-	General	No
Ahuja et al. (2017)	The implementation of four BIM capabilities-MEP system modeling, energy and environmental analysis, constructability analysis, and structural analysis-can improve project outcomes, to be lean and green, according to a study that explored the causal relationships between different BIM capabilities. The research advises AEC businesses to explore implementing BIM on projects.	- A limited sample of architectural firms - LC and green's synergies and combined advantages still need to be better appreciated in practice. Few studies have examined the processes that enable simultaneous green and lean project improvements.	Qualitative comparative analysis by using crisp set qualitative comparative analysis (csQCA) method	No.	-	General sample from architect ural firms	Yes
Ahuja,et al. (2018)	The article has created a framework for organizational skills based on BIM that will enable the implementation of lean and green advantages. A road map for using BIM to provide a lean and green effect on building projects is presented.	It was found that in order to achieve the desired project outcomes, a company must adopt a fundamental BIM adoption culture throughout its project teams and the business as a whole.	Mixed-method by Semi-structured interviews, focus groups, and qualitative comparative analyses.	Yes	Yes	General construc tion	No
Bostancı et al.(2022)	The use of BIM and LC principles has increased the interest in this bilateral relationship since 2010. The analyses that are done show that a study's focus is on the chosen keywords. It aims to create a dynamic platform for further investigations.	-Using the Scopus database between 2011 and 2020 -Didn't demonstrate quantified benefits. There are extremely few studies that include all three of these terms. BIM, Lean, sustainability	The association between the phrases BIM, Lean, and Sustainability was examined using bibliometric analysis.	No.	-	General construc tion	No
Sepasgozar et al.(2020)	The study presented the most recent development tools BIM including LC principles. In order to use LC approaches more effectively. Results showed a significant synergy between LC & BIM in control interactions and a decrease in variability. The study provided a FW. that, together with the analysis, may be utilized as an illustration of the linkages between IT and production systems.	The articles relevant were from the Scopus database. There is a gap regarding the synergy of LC and the modeling of digital information and sensor-based technologies in particular construction domains, such as sustainable infrastructure projects, megaprojects, and stakeholders' involvement. The FW. needs to test empirical research. The paucity of research that examination of synergies.	A systematic review method 2000-2020	Yes	No.	General construc tion	No
Enache et al.(2010)	This study integrated green building practices, LC manufacturing techniques, and BIM to create an early conceptual model for the construction of healthcare facilities. The concept was developed with the early phases of planning and design for healthcare facilities in mind.	The concept was developed for healthcare facilities The use of only a few concepts that are appropriate for healthcare facilities, without a clear emphasis on the project's whole life cycle. Developed integrated model validation support is needed.	Multiple case study technique. Utilized were three case studies of healthcare facilities in the design stages.	Yes	Yes	healthca re projects	No
Koskela et al. (2010)	He examined the links between S, LC, and BIM. It was suggested that it is opportune to discuss action options of BIM, LC, and S coverage of requirements by the biggest construction client in each state. Mainly emphasized how methodologies might be used collaboratively; But other issues, for this integration, have not yet been resolved.	Their research is limited to the use of these concepts in collaborative settings; it has not yet addressed issues like a comprehensive framework for integration. FW. for integration, have not yet been addressed.	Examines the interactions between three present drivers.	No	-	General construc tion	No
Rahman, et. Al.(2013)	The research developed a proposed conceptual framework, to reveal the maximum "sustainable value. It studied a conceptually-level integrated approach that links BIM and LC to promote sustainable principles across a project's whole life cycle in the AEC sector.	It is essential to examine the various facets of this integrated strategy through collaboration between academia and industry.	Review to develop framework	Yes	No.	General construc tion	No
LEKAN et al. (2018)	highlighted the obstacles to LC, BIM, and S with The crucial components of Lean-BIM integration for sustainable construction. The research presented the benefits of applying BIM and LC in the various construction stages, which were obtained through a field survey of two hospital projects. The research also presented the sequence of these benefits in terms of importance, which was also obtained from the field questionnaire. The index of relative agreement with BIM principles was determined	The framework has to be verified by applying to a project's life cycle process and carrying it through each stage.	Data from the sample population was gathered using questionnaires to document the opinion of the workforce about the viability of integrating lean construction and BIM for sustainable building on a Likert scale of 1 to 5.	Yes	yes	Hospital s	No
Ahuja, et al.(2014)	An assessment performance framework for BIM was created as a prototype using the GRIHA evaluation process. The findings suggest that BIM-enabled projects may more successfully integrate lean and green practices and provide value. By citing 8 lean principles and 15 specific Green Rating Integrated Habitat Assessment (GRIHA) criteria.	The proposed framework addresses only the environmental linkages to sustainability. The proposed framework needs to be refined by additional research	It includes conceptualizing a BIM-based framework, feedback from business leaders, revising the framework in light of the feedback, and testing the framework on 3 case studies.	Yes	Yes.	General construc tion	Yes

Selected Studies

The beginning of the emergence of a study of the framework that combines the three concepts of BIM, LC, and S was in the year 2010 when the study demonstrated the possibility of integrating three ideas and introducing a BIM-LC-S strategy in the AEC sector. Enache et al. (2010) illustrated the relation using a conceptual construction delivery model. During the programming and preliminary design phases of healthcare facilities, Figure 6 shows a representation of the factors investigated in this study, along with an early conceptual model.

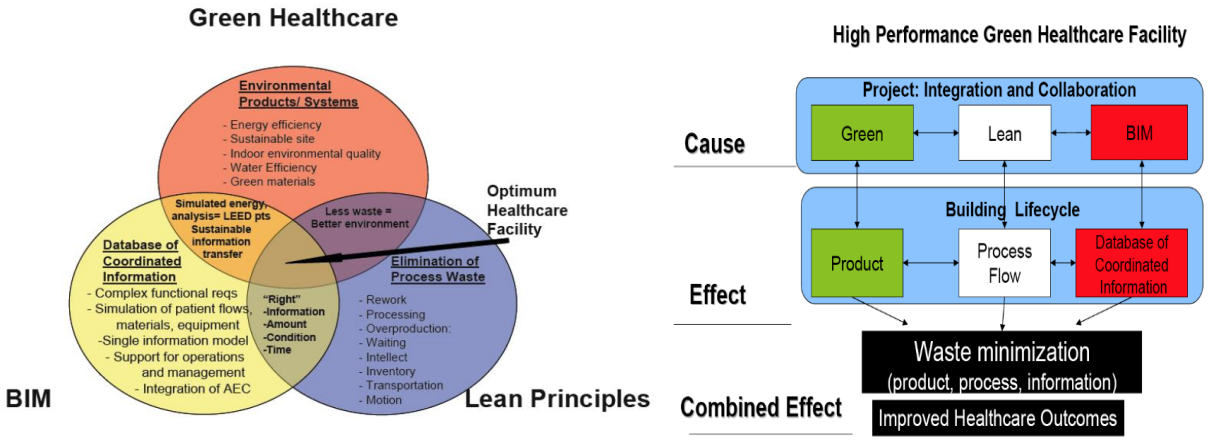


Figure 6: Early adoption of BIM, LC, and green initiatives (Enache et al., 2010).

Koskela et al. (2010) explored how BIM, LC, and S are related. Their study mainly emphasizes how methodologies might be used collaboratively; But other issues, such as a fundamental structure for this integration, have not yet been resolved.

According to Rahman, et al. (2013), BIM and LC that complement sustainable principles are the main goals of this integration. these construction concepts are illustrated through decreased material waste, computer-controlled production, and reduced variability. The supporting connection is represented by the color coding as in Figure 7 & Figure 8.

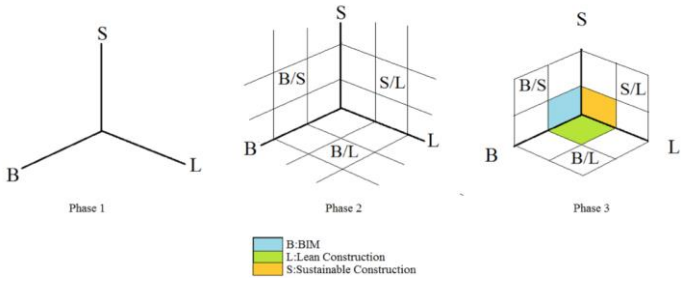


Figure 7: Integrated BIM, LC and, S Framework (Rahman et al., 2013).

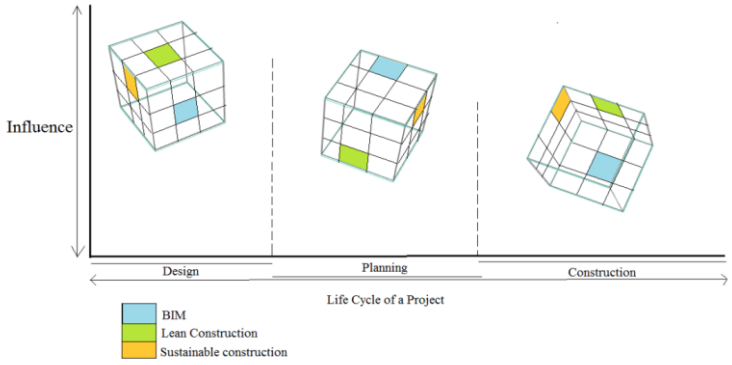


Figure 8: Implementing BIM, LC, and S at various project phases (Rahman et al., 2013).

Ahuja, et al. (2014) created a theoretical assessment framework for BIM as a prototype using Green Rating Integrated Habitat Assessment (GRIHA), an environmental assessment schemes system for directing and measuring performance. They suggested that BIM can integrate LC

and green practices more successfully and provide value by identifying 8 LC principles and 15 chosen (GRIHA) criteria. Study interlinkages LC and green driven by BIM were captured as shown in Figure 9.

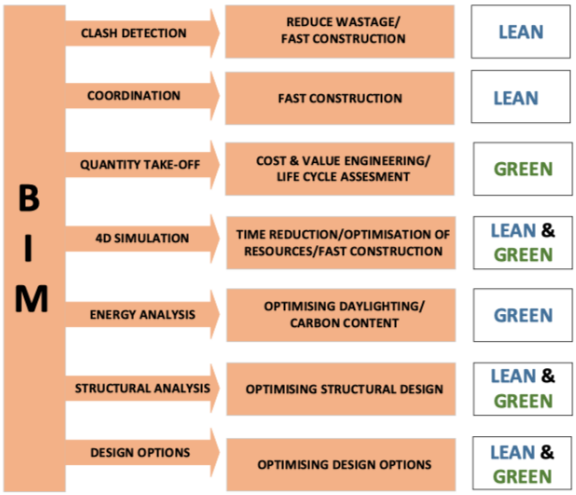


Figure 9: Different BIM components that contribute to lean and green (Ahuja et al., 2014).

In addition, Ahuja et al. (2017) analyzed 16 projects in architectural firms. Three BIM capability sets that result in lean and green outcomes were discovered through analysis. According to their research, "independent BIM capabilities of Energy and environment analysis (E&EA), structural analysis (SA), MEP system modeling (MEP), and constructability analysis (CA)" are the four main BIM capabilities that a design organization has to focus on. They found the effect of LC and BIM implementation on economic, social, and environmental performance. Further, Ahuja, et al. (2018) created a framework for organizational capabilities based on the previous BIM framework.

Saieg et al. (2018) considered three ideas (S/green, lean, and BIM). A systematic review was utilized. The study developed BIM, LC, and Green integration matrix depending on the perception by Sacks et al. (2010) that identified BIM function and LC principles as shown in Table (4-5). According to Figure 10, cells with numbers reflect positive interactions (green), while cells with parentheses and orange reflect negative interactions. LEKAN et al. (2018) highlighted the obstacles to LC, BIM, and S with The crucial components of Lean-BIM integration for sustainable construction. The research presented the benefits of applying BIM and LC in the various construction stages, which were obtained through a field survey of two hospital projects they were: "Improves safety & environmental issues, improves time, cost, and quality, helps to identify constraints within the construction, focuses on value than cost; optimizes resource delivery schedules; aids reduction in on-site transportation, results in standardization of work practices". The research also presented the sequence of these benefits in terms of importance, which was also obtained from the field questionnaire. In addition, the index of relative agreement with BIM principles was determined through a questionnaire.

Table 5. BIM function (Sacks et al., 2010).

Table 6. LC principles (Sacks et al., 2010).

BIM functionalities.

BIM functionalities		Row
Visualization of form	Aesthetic and functional evaluation	1
Rapid generation of design alternatives		2
Re-use of model data for predictive analyses	Predictive analysis of performance	3
	Automated cost estimation	4
	Evaluation of conformance to program/client value	5
Maintenance of information and design model integrity	Single information source	6
	Automated clash checking	7
Automated generation of drawings and documents		8
Collaboration in design and construction	Multi-user editing of a single discipline model	9
	Multi-user viewing of merged or separate multi-discipline models	10
Rapid generation and evaluation of construction plan alternatives	Automated generation of construction tasks	11
	Construction process simulation	12
	4D visualization of construction schedules	13
Online/electronic object-based communication	Visualizations of process status	14
	Online communication of product and process information	15
	Computer-controlled fabrication	16
	Integration with project partner (supply chain) databases	17
	Provision of context for status data collection on site/off site	18

Adapted from Sacks et al. (2010).

Lean principles.

Lean principles		Col.
Reduce variability	Get quality right the first time (reduce product variability)	A
	Focus on improving upstream flow variability (reduce production variability)	B
Reduce cycle times	Reduce production cycle durations	C
	Reduce inventory	D
Reduce batch sizes (strive for single piece flow)		E
Increase flexibility	Reduce changeover times	F
	Use multi-skilled teams	G
Select an appropriate production control approach	Use pull systems	H
	Level the production	I
Standardize		J
Institute continuous improvement		K
Use visual management	Visualize production methods	L
	Visualize production process	M
Design the production system for flow and value	Simplify	N
	Use parallel processing	O
	Use only reliable technology	P
	Ensure the capability of the production system	Q
Ensure comprehensive requirements capture		R
Focus on concept selection		S
Ensure requirement flowdown		T
Verify and validate		U
Go and see for yourself		V
Decide by consensus, consider all options		W
Cultivate an extended network of partners		X

Adapted from Sacks et al. (2010).

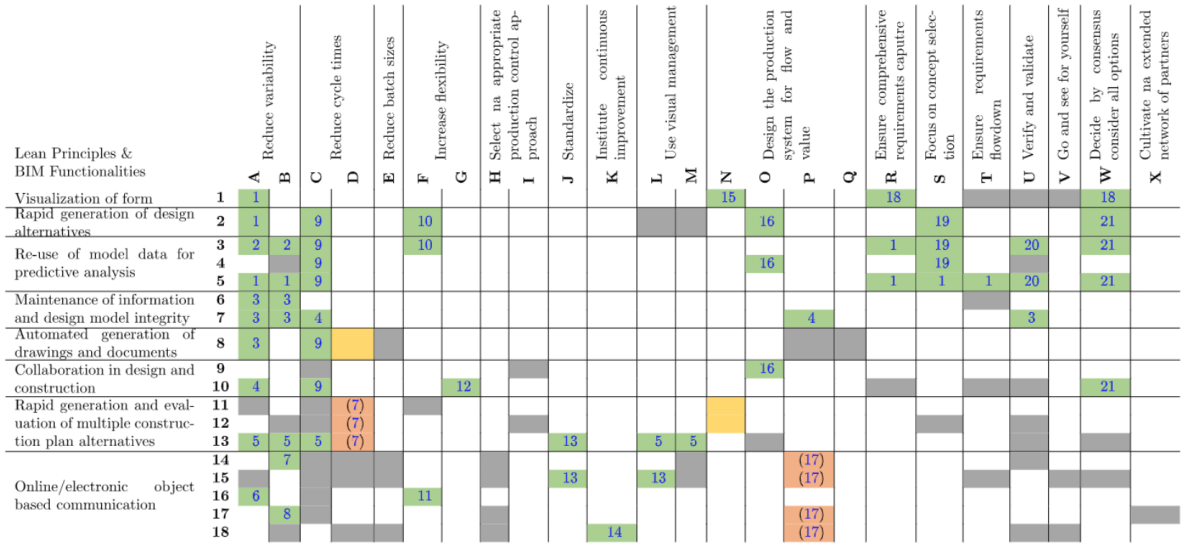


Figure 10: BIM, lean and green integration matrix (Saieg et al.,2018).

Mellado et al. (2020) recommended a framework for connecting the three ideas since it found that waste reduction is crucial for the integration between BIM and LC towards sustainability by encouraging environmental considerations. It identified crucial success elements. Stakeholder integration is one of the most crucial factors to take into account. The findings demonstrated a deficiency in social integration, one of the three elements of sustainability. Figure 11 shows the theoretical framework and its components.

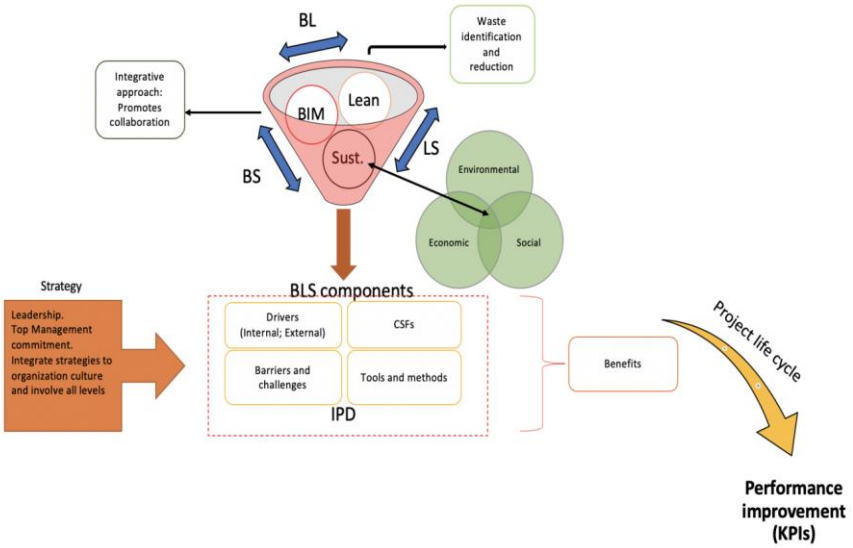


Figure 11: Theoretical framework and its components (Mellado & Lou, 2020).

Sepasgozar et al. (2020) presented the most recent development of digital tools (BIM) including LC principles, like:

-Structural Building Information Modeling (S-BIM) with Set-based Design (SBD), where SBD is a lean approach which increases efficiency throughout all stages of a project by sharing information and working with relevant sectors to eliminate waste components.

-Using KanBIM idea that is "a lean construction production management system that uses BIM." This system offers site-specific interfaces to address the resource management constraints of the construction project. The study concludes that there is significant synergy between LC-BIM in design-related and construction-related activities. That enables time and overall cost optimization while raising project quality reducing waste and non-value-added activities, optimizing processes, enhancing oversight, and enabling digitization so that the project can be seen. Finally, in 2022 a bibliometric study was conducted to look at how the phrases BIM, LC, and S relate to one another, a study's focus is on the chosen keywords, and aims to create a dynamic platform for further investigations. They conclude that there are extremely few studies that include all three of these terms. BIM, Lean, sustainability. (Bostancı et al., 2022).

Results and Discussion

By reviewing selected articles, the first proposed framework was for a big project for the healthcare facilities sector (hospitals) in America by Enache et al. (2010). He outlines the integration of BIM, LC, and S through a conceptual build delivery strategy during the early programming and design stages through a case study of three projects. For the same sector, For the same sector, CSFs for sustainable construction in hospitals were highlighted through a field survey and case study of two hospitals by Lekan et al. (2018), where the most important CSFs were: Regular training in Management commitment, Great work environment, collaboration between partners, and communication. Also, the main obstacles were: Fragmented nature of the industry, the extended implementation duration, and the Lack of adequate skills. As a result, the authors believe that it is possible to apply the proposed framework while overcoming obstacles and tracking the CSFs for the integration of LC-BIM for sustainable construction in hospitals projects, which were presented in these two articles,

with the possibility of expanding the examination scope of the proposed model further and a case study of more projects according to the geographical area because the conditions of the place govern the extent of success and the applicability of this framework. On the other side, another developed framework for linking the three ideas in small and middle organizations was found. This article mentions that waste minimization is critical for the incorporation of BIM and LC towards sustainability by encouraging environmental considerations and stakeholder integration is one of the most crucial factors to take into account (Melado et al., 2020). However, this framework needs to be implemented in practice to prove it. Most authors examined how the integration of BIM, LC, and S be in the project. This enables eliminating waste and non-value-added tasks, enhancing project quality, strengthening supervision, and enabling digitalization so that the project can be observed while also decreasing overall time and cost (Sepasgozar et al., 2020). But, the authors believe that the Green integration matrix developed by Saieg et al. (2018) is more mature to demonstrate the integration aspects (S/green, lean, and BIM) because it is based in detail on BIM function and LC principles defined by Sacks et al. in 2010. In addition, the advantages and disadvantages of BIM were merged into the matrix. The review introduced also a simple framework for integration that showed that sustainability is the main goal of this integration, mainly emphasizing how methodologies might be used collaboratively; other issues, such as a fundamental structure for this integration, have not yet been resolved (Rahman et al., 2013; Koskela et al., 2010).

According to several sequential studies conducted by Ahuja et al. (2014, 2017, 2018), starting with the identification of 8 LC principles and 15 criteria for the selected Scheme Environmental Assessment (GRIHA) scheme, then he analyzed 16 projects in architecture firms. Three groups of BIM capabilities that result in lean and green outcomes were identified through analysis. They found that a design organization should prioritize independent BIM capabilities for energy and environmental analysis (E&EA), structural analysis (SA), mechanical, electrical, and plumbing systems Modeling (MEP), and construction analysis (CA). They found the impact of LC and BIM implementation on economic, social, and environmental performance. Then in 2018, he created a framework for organizational capabilities based on the previous BIM framework. The author believes that these studies are very important because they took into account the capabilities of BIM that lead to simple and green results. Three paths that lead to resilience and sustainability in projects were identified as follows:
Path1: BIM-based MEP system modelling with energy and environment analysis (E&EA) at the design stage and performing structural analysis (SA).
Path2: BIM-(MEP) with use of energy and environment analysis (E&EA) at the design stage and absence of constructability analysis (ca).
Path3: BIM-(MEP) with absence of use of energy and environment analysis (e&ea) and having a clear understanding of constructability analysis (CA).

Figure 11 shows a suggested diagram prepared by the authors depending on Ahuja et al. (2017). We suggest by tracing the same paths on megaprojects, it is possible to evaluate the optimal path that can be taken according to the type of project, to reach benefit. The search has produced a set of the gap that can be summarized in the Table 5. Which opens the path towards completing their search in them.

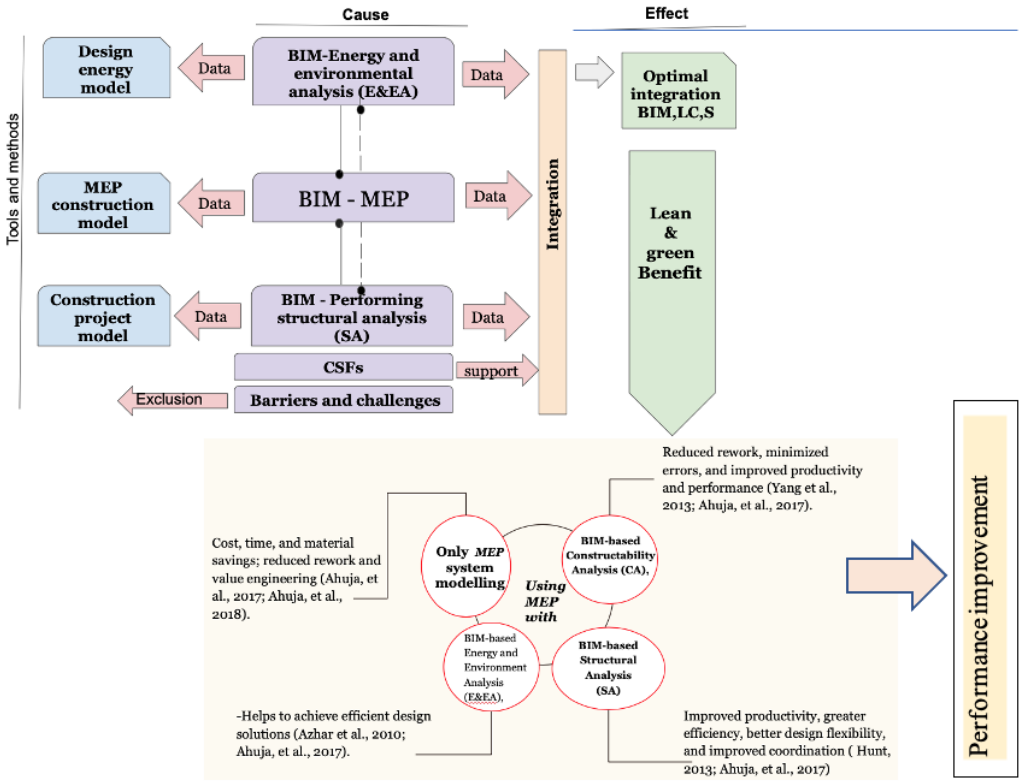


Figure 11: Graphical representation of proposed model.

Table 5. The gaps in selected articles.

Ref.	Gaps
(Mellado et al., 2020; Bostancı et al., 2022; Koskela et al., 2010)	There are extremely few studies that include all three of these terms. BIM, LC, and S
(Mellado et al., 2020)	CSF validation is still necessary.
(Mellado et al., 2020; Ahuja et al., 2017; Rahman et al., 2013)	There is a dearth of studies on how integration would improve project performance, and each performance factor has been examined in each concept separately.
(Mellado et al., 2020; Saieg et al., 2018; Ahuja et al., 2014)	There is no enough models and thorough frameworks to be compared with suggested BLS framework.
(Mellado et al., 2020)	Results indicated that social integration, a component of sustainability, was lacking.
(Saieg et al., 2018; Arayici et al., 2017; Sepasgozar et al., 2020; Enache et al., 2010)	Seek and gradually verify real-world evidence for the purpose of improving the framework and exploring it in depth.
(Sepasgozar et al., 2020; Mellado et al., 2020)	In some areas of construction, such as sustainable infrastructure projects, megaprojects, and SMEs' capabilities, there is a glaring knowledge gap regarding the synergistic interactions of LC principles and the modelling.
(Lekan et al., 2018)	Most studies were without a clear emphasis on the project's whole life cycle.

Performing

The similarities between LC and green outcomes as performance measures when applying BIM on they were: reduced rework, lower costs, reduced waste, a safe workplace, value engineering, quicker construction, shorter lead times, increased trust, resource optimization, and material conservation (Ahuja et al., 2017). According to previous studies, the use of BIM in conjunction with LC and green efforts on construction projects enhanced project results (Yang et al., 2013; Azhar et al., 2010; Ahuja et al., 2017; Ahuja et al., 2018; Hunt, 2013) as shown in Figure 11.

Barriers & (CSFs)

A crucial component of the framework is defining key success factors (CSFs) (Lou & Alshawi, 2009). Several studies have looked into the obstacles, difficulties, (CSFs) of BIM adopted and their effects on the execution of construction projects. (Olawumi & Chan, 2019; Dave et al., 2013; Ghaffarianhoseini et al., 2017; Chan, 2014; Azhar et al., 2012; Sacks et al., 2010; Chan et al., 2019; Sacks et al., 2018). But Evans et al. (2021) investigated how BIM and LC worked together in construction mega projects in the MENA region. Additionally, it looked into difficulties, crucial success factors (CSFs), and crucial failure factors, but the researchers did not consider the interaction of sustainability with BIM and LC in their study of megaprojects. Through a review of the research covered in this study, the critical success factors and barriers to achieving integration in BIM, LC, and S have been identified as follows:

a. Critical success factor

Management commitment, a beneficial work environment, coordination, teamwork, training, early involvement, dedication, qualified people, and culture of praise, customer service, and integration, system and procedure change management, routine workforce training, proper planning, team integration, integration of the whole supply chain, promotion of a culture of continuous improvement, benchmarking of suppliers, coordination and communication between stakeholders,, the using MEP system modeling, energy, and environmental analysis, constructability analysis, and structural analysis (Lekan et al., 2018; Mellado & Lou, 2020; Azhar et al., 2008).

b. Barriers

Lacking managerial commitment, a long implementation duration, improper training, insufficient knowledge and skills, a failure to use core strategies, standards and methodology gaps, the industry's fragmented nature, cultural obstacles, a lack of application of concepts and understanding, objection to change, government inefficiency and instability, a protracted supply chain, a lack of confidence, and other elements (Lekan et al., 2018; Mellado & Lou, 2020; Sepasgozar et al., 2020). Organizations, nations, and regions differ in their willingness to use BIM technology (Azhar et al., 2012). In addition, researchers did not consider the interaction of BIM with LC and S in their study of megaprojects and obstacles that prevent their implementation. Therefore, away from previous studies, Evans et al. (2021) investigated how BIM and LC collaborated on Mega projects, but without sustainability content. Further, they looked at significant obstacles that important construction players had while attempting to integrate BIM-LC into megaprojects in the MENA region only. They only looked at CSFs that enhance BIM and LC integration for mega projects in the MENA area (Evans et al., 2020a,b).

Conclusion

There are frameworks mentioned in the previous studies to study the possibility of applying the BIM, LC, and S concepts in the project. It can be concluded we need to study the functions of BIM that serve the principles of LC and achieve sustainability in accordance with the objectives (environmentally -economically-socially). It can be done by following the success factors and overcoming obstacles, thus achieving this mission.

Mega projects are big, complicated projects, that have a lot of uncertainty which can result in weak performance (Flyvbjerg et al., 2017; Bruzelius et al., 2002; Priemus et al. 2008; Liu et al., 2014). Through chosen prior studies, the foundational knowledge and structure for the integration of BIM, L, and S were discussed. However, no prior study has done a thorough assessment of how BIM, L, and S are applied in megaprojects. Therefore, including the usage of BIM, L, and S in the management of megaprojects call for a pretty robust methodology.

The PRISMA approach was used. Scholarly publications were chosen and subjected to a qualitative study. It is discovered that after 2010 the documentation of the BIM, LC, and S interrelation began, while there are several papers linked to every two concepts. There are only 11 publications specifically addressing how LC, BIM, and S practices interact, while nine pieces had more than 366 citations. The results revealed the existence of frameworks linking the three concepts, but the majority of the frameworks that were seen either explain some general concepts only or are formulated according to the circumstances of the study area or it is only a theoretical study that needs proof of the validity in a realistic study. In addition, only two researchers identified BIM functions and capabilities that support LC concepts toward sustainable buildings by identifying three possible paths through collecting data from realistic projects. The results suggested one framework that used some paths to integrate BIM, LC, and S on megaprojects then we can evaluate each path to find the most beneficial one. The search has produced a set of gaps that are summarized in table 5 which opens the path toward completing the investigation in them. Moreover, there is a big and obvious gap in the availability of an integrated framework for sustainable infrastructure projects. That means the majority of organizations are still at the beginning of the learning curve in this regard. The results also indicated that social integration, an element of sustainability, was missing.

Future Study

In order to fill these gaps, we propose these research subjects and areas.

1- Identification of the CSFs for the integration of BIM, L, and S of infrastructure projects.
2- Studying the obstacles to achieving the integration of BIM, L, and S of infrastructure projects.
3- Applying the proposed path to infrastructure projects, finding the optimal path, and making the necessary corrections to update the framework.

The study's overall conclusion is regarded as providing both researchers and practitioners with important advice to successfully plan and execute BIM, LC, and S. It is important to identify the targeted interest to accumulate experience and develop gradually to take more advantageous linkages between them.

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Investigation of Digitalization Tools for Circular Economy in Construction Industry

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Abstract

The seek for global solutions and applications is ongoing as the relevance of the struggle against the climate problem grows by the day. One of the most crucial strategies for resolving the climate crisis is the Circular Economy, which has gained prominence in recent years. Circular Economy is a sustainability strategy that combines zero waste, lean production, and life cycle thinking, aids in the fight against the climate crisis in many different fields. Considered of construction industry is responsible for more than 90% of water use and biodiversity loss and only 12% of the materials used in the construction industry are circular, these conditions practically force the industry to expand itself to meet the Sustainable Development Goals. On the other hand, with the use of digital technology, it may be possible to estimate demand, manage inventory, reduce waste by evaluating the best methods for recycling and remanufacturing, and improve sustainable operations. However, technology adaption is still at low levels in construction industry when compared to other sectors. In this context, this study aims to create a foundation for the circular economy models by identifying the digital tools that might contribute the circular economy in the construction industry with the help of a comprehensive literature review. The tools employed in the literature were explored for this purpose, and the findings were compiled in a frequency analysis table. Results show that the contribution of building information modelling, artificial intelligence, robotic and additive manufacturing technologies, which are frequently used in Construction 4.0, also play a major role for the circular economy. Furthermore, it has been recognized that inter-sectoral cooperation, governmental regulations, and incentives are necessary for a circular construction economy in addition to the development of most new technologies and their proper application through integration.

Keywords: *Circular Economy, Digitalization, Construction Industry.*

Introduction

At the Royal Meteorological Society of London in 1938, engineer Guy Stewart Callendar gave a speech on climate change in which he quantitatively demonstrated that the world is warming and claimed that human-created industries are to blame (Weart, 2015). At the UN Conference on the Human Environment (Stockholm Conference), held in Stockholm in 1972,

many countries with different socio-economic structures and development levels came together for the first time on the subject of "environment". Since then, many regulations have been made on climate change and the environment. However, the European Green Consensus, which enabled the most important process in recent years to be taken on behalf of the climate crisis, has very serious goals. This agreement is a new growth strategy that aims to transform prosperous society with a modern, resource-efficient, and competitive economy without net greenhouse gas emissions where economic growth is decoupled from resource use by 2050. The agreement is built on basic principles such as the transition to a clean and circular economy, the efficient use of resources, the protection of biodiversity and the reduction of pollution. After the announcement of the European Green Deal which aims to boost the efficient use of resources by moving to a clean, circular economy and stop climate change, revert biodiversity loss and cut pollution, companies start to seek sustainable business models to ensure an inclusive transition. To achieve this transition, countries and companies need to internalize the circular economy model in many sectors (Smol et al., 2020). In circular economy, all the benefits that may occur from the raw material choice to the end of the process where the product turns into waste from an economic and environmental perspective get into focus whereas the linear economy focus on the buy-build-use-dispose process.

Various disciplines have developed ideas related to the circular economy over many years, such as natural capitalism, regenerative design, cradle-to-cradle concepts, biomimicry, blue economy, industrial symbiosis, and industrial metabolism. A foundational principle of Circular Economy (CE) has been established by all these fields and concepts (Haas et al., 2020). The CE concept and border is still not clarified and there are no standards to contribution for sustainable construction (Kristensen & Mosgaard, 2020). But there is a vast scale of research that mainly focus on study below related to the circular economy.

In recent years investigators have created some index-based methodologies to measure the performance of CE (Kalmykova et al., 2018; Parchomenko et al., 2019; Mhatre et al., 2021). Kirchherr et al., (2017) mentioned that there are 114 definitions of circular economy in the literature and analyzed these definitions. As emphasized at the end of the study, it is important to draw the boundaries and define the words for their permanence and correct use. Lacy et al., (2016) mentioned resource use, which is about the world resource consumes more than 1.5 times its natural resource capacity. Studies conducted on a global scale show that while the circularity rate was 9.1% in 2018, it decreased to 8.6% in 2020, that is, a gap that needs to be closed is opening more and more as time goes on (Circularity Gap Reporting Initiative, 2020). Wilson & Velis, (2015) emphasized that generally datas on the life cycle of solid wastes recorded in high-income countries and also C&D waste is the most important type of waste with a rate of 36%. Terra dos Santos et al. (2022) investigates the relationship between circular economy and sustainability. Study mainly focusses on the social dimension, which is the absence part of CE. They created a model for this and after analyzing they could not conclude that circularity alone guarantees sustainability. Geissdoerfer et al., (2017) revealed that the circular economy is seen as a condition for sustainability, a beneficial relationship or an exchange. Stahel, (2010) says that the connection between the Circular Economy and emerging concepts such as the Performance Economy, the Sharing Economy, and new business forms such as benefit companies can be explored. Bocken et al., (2016) stated in his study that the circular economy will contribute to "strong sustainability" and slower consumption patterns, that is, to close resource cycles as well as to slow them down. Dantas et al., (2021) conducted a systematic literature review to determine how the "CE-I4.0"

connection, which is a combination of circular economy practices and Industry 4.0 technologies, can contribute to the achievement of Sustainable Development goals. The objectives related to the application of circular economy practices and Industry 4.0 technologies are explained.

When circularity is mentioned in the construction industry, studies on waste & demolition management come predominantly. However, in the report announced by Green Deal, it is emphasized that buildings consume 40% of the total amount of energy consumed. Despite this, the building stock renewal rate is in the range of 0.4%-1.2%. Although the EU's climate targets aim to double these rates in terms of energy efficiency, this situation shows the importance of circularity for us Facility Management. Some academic studies in the construction industry are as follows: Kristoffersen et al. (2020) has established a detailed framework for the use of digital technologies in the manufacturing sector for the circular economy. Bocken et al. (2016) explained the terminology of slowing down, closing and narrowing resource cycles and created a list of product design strategies and business model strategies for key decision makers in businesses to facilitate the transition to a circular economy. López Ruiz et al., (2020) presented a theoretical framework in which they identified the factors that may affect the concept of the circular economy in the construction and demolition sector. Hossain et al. (2020) aimed to identify the impacts, assessments, contributions, and challenges of CE in the construction industry. Emphasis on design, material selection, supply chain, business model, uncertainty and risk, collaborations between actions, knowledge of understanding, relevant policy, integration of urban metabolism, and challenges for CE. Ghaffar et al. (2020), explored current applications of construction & demolition waste (C&DW) management and awareness of the concept of circular construction (materials reuse, recycling, and recovery) in the UK. As a result of the research, he mentioned that the legislation to be created by the state can significantly affect the circularity. He says the focus should be on smart dismantling or demolition of buildings and ways to optimize cost-effective processes. Foster G. (2020) has studied the circular economy that can reduce environmental impacts in cultural heritage buildings and proposed a comprehensive circular economy framework for adaptive reuse. Balbay et al. (2021) conducted a circular economy SWOT and Pest analysis of Turkey. The high rate of waste imports, the lack of incentives and inspections, and the development of new job opportunities by the circular economy despite high inflation rates are just a few of the key results from the PEST analysis. The lack of knowledge about investigations conducted to ascertain the waste analysis or the sort and quantity distribution of the wastes is one of the SWOT analysis's results. It is vital to recognize the potential for manufacturing that complies with European market criteria inside the Green Deal framework.

Many studies have created a model for the circular economy by using digital technologies or have obtained results with some analysis. However, the number of studies on which digital technologies will be used extensively to achieve the Circular Economy in the construction industry is few. As a result of the literature review conducted in this study, with the use of digital technologies, prediction of demand and manage inventory, thereby minimizing waste by assessing the best practices for remanufacturing and recycling and enhancing sustainable operations may arise. With the Construction 4.0 revolution, sustainable buildings and smart green cities can be built. In structures where digital twins can be created, cost-effective operating modes can be used with new cyber-controlled HVAC systems. At the same time,

the building's dynamic response to changes in energy supply is analyzed to show the building's need for maintenance or renovation. By using real-time data with IOT, accurate data can be accessed quickly without going to the construction site. It enables tracking of construction materials, vehicles, and equipment, and instantly detects the need for repair and repair of the machine. Thanks to devices with internet connection, carbon emissions can be measured during and after the construction process, and economic and environmental effects can be minimized by optimizing the data correctly. One may argue that digitization is what has changed the construction industry the most. It may be claimed that the circular economy strategy will be significantly impacted by digitization. Investigating how and how frequently these technologies are employed for the circular economy is crucial in this regard. Circular economy models vary according to sectors and policies of countries. It is classified according to strategies ranging from R0 to R9 in circular economy approaches, which include what will be done from the production stage to the life cycle (Khaw-Ngern et al., 2021). In each model used, the circular economy approach differs according to each strategy or country, as well as the digital tools used. Finding the digitalization tools used in the circular economy approach and how often they are used will shed light on researchers who will make a comprehensive circular economy model in the construction industry.

Research Methodology

There are over 16000 documents on the "circular economy" in the Scopus database. 9000 of these studies are published since 2020. Especially after the European Green Deal held in 2019, it is seen that the work of the academy in this field has increased. Because of this reason this study mainly focusses on last 4 years. In this study, articles that contribute to the circular economy with digital technologies are filtered. For this, 3550 documents were reached by using “("built environment" OR "building" OR "construction") AND ("digit*" OR "digital technology" OR "industry 4.0") AND "circular economy" AND (LIMIT-TO (OA , "all"))” filters in the Scopus database. Among these articles, 15 articles related to the research topic were examined. The main topics covered in 15 articles are briefly as follows:

- According to Cetin et al. (2022), the Dutch government applies circular principles in construction, renovation, maintenance and demolition projects. A case study was conducted in social housing institutions. He said that artificial intelligence, digital twins, and scanning technologies are beneficial to circularity, and 12 challenges were identified for digital technology adoption. He emphasized that material passports are unfortunately only implemented in pilot projects, while artificial intelligence and digital twin are only used in resource optimization and data-driven maintenance operations. They say that these technologies need to be developed and their interoperability increased. Baduge et al. (2022) study is about machines and deep learning methods and applications in Construction 4.0. They benefit from artificial intelligence for the circular economy, especially for the production process efficiency. They also highlight the importance of strategies for the challenges of developing models on data collection, storage and deletion with intelligent vision and sensors.
- Elghaish et al. (2022), conducted a comprehensive and critical overview scientometric study on 115 papers in the circular supply chain in the construction industry. Lack of capital required for CE adaptation and regulatory shortcomings and complexity of

estimating the salvage value of building materials that will motivate the construction industry for CE adoption. It is said that the most important in this field is the integration of the CE concept into new smart cities. However, for this, researchers on behalf of existing buildings/cities need to be increased. In addition, the authors aimed to contribute to the operation stage by analyzing existing solutions in order to apply them on behalf of CE in the construction industry, producing a conceptual model integrated with blockchain and IoT.

- Kromoser et al. (2022) outlined the importance of circular structures. Their research on walls with additive manufacturing on fully recyclable wood to produce circular economic structures. In the model developed on the 3DP Biowall concept, the advantages and disadvantages of construction strategies are discussed.
- Maiurova et al. (2022) conducted a case study that shows how an integrated waste management with digitalization which controls municipal solid waste generation in Berlin could be applied in Moscow. Thanks to digitalization in recycling in Moscow, it has improved local waste management practices during the Covid-19 process and created 5000 new jobs and reduced operating costs by 75%. In addition, the robot arms used with AI and ML reduced the volume of non-recycled waste by 20%.
- Elghaish et al. (2022) conducted a systematic review of 115 papers, interrelationship between different technologies of Industry 4.0 investigated to encourage the implantation of circular economy in the construction industry. It has created a conceptual model for the optimized circular economy by using different technologies for reuse to improve building performance.
- Colorado et al. (2022) revealed an econometric analysis as a result of their research on construction and demolition wastes in Colombia. Experimental characterization and analysis of the C&D waste type was carried out with X-ray diffraction and scanning electron microscopy for infrastructure projects.
- Charef (2022a) research suggests that there is a lot of interest for the circular economy, but organizational tools for the construction industry's CE transition are dramatically lacking. For this, they have created a BIM-based trans-scalar theoretical framework. This framework detailed the use of BIM throughout the building lifecycle and visualized interactions between phases and relevant stakeholders in the UK context.
- Caldas et al. (2022) classified the 30 papers reviewed in total as slowing loops, closing loops, and narrowing loops. In terms of CE strategies and climate change mitigation, closed loops constitute the majority. They mainly relate to recycling and end-of-life reuse and use of recycled materials. As a result of the study, it has been determined that LCA and BIM are the most useful tools in terms of the conventional building design process or in the disassembly project.
- Charef (2022b) highlighted doubts about the use of BIM in end-of-life (EOL) activities. It also states that BIM's adoption of the Circular economy is still in its infancy. The study aims to improve their understanding and application of the CE approach with a trans scalar theoretical framework in BIM contexts.
- Çetin et al. (2021) investigates which digital technologies potentially enable the circular built environment and in what ways it can be achieved is the subject of research. He classified circular economy strategies according to the core principles of regenerate, narrow, slow, close, and collaboration. As a result of the framework

created and the workshops conducted, it is important to note that interactions between Digital Technologies demonstrate leveraged capabilities towards achieving CE goals.

- Lekan et al. (2021) conducted research aimed at providing a pathway to sustainable innovations through technological and infrastructure developments. The data obtained as a result of the survey conducted on 150 construction companies were analyzed. He proposed a technical, circularity and innovative system that would correctly adapt the I4.0 tools to the C4.0.
- Kovacic et al. (2020) It assesses the extent to which digital technologies are used and for what purpose and identifies their potential and challenges for achieving CE targets. It also proposes a framework for a Digital Platform for Circular Economy (DEEP). This framework mentioned to BIM specifications that public policies, manufacturers' environmental product declaration, and eco-repository data should be integrated throughout the lifecycle of control.
- Khadim et al. (2022) He says that there is no consensus about opinion and practice in the name of circular economy in the building and construction industry. For this, building circularity indicators have been proposed and a comprehensive systematic literature review has been carried out. He emphasized that innovative technical solutions on behalf of adaptability and disassembly are effective in measuring the circular potential of structures.
- Yu et al. (2022) stated that the efficiency and challenges of implementation of information communication technologies have not yet been determined. In this direction, it is aimed to develop decision support tools based on IT technologies to apply the circular economy in the construction sector.

The summary on the use of digitalization tools in construction industry towards CE was also presented as a frequency analysis table (Table 1) below.

Table 1. Frequency of digitalization tools uses across the construction industry towards Circular Economy.

Digitalization Tools	Çetin et al. (2022)	Baduge et al. (2022)	Elghaish et al. (2022)	Kromoser et al. (2022)	Maiurova et al. (2022)	Maiurova et al. (2022)	Colorado et al. (2022)	Charef (2022a)	Caldas et al., (2022)	Charef (2022b)	Çetin et al. (2021)	Lekan et al. (2021)	Kovacic et al. (2020)	Khadim et al. (2022)	Yu et al. (2022)	Total
BIM	X					X		X	X	X	X	X	X		X	9
VR		X										X				2
AR		X							X							2
MR									X							1
AI	X		X		X	X					X	X				6
DT	X					X					X	X				4

Table 1. Frequency of digitalization tools uses across the construction industry towards Circular Economy (continued).

DP	X									X	X		X			4
Scan tech.	X						X						X			3

IoT						X					X	X			X	4
ML		X			X											2
DL		X				X										2
RM & AM		X		X	X						X	X				5
Cloud		X				X						X	X			3
Blockchain			X			X					X				X	4
3D printing				X												1
Real time data						X									X	2
LCA									X				X			2
WMP									X							1
BMP	X								X		X		X			4
GIS											X				X	2

BIM: Building information modelling, VR: Virtual reality, AR: Augmented reality, MR: Mixed reality, AI: Artificial intelligence, DT: Digital twin, DP: Digital platforms, Scan Tech: Scanning technologies, IoT: Internet of things, ML: Machine learning, DL: Deep learning, RM & AM: Robotic and additive manufacturing, LCA: Life cycle assessment, WMP: Waste management plan BMP: Building material passports, GIS: Geographic information system.

The study's findings show that BIM, AI, RM, and AM technologies are referenced more frequently than others.

Discussion & Conclusion

The global warming-related climate catastrophe is largely attributable to the linear understanding in the production and consumption sectors. In a linear economy, value is determined by the quantity produced, and the cycle of "buy-build-use-demolish" is maintained. The circular economy includes the concepts of zero waste, lean production and life cycle. Not only is it process-oriented, but it also offers the chance to assess all potential advantages of the choice of raw materials through the point at which the product becomes wasted from an economic and environmental standpoint. Even if there are several research on sustainable building practices and the use of digital technologies in these studies, there should be more applications and studies on the circular economy. The decisions made with Greendeal (2019) have led to more people becoming interested in the circular economy theory. Knowing how and when to take use of Construction 4.0 technology is crucial to maintaining this growing interest. In this study, it has been identified which technological instruments the circular economy may benefit from by looking at the useful items. The construction industry's circular economy studies were researched in this literature between 2018 and the present, and it defined the technological tools that were used and their frequency.

The results obtained from the technologies used in 15 articles with the aim of circular economy in the construction industry show that Building Information Modeling, Artificial Intelligence, RM, and AM technologies are used more frequently than other technologies. In the world today, managing a construction firm is impossible without keeping information about the construction process. When it concerns time, money, quality, or anything else, a company should gather and evaluate this data. The BIM is the modeling method for accomplishing this since it allows for merge collaboration and interoperability. Additionally, BIM level changes to 6D and 7D BIM for digital tools that are used for sustainability and facilities management. This circumstance led us to predict that BIM would be one of the most popular techniques in literature, and our findings corroborated this expectation.

You cannot handle all the analyse findings manually if your organization has data from sensors or other technology tools to manage better and obtain effective solutions, such as cost or time management. At this stage, AI aids in coordination and supervision of both the construction process and the facility management part, such as HVAC and lighting controls. Additionally, thanks to AI, trash management for the demolition project may be made simpler and more effective by employing digital twins and material passports. The circular economy includes nine strategies, and when we compare digital tools to those strategies, RM and AM really fulfil most of them. Because of this, as well as the rising need for this form of manufacturing, these tools are among the most often used ones in our study findings.

However, although this shows that these technologies are more inevitable to achieve a circular approach than others, we must emphasize that these technologies are also extremely important. As an example, we can say that the number of mentions of blockchain technology in articles is low compared to other technologies. However, the opportunities created by this technology will reduce the amount of paperwork's by shortening the paperwork processes, prevent time losses in the production process, and thus reduce the carbon footprint and environmental impacts that will occur indirectly with the reduced project duration. In addition, it can contribute to resource management thanks to the life cycle and raw material verification method, in the management of tracking and monitoring of wastes, in energy management to obtain a smart grid.

Findings show that Circular Economy goals may be achieved with the proper adaptation of the technologies used for Construction 4.0 and the integration of digital technology in the built environment. Instead of developing or discovering new technologies, employing existing technologies wisely and focusing on circularity methods offers suitable answers in our circular economic existence. Therefore, this study serves as a starting point for identifying the theoretical and practical gaps in literature. The proposed table of technologies is not sufficient to develop a model for circular economy, despite the fact that this research examined important published studies on the use of digital technologies to achieve circular economy in the construction sector. It must be created with additional technological applications and with information on how to utilize it during the construction phases in order to support further research. Among the studies analysed, Çetin et al. (2022) and Yu et al. (2022) will be helpful to researchers working in this field by outlining at what stage of construction and for what purpose technologies that can utilize circular economy may be used, as well as by providing a lot of digital technology in detail.

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Organizational Resilience and Agility: The Impact of COVID-19 Pandemic on the Construction Industry

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Abstract

With the World Health Organization (WHO) announcing the coronavirus 2019 (COVID-19) outbreak as a pandemic, many organizations faced uncertainty. This pandemic process has had both positive and negative effects on organizations. Many organizations, with the desire to adapt to change and survive, have determined and implemented new strategies by making use of technological resources. Construction organizations, which take slower steps in adopting and applying technology compared to other organizations, have also become open to change with the pandemic. The positive and negative developments experienced during the COVID-19 pandemic process have revealed that organizations should be prepared for all kinds of changes. Therefore, in the post-pandemic "new normal" period, it is important for construction organizations to adapt quickly to change and develop survival strategies. Resilience and agility are key factors in adapting to and coping with change and fostering future success. Resilience is the ability to bounce back and adapt in the face of difficulties. Agility is the ability to adapt to change and react quickly. Therefore, this research which is an evaluation of the literature examines the effects of the pandemic on construction organizations and encourages organizations to adopt advanced technologies and build resilience and agility against future unexpected events.

Keywords: *construction organizations, COVID-19 pandemic, organizational agility, organizational resilience, technology.*

Introduction

Organizations often face unexpected events in highly volatile and uncertain times. The importance and magnitude of the effects of these unexpected events, which are also expressed with concepts such as rare events, surprises, disasters, and crises, on organizations can be surprising (Duchek, 2020). For example; Unexpected events such as severe flooding in the Netherlands in 1953, a severe earthquake in Turkey in 1999, the extreme tsunami in Indonesia in 2004, a severe earthquake in Pakistan in 2005, and Hurricane Harvey in 2017 affected the economy and organizations in these countries and threatened business continuity (Iqbal et al., 2021). Today, the unexpected event that the whole world is facing is the COVID-19 pandemic. Covid-19, first identified in Wuhan, China in December 2019, has become a global pandemic at the end of March 2020. Due to the spread of this virus, which was not seen in humans before, both by air and through direct and indirect contact, life has practically come to a halt in many countries. To date (28 June 2022), there have been approximately 542 million

COVID-19 confirmed cases, and 6.3 million deaths due to COVID-19 (World Health Organization, 2020).

The construction industry is one of the industries most affected by the coronavirus. The construction sector is an important driving force of the economy of countries, as it forms the organizational backbone of the economy. The construction sector accounts for around 13% of the gross domestic product (GDP) of many countries and is important for sustainable development worldwide (Chih et al., 2022). This sector has a wide range of stakeholders and is, therefore, a complex sector of the economy as it is directly and indirectly linked to other sectors of activity such as production and energy use, finance, materials, equipment, and labor. The chain reaction of negativities in this sector may adversely affect the economy (Ogunnusi et al., 2021). With the emergence of this pandemic, construction organizations have been faced with negative effects such as closures, restrictions, low cash flow, procurement, occupational health and safety, work from home, workforce, and contract problems (Ogunnusi et al., 2021; Assaad & El-adaway, 2021). Despite the negative effects of the pandemic, it has affected construction organizations in a positive way, such as technology adoption, acceleration of technology, expansion of prefabricated construction, and implementation of industry 4.0 technologies.

Organizations must be prepared and continually adapt to change to gain a competitive advantage and survive in uncertain environments (Burnard & Bhamra, 2011). Construction organizations must deal with unexpected events, adapt, and act quickly (Padalkar et al., 2016). Organizations need resilience capacities to cope with, adapt to, and recover from the COVID-19 pandemic (Nah & Siau, 2020). Agility triggers construction organizations to adapt and react quickly to uncertainty and change (Chen & Siau, 2020). Besides, important to follow technological developments to adapt to change. Technology enables flexibility and agility (Nah & Siau, 2020). Therefore, in these uncertain times, it is important for construction organizations to develop resilience and agility and adopt new technologies to support organizational adaptation to change and uncertainty.

In this study, based on the example of COVID-19, inferences will be made by evaluating the literature for the construction organizations to adopt new behavioral models, application steps, and technologies by adapting to sudden and new strategies in the face of unexpected sudden events. In this context, this study aims to contribute to the future direction of construction organizations in the post-COVID-19 period by focusing on the effects of the COVID-19 pandemic on construction organizations. The research aims to (1) determine the positive and negative effects of the COVID-19 pandemic on construction organizations; (2) present the role of advanced technologies in the construction industry, and (3) emphasize the importance of resilience and agility in organizations.

Methodology

The aim of this research is to present the importance of the construction organizations to adopt advanced technologies and develop resilience and agility against unexpected situations such as pandemics. For this purpose, the method of this research consists of two steps. First, the words "pandemic" and "construction organizations" were scanned together and the research made between 2020 and 2022 was examined in the literature. Research related to this method has been reached and the negative and positive effects of the pandemic process, which are scattered in the literature, are grouped. Then, the words of "construction organizations",

"organizational resilience", "organizational agility", and "technology" were scanned together. The studies reached by this method were examined and the benefits that construction organizations can apply to be prepared for unexpected situations in the future are presented.

The Impact of COVID-19 Pandemic on the Construction Organizations

According to the literature research, one of the organizations most affected by the COVID-19 pandemic is construction organizations. These effects are both positive and negative. In this section, the negative and positive effects of the COVID-19 pandemic on construction organizations are presented.

Negative Effects

Construction organizations faced many challenges due to the measures taken to prevent the spread of the rapidly spreading COVID-19. These downsides need to be understood before suggesting strategies to counter the adverse effects caused by the unprecedented COVID-19 pandemic (Assaad & El-adaway, 2021). This research presents the negative effects of the pandemic on construction organizations, which is scattered in the literature review, by gathering them under the following headings.

Closures and restrictions. The world has come to a standstill with the outbreak of the COVID-19 pandemic. Social distancing and quarantines necessary to support people's health and safety have halted most activities (Assaad & El-adaway, 2021). The normal functioning of construction activities was also hindered (Spieske & Birkel, 2021). Construction organizations have been forced to close or operate with restrictions on their national or international sites (Chih et al., 2022). Due to these restrictions and closures, construction organizations have moved towards collapse (Ogunnusi et al., 2020). Planned projects were canceled, and existing projects were suspended or postponed (Assaad & El-adaway, 2021).

Cash flow. Maintaining cash flow is one of the main challenges faced during the COVID-19 pandemic (Sierra, 2021). Construction organizations have been adversely affected by the complexity and uncertainty in estimating cash flow during the pandemic era (Ayat & Kang, 2021). The reduction of construction work resulted in lower-income. With the cessation of construction sites, customers that supported the continuation of the projects suspended their financial flow. Construction materials cost increased due to delays. The fact that the stakeholders had to cut their financial support had negative effects (Ogunnusi et al., 2021). For construction organizations that rely heavily on cash flow, these cuts have created significant financial stress (Chih et al., 2022). According to Ogunnusi et al. (2020), critical challenges that construction organizations face with cash flow include: "poor capital input; low/no income generation; poor business sustainability; revenue loss; increase in cost; lack of fund; client paused funds; financial impact and disruptions; extra budget; delayed project financial commitment".

Delay. Delays are one of the biggest setbacks that construction organizations have to deal with. These delay challenges have become more complex with the pandemic (Ogunnusi et al., 2020). Construction projects have been adversely affected by many delays due to measures taken for health and safety reasons, reduction in the number of workers, lack of craftsmen, the inability to obtain necessary permits due to the closure of establishments, difficulties in

supplying materials and equipment, and discontinuation of work due to health concerns (Ogunnusi et al., 2021; Assaad & El-adaway, 2021). Delays in ongoing projects, payments, deliverables, planning, and more due to closures and restrictions have had a negative impact. Delays in making decisions by customers resulted in wasted time and late payments (Ogunnusi et al., 2021). COVID-19 disrupted the project schedules, extended the total duration of the project, and an average of 20% reduction in onsite production due to these sudden slowdowns (Sierra, 2021). These delays have reduced construction productivity during the pandemic (Ogunnusi et al., 2021).

Health and safety. Another challenge faced by organizations during the pandemic period is occupational health and safety (Lingard et al., 2021). Workers and professionals in construction organizations are at high risk of infection (Ayat & Kang, 2021). Therefore, with the emergence of the COVID-19 pandemic, health and safety in construction organizations has become even more important. The World Health Organization has presented procedures such as paying attention to the social distance that must be followed at active construction sites, paying attention to hygiene, and working remotely if there is someone in the employee's family with COVID-19 to prevent the spread of the pandemic (Spieske & Birkel, 2021). These procedures have negatively affected construction organizations in many ways (Wang et al., 2021). Health and safety rules, which must be strictly enforced, have caused extra costs and it has been stated that establishments that do not comply with these rules will have to close. These procedures have caused delays in the supply chain and in the work of contractors (Sierra, 2021). It has changed the way of doing business as employees in the workplace have to comply with social distance (Wang et al., 2021). In addition, communication problems and sharing of resources caused problems in business processes (Ayat & Kang, 2021).

Supply chain. Changes made to slow the COVID-19 pandemic have disrupted the supply chain of construction projects (Iqbal et al., 2021). The quarantine, which started with the emergence of the virus in China, started to have an impact on construction materials in early 2020. With the spread of the virus all over the world in March, all stakeholders involved in the supply chain, such as raw material suppliers, manufacturers, or shippers, faced obstacles (Sierra, 2021). Many international suppliers and logistics organizations stopped operations to contain the epidemic. Almost 50% of organizations have experienced COVID-19-related delays in receiving supplies and products from suppliers (Assaad & El-adaway, 2021). Organizations faced significant disruptions in their supply chains, such as labor, materials, and equipment (Chih et al., 2022). The problems, which first started with the shortage of material supply, deteriorated to a great extent, affecting construction organizations (Gamil & Alhagar, 2020). This showed how vulnerable construction organizations are to suppliers (Assaad & El-adaway, 2021). Disruptions in the supply chain caused financial shocks, delays, and disruption of the normal functioning of construction activities (Ogunnusi et al., 2021). For this reason, construction organizations have faced many difficulties due to supply chain disruptions and logistics bottlenecks during the pandemic period.

Remote-working. Professionals, managers, workers, and many employees of construction organizations have switched to remote work to reduce the number of people in the working environment and to comply with social distance rules (Lingard et al., 2021). Remote working has created many challenges and reduced productivity in construction organizations (Ogunnusi et al., 2020). Construction organizations differ from other organizations in that they require the participation of all employees to monitor whether activities are carried out correctly. Insufficient information transfer, and inability to follow up and control work hindered construction activities (Gamil & Alhagar, 2020). The training of workers was

difficult due to the fact that the training, which should be given practically at the construction site, was conducted online (Assaad & El-adaway, 2021). In addition, employees were negatively affected by the way of working remotely due to factors such as difficulty in focusing, increased workload, inability to provide a suitable workspace, feeling of loneliness, work burnout, disorders in work-life balance, and mental health disorders (Ogunnusi et al., 2021; Assaad & El-adaway, 2021; Lingard et al., 2021).

Workforce-related. Construction organizations faced many labor problems such as lack of labor force, protection of workers, sheltering workers, and taking health and safety precautions during the pandemic era (Assaad & El-adaway, 2021). The construction program was re-planned in such a way that the contractors did not overlap, ensuring a limited number of employees in the field. This caused the work to be prolonged and the days of filling the construction site with workers to get the job done quickly are over (Sierra, 2021). Construction organizations have had difficulties in housing the workforce. While many people were living in the same room in the pre-pandemic era, this is no longer possible due to the rules introduced during the pandemic period. It was very difficult to find shelters that comply with the hygiene rules required for the workers to stay (Assaad & El-adaway, 2021). Cash flow problems of construction organizations were first reflected in the workers (Ayat & Kang, 2021). Workers or professionals who contract COVID-19 are required to undergo a 14-day quarantine, which further delays field operations (Assaad & El-adaway, 2021). It led to a shortage of manpower due to illness and quarantine of employees (Sierra, 2021). Due to the social distancing rules, the work done by less than necessary people caused the workers to work long hours (Assaad & El-adaway, 2021). The unemployment problem has emerged due to closures and restrictions (Ogunnusi et al., 2020). About 40% of organizations have had to lay off workers (Assaad & El-adaway, 2021). Many temporary workers fell below the poverty line due to unemployment (Spieske & Birkel, 2021). Additionally, the pandemic has had negative effects on construction workers, such as the risk of getting sick, the absence of worker protections such as sick leave and paid leave, job loss and salary cuts, late payments, inability to find new jobs, and housing (Gamil & Alhagar, 2020; Ogunnusi et al., 2021; Assaad & El-adaway, 2021; Sierra, 2021; Ayat & Kang, 2021).

Contract. There are concerns that construction organizations will engage in costly and protracted disputes due to the impact of the pandemic. Legal disputes cause expensive disruptions due to both time and cost (Sierra, 2021). COVID-19 pandemic negatively impacted contract disputes (Ayat & Kang, 2021). These effects on contracts varied from contract to contract, from nation to nation (Ogunnusi et al., 2020). Since the pandemic is an unexpected event, the contracts did not specify what to do in the face of this situation (Ogunnusi et al., 2021). The possibility of construction organizations encountering such a deadlock was not foreseen during the tender and contract (Ogunnusi et al., 2020). Delays, time and cost overruns, and barriers to field operations have disrupted contract flow (Gamil & Alhagar, 2020). Organizations face potential contract penalties and cancellation of contracts due to project delays (Assaad & El-adaway, 2021). Problems arising from this unexpected situation can be accepted as force majeure. Counting the pandemic as force majeure ensures that the delay period is extended and no compensation is paid for the cost. However, the legal definition of force majeure depends on the contract text and most definitions do not include the word pandemic. Therefore, this situation creates a gray area and is left to the interpretation of the parties. Therefore, lengthy and costly legal problems have arisen, which has made the situation worse (Sierra, 2021).

Positive Effects

The literature review mentions that besides the negative effects of the COVID-19 pandemic on construction organizations, many positive effects have also occurred. Construction organizations faced some improvements and changes in this process. This research presents the positive effects of the pandemic on construction organizations, which is scattered in the literature review, by gathering them under the following headings.

Adoption of technology. The COVID-19 pandemic highlights the importance of using technologies for organizations to survive and move forward in development (Nah & Siau, 2020). The fact that COVID-19 is forcing organizations to rapidly transform the way they do business using digital technologies provides organizations with an opportunity to participate in innovation and transformation (Lingard et al., 2021). Construction organizations, slower than other organizations in adopting advanced digital technologies due to factors such as high implementation and investment costs, insufficient information, resistance to change, hesitation in the security of data, and reluctance (Spieske & Birkel, 2021), have made great strides towards implementing advanced digital technologies such as cyber-physical systems, big data, blockchain, digital twin, augmented reality, robots, three-dimensional printing, among others since the outbreak of the pandemic (Wang et al., 2021). Adoption of technology by construction organizations reduces the spread of COVID-19, as well as reduces cost and time wastage, improves quality and efficiency, improves processes, and increases occupational safety (Spieske & Birkel, 2021).

Remote working environment. Many construction organizations to contain the spread of the pandemic, have had to work remotely in face-to-face formats due to restrictions. It was discovered that construction organizations are not office-based and can be run remotely (Ogunnusi et al., 2020). By working from home, the time spent in traffic decreased, so employees continued their work in a more motivated way by spending more time on their personal life and their work efficiency increased. Travel costs, general costs such as water and electricity in the office, and the costs used in face-to-face working such as printing and stationery have decreased (Ogunnusi et al., 2021). The use of advanced technologies in construction organizations has increased (Biorck et al., 2020). The fact that the training to be given to the employees had to be given remotely created an opportunity for the adoption of technology-based training methods such as virtual and mixed reality (Assaad & El-adaway, 2021). Technology had to be used compulsorily to meet operational needs such as face-to-face meetings and seminars. This situation has revealed more flexible and new working models that are not normally tried, providing more online communication and the opportunity to develop virtual alternatives (Ogunnusi et al., 2021). Some job interviews were conducted using digital technologies through Virtual recruitment. It has been proven that communication can be made with web-based technologies such as zoom meetings, micro team meetings, and video calls over the internet (Spieske & Birkel, 2021). Construction organizations have adapted to different ways of working and it is expected that their way of working in the virtual environment will be integrated into construction activities in the post-pandemic period (Goodman, 2020).

Interactive collaboration. Collaboration and accurate information flow were ensured with the use of advanced technologies during the pandemic period. "Digitization and virtualization" technologies were used to run works remotely with collaboration (Spieske & Birkel, 2021). With the use of BIM, designers and engineers work collaboratively and confidently (Wang et al., 2021). Work plans were prepared with 4D and 5D simulations. Materials, resources,

workforce, employee welfare, and cash flow were managed with the help of online channels (Biorck et al., 2020). Before the pandemic period, construction organizations that only exchanged information on paper and by communicating face to face, benefited from cloud-based solutions to cope with the changing ways of doing business due to the rules brought by the pandemic, to provide accurate information flow, and observe the construction process. With cloud-based solutions, workforce monitoring is done via smartphones, tablets, iPads, or other devices, data such as field reports are accessed accurately and quickly, and project tracking is provided (Remkes, 2020). With these technologies, construction organizations realized that it would be possible to work collaboratively during the time of the pandemic.

Health and safety. The pandemic has encouraged construction organizations to improve occupational health and safety measures (Ogunnusi et al., 2021). Workers worked in suitable housing conditions in accordance with social distance and hygiene rules (Ayat & Kang, 2021). Industry 4.0 technologies were used to increase security measures and the tendency toward technology increased (Spieske & Birkel, 2021). For example, a construction organization took precautions against the possible risk of COVID-19 by enabling workers to fill out health forms through a special technology platform (Assaad & El-adaway, 2021). Construction organizations can monitor security measures such as face masks, social distance rules, real-time employee health, COVID-19 symptoms, construction processes, and disinfection of tools and equipment, through advanced technologies such as automation, robotics, 3D printing, and cloud-based applications (Assaad & El-adaway, 2021). Cloud-time monitoring applications were used to protect the health of field workers and to monitor their compliance with social distance rules and their entry and exit. These applications are agile applications that can be changed quickly and easily (Remkes, 2020). Besides, wearable IoT devices can be used to monitor people's compliance with social distancing rules to control the spread of COVID-19 and with IoT systems capable of detecting temperature ranges, it can monitor the movement of employees with high temperatures and inform those concerned (Nah & Siau, 2020). The measures taken during the COVID-19 process have encouraged construction organizations to increase future health and safety measures and to anticipate, plan, take precautions, implement and maintain potential risks (Lingard et al., 2021).

Productivity increase. During the pandemic era, the use of digital tools that increase efficiencies such as real-time job tracking, digital workflow management, simulation, and advanced software has become stronger (Biorck et al., 2020). Mobile technologies such as photos and videos were used to reach and manage the data in the field as quickly as possible. Thus, teams and resources were executed more efficiently (Remkes, 2020). Besides, during the pandemic era, construction organizations have adopted BIM technology to increase construction efficiency. In the city of Wuhan, China, two hospital projects were designed, built, and opened for use in a short time, 9 and 12 days, respectively, with extraordinary efficiency, by utilizing BIM technology. BIM technology facilitated the collaboration of project participants and enabled high-quality projects to be completed in a short time (Wang et al., 2021).

Off-site construction. Construction organizations had the opportunity to improve their off-site work to minimize employee interaction during the pandemic period (Iqbal et al., 2021). For instance, although many projects were stopped during the pandemic period, some projects such as hospital projects continued, one of these projects was built as modular structures using high technologies, and the project costs decreased and the construction speed increased (Chen et al., 2021). Construction organizations became more motivated and willing to make off-site construction or use precast elements (Goodman, 2020).

Workforce. Countries have had to close their doors to different countries due to COVID-19. This situation encouraged the involvement of local workforce in construction activities (Ayat & Kang, 2021). The lack of sufficient number of workers in the field due to social distancing rules also encouraged the use of advanced digital technologies. Construction organizations have tended to use technologies such as artificial intelligence, robots, and cloud systems to compensate for the absence of workers (Spieske & Birkel, 2021).

Sustainability. COVID-19 proved to be an opportunity to achieve sustainability goals (Ogunnusi et al., 2021). The remote working imperatives brought about by COVID-19 have resulted in less carbon footprints at the project site. The reduction of time spent in traffic and food and plastic waste due to remote working reduced carbon emissions (Ogunnusi et al., 2021). Besides, off-site production can contribute to sustainable goals by reducing noise and air dust in the construction site environment (Biorck et al., 2020).

Rethinking project management. The pandemic had positive effects that broadened the management perspective of construction organizations and opened their horizons (Ogunnusi et al., 2020). These positive effects can be listed as; new strategies emerging through the use of technological tools, lessons learned, virtual management, predicting future planning, minimizing losses, improving job performances, adopting safety practices, assessing risks, off-site management, appropriate planning and coordination of construction activities, accepting changes, and greater awareness of force majeure (Ogunnusi et al., 2021; Iqbal et al., 2021). The fact that the pandemic restrictions caused the projects to be managed remotely had positive effects that highlight the role of technology in project management. Software was used to manage teams and resources remotely without field visits. The management process was followed by the mobile forms filled by the workers in real time. In case of possible unexpected events, construction organizations realized the importance of data collection obtained during the pandemic period for future management (Remkes, 2020). Construction organizations have benefited from BIM technology to manage projects during the pandemic era (Wang et al., 2021). Artificial intelligence encourages more informed decision making against unexpected situations like COVID-19. COVID-19 has drawn attention to blockchain applications in cost, procurement and contract management in construction projects (Spieske & Birkel, 2021).

The Future Direction of the Construction Organizations

Understanding the negative and positive effects of the sudden outbreak of the COVID-19 pandemic on construction organizations supports preparation for unexpected events in the post-pandemic period. Construction organizations can cope with the negative effects of the pandemic, survive and turn these effects into positive effects, by developing the organization's resilience and agility capabilities and adopting advanced technologies.

Organizational Resilience

Organizational resilience is the organization's capacity to anticipate possibilities, identify risks, develop situation-specific responses, cope positively with unexpected complexities, constantly innovate, adapt quickly to changes, act proactively, and take transformative actions to take advantage of unexpected events that threaten the organization's survival (Burnard &

Bhamra, 2011; Annarelli & Nonino, 2016; Nah & Siau, 2020; Duchek, 2020). Organizations are systems that operate in a dynamic, uncertain, and changing environment (Goodman, 2020). In highly volatile and uncertain times, organizational resilience enables organizations to deal effectively with unexpected events, bounce back from crises, foster future success, gain strategic awareness, and gain competitive advantage (Duchek, 2020). This resilience capability is an important success factor in mitigating any threats that organizations face, being prepared to reach a new desired state, maximizing recovery speed, and managing unexpected situations (Annarelli & Nonino, 2016). In a pandemic like the COVID-19 pandemic, organizations need resilience capacities to cope, adapt, and recover from the pandemic (Nah & Siau, 2020). Therefore, organizations need to consciously develop their flexibility capacity. Resilient organizations can learn and develop appropriate capabilities that improve future preparedness. With the ability to adapt and change as an aspect of resilience, organizations can turn threats into opportunities, develop new capabilities, and achieve breakthrough growth when change becomes the new normal (Burnard & Bhamra, 2011). Therefore, beyond surviving the pandemic, construction organizations need to engage in transformative activities, act proactively, adapt, and be prepared for the future to maintain their competitive advantage and improve their resilience. The adoption of technology by construction organizations forms the basis of a roadmap that will enable the organization to transform, be prepared for unexpected situations, and improve their resilience (Syed et al., 2020).

Organizational Agility

The origin of the word "agile" comes from the Latin word "agere" which means going forward, changing direction quickly and easily (Online Etymology Dictionary, 2022). Agility represents the speed aspect of resilience (Chen & Siau, 2020). Agility is the ability to spot opportunities quickly, change direction, and avoid collisions (Duchek, 2020). This ability enables detect opportunities and threats and responds quickly by anticipating possible scenarios in an unstable and rapidly changing environment (Chen & Siau, 2020). Agility has its origins in lean manufacturing and is rooted in the manufacturing industry. In the early 1990s, organizations started implementing agile approaches to adapt to changes (Harraf et al., 2015). These agile approaches have started to be implemented primarily in the software industry to respond quickly to changes, uncertainties, and risks. The fact that these applications in the software sector increase productivity have been a driving force for other sectors to use agile approaches (Cobb, 2015). Organizational agility is a competence that makes it possible to be aware of the nature of the changes occurring within and around the organization, to think strategically, adopt an innovative mindset, manage change successfully, adapt to changes and turn them into opportunities, and to be proactive. Implementing agility involves the organization's perception, foresight, entrepreneurial vigilance, and proactivity (Harraf et al., 2015). This competence is related to the ability to innovate quickly, accurately, and efficiently in all processes of the organization. An agile organization has the capabilities to quickly detect and respond to opportunities and threats (Chen & Siau, 2020). Agility is an important pillar for development and keeping competitive power (Chih et al., 2022). Speed and responsiveness, the two main components of agility, are critical to organizational success in today's competitive environment (Harraf et al., 2015). Organizational agility improves the organization's ability to provide high-quality products and services and increases the competitiveness of the organization by enabling the organization to integrate with new and advanced technology (Crocitto & Youssef, 2003). Besides, in a dynamic, challenging, and often unpredictable environment of change, organizational agility bridges the relative inertia

gap between the pace of organizational learning and the pace of environmental change and enables the organization to gain a competitive advantage by adding proactivity, adaptability, flexibility, speed, and learning and innovation skills to the organization (Appelbaum et al., 2017). Organizational agility allows organizations to sense the changes caused by the current COVID-19 pandemic and quickly anticipate what needs to be done (Al-Omoush et al., 2020). Therefore, it is important for construction organizations to adopt agile organizational competence against the uncertainties, difficulties, and changes they face due to these unexpected events such as pandemics, to be prepared for unexpected events, to survive, to gain competitive advantage, to react quickly, to adapt, and to adopt new technologies.

Conclusion

In conclusion, in this research conducted with the aim of encouraging construction organizations to develop their organizational resilience and agility skills against unexpected events such as COVID-19 and to adopt advanced technologies; identified the positive and negative effects of the COVID-19 pandemic on construction organizations; presented that the COVID-19 pandemic is a driving force for construction organizations to adopt technology, and encouraged construction organizations to adopt advanced technologies and develop their resilience and agility capabilities in the post-pandemic era.

The COVID-19 pandemic has had both positive and negative effects on construction organizations. In this research, the negative effects are presented under eight titles as closures and restrictions, cash flow, delay, health and safety, supply chain, remote-working, workforce-related, and contract challenges, and the positive effects are presented under nine titles, as adoption of technology, remote working environment, interactive collaboration, health and safety, productivity increase, off-site construction, workforce, sustainability, and rethinking project management. By investigating these effects, construction organizations can be prepared for the 'new normal' situation after the pandemic and unexpected events that may occur in the future. Construction organizations must combat the negative effects of the COVID-19 pandemic and turn the positive effects into opportunities. The COVID-19 pandemic has forced organizations to adapt their business processes and operational practices, rethink traditional methods to survive, and highlighted the importance of using technologies for organizations to build resilience and move forward in development. The adoption of new technologies increases the resilience and agility of organizations. Resilient and agile organizations can learn and develop appropriate capabilities that improve future preparedness. Organizational resilience triggers organizations to deal effectively with unexpected events, support future success, and gain competitive advantage. Organizational agility enables construction organizations to react and adapt quickly to uncertainty and change. Developing organizational resilience and agility capabilities and adopting advanced technologies can effectively help construction organizations to be prepared for unexpected events such as COVID-19 that they may encounter in the future, to cope with, adapt to change, and turn these events into opportunities. Therefore, this research which is an evaluation of the literature encourages construction organizations to develop resilience and agility skills and adopt advanced technologies.

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Risk Assessment in Construction Projects: A Case of Housing Project

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Abstract

Development of technology and rapid change in customer needs; increase the competition in the construction sector and decrease the profit share of the projects. This situation makes it mandatory for companies to minimize the deviations that may occur in the project's time, quality, and cost objectives. Studies show that risk management will contribute positively to achieving these objectives successfully. Risk management is a cycle consisting of the stages of identifying and evaluating risks, taking counter-strategies and monitoring risks. In line with the studies carried out, it has been revealed that the realistic identification and evaluation of risks is inevitable for a successful risk management. In this study, it is aimed to determine and evaluate the risks frequently encountered in construction projects. A housing project was taken as a case study and risks were identified and evaluated as a result of expert opinions and literature review. According to the results obtained, the three risk groups with the highest impact for construction projects are organizational risks, financial risks and construction risks.

Keywords: *construction risks, construction sector, Monte Carlo simulation, risk analysis, risk management.*

Introduction

In the business world, risk is an inevitable factor for all sectors, and risks that cannot be managed effectively hinder the successful of the projects. However, the one-off, complex structure of construction projects requiring a combination of different expertise makes the construction industry more risk-prone compared to other sectors.

Risk management has many features that can provide many advantages for the construction sector, which is the locomotive of the economy, especially in developing countries (Birgönül & Dikmen, 1996). Due to the fact that each construction project is unique and dynamic, the construction operation involves numerous uncertainties, multiple intricacies, varies techniques, and divergent environments. Therefore, identifying and managing the potential risk factors, which can significantly vary from project to project depending on several conditions, plays a crucial role in enhancing the performance and accomplishing the successful delivery of the enterprise (Jarkas & Haupt, 2015).

This study aims to identify and prioritize the risks frequently encountered in construction projects. Within the scope of the study, initially, the risks that may be encountered in

construction projects were determined and classified in line with the literature research and expert opinion. In the continuation of the study, the risks were prioritized by considering the probability of occurrence of each risk factor, the degree of impact on the time and cost objectives. Subsequently, a risk analysis based on simulation was carried out on the project selected as a case study.

Risk Management in Construction Sector

The construction industry plays a significant role in the development of every nation's economy through value creation, employment and contribution to Gross Domestic Product (GDP) (Schoonwinkel & Fourie, 2016; Owoo et al., 2018; Urbański et al., 2019; Boateng et al., 2020).

Risk is an inevitable factor for all sectors in the business world and causes the project to fail when it is not managed effectively. As a result of its unique structure, the construction industry is exposed to greater risks in comparison with other industries. It has unique features as:

- Projects taken long periods, with processes that are complicated
- Financial intensity
- Dynamic organization structures (Taylan et al., 2014).

In construction projects, the target is generally determined as function, cost, time, and quality limits. For this reason, the most important risks encountered in constructions are exposure to these limits. The result of this situation is described as a failure (Baloi & Price, 2003). Arıkan (2005) stated that construction projects contain many uncertainties arising from the project, country, and market, making it difficult to implement risk management in construction projects. He also emphasized that in order to carry out the projects systematically, risk management systems that cover topics such as measuring project performance under varying scenarios and using past project experiences for new projects should be developed and used.

According to a study by Bowers and Khorakian (2014), it is stated that successful implementation of risk management systems is very rare in most construction companies in the developing countries of the world (Bahamid & Doh, 2017).

Currently the practice of risk management is reactive, semi-permanent, casual and unstructured within the construction industry, resulting in a lack of capacity to manage risks appropriately. The main barriers that were found for the implementation of an effective risk management system are the lack of formality of the system and the lack of integrative mechanisms of risk management among the parties involved in the project (Choudhry & Iqbal, 2013)

In addition to the above-mentioned features of the construction industry; the fact that globalization and technological developments have accelerated the competition in the construction sector both increase and diversify the risks related to the sector. These risks, which are numerous and diverse, constitute an obstacle in achieving the basic objectives such as completing the project in the planned period, not exceeding the foreseen costs, and achieving the targeted quality. This situation makes it imperative to analyze the risks in detail in all projects aimed at success and to determine and apply the necessary methods to minimize the possible negative effects. The need to analyze the risks and demonstrate the necessary attitude towards the risks makes effective and successful risk management inevitable.

Methodology

The aim of this study is to identify and prioritize the risks frequently encountered in construction projects and to examine the effects of risks on the time and cost performance of the projects. In line with the purpose of the study, first of all, construction project risks were determined and classified based on expert opinion and literature review. Then, a risk analysis of the project selected as a case study was conducted to investigate the effects of identified risks on the time and cost performance of construction projects. The project, which is considered as a case study, is a 4-block superstructure project for residential and office use in Turkey. The total area of the project is 89,065 m^2 and unit price contract type was used in the project. The site plan of the exemplary project is shown in Figure 1.

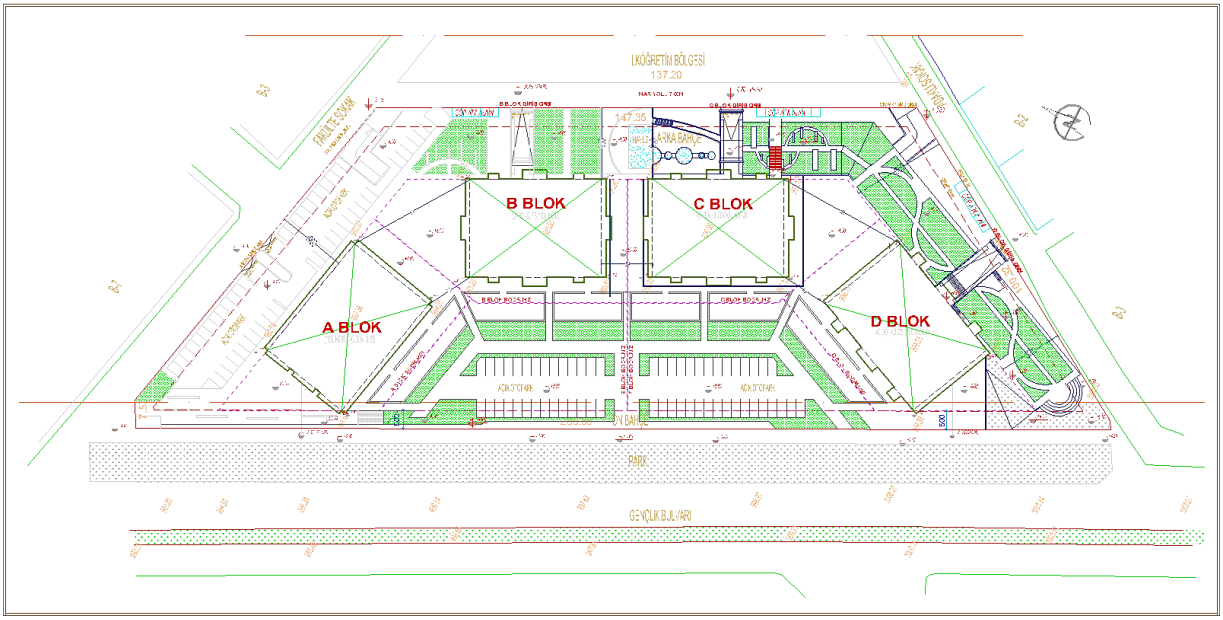


Figure 1: Layout plan of the project.

After the risks were determined, the project, which was taken as a case study, was planned with Primavera Risk Analysis (PRA) software and the risk analysis of the project was carried out with the help of Monte Carlo Simulation technique under the determined risks. In line with the results obtained, the effects of risks on the time and cost performance of the project were determined and revealed.

Monte Carlo method, one of the simulation techniques, is a system based on probability theory. It was created based on statistical and mathematical techniques. In this way, an experiment or a physical event that needs to be solved is animated and solved by using random numbers repeatedly in the computer environment. It facilitates the understanding of the behavior of highly complex systems whose analytical results are not easily accessible (Yıldız, 2011; Kaplan, 2014).

Findings and Discussion

In the first part of the study, the risks that can be encountered frequently in construction projects were determined and classified based on expert opinion and literature review. Within the scope

of the research, 63 risk factors were identified and classified under 8 main risk groups: design, contract, political, financial, managerial, organizational, construction and environmental. For the case study, the risk score for each risk determined within the scope of the research was determined by evaluating the risk probabilities and the effects of the risk on time and cost. While evaluating the possibility of risk and the effect of risk on time and cost; very low (VL), low (L), medium (M), high (H) and very high (VH) levels were used as ratings. The probability and impact assessments of the identified risks are given in Table 1.

Table 1. Identified risks and risk scores.

Risk Group	Risk Explanation	Prob.	Time Effect	Cost Effect	Risk Score
Design	Incompatibility between design projects	VH	M	L	15
	Change of design standards	L	L	L	4
	Faulty design	VL	M	VL	2
	Low performance of the design team	VL	VL	VL	1
	Adaptation problem of designers to the standards of different countries	N	N	N	0
	Revision request	VH	VH	VH	25
Contractual	Lack of contract documents	L	N	N	0
	Uncertainty in contract clauses	L	L	VL	4
	Unbalanced distribution of responsibility (risk)	VL	M	M	3
	Unclear project scope	M	H	H	12
	Absence of clauses related to the settlement of disputes in the contract	VL	VL	VL	1
Political	War, coup etc. disruption of business	N	VH	H	0
	Terrorism etc. business interruption due to security issues	N	H	M	0
	Prolongation of bureaucratic procedures	VH	H	L	15
	Embargo and quota applications	N	N	N	0
	Nationwide strike	N	N	N	0
Financial	Cash flow shortage	L	VH	VH	10
	Incorrect cost estimation	VH	L	VH	20
	Increase in material prices	VH	L	VH	20
	Increase in labor costs	VH	L	M	15
	Global crisis	M	H	VH	15
Management	Delay of management decisions/approvals	VH	M	M	15
	Top management change	VL	VL	VL	1
	Failure to choose the appropriate contract type for the project	L	L	M	6
	Incorrect contractor/subcontractor selection	L	M	M	6
	Incorrect consulting firm/controller selection	M	L	VL	6
Organizational	Lack of material/delay in supply	M	VH	H	15
	Lack of equipment/delay in supply	M	VH	H	15
	Poor performance of the project team	M	M	M	9
	Inadequacy of the project team	M	L	L	6
	Incompatibility of the project team	M	M	L	9
	Ineffective/Insufficient organizational structure	M	M	L	9
	Public opposition to the project	N	VL	VL	0
	Stakeholder communication difficulties	M	M	M	9
	Intellectual property violation	N	L	L	0
	Failure to take optimum OHS measures	VL	VL	VL	1
	Delay in the delivery of the site	VL	L	VL	2
Organizational	Infrastructure shortage	VL	L	L	2
	Socio-cultural problems	N	N	N	0
	Layout problem	M	VL	VL	3
	Incorrect/inadequate planning	VH	H	M	20
	Insufficient project control	L	M	H	8
	Demobilization issues	VL	VL	VL	1

	Equipment and material theft	M	N	VL	3
Construction	Faulty construction	M	H	H	12
	Equipment Failure	M	VL	VL	3
	Poor material quality	M	VL	VL	3
	Problems with temporary admission	L	VL	VL	2
	Problems with final admission	L	M	VL	4
	Material loss	VL	VL	VL	1
	Faulty construction technique	VL	VL	VL	1
	Geological problems	VL	L	L	2
	Finding historical artifacts	VL	M	VL	2
	Environmental damage from construction	M	VL	VL	3
	Labor shortage	VL	M	VL	2
	Low labor performance	VL	L	VL	2
	Occupational accident resulting in death or serious injury	H	L	H	12
	Occupational accident resulting in moderate to minor injury	H	VL	VL	4
	Adverse weather conditions	VL	L	L	2
Environmental	Earthquake	VL	VH	VH	5
	Flood	VL	H	H	4
	Soil shift, erosion	VL	L	VL	2
	Epidemic disease	VL	VL	VL	1

The ranking of the main risk groups according to the risk scores for the selected project is shown in Figure 2. Considering the risk scores of the risks affecting the project, it is seen that the risk group with the highest impact is organizational risks with a rate of 30%. Organizational risks are followed by financial risks with 21% and construction risks with 15%. Construction risks are followed by design risks (13%), management risks (9%), contract risks (5%), political risks (4%) and environmental risks (3%).

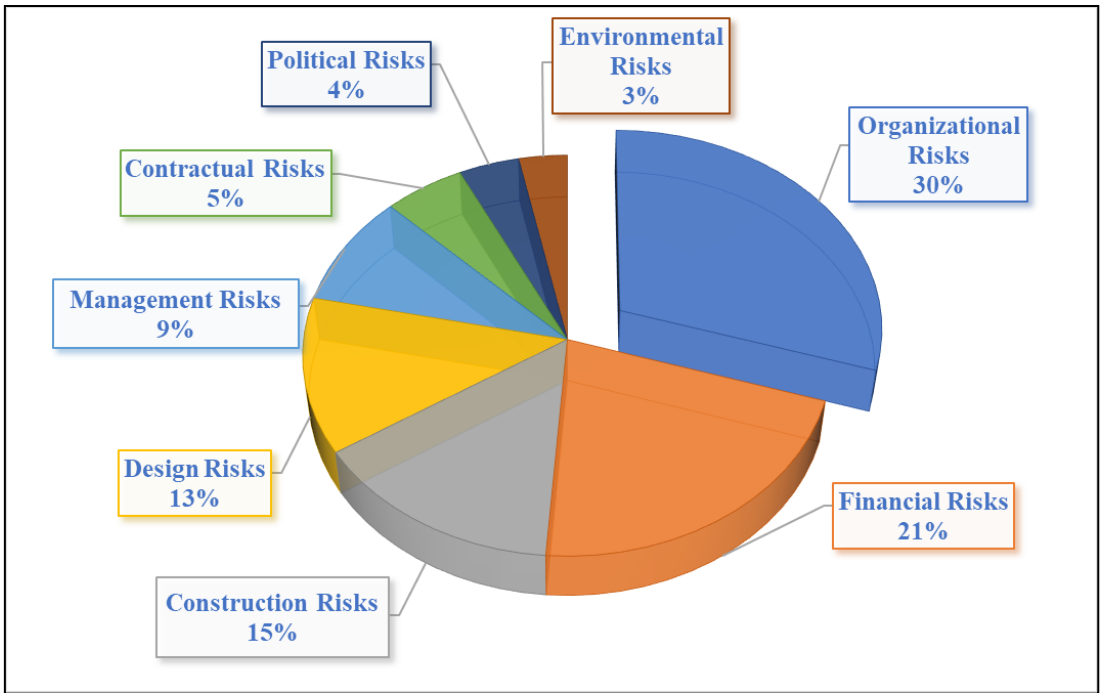


Figure 2: Ranking of risk groups according to risk scores.

The ranking of risk factors belonging to organizational risks, which are in the first place according to risk scores, is given in Figure 3. In the ranking made on the basis of risk scores, it has been revealed that the risk factor with the highest impact among organizational risks is the risk of faulty and or inadequate planning.

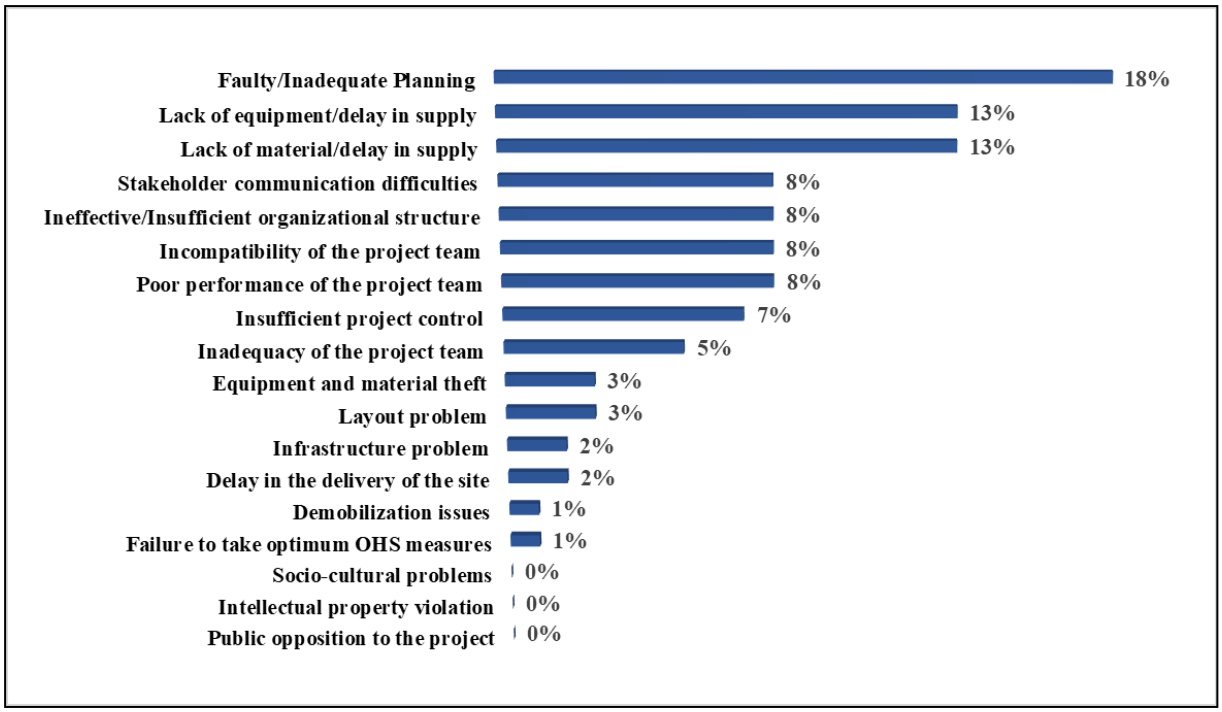


Figure 3: Ranking of organizational risks according to risk scores.

The highest risk factors within the financial risk group are the risks of increase in material prices and incorrect cost estimation with a rate of 25%. In the financial risk group, the third and fourth rank is the risk of experiencing an economic crisis and an increase in labor costs with a rate of 19%. Cash flow shortage ranks last among financial risk factors with 13% (Figure 4).

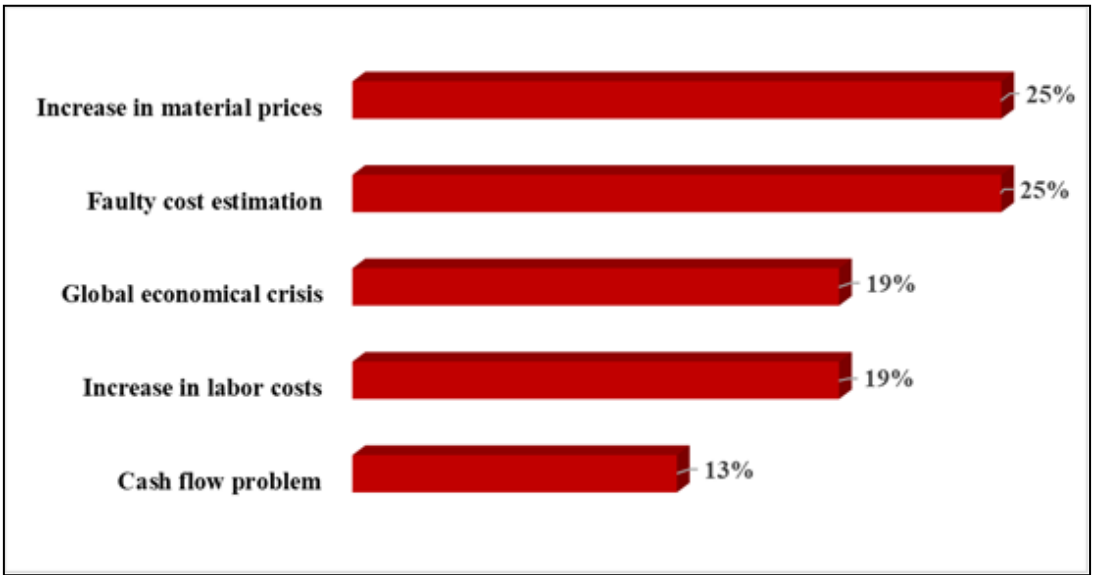


Figure 4: Ranking of financial risks according to risk scores.

In terms of risk scores, construction risks are the most effective risk group after organizational and financial risk groups. Among the risk factors constituting construction risks, occupational accidents resulting in death or serious injury and faulty construction practices were determined as the most effective construction risks with a rate of 22%. In the third and fourth rank, there

are the risks of occupational accidents resulting in moderate and mild injuries and problems in final admission (Figure 5).



Figure 5: Ranking of construction risks according to risk scores.

The project was planned with the help of PRA software and the basic processes of the project were determined as design, contract, site delivery, rough construction works, finishing works, mechanical works, electrical works, landscape works and control/delivery process. If the risks are not taken into account as a result of the planning, it is foreseen that the project will be completed in 904 days and with a cost of 107,197,703 TL. The durations, costs and planned start and end dates of these processes are listed in Table 2.

Table 2. The durations, costs and planned start and finish dates of the processes.

Project Main Processes	**Activity Duration (Day)**	**Planned Start Date**	**Planned Finish Date**	**Activity Cost (TL)**
Design	97	16.01.2017	22.04.2017	₺2,015,000
Contract	25	24.03.2017	17.04.2017	₺20,00
Site Delivery	50	18.04.2017	6.06.2017	₺90,00
Rough Construction	509	7.06.2017	28.10.2018	₺31,632,194
Finishing Works	833	16.01.2017	28.04.2019	₺32,232,337
Mechanical Works	510	2.09.2017	24.01.2019	₺11,776,523
Electrical Works	596	6.09.2017	24.04.2019	₺14,608,349
Landscape Works	110	28.01.2019	17.05.2019	₺3,100,000
Project Control and Delivery	70	29.04.2019	7.07.2019	₺80,00
General Expenses				₺11,643,300
Total	**904**	**16.01.2017**	**7.07.2019**	**₺107,197,703**

The risks were defined to the relevant project activities in the case study and simulation analysis was carried out with the help of PRA software. The changes that may occur in the project duration as a result of the simulation analysis for the case where the risks are included in the calculation, but no risk measures are taken are shown in Figure 6.

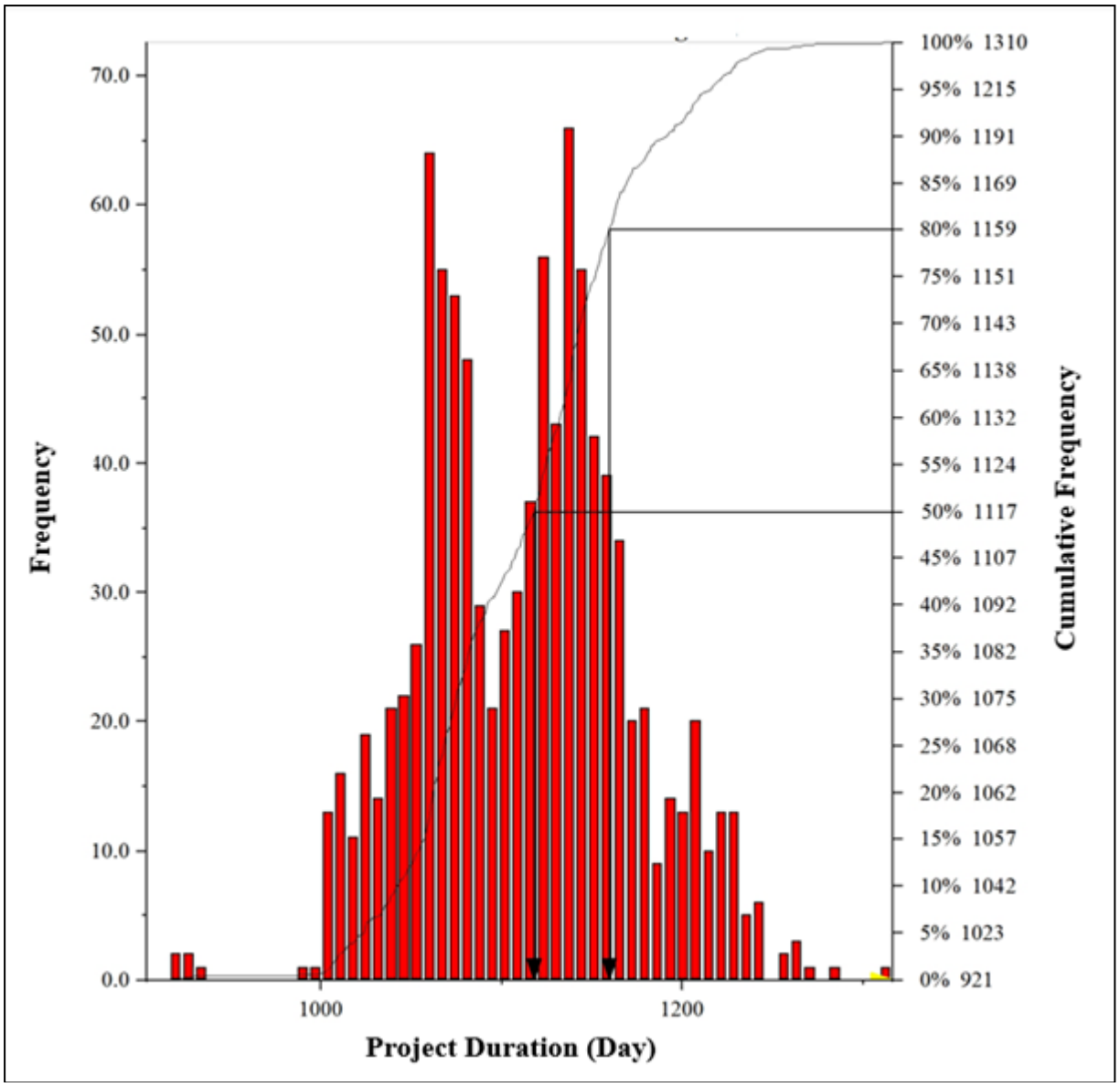


Figure 6: Project duration frequency distribution.

It is seen from the frequency distribution of the duration given in Figure 6 that the probability of completion of the project within the predicted 904 days after the simulation analysis with 1000 iterations under the determined risk effects is less than 1%. Considering the risks, it is predicted that the project can be completed in 1159 days with 80% probability. After the risk assessment, it was determined that the project could be completed in 1310 days at the latest.

As a result of the impact of the risks foreseen for the case study on the relevant activities of the project, it was observed as a result of the simulation analysis that the project cost could vary from 114,194,086 TL to 183,102,029 TL. The cost-frequency distribution obtained as a result of the analysis for the situation where the risks are taken into consideration is shown in Figure 7.

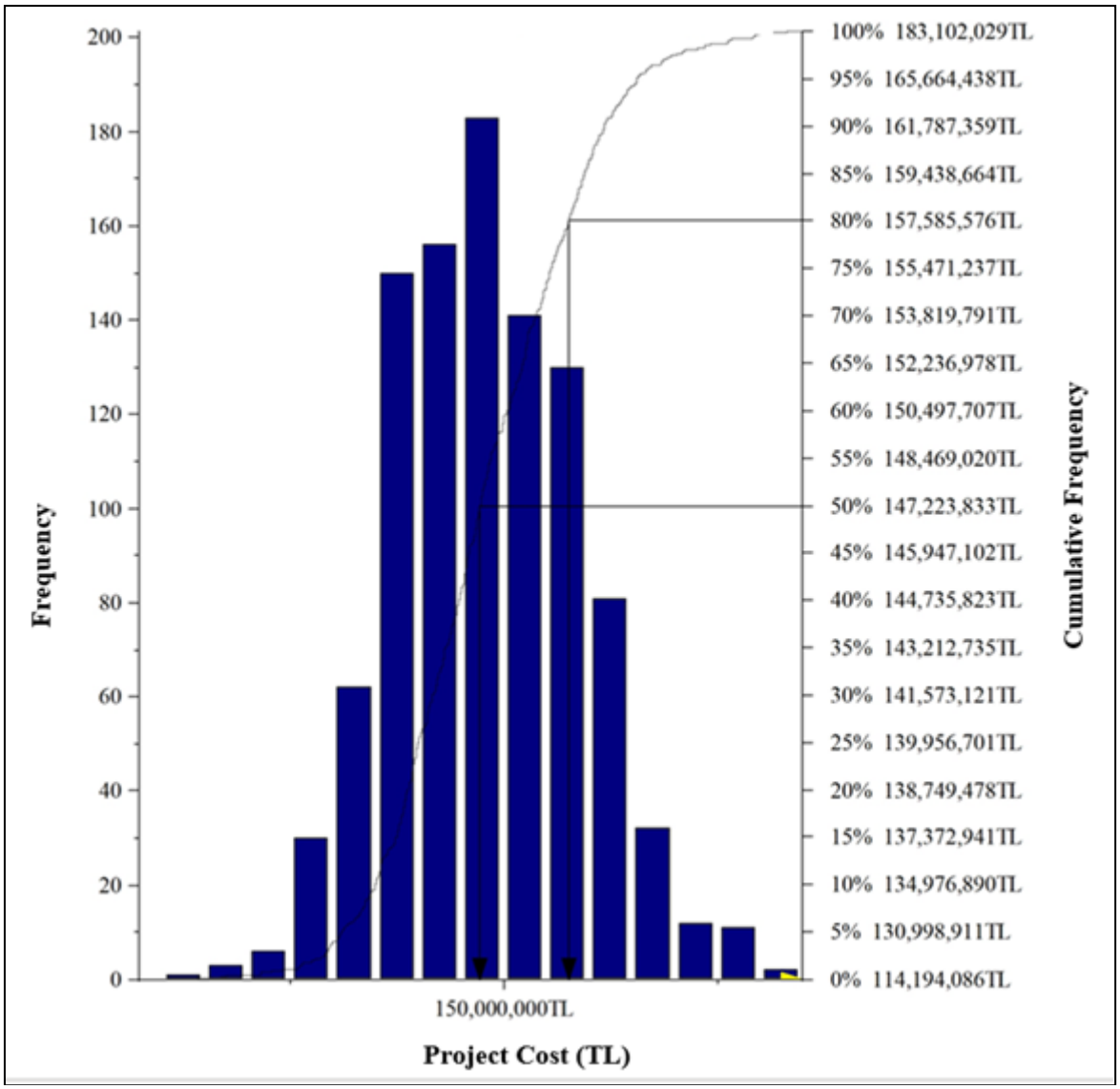


Figure 7: Project cost frequency distribution.

As a result of the analysis made for the scenario where risks are included in the calculation, but no measures are taken against any risk, it is predicted that the project will be completed with a probability of 80% with a cost of 157,585,576 TL. The probability of realization of the cost target of 107,197,703 TL determined for the project during the planning phase is less than 1%, as is the time target. The fact that the probability of reaching the values determined for the time and cost targets is less than 1% indicates that a realistic and accurate planning has not been made for the project.

As a result of the analysis of the project, which was taken as a case study, it was determined that the risks would increase the duration of the project by 28% and the cost by 47% when the projected values for the duration and budget of the project were examined, in the case where the risks were taken into account, but no risk response was given.

Kazaz et al. (2012) stated that the first three factors that affect time and cost overruns in construction projects are financial factors, government effects and labor-related factors, respectively. In 2015, Eker stated that among the internal risks in the construction industry, the

first three risk factors that highly affect the cost are designs that require advanced technology, insufficient information about the place where the project will be built, and faulty construction practices. Among the internal risk factors, it has been revealed that the risk factors that affect the project duration the most are stopping all or part of the work, faulty budget and time planning, and faulty construction practices. It is stated that war, inflation and fluctuations in the exchange rate difference are the external risk factors that affect the cost the most while the risks of war, natural disaster and prolongation of bureaucratic procedures are the first three risk factors that affect the duration the most.

İncir (2003) stated in his study that the most effective risks for the construction sector are economic and financial risks, and as a result of the simulation analysis he made on a case study, the project cost increased by approximately 22%. In the study carried out by Uzuntaş in 2010, a retrofitting project was taken as a case study and simulation analysis was made. As a result of the analysis, it has been revealed that risks can increase the cost of the project by approximately 92%. In a similar study, in which the Marmaray project was considered as a sample project, Abdollahi (2010) stated that as a result of the simulation analysis carried out, the risks could cause a 177% deviation in the project duration and a 50% increase in the project cost. In 2015, Türker conducted a study to investigate the effects of risks on the time and cost of a 13-floor housing project. At the end of the study, it was estimated that risks could increase the duration of the project by 34% and the cost of the project by 12%.

As the common point of different studies, it is seen that the most effective risk factors in the time and cost performance of projects are financial risks. The results of the study also show that the risks cause the construction projects to exceed the time and cost targets at a high rate. Considering this situation, it is understood that an effective risk management is inevitable for the successful conclusion of construction projects.

Results

The aim of this study is to determine the most effective risks for construction projects and to investigate their effect on time and cost targets. For this purpose, a risk analysis of a housing project, which was taken as a case study, was made and the results were examined. The findings revealed that the most influential risk factors for construction projects are financial, organizational and construction risks. Considering only the time and cost target in the risk analysis constitutes the limitation of this study.

It is thought that the numerical data obtained from this study will shed light on risk management for project owners and managers, especially in small-scale construction projects. In addition, it is thought that future studies with different types and sizes of construction projects will reveal the relationships between the main factors affecting risk management in construction projects and contribute to the development of risk management practices in construction projects.

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A Decision Support Model on Risk Management in Construction Projects

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Abstract

Technological developments, the increase in the world population and the rapid change in customer needs have increased the competitive environment in the construction sector. The highly competitive environment makes risk management mandatory for construction companies. Construction projects are exposed to many risks due to their unique structure. A successful risk management requires a realistic assessment of these many risks and the determination and implementation of appropriate strategies. Within the scope of the study, firstly, the risks that may be encountered in construction projects were determined and grouped through expert opinions and literature review. AHP method, one of the multi-criteria decision-making techniques, was used to prioritize risks. The strategies that can be taken against the identified risks were determined in line with the expert opinions and the TOPSIS technique was used to choose between the strategies that could be applied. It is thought that the obtained model will contribute to decision makers in risk management in construction projects.

Keywords: *AHP, construction Risks, construction Sector, MCDM, risk management, TOPSIS.*

Introduction

In today's rapidly changing, developing, and globalizing world; technological, economic and political changes cause to increasing of uncertainties. In an environment of increasing uncertainty, companies need to understand and successfully implement the risk management system in order to determine their future strategies and achieve their goals and missions. Construction projects are exposed to lots of various risks, from the design stage to the tender process, from construction to delivery, and even to operation processes. These risks cause the construction projects not to be completed in the desired time, at the desired quality and at the determined cost. These risks, which arise in different processes of the project, adversely affect one or more of the project stakeholders if they are not managed effectively. Construction projects that have various risks according to the project structure, size, complexity and construction type; are among the priority project types that risk management should be applied. The aim of this study is to generate a decision support model for the prioritization of the risks frequently encountered in construction projects and the risk strategies that can be applied. For this purpose, initially, based on literature review and expert opinions, construction project risks and measures that can be taken against these risks have been determined. Considering the main objectives of the projects, the ranking of the project risks was carried out through the AHP (Analytical Hierarchy Process) technique. Fuzzy-TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) technique was used to select among the risk measures that can be

applied for prioritized risks. It is thought that the findings can guide risk management practices in the construction industry and foreseen that the developed model can be improved by restructuring for different construction projects in future studies and contribute to the literature.

Risk Management in Construction Projects

Compared to other sectors in the construction sector; scope, quality, time, and cost deviations are observed more frequently. The long-term and complex stages of construction projects, the fact that each project has different characteristics, being under the influence of external factors, it's high cost, diversity of techniques used in construction and dynamic organizational structure cause this situation (Flanagan & Norman, 2003; Akintoye & Macleod, 1997; Smith et al., 2006). Construction projects are carried out with the participation of many stakeholders such as employers, designers, contractors, subcontractors, suppliers. The risks that may affect these participants at different processes and levels, and the effective analysis and management of these risks pose a major challenge for practitioners in the industry (Chatterjee et al., 2018).

Al-Bahar and Crandall (1990) define the risk management process for contractors as follows: Risk management is a set of processes consisting of systematically identifying risks, analyzing identified risks, and developing strategies against risks in order to eliminate, reduce or control risks. Risk management is the systematic application of management policies, procedures and practices, communication, consulting, context and identifying, analyzing, evaluating, processing, monitoring and reviewing risks. The main purpose of risk management is to identify, evaluate and control risks for project success (Hey, 2017; Süllüoğlu, 2019).

When the studies conducted by different researchers on the classification of construction project risks are examined, it is observed that financial, construction, political, design and managerial risks take place in the common denominator. Numerous studies have also been conducted on prioritization of construction project risks. For example, Befrouei and Taghipour (2015) stated in their study that the factors that most affect cost risk are tight programming schedule, increase in material prices and disagreement between stakeholders. In the same study, it was revealed that the factors affecting the time risk the most were the tight programming schedule, design revisions and prolongation of bureaucratic procedures. It has been revealed that tight programming schedule, problem of communication between stakeholders and lack of skilled workforce have a high impact on the quality risk and; is also stated that tight schedule, noise pollution from the construction and the lack of information about the construction site have the highest impact on environmental risks. It has been also stated that the factors that affect the occupational health and safety risk the most are tight work schedule, insufficient security measures and ineffective subcontractor management. In the study conducted by Lin and Chen (2021), the researchers stated that the risk groups that affect the project objectives the most are the contractor, subcontractor and design risks, and the external risks do not have much effect on the project objectives. Insufficient site control, faulty construction, insufficient training to the operators, and lack of knowledge and experience of the design team were the risk factors that most negatively affected the project objectives. On the identification and assessment of sustainable construction project risks, El-Sayegh et al. (2021), 30 risks were classified under management, technical, green team, green material, and economic risk groups. The top 5 risk factors with the highest impact were employer's financing shortage, faulty sustainable design, design changes, tight schedule and faulty scope definition. In another research, a risk analysis was carried out for a construction project in Vietnam, which will be carried out with the design-build delivery method chosen as a case study. Within the scope of the study, a total of 28 risks

were determined and these risks were divided into 5 different groups as political and legal, economic and financial, construction, design, contract and tender risks. As a result of the risk analysis, it has been stated that the top 3 risk factors are delay in project approval, inflation and faulty design-design change factors (Nguyen & Nguyen, 2020).

Ahmadi et al. (2017) developed a decision support model for the selection of risk responses with the help of multi-criteria decision-making techniques, in which they identified risk and risk responses specific to road projects. As a result of the study, the first five risk events that are most effective in the highway project were insufficient budget allocation, delay in payments, increase in tar prices, contractor's equity shortage and sudden price increase in other materials other than tar. For the risk of increase in tar prices; four risk responses have been identified: Allocating an additional budget, developing a new design using compressed concrete instead of tar, accepting price increases, and pre-procurement and storage of tar. As a result of the analysis made by using multi-criteria decision-making techniques among the identified risk responses, it was revealed that the most effective risk response would be a design change.

In their study, Beltrão and Carvalho (2019) developed a decision support model based on the Fuzzy AHP technique in order to create a risk breakdown structure for public construction projects in Brazil and to prioritize construction risks. Within the scope of their studies, they identified 54 risks under 8 main risk groups. From 8 main risk groups, including social, project, construction, financial, economic, political, environmental, and managerial risks; it has been revealed that the most effective risk group were project and political risks. The most effective project risks were identified as bid package and contract deficiencies, cost underestimation or overestimation and design errors. It was stated that the risks of corruption, bureaucracy and political interference were the risks with the highest impact within the political risk group. Based on risk factor, it was stated that the three most effective risks were, respectively, difficulty in environmental licensing, design revision request during construction and corruption risk.

Methodology

Due to the characteristics of construction projects, the importance of risk management practices in construction projects is increasing day by day. The stages of identifying and analyzing risks, developing strategies against risks and monitoring risks constitute the risk management process. As in all sectors, it is critical to identify risks and create response strategies for risk management in construction projects. Within the scope of this study, a hybrid decision support model based on the AHP-Fuzzy TOPSIS technique has been developed in order to identify and prioritize risks and risk responses. In the first part of the study, risk and risk strategies were determined in line with expert opinion and literature review. The identified risks have been weighted with the help of the AHP technique, taking into account the cost, duration, quality, sustainability and occupational health and safety criteria determined as the main objectives of the construction projects. After the weighting of the project risks, the Fuzzy-TOPSIS technique was used for the selection of the determined risk measures. The flow chart of the study methodology is given in Figure 1.

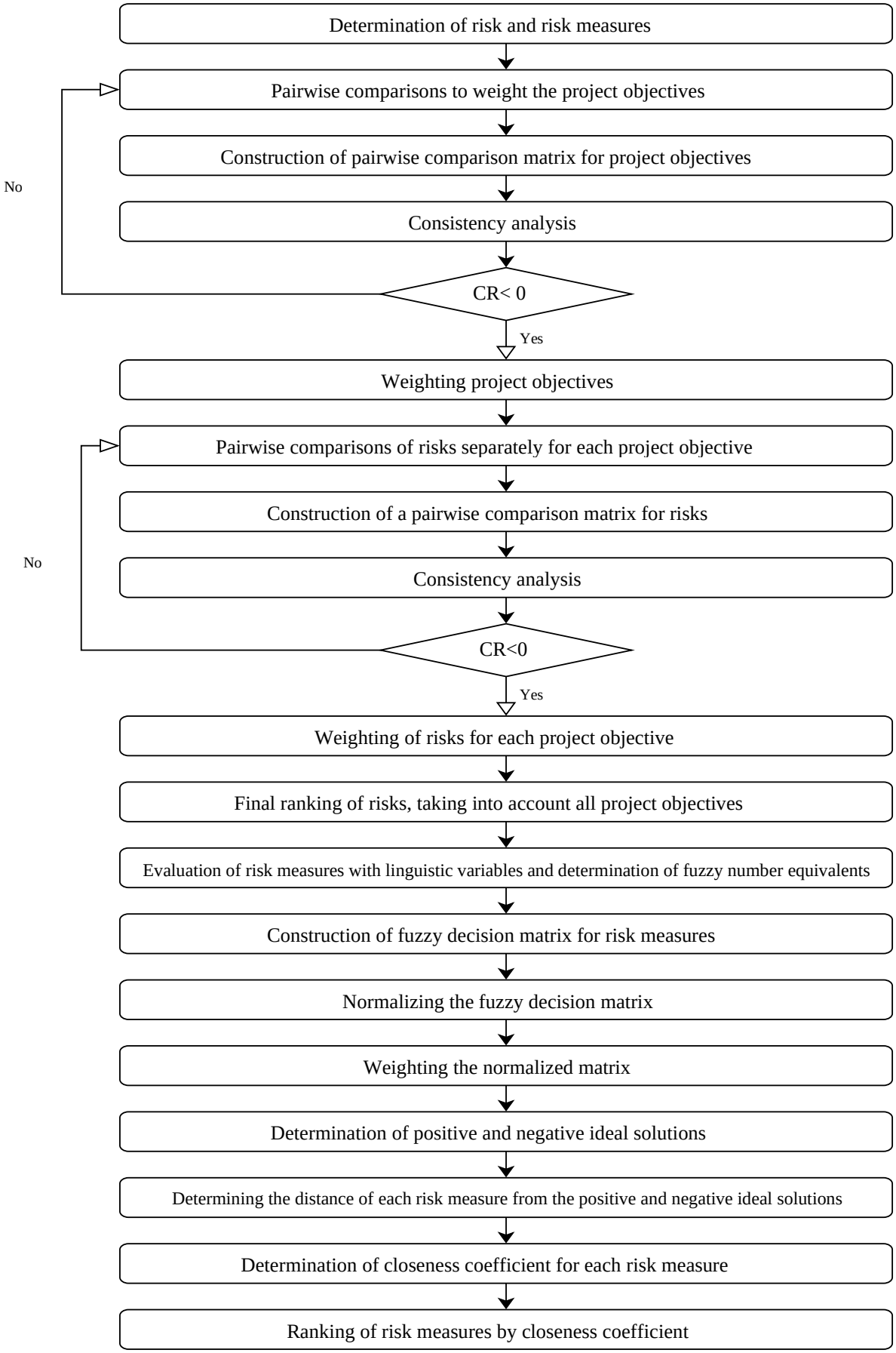


Figure 1: Framework for risk and risk measure prioritization by the proposed model.

Findings and Discussion

In the light of the results of the literature research on the determination and classification of risks in construction projects and the expert opinions; 7 main risk groups were determined as design risks, contractual risks, political risks, financial risks, management and organizational risks, construction risks and environmental risks (Table 1). As shown in Table 3, 20 risk measures that can be taken against the risks determined for construction projects have been determined in line with previous studies and expert opinion.

Table 1. Risk classification and explanations.

Risk Code	Risk Classification	Risk Explanations
CR01	Design Risks	Incompatibility between design projects, incorrect design, low performance of the design team, design revision demand
CR02	Contractual Risks	Lack of contract documents, Uncertainty in contract clauses, Unbalanced responsibility (risk) distribution, Unclear project scope
CR03	Political Risks	Business interruption due to security problems such as War, coup, terrorism, etc., Prolongation of bureaucratic procedures, Embargo and quota applications, Nationwide strike
CR04	Financial Risks	Cash flow shortage, incorrect cost estimation, increase in materials and labor prices, economic crisis
CR05	Management and Organization Risks	Delayed management decisions/approvals, Wrong selection of contractor/subcontractor/consultant firm, Wrong supplier selection, Selection of contract type that is not suitable for the project, Low performance of the project team, Ineffective/Insufficient organizational structure, Stakeholder communication problem, Layout plan problem, Incorrect/insufficient planning
CR06	Construction Risks	Faulty construction practices, Poor quality of material/equipment , Incorrect construction technique / method, Geological problems, Low labor force performance, Occupational accident, Insufficient material/equipment
CR07	Environmental Risks	Adverse weather conditions, Natural disasters (earthquake, flood, erosion, fire, etc.), Ecological damage potential, Epidemics

Table 2. Measures against risks.

Risk Measure Code	Risk Measures
RM1	Artificial Intelligence Based Decision Support Systems
RM2	Detailed examination of contract clauses/ consultancy for the preparation of contracts
RM3	Checking on -site feasibility
RM4	Keeping good relations with bureaucratic structures
RM5	Detailed preparation of insurance policies
RM6	Effective market analysis and good feasibility study
RM7	Effective and Realistic Planning/Work Program
RM8	BIM -based project management
RM9	Ensuring the reliability of credit institutions
RM10	Including the escalation condition in the contract
RM11	Performing Life Cycle Analysis
RM12	Influencing risk premiums on business items
RM13	Adopting the lean management understanding
RM14	Effective procurement and resource planning
RM15	Organizing events to increase productivity
RM16	Ensuring regular and effective construction site/project control
RM17	Providing regular and effective trainings to employees

RM18	Accurate information of employees on OHS and taking optimum OHS measures
RM19	Clear Determination of the Scope of the Project
RM20	Defining force majeure clearly and accurately in contracts, adding clauses about cost increase and delays caused by natural disasters

The main targets set for the successful conclusion of construction projects generally consist of cost, time, quality and safety criteria. Considering the energy crisis, which the critical importance of it continues to increase in recent years, it is clearly seen that it would be more beneficial to include the sustainability criterion among the success targets of construction projects. Within the scope of this study, cost, time, quality, occupational health and safety and sustainability criteria for construction projects have been determined as criteria to be considered for a successful project. Within the scope of the study, initially, the weights of these criteria were tried to be determined. In the weighting of the criteria, AHP technique was used in line with the expert opinion.

AHP was developed by Thomas L. Saaty in 1977 and provides a structured approach to the determination of multiple criteria and importance levels. AHP is mainly based on pairwise comparisons of criteria. In this study, project risks were accepted as criteria, and measures that could be taken against risks were accepted as alternatives. AHP technique was used to prioritize risks (criteria) and, Fuzzy-TOPSIS technique was used in the selection of risk measures (alternative). The pairwise comparison scale used to prioritize risks according to project objectives is given in Table 3.

Table 3. Pairwise comparison scale (Saaty, 1990).

Importance level	**Value Definitions**	**Description**
1	Equality	Each activity contributes equally.
3	Less important	As a result of experience and evaluations, an activity is a little more preferred than the other.
5	Quite important	As a result of experience and evaluations, one activity is much more preferred than the other.
7	Very important	An activity is preferred very strongly compared to the other.
9	Highly important	An activity is preferred as the highest possible degree compared to the other.
2,4,6,8	Intermediate values	If words are insufficient to make an assessment, a value in the middle of numerical values is given.

The comparison matrix used for the weighting of the project objectives, the normalized matrix and the weights of the project objectives are shown in Table 4 and Table 5.

Table 4. The comparison matrix of the priority of the project objectives.

	Cost	**Time**	**Quality**	**Sustainability**	**Safety**
Cost	**1.00**	3.00	7.00	8.00	4.00
Time	0.33	**1.00**	5.00	8.00	3.00
Quality	0.14	0.20	**1.00**	4.00	0.33
Sustainability	0.13	0.13	0.25	**1.00**	0.25
Safety	0.25	0.33	3.00	4.00	**1.00**

Table 5. Normalized comparison matrix and criterion weights of project objectives.

	Cost	Time	Quality	Sustainability	Safety	Weight	Ranking
Cost	0.54	0.64	0.43	0.32	0.47	0.48	1
Time	0.18	0.21	0.31	0.32	0.35	0.27	2
Quality	0.08	0.04	0.06	0.16	0.04	0.08	4
Sustainability	0.07	0.03	0.02	0.04	0.03	0.04	5
Safety	0.14	0.07	0.18	0.16	0.12	0.13	3

In order to evaluate the consistency of pairwise comparisons in the AHP technique, the consistency index (CI) should be determined, and the consistency ratio (CR) should be below 0,10. The equations given below are used to calculate the consistency index and consistency ratio (Yıldırım & Önder, 2014).

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} \quad (2)$$

λmax, which will be used in the calculation of the consistency index and consistency ratio, indicates the largest eigenvalue of the matrix, n indicates the number of criteria, and RI indicates the random index. The consistency ratio (CI) in ranking the project objectives was found to be 0.070 and it was accepted because it was less than 0.10. It has been determined that the most important criterion among the project objectives was the cost and, the cost criterion is followed by time, OHS, quality and sustainability factors, respectively. The processes followed in the sequence of the project target criteria were also applied in the prioritization of the risks for each project target separately. The risk rankings obtained as a result of considering each project objective separately are given in Table 6.

Table 6. Ranking of construction project risks in line with the project objectives.

Project Target	Risk Code	Project Risks	Weight	Ranking	Consistency Rate
Cost	CR04	Financial Risks	0.41	1	**0.062 < 0,10**
	CR05	Man. and Org. Risks	0.24	2	
	CR06	Construction Risks	0.14	3	
	CR01	Design Risks	0.08	4	
	CR03	Political Risks	0.07	5	
	CR07	Environmental Risks	0.04	6	
	CR02	Contractual Risks	0.02	7	
Time	CR05	Man. and Org. Risks	0.37	1	**0.040 < 0.10**
	CR04	Financial Risks	0.30	2	
	CR06	Construction Risks	0.14	3	
	CR01	Design Risks	0.08	4	
	CR02	Contractual Risks	0.04	5	
	CR07	Environmental Risks	0.03	6	
	CR03	Political Risks	0.03	7	
Quality	CR06	Construction Risks	0.36	1	**0.042 < 0.10**
	CR05	Man. and Org. Risks	0.25	2	
	CR04	Financial Risks	0.19	3	
	CR01	Design Risks	0.09	4	
	CR02	Contractual Risks	0.05	5	
	CR07	Environmental Risks	0.03	6	
	CR03	Political Risks	0.02	7	

Sustainability	CR07	Environmental Risks	0.33	1	**0.095 < 0.10**
	CR01	Design Risks	0.22	2	
	CR04	Financial Risks	0.19	3	
	CR05	Man. and Org. Risks	0.12	4	
	CR06	Construction Risks	0.08	5	
	CR02	Contractual Risks	0.03	6	
	CR03	Political Risks	0.02	7	
Safety	CR06	Construction Risks	0.39	1	**0.091 < 0.10**
	CR05	Man. and Org. Risks	0.25	2	
	CR07	Environmental Risks	0.15	3	
	CR01	Design Risks	0.10	4	
	CR04	Financial Risks	0.05	5	
	CR02	Contractual Risks	0.04	6	
	CR03	Political Risks	0.02	7	

Consistency ratios for the pairwise comparisons of risks, which were made by considering each project objective, were calculated as less than 0.10 and the ranking of the risks was carried out. In the continuation of the study, a final ranking was made for the risks by using the project target weights for the case where all the project objectives are considered together. As shown in Table 7, in the risk ranking made for the situation where all of the cost, time, quality, OHS and sustainability targets are included; It is seen that financial, management and organization and construction risks have critical importance and taking precautions against these risks will contribute to the successful conclusion of the projects. It is also thought that financial risks may have a much more critical importance for construction projects, especially for developing countries whose economic stability has not been ensured. It is estimated that financial difficulties have the highest impact among the identified risks as they can cause both managerial problems and poor construction quality. Management and organizational risks, on the other hand, were thought to be caused by the traditional management approach away from the use of information technologies, inadequate decision mechanisms and the lack of competent personnel. It is assumed that the first two risk groups will seriously affect the construction risks. It is believed that unstable cash flow, poor site order and inadequate site control will adversely affect construction quality, especially material and equipment quality. In addition, it is thought that the irregular site environment and the lack of OHS, and technical knowledge will increase the probability of occupational accidents, and this could have a negative effect on the construction process.

Table 7. Final risk ranking.

Risk Code	Risk	Weight	Ranking
CR04	Financial Risks	0.31	1
CR05	Man. and Org. Risks	0.27	2
CR06	Construction Risks	0.19	3
CR01	Design Risks	0.09	4
CR07	Environmental Risks	0.06	5
CR03	Political Risks	0.04	6
CR02	Contractual Risks	0.03	7

For a successful risk management determining the measures to be taken against the risks and monitoring the risks are inevitable as identifying and classifying risks. In this part of the study, it is aimed to determine the most appropriate risk measures for the prioritized risks. For this purpose, risk measures were accepted as an alternative and Fuzzy TOPSIS technique was used for the most ideal alternative selection. As the first step in the evaluation of alternatives; expert opinion was sought on how effective the risk measures were for the identified risks through the

linguistic variables shown in Table 8. A fuzzy decision matrix was created in line with the views received using triangular fuzzy numbers.

Table 8. Linguistic variables and triangular fuzzy number equivalents in alternative evaluation (Chen, 2000).

Linguistic Variables	**Triangle Fuzzy Numbers**
Very Good (VG)	(9,10,10)
Good (G)	(7,9,10)
Medium Good (MG)	(5,7,9)
Fair (F)	(3,5,7)
Medium Poor (MP)	(1,3,5)
Poor (P)	(0,1,3)
Very Poor (VP)	(0,0,1)

By using the fuzzy decision matrix, a normalized fuzzy decision matrix is obtained, and the matrix is denoted by "*R*" and expressed by $R = [r_{ij}]_{mxn}$. The equation shown in (3) and (4) was used for the normalization process of fuzzy decision matrix (Türkben, 2022).

$R = [r_{ij}]_{mxn}$ i =1, 2, …. m; j = 1,2, …. n ;

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}\ \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad c_j^* = max_i c_{ij} \tag{3}$$

$$r_{ij} = \left(\frac{a_j^-}{c_{ij}}\ \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad a_j^* = min_i a_{ij} \tag{4}$$

Weighted normalized decision matrix is created, since each existing criterion has different degrees of importance. The equation shown in (5) was used to determine the elements of this matrix (Türkben, 2022).

$$V = \left[v_{ij}\right]_{mxn} \quad v_{ij} = r_{ij}\ x\ w_j \tag{5}$$

The values of FPIS (A^*), which is the fuzzy positive ideal solution, and FNIS (A^-), which is the fuzzy negative ideal solution, are shown in (6) (Chen, 2000).

$$A^* = (v_1^*, v_2^*, \ldots, v_n^*)\ v_j^* = (1,1,1)\ v_j^- = (0,0,0) \tag{6}$$

For each of the alternatives, their distances from the fuzzy positive ideal solution and the fuzzy negative ideal solution are determined. The distance to FPIS (A^*) and FNIS (A^-) is given in (7).

$$d_i^* = \sum_{j=1}^{n} d\left(v_{ij}, v_j^*\right) \qquad d_i^- = \sum_{j=1}^{n} d\left(v_{ij}, v_j^-\right) \tag{7}$$

Closeness coefficients are used to rank the alternatives whose results are obtained. For each alternative, the closeness coefficients CC_i are determined by using the formula in (8) separately.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \tag{8}$$

Finally, the alternative selection process was completed by sorting all the alternatives from the largest to the smallest according to their closeness coefficients. Weighted normalized fuzzy decision matrix, FPIS (A^*), FNIS (A^-), and closeness coefficient (CC_i) are shown in Table 9.

Table 9. Weighted normalized fuzzy matrix and closeness coefficients.

Risk Measures	CR01 (%9)	CR02 (%3)	CR03 (%4)	CR04 (%31)	CR05 (%27)	CR06 (%19)	CR07 (%6)	FPIS (A^*)	FNIS (A-)	CC_i
RM1	0.079	0.010	0.002	0.271	0.236	0.137	0.032	6.248	0.767	0.109
RM2	0.016	0.029	0.014	0.163	0.142	0.100	0.020	6.547	0.485	0.069
RM3	0.079	0.010	0.002	0.106	0.142	0.100	0.032	6.562	0.471	0.067
RM4	0.016	0.005	0.035	0.057	0.092	0.035	0.020	6.786	0.261	0.037
RM5	0.005	0.022	0.029	0.223	0.092	0.065	0.058	6.538	0.494	0.070
RM6	0.031	0.010	0.002	0.271	0.092	0.035	0.011	6.582	0.453	0.064
RM7	0.047	0.010	0.002	0.271	0.261	0.137	0.020	6.266	0.750	0.107
RM8	0.087	0.016	0.002	0.271	0.261	0.166	0.053	6.152	0.857	0.122
RM9	0.016	0.005	0.002	0.223	0.092	0.100	0.003	6.591	0.443	0.063
RM10	0.005	0.026	0.007	0.223	0.142	0.100	0.003	6.520	0.507	0.072
RM11	0.079	0.002	0.002	0.223	0.049	0.035	0.053	6.592	0.442	0.063
RM12	0.016	0.026	0.007	0.271	0.142	0.100	0.011	6.453	0.574	0.082
RM13	0.065	0.022	0.007	0.223	0.236	0.166	0.011	6.290	0.730	0.104
RM14	0.016	0.010	0.002	0.271	0.261	0.166	0.011	6.277	0.739	0.105
RM15	0.065	0.005	0.002	0.106	0.236	0.166	0.003	6.441	0.585	0.083
RM16	0.031	0.016	0.007	0.223	0.236	0.184	0.011	6.313	0.708	0.101
RM17	0.031	0.002	0.002	0.057	0.142	0.137	0.032	6.634	0.402	0.057
RM18	0.016	0.002	0.002	0.057	0.142	0.166	0.032	6.617	0.417	0.059
RM19	0.079	0.029	0.002	0.163	0.142	0.137	0.011	6.464	0.563	0.080
RM20	0.016	0.029	0.007	0.223	0.142	0.065	0.053	6.496	0.535	0.076

Table 10. Final ranking on risk measures.

Code	Risk Measures	Ranking
RM8	BIM -based project management	1
RM1	Use of artificial intelligence-based decision support systems	2
RM7	Effective and realistic planning/work program	3
RM14	Proper procurement and resource planning	4
RM13	Adopting the Lean Management Understanding	5
RM16	Ensuring regular and effective construction site/project control	6
RM15	Organizing events to increase productivity	7
RM12	Influencing risk premiums on business items	8
RM19	Defining the project scope clearly	9
RM20	Defining force majeure clearly and accurately in contracts, adding articles about cost increase and delays caused by natural disasters	10
RM10	Including the escalation condition in the contract	11
RM5	Detailed preparation of insurance policies	12
RM2	Detailed examination of contract articles / consulting for the preparation of contracts	13
RM3	Checking the applicability/feasibility on site	14
RM6	Effective market analysis and proper feasibility study	15
RM9	Ensuring the reliability of credit institutions	16
RM11	Performing Life Cycle Analysis	17
RM18	Accurate information of employees on OHS and taking optimum OHS measures	18
RM17	Providing regular and effective trainings to employees	19
RM4	Keeping good relations with bureaucratic structures	20

When the final ranking of risk measures is examined, it is seen that the first five risks that can be most effective against risks are: BIM-based project management, use of artificial intelligence-based decision support systems, effective and realistic work schedule, effective procurement and resource planning and lean management approach (Table 10). In the light of the findings, it was concluded that the rapid change of technology and globalization can increase the risks of construction projects. However, these rapid changes can also provide

facilitating access to information, achieving a systematic and effective decision-making and management environment with the help of technologies such as artificial intelligence, virtual reality, cloud systems, etc. Considering these benefits; it is thought that the increase in the pace of globalization and technological development can be used as a powerful tool for measures to be taken against risks and more successful construction projects can be realized.

Results

This research aimed to develop an AHP-Fuzzy TOPSIS-based decision support model to identify and prioritize general risks related to construction projects and to choose between the measures that can be taken against these risks. Within the scope of this study, all project objectives were considered as a whole in the prioritization of risk and risk measures. A holistic approach has been tried to be achieved by including sustainability and safety objectives in addition to the basic project objectives such as cost, time, and quality in the developed model. The results of the study revealed that the risk group with the highest impact for construction projects is financial risks, while managerial and construction risks follow financial risks. The study also demonstrated that; BIM supported project management, the use of artificial intelligence-based decision support systems, realistic and effective work schedule, solid procurement and resource planning and the adoption of lean management approach are the most effective measures that can be taken against risks.

It is foreseen that the model developed within the scope of this study and the information obtained can guide the sector on risk management practices and contribute to the literature. Addressing construction project risks at a general level, failure to evaluate risk impact and probability levels separately, not considering sub-risk factors in the risk breakdown structure; constitutes the limitations of this study. In future studies, it is predicted that these limitations can be eliminated, and the model can be applied for specific construction projects by supporting artificial intelligence technologies.

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Stress-Performance Relationship in Architectural Offices: The Effect of Covid-19 Pandemic

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Abstract

Construction industry is among the sectors with high organizational stress levels due to its structure. High stress levels affect not only work performance but also the success of the projects. In addition, the Covid-19 pandemic, which emerged in China in December 2019 and spread rapidly all over the world, has greatly affected the lives of employees. The purpose of this study is to investigate the effect of the Covid-19 pandemic on the stress-performance relationship of architectural office employees. The survey was conducted to 55 architects in Turkey and the outcome was analyzed in SPSS. In the relevant literature, the stress-performance relationship has been discussed with four different models: positive relationship, negative relationship, inverted U-shaped relationship and non-relationship models. As expected, the stress-performance relationship was positive in the pre-Covid-19 (ß=.52, p<.01) but interestingly it reversed in the Covid-19 period (ß=-.45, p<.01). Research outcome indicates that with the Covid-19 pandemic, the stress (t_{54}=9.88, p<.05) and performance (t_{54}=2.87, p<.05) levels of employees decreased compared to pre-Covid-19 period. Even though they both decreased, they did not decrease at the same magnitude. It is expected that the outcome of this study will contribute to develop strategies to increase the performance of employees.

Keywords: *Architectural offices, Covid-19 pandemic, organizational stress, job performance.*

Introduction

Stress has originated from the Latin Word "estrictia". Starting from the 17th century, it was used in the sense of disaster, trouble, grief and then power and pressure (Güçlü, 2001). With its meaning in psychology, the concept was first discussed in 1936 by Hans Selye, who was called the father of stress (Senaratne & Rasagopalasingam, 2017). Selye (1976) defines stress as the body's response to a demand directed at the person. However, he states that it does not matter whether this demand arises from positive or negative conditions.

Today, workplaces where people spend most of their time have turned into uncertain environments with intense competition for employees (Güçlü, 2001). Uncertainty in organizations causes stress in employees (Şimşek et al., 2001). Organizational stress can occur as a situation that excites, disturbs, or puts pressure on the person (Saikala & Selvarani, 2015). Organizational stress which is among the most common work-related health problems

in Europe, has become an important issue for many industries in recent years (Leung et al., 2015).

Construction industry is among the high-stress industries due to task complexity, multi-stakeholder structure, communication problems between stakeholders and various business processes (Enshassi & Al-Swaity, 2015). In addition, tight deadlines, limited resources, and long working hours also play an important role in increasing the stress levels of the employees (Bowen et al., 2014). According to the research conducted by Great Place to Work (2020), which includes various sectors from 13 countries including Austria, Denmark, France, Greece, Germany, Italy, Norway, Sweden, Spain, Switzerland, Netherlands, Turkey and England, construction industry is the sector with the highest stress level. In addition, pressure in tight project delivery deadlines and long working hours are the most important factors causing work-related stress.

Regardless of the positions in the organizations, certain amount of stress is expected in construction industry (Soni, 2014). Architectural offices, one of the main stakeholders of the sector, are also involved in all stages of projects from the initiation stage and have high work-related stress for their employees.

Covid-19 disease, which emerged in Wuhan, China in December 2019 and spread all over the World, was defined as a pandemic by the World Health Organization (WHO) on March 11, 2020, (Hamouche, 2020). With the Covid-19 pandemic, working conditions of many businesses changed, and employees experienced remote working (Bouziri et al., 2020). This change has greatly affected the social and professional lives of people (Tekin, 2020). According to a study conducted by Akça and Tepe Küçükoğlu (2020), the remote working model causes people to spend a lot of time in the same environment, restricting their social lives and increasing their stress levels. An increase in the stress level can result in a decrease in employee performance (Serinikli, 2021).

In this context, the aim of this study is to examine the effect of Covid-19 pandemic on the organizational stress-job performance relationship of architectural office workers. The study targets the construction industry as a sector and architectural offices in particular. The population in this study are architects working in architectural offices operating in Turkey. A survey was conducted to 55 architects to measure organizational stress and job performance. The outcomes were analyzed with SPSS.

It is anticipated that this study will raise awareness about the effect of Covid-19 on the relationship between organizational stress and job performance in architectural office managers and office owners. With this awareness, managers are expected to develop strategies to increase employee performance and to create a win-win situation in the manager-employee relationship. This improvement which will take place at the office level, will also contribute to the construction industry.

Organizational Stress and Job Performance Relationship

Stress, which is among the concepts adopted by industrialized societies, is the effort of a person by pushing her/his physical and psychological limits due to unsuitable conditions (Cüceloğlu, 2002). The employee tends to experience stress when the employee's competence does not match the expectations and the requirements of the job (Colligan & Higgins, 2006).

Organizational stress has great importance as a factor that affects the behavior of individuals, relationships with people and productivity (Korkut, 2014).

Although it is generally believed that there is a negative relationship between organizational stress and job performance, this relationship is much more complex (Riggio, 2014). In the relevant literature, the stress-performance relationship is explained with four different assumptions: positive, negative, inverted U-shaped relationship and non-relationship models. According to the positive relationship model, there is a positive linear relationship between stress and performance. Low stress level cannot activate the person, it will result in low performance, while the person's performance will increase with high stress level. In the negative relationship model, there is a negative linear relationship between stress and performance. Accordingly, as the stress level increases, a decrease in the performance is expected. In the inverted U-shaped relationship model (Figure 1), it is assumed that low-level stress will not activate the person and causes low performance in addition to this, excess of stress also causes low performance, because the person will spend all time to cope with stress. In this model, the optimum level of stress is needed for high performance. Finally, in the non-relationship model, it is assumed that there is no significant relationship between stress and performance (Sullivan & Bhagat, 1992). Among these models, in the relevant literature there is a consensus in inverted U-shaped relationship model (Cohen, 1980).

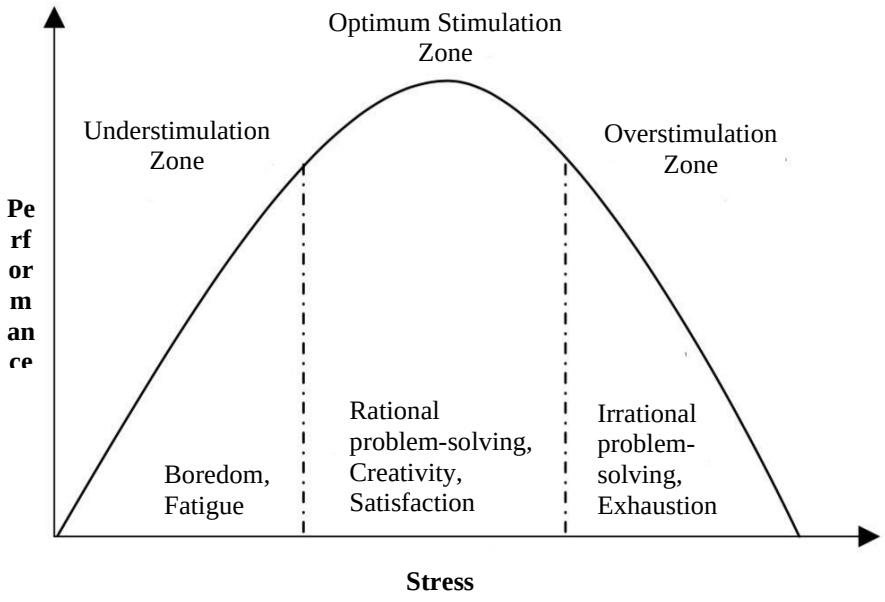


Figure 1: Inverted U-shaped relationship between stress and performance (Leung et al., 2015).

The negative effects of stress have a wave effect, starting from individuals, spreading to family, social environment and then society (Bowen et al., 2014).

Methodology

In this research, a demographic form and three different scales were used to collect data from architects. The *organizational stress scale*, developed by Theorell et al. (1988) and adapted to Turkish by Yıldırım et al. (2011), measures the organizational stress level of architects. The Cronbach Alpha value of this scale was determined as 0.80. The scale consists of 14 items in

a 5-point Likert scale (1=Never and 5=Always). The scale consists of four sub-dimensions: *social support*, *workload*, *skill use* and *decision making*. High scores obtained from the overall scale indicate high stress and low scores indicate low stress. Two negative sub-dimensions on this scale are reverse scored: Social support and decision making. For these two sub-dimensions, high scores indicate low and low scores indicate high social support and decision-making. Ergun's (2008) *job performance scale* was used to measure the job performance levels of architects. The Cronbach Alpha value of the scale was determined as 0.83. The scale consists of 9 items in a 5-point Likert scale (1=Too much and 5=Too few). This scale consists of two sub-dimensions: *job success* and *job satisfaction*. High scores obtained from the overall scale indicate high performance, while low scores mean low performance. Finally, Paşa's (2007) *performance appraisal scale* was used to measure the factors affecting the job performance of the employees. The Cronbach Alpha value of this scale was determined as 0.90. Similar to the first scale, it consists of 14 items in a 5-point Likert scale (1= Strongly disagree and 5=Strongly agree). Considering the Covid-19 pandemic, pre-Covid-19 and Covid-19 period options were added for all the items in the scales, and the participants were asked to make their evaluations for the pre-Covid-19 and Covid-19 period.

Among the three different scales used in this study, Yıldırım et al. (2011)'s organizational stress scale and Ergun (2008)'s job performance scale were associated with the aim of examining the relationship between organizational stress and job performance. In addition, Paşa (2007)'s performance appraisal scale was included in the study to examine the other factors affecting job performance in more detail.

An online survey was conducted to architects working in architectural offices in Turkey in a four-month period between June 2, 2021, and October 2, 2021. A total of 123 questionnaires were responded, 8 of them were left out due to incomplete response. Of the remaining 115 questionnaires, 60 were left out of the scope of this study because the respondents changed their workplace, and the change of stress level could not be measured due to the environment change. Therefore, 55 respondents were included in this study.

While the effect of the Covid-19 pandemic on organizational stress and job performance was examined with two dependent samples t-test, the bilateral relationship between organizational stress and job performance was examined by using correlation analysis. In addition, the factors affecting the performance of the employees were also analyzed with frequency analysis. Statistical analysis was evaluated using the 'SPSS 26.0 for Mac' software program. Demographic characteristics of the participants are given in Table 1.

Table 1. Frequency analysis of demographic profile of participants.

Demographic Variables	**Frequency (f)**	**Percentage (%)**	**SD**
Age			
<30 years	43	78.2	0.52
31-40 years	10	18.2	
41-50 years	2	3.6	
Gender			
Female	41	74.5	0.44
Male	14	25.5	
Education			
Bachelor	37	67.3	0.69

Master's degree (Student)	12	21.8	
Master's degree	6	10.9	
Income Status			
<3000 Tl	3	5.5	0.85
3001-5000 Tl	26	47.3	
5001-7000 Tl	16	29.1	
>7001 Tl	10	18.2	
Total	55	100.0	

The frequency analysis of the participants' working conditions in the pre-Covid-19 and Covid-19 period is given in Table 2. This analysis shows that remote working increased in the Covid-19 period either partially or completely.

Table 2. Frequency analysis of participants' working conditions in the pre-Covid-19 and Covid-19 period.

Working Conditions	**Pre-Covid-19**			**Covid-19 Period**		
	Frequency(f)	**Percentage(%)**	**SD**	**Frequency(f)**	**Percentage(%)**	**SD**
Working in the office every day	51	92.7	0.42	28	50.9	0.84
Working remotely on certain days	2	3.6		13	23.6	
Working remotely every day	2	3.6		14	25.5	

Findings

Organizational Stress Levels in the Pre-Covid 19 and Covid-19 Period

Yıldırım et al.'s organizational stress scale (2008) was used to measure the organizational stress level of the participants. The scale addresses organizational stress with four sub-dimensions: workload, skill use, decision making, and social support. The workload sub-dimension consists of 3 items, including the example statement "Do you have to work too fast?". The skill use sub-dimension consists of 3 items, including the example statement "Does your job require high-level skills and expertise?". Decision-making sub-dimension consists of 2 items, including the example statement "Can you decide on your own how to work in your job?". Finally, the social support sub-dimension consists of 6 items, including the example statement "I get along well with other employees at my workplace". High scores on workload and skill use increase the stress level, while high scores on decision making and social support decrease.

Two dependent sample t-test analysis were applied to measure the organizational stress levels in the pre-Covid-19 and Covid-19 period (Table 3). The analysis indicates that the change in organizational stress level is statistically significant between pre-Covid-19 and Covid-19 period (t_{54}= 9.88 and $p<0.05$). In the Covid-19 period, stress levels of employees decreased. In the sub-dimensions, the workload and skill use levels of the employees decreased, and the social support and decision-making (reverse scoring) levels increased in the Covid-19 period.

Analysis also shows that all sub-dimensions have statistically significant effect on the change in organizational stress, but the effect of social support is the most (t_{54}=11.69 and $p<0.05$).

Table 3. Two dependent sample t-test analysis of organizational stress level in the pre-Covid-19 and Covid-19 period.

Variable		**Mean ($\bar{X}$)**	**SD**	**df**	**t**	**p**
Organizational Stress	Pre-Covid-19	3.77	0.49	54	9.88	0.00
	Covid-19 Period	2.81	0.37			
Sub-Dimensions		**Mean ($\bar{X}$)**	**SD**	**df**	**t**	**p**
Workload	Pre-Covid-19	3.98	0.66	54	3.11	0.00
	Covid-19 Period	3.85	0.73			
Skill Use	Pre-Covid-19	3.76	0.78	54	4.82	0.00
	Covid-19 Period	3.29	0.48			
Decision Making	Pre-Covid-19	3.18	1.06	54	2.09	0.04
	Covid-19 Period	2.63	0.96			
Social Support	Pre-Covid-19	3.87	0.60	54	11.69	0.00
	Covid-19 Period	2.11	0.56			

Job Performance Levels in the Pre-Covid 19 and Covid-19 Period

Ergun (2008)'s job performance scale was used to measure participants' job performance. The scale addresses job performance with two sub-dimensions: job success and job satisfaction. The business success sub-dimension consists of 4 items, including the example statement "Sometimes I make mistakes at work.". The job satisfaction sub-dimension consists of 5 items, including the example statement " Sometimes I am reluctant to go to work.". High scores on job success and job satisfaction increase the job performance.

Two dependent sample t-test analysis were applied to measure the job performance level in the pre-Covid-19 and Covid-19 period (Table 4). The analysis indicates that the change in job performance level is statistically significant between pre-Covid-19 and Covid-19 period (t_{54}= 2.87 and $p<0.05$). Even though, job performance levels of employees decreased in the Covid-19 period, this decrease is not as much as in the organizational stress variable. Analysis also shows that job satisfaction sub-dimension has statistically significant effect on the change in job performance, but job success sub-dimension has no significant effect (t_{54}=1.67 and $p>0.05$).

Table 4. Two dependent sample t-test analysis of job performance level in the pre-Covid-19 and Covid-19 period.

Variables		**Mean ($\bar{X}$)**	**SD**	**df**	**t**	**p**
Job Performance	Pre-Covid-19	3.71	0.75	54	2.87	0.01
	Covid-19 Period	3.53	0.81			
Sub-Dimensions		**Mean ($\bar{X}$)**	**SD**	**df**	**t**	**p**
Job Success	Pre-Covid-19	3.73	0.79	54	1.67	0.10
	Covid-19 Period	3.63	0.80			
Job Satisfaction	Pre-Covid-19	3.69	0.84	54	2.83	0.00
	Covid-19 Period	3.45	0.98			

Organizational Stress and Job Performance Relationship in the Pre-Covid-19 and Covid-19 Period

To examine the relationship between the organizational stress levels of the participants and their job performance, Yıldırım et al. (2011)'s organizational stress scale and Ergun (2008)'s job performance scale were associated. The evaluation of this bilateral relationship was carried out by accepting the inverted u-shaped relationship model, which there is a consensus about in the relevant literature.

The relationship between organizational stress and job performance of the participants in pre-Covid-19 and Covid-19 period was examined by correlation analysis and the results are given in Table 5. If the correlation coefficient is $r<0.2$, as very weak correlation or no correlation, if it is between 0.2-0.4, as a weak correlation, if it is between 0.4-0.6, as a moderate correlation, if it is between 0.6-0.8, as a high correlation and if it is $r>0.8$, it is interpreted as a very high correlation (Prapanjaroensin, 2017).

According to the findings, there is a significant, moderate level and positive relationship between stress and job performance in pre-Covid-19 ($r(55) = -0.52$ and $p<0.01$). In the Covid-19 period, there is a significant, moderate level and negative relationship between stress and job performance ($r(55) = -0.45$ and $p<0.01$). In other words, in this study conducted with the same sample group, while the relationship between organizational stress and job performance was positive in the pre-Covid-19, this relationship was reversed in the Covid-19 period. Outcome of the analysis are not supported by the inverted u-shaped relationship model.

Table 6. Correlation analysis of the relationship between organizational stress and job performance in pre-Covid-19 and Covid-19 period.

Variables		**Mean ($\bar{X}$)**	**SD**	**1**	**2**
Pre-Covid-19	1. Organizational Stress	3.77	0.49	-	0.52**
	2. Job Performance	3.71	0.75	0.52**	-
Covid-19 Period	1. Organizational Stress	2.81	0.37	-	-0.45**
	2. Job Performance	3.53	0.81	-0.45**	-

* $p<0.05$, ** $p<0.01$

Factors Affecting Job Performance

Pasha's (2007) performance appraisal scale was used to examine job performance in more detail. The scale consists of 14 items, including the example statement "Safety of my job affects my performance" and aiming to find the factors that affect the job performance of the participants.

The frequency analysis results of the factors affecting the work performance of the employees in the pre-Covid-19 and Covid-19 period are presented in Table 5. Among the factors affecting the performance of 55 employees in both periods, while item 5 The fairness and respect of my supervisors affect my performance' has the highest average (4.87/4.82), item 13 Competitive opportunity in the workplace affects my performance' has the lowest average (3.55/3.16). However, analysis results show that both in the pre-Covid-19 and Covid-19 period, the greater part of the items in the scale have high degree of impact on job performance.

Table 5. Frequency analysis of factors affecting job performance in pre-Covid-19 and Covid-19 period.

Factors Affecting Job Performance		**Mean ($\bar{X}$)**	**SD**
1. The assurance of my job affects my performance.	Pre-Covid-19	4.35	0.70
	Covid-19 Period	4.29	0.83
2. The salary amount and promotions affect my performance.	Pre-Covid-19	4.55	0.72
	Covid-19 Period	4.56	0.74
3. Personal and professional development opportunities affect my performance.	Pre-Covid-19	4.55	0.72
	Covid-19 Period	4.56	0.76
4. My co-workers affect my performance.	Pre-Covid-19	4.64	0.70
	Covid-19 Period	4.51	0.84
5. The fairness and respect of my supervisors affect my performance.	Pre-Covid-19	**4.87**	0.39
	Covid-19 Period	**4.82**	0.64
6. Being appreciated affects my performance.	Pre-Covid-19	4.69	0.60
	Covid-19 Period	4.56	0.90
7. The opportunity to socialize with my co-workers affects my performance.	Pre-Covid-19	4.15	1.01
	Covid-19 Period	3.95	1.11
8. The support and guidance of my supervisors affect my performance.	Pre-Covid-19	4.67	0.51
	Covid-19 Period	4.56	0.74
9. The fairness of my salary affects my performance.	Pre-Covid-19	4.78	0.46
	Covid-19 Period	4.75	0.64
10. Having decision authority affects my performance.	Pre-Covid-19	4.47	0.72
	Covid-19 Period	4.44	0.83
11. The desire to pursue my career at my workplace affects my performance.	Pre-Covid-19	4.04	1.02
	Covid-19 Period	3.82	1.20
12. The opportunity to help employees at work affects my performance.	Pre-Covid-19	4.00	0.92
	Covid-19 Period	3.93	0.10
13. Competitive opportunity in the workplace affects my performance.	Pre-Covid-19	**3.55**	1.07
	Covid-19 Period	**3.16**	1.23
14. Management's attitude affects my performance.	Pre-Covid-19	4.58	0.53
	Covid-19 Period	4.49	0.74

Conclusion

In this study, the effect of the Covid-19 pandemic on the organizational stress and job performance levels of architects working in architectural offices and the correlation between these variables are examined. In addition, the factors affecting the performance of employees in pre-Covid-19 and Covid-19 period are also analyzed. The outcome of the analysis indicate that social support, which has the greatest effect on reducing the stress levels of employees increased in the Covid-19 period. This is an interesting result and requires further analysis to be supported because in the relevant literature, it is expected that social support will decrease in the remote working model in the Covid-19 period. The fact that the increase in social support reduces the stress level is coherent with the relevant literature. In addition, the decrease in skill use of people may have reduced their job satisfaction, which is the most important reason for the decrease observed in job performance. The change in the organizational stress - job performance relationship during the Covid-19 process may have resulted from the excessive decrease in the stress level. It was also observed that the Covid-19

pandemic did not influence the factors affecting job performance. As a result of these findings, this study provides an insight into how the stress and performance of employees will be affected in potential future remote working situations. This study is limited to 55 architects working in architectural offices in Turkey. It is expected that this study will be supported by future analyzes. As a result, the performance of the employees will be increased with various strategies to be developed and this improvement at the office level will also have a positive impact on the construction industry as well.

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A Bibliometric Analysis of Covid-19 Research in Built Environment Literature

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Abstract

The disaster of "Covid-19 pandemic" which has been introducing various radical changes on the life style of people such as (1) the usage of urban spaces, (2) spatial problems, (3) the transformation of shared spaces and (4) working practices. These radical changes have been receiving an overwhelming interest from scholars from various disciplines since SARS-CoV-2 corona (i.e., Covid 19) virus set a global pandemic. As a result of this overwhelming interest, a rich but a fragment literature prevails on the radical changes caused by Covid 19 pandemic in built environment studies. The research presented herein explores this rich but fragmented literature on the effects of Covid-19 pandemic by adopting a systematic research design strategy namely bibliometric analysis. Bibliometric analysis is a research approach which enables to scholars to map the evolution of a concept, a research theme, a research stream or domain. It uses scholarly data to identify the publication patterns based on authors, research subjects, keywords, geographic locations, and time and source type. A bibliometric analysis of the concept of Covid-19 pandemic presented herein is a timely response to the maturity level the research on the radical changes caused by Covid 19 evolved. The research presented herein offers bibliometric analysis of built environment studies on the disaster of Covid-19 based on 843 scholarly papers published between years 2020 and 2022. The research results reveal that the most commonly used research keywords or subject terms used in these scholarly published scholarly papers include epidemiology, risk assessment, aesthetic values, human activity, and construction projects. It is also observed that research studies predominantly driven by two countries namely US and China. The results of bibliometric analysis also reveal that the main theme of the radical changes caused by Covid-19 pandemic includes housing, spatial, reorganization, neighborhood issues, city planning, and sustainable development and working practices. It is also discovered that the spatial reorganization response of countries to Covid 19 pandemic to varies from country to country mainly due to the regional characteristics of the countries.

Keywords: *bibliometric analysis, Covid-19, pandemic, spatial reorganization, working conditions.*

Introduction

The rapid spread of the Covid-19 pandemic in 2020 has interrupted and transformed our daily life routines and in turn it has profound impact on the built environment. Covid-19 pandemic has unpredictably changed not only the built environment but also our practices and activities

to conceptualize, design and construct it. A wide range of our daily practices has been sharply interrupted, constrained or/and transformed beyond our imaginations. The interruptions, restrictions and transformations observed in our daily practices obviously captured the central agenda of the built environment researchers, like any other researchers. The term "built environment" is a broad concept and in turn a difficult concept to define. It refers "to human-made structures (e.g., urban and rural design characteristics, recreational structures) that may facilitate or impede an individual's ability to be physically active access to the existing built environment has been taken under control all over the world, and measures have been taken for social and economic life by transforming the built environment with short-term solutions" (Gray et al. 2012). It is clear that from this definition that the boundaries of research in "the built environment" is difficult to define. Yet the complex interplay of activities and entities expressed in this definition should be holistically understood and analyze. Failing to appreciate the subtle interplay of these activities and entities can significant slows down scientific progress in the built environment research with respect to the Covid-19 spread.

Wolf (2016) argues that infectious diseases are not the main reason why we are constrained and/or forces to transform our daily life in context the built environment but it is the subtle operation of social and spatial inequalities in access to housing, health, education, economic and other resources. A brief review of the current state of the built environment research reveals that spatial, social and economic inequalities, transformation of values with regarding the built environment, nature of human activity become more visible especially during major pandemics. With a similar foresight, Corburn (2004) points out that there is a clear link between built environment and public health issues and points out that this relationship becomes more evident under conditions of the major pandemics. However, the link between the built environment and major infectious diseases such Covid - 19 has rarely been studied before Covid-19 pandemic (e.g., Alirol et al., 2011; Matthew & McDonald, 2006). But following the Covid - 19 pandemic, analysing and identifying the relationship between the built environment and the Covid - 19 outbreak have become a worldwide research priority (e.g., Amerio et al., 2020; Frumkin, 2021; Megahed & Ghoneim, 2020; Pinheiro & Luís, 2020; Rojas-Rueda & Morales-Zamora, 2021).

Pinheiro and Luís (2020) argue that there has been an increase in the number of publications related to Covid-19 on Web of Science (WoS), and so many references can be found on Science Direct, but less than 1% of them relate to the built environment in 2020. The primary objective of the analyzed research studies in past appears to be on the examination of spatial-temporal variations of Covid-19 in different contexts (Liu et al., 2021). The research studies reports the association between the built environment and Covid-19 pandemic based on variables such as population density (Carozzi et al., 2020; Hamidi et al., 2020), housing (Amerio et al., 2020; Rogers & Power, 2020), social and economic issues (Andersen et al., 2021).

Previous research studies on Covid-19 based on spatial analysis are precious for public health measures. Additionally some researches indicate that social isolation and distancing are important for community responses which provides people to have safe access and secure housing (Rogers & Power, 2020). Furthermore, it reveals the necessity of comprehensive transformations that will ensure spatial justice for all users rather than temporary solutions in the design of the post-pandemic built-environment. For this reason, each situation should be considered, from subjective/local suggestions to spatial problems arising from the pandemic, to consequences that are likely to bring a more inclusive and holistic approach to the built environment from an objective/global perspective. However, this requires a detailed analysis

of every issue discussed in the relevant literature on the Covid -19 pandemic related to the built environment.

The worldwide spread of Covid-19 has resulted in numerous research studies which focus on the identifying the impact of Covid-19 pandemic on the built environment. It is clear that built environment does not have a universal practices, organizations, forms or structures. Therefore, the impact the Covid-19 pandemic and action plans to mitigate its negative outcomes have not been purely identical or generic on contrary they should be context dependent. Various analytical lenses should be used to explore the built environments because the built environments are produced and shaped at different social, political, biological, economic domains and scales. The challenges presented pandemics life Covid-19 can only be address by adopting multiple and different frameworks (Wolf, 2016). Furthermore, the built environment in different parts of the world is affected differently by climatic conditions, life expectancies, water infrastructures, legal regimes, transnational mobility, financial resources, population density, health beliefs and practices, development plans and governance structures (Wolf, 2016).

A critical analysis of the Covid-19 pandemic and built environment research can provide important insights on how the built environment research is positioning itself and developmental trajectory, in particular, sensitivity to local context and the presence of pluralist approach, how the diverse research perspective of the built environment responding to the multiple, complex and highly localized nature of Covid-19.

Analyzing Covid-19 research studies related to the built environment requires an analytical method that fits its purposes. In this study, bibliometric analysis method has been used to examine built environment factors related with the pandemic. Bibliometric analysis is a research approach which enables to scholars to map the evolution of a concept, a research theme, a research stream, or domain. It uses scholarly data to identify the publication patterns based on authors, research subjects, keywords, geographic locations, time, and source type (Ellegaard & Wallin, 2015).

Research Methodology

The objective research presented herein is to conduct a bibliometric analysis on the Covid 19 pandemic in the built environment. The search for the relevant articles was performed at the Scopus database. The search yielded 843 articles published between 2020 and 2022. The search results were analyzed by using bibliometric analysis software (VOSviewer). The research presented herein uses descriptive and quantitative approach to explore the response of built environment research to Covid 19 pandemic and trace the trajectory of emerging research field. It adopts bibliometric analysis method based on articles indexed at Scopus database. The bibliometric analysis method used in the research presented herein was designed in the light of guidelines recommended by Prado et al. (2016). The research design adopted herein includes five main stages: (1) research operation, (2) search procedures, (3) selection procedures, (4) data adequacy and (5) scientific production analysis (Figure 1). The scientific production analysis, Stage 5, is the core bibliometric analysis and yields results in two categories: (1) performance analysis and (2) scientific trajectory mapping. The performance analysis in bibliometric analysis explores the *contributions* of research constituents, whereas scientific trajectory mapping focuses on the *relationships* between research constituents (Donthu et al., 2021). The Boolean operators “AND” and “OR” were

used to identify the relevant articles (Figure 2). The search in the Scopus database was performed through topics including title, keywords and abstract. The topics used in this search process includes: Covid-19, construction industry, architectural and design. Four search filters were also applied: (1) the search will be limited to articles, only; (2) the search time will comprise all the years; (3) the search will be performed in only engineering, social, business, energy, arts, economy and health subject areas; and (4) the search will be conducted in English. The search on Scopus database was performed in July 2022.

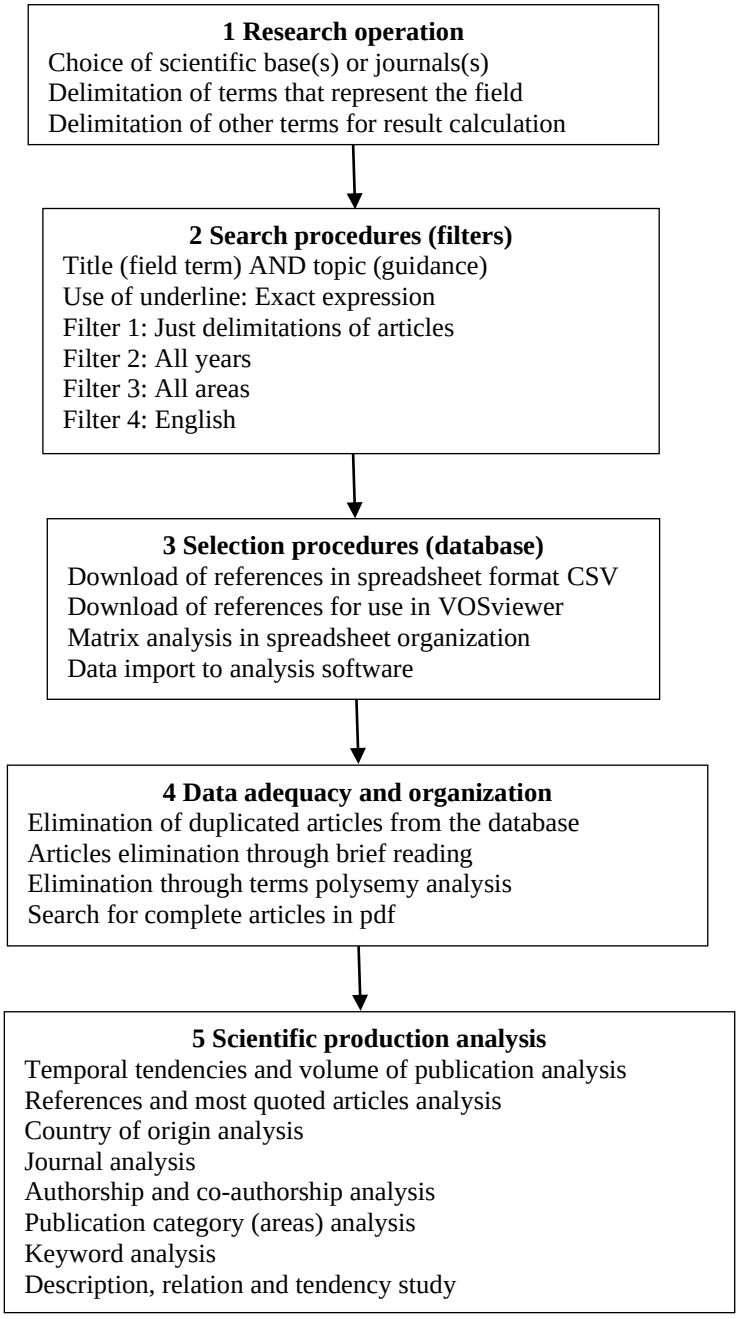


Figure 1: The research design (adapted from Donthu et al., 2021; Prado et al., 2016).

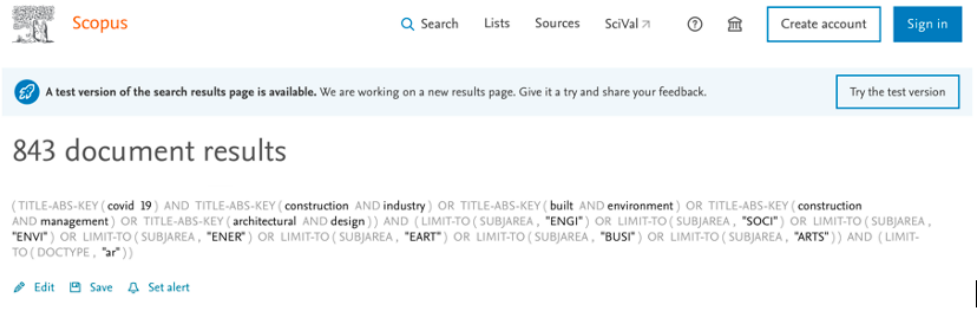


Figure 2: Search criteria for bibliometric analysis

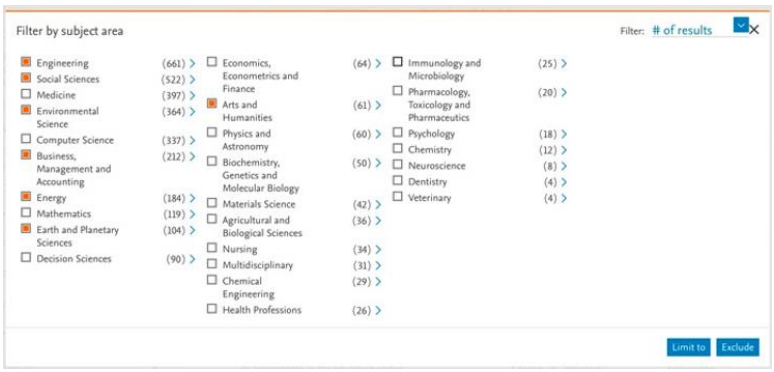


Figure 3: Subject areas filters used for bibliometric analysis.

Research Findings and Discussion

The main search yielded to 843 articles between 2019 and 2022. These articles were used as the basis for the bibliometric analysis presented herein. Table 1 presents the 10 highly cited articles among the 843 articles analyzed. The number of citations for articles is based on Scopus database.

Table 1. The most highly cited articles (top ten).

	Authors	Title	Year	Source Title	Cited by
1	Li et al.	Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region	2020	Science of the Total Environment	293
2	Zhou et al.	COVID-19: Challenges to GIS with Big Data	2020	Geography and Sustainability	282
3	Venter et al.	Urban nature in a time of crisis	2020	Environmental Research Letters	232
4	Megahed & Ghoneim	Antivirus-built environment: Lessons learned from Covid-19 pandemic	2020	Sustainable Cities and Society	231
5	Amerio et al.	Covid-19 lockdown: Housing built environment's effects on mental health	2020	Int. J. Env. Res & Pub. Health.	159
6	Qian et al.	Indoor transmission of SARS-CoV-2	2021	Indoor Air	147
7	Mandal & Pal	Covid-19 pandemic persuaded lockdown effects on environment over stone quarrying and crushing areas	2020	Science of the Total Environment	104
8	Giani et al.	Short-term and long-term health impacts of air pollution reductions from Covid-19 lockdowns in China and Europe: a modelling study	2020	The Lancet Planetary Health	98
9	Alsharef et al.	Early impacts of the Covid-19	2021	Int. J. Env. Res & Pub. Health.	90

		pandemic on the United States construction industry			
10	Mitra et al.	Healthy movement behaviours in children and youth during the Covid-19 pandemic	2020	Health and Place	76

Li et al. (2020) analyze the air quality changes during the Covid-19 pandemic in a selected region and use an empirical model investigate impact of decreased human activities on air quality changes. Zhou et al. (2020) proposes a decision support model based on geographical information system to address the challenges presented by Covid-19 pandemic. Venter et al. (2020) explores the influence of Covid 19 pandemic on mobility patterns, recreational activity, ecosystem service, aesthetic values, spatial analysis and issues regarding the environmental green justice. Megahed and Gohneim (2020) propose a road map for construct "the antivirus-built environment" based on lessons learned from Covid- 19 pandemic. Amerio et al. (2020) explore the psychological effects of Covid-19 pandemic. They report that housing plays a major role in influencing people mental health and wellbeing during Covid-19 pandemic and suggest that strengthened multi-interdisciplinary approach involving urban planning, public mental health, environmental health, epidemiology, and sociology, is needed to inform the planning implementation and monitoring of housing policies centered on population health.

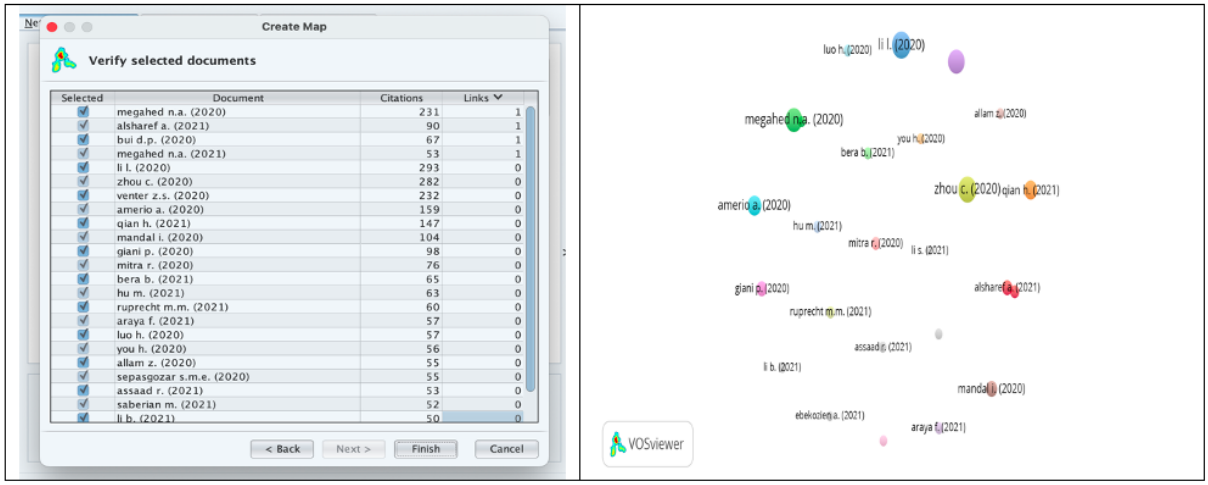


Figure 4: The ranking of articles based on number of citations and links.

A succinct review of top ten highly cited articles reveals that they adopt pluralist approach to address the multidimensional challenges presented by Covid 19 pandemic in the built environment (See Figure 4). The link between and among the highly cited articles appear to be very weak (i.e., the link strength =1). The observed very weak strength link can be attributed to the fragmented and nature of the built environment literature.

Two of out of ten highly cited articles (Li et al., 2020; Mandal & Pal, 2020) are published by "Science of the Total Environment" journal. Furthermore "Science of the Total Environment" journal has highest citations based on the search criteria used in this study (Total Number of Citations = 449). It is also becomes evident that "Sustainable Cities" journal (Total Number of Citations = 420) and "International Environment Research and Public Health" journal (Total Number of Citations =305) and are ranked 2nd and 3rd in the number of citations, respectively.



Figure 5: The ranking of journals based on the number of citations and total link strength.

Top three countries based the number of citations are China (6 articles and 885 citations), United States of America (8 articles and 646 citations) and Malaysia Australia (2 articles and 333 citations) (See Figure 6).

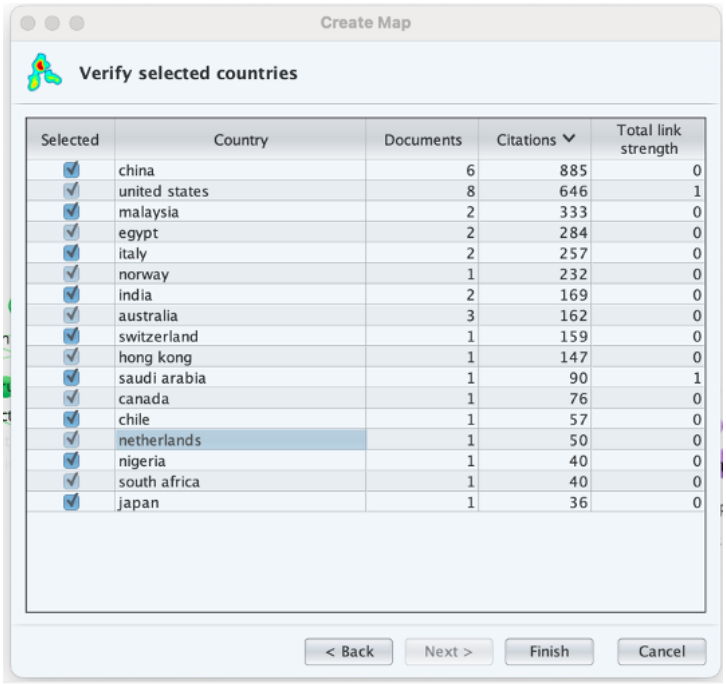


Figure 6: The ranking of countries based on the number citations.

The analysis of keyword co-occurrences yields Cluster ten clusters (See Figure 7). Cluster 1 is centered on nodes of pandemic and Covid-19. Cluster 2 is located at the periphery of the nodes of construction, construction projects and construction sectors. Cluster 3 is centered on the nodes urban planning, human activity, viral disease, aesthetic value cities. The remaining clusters are located on various nodes such as research methods, country, space design, social issues, and health issues.

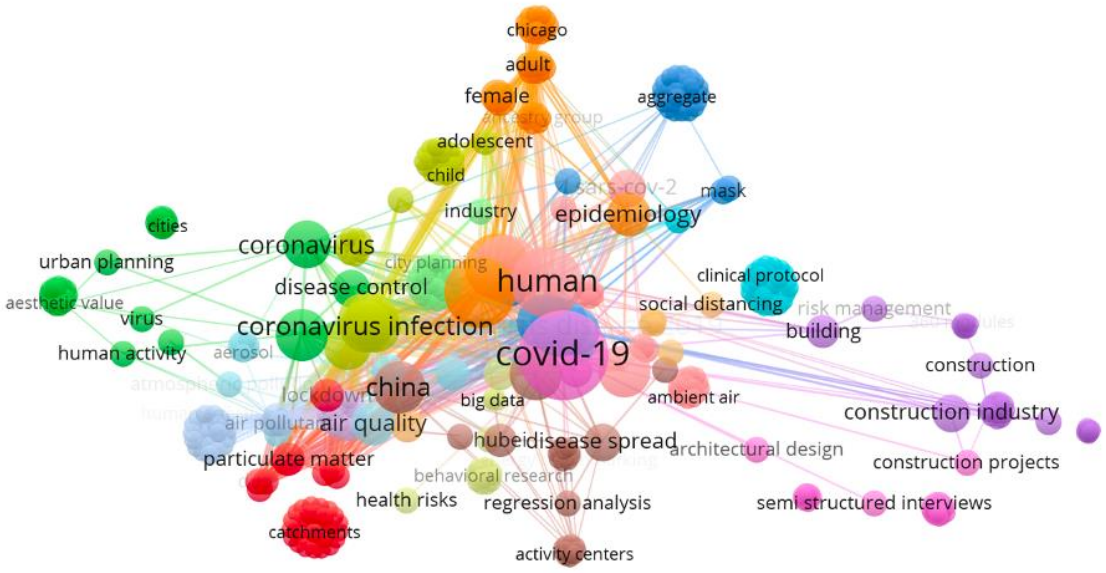


Figure 7: Keyword co-occurrence analysis map.

Conclusion

In this study, a bibliometric analysis of Covid-19 pandemic in the built environment literature is presented. The main research finding is that built environment has a rich but fragmented nature. As a direct result of its nature, the strength between and among research studies in the build environment appear to be very weak. The weak strength link while promotes diversity in turn fuels pluralist approach. Yet it prevents the cross fertilization of outputs of sub-research streams.

The theoretical frameworks and/or concepts that are expected to play a role in the shaping of the built environment literature after the Covid -19 pandemic, especially by analyzing the research findings obtained can have fruitful outcomes for future studies. The integration of competing or even conflicting theoretical frameworks and/or concepts and their reflections in the built environment literature can shed some light on the direction in which the built environment research studies will evolve in the years to come.

The research presented herein has a number of limitations. Firstly, the bibliometric data used in this study has a limited capacity to represent all of the scholarly research on Covid -19. Secondly, the actual reason for an article's citation cannot be easily inferred by performing bibliometric analysis. Thirdly, a highly cited article implies that it is influential in the literature. Yet an article citation count does not mean that the article provides a major scientific breakthrough or not. Fourthly, articles in non-English language were excluded in this research. Fifthly, articles published in scholarly journal were only included in this study. Sixthly, the time span of the (the window of analysis) bibliometric analysis presented herein is relatively short.

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Preliminary Impacts of Covid-19 on the Construction Industry: A Regional Study

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Abstract

The COVID-19 pandemic brought unprecedented challenges to the U.S. construction industry, which vary across different geographic regions due to variations in local government policies and regional economies. To effectively handle similar challenges, it is critical to understand the magnitude of regional impacts. This research aimed to assess the negative effects of COVID-19 on the construction industry across six U.S. regions as classified by the U.S. Census Bureau. The research methodology included a literature review, followed by data collection through survey questionnaire responses from construction professionals. The following negative impacts of COVID-19 were evaluated in this study: canceled projects, forced layoffs, delayed schedules, and reduced productivity. A mean ranking analysis on 211 survey responses indicated regional differences in perceived negative impact scores. The most significant impact due to canceled projects was reported in the Northeast. The Pacific West reported the highest impact score on construction layoffs and productivity reductions. And the Pacific West and Northeast reported the highest impact to delays in project schedules. Overall, the Pacific West and Northeast regions reported the highest negative impact scores, potentially due to state shutdowns and quarantine policies. The findings will help policymakers and construction firms develop strategies relevant to regional needs and circumstances caused by future outbreaks.

Keywords: *construction industry, construction layoff, COVID-19, COVID-19 impacts on construction, pandemic, productivity, canceled construction projects, construction delays.*

Introduction and Purpose

The coronavirus, commonly referred to as COVID-19 or 'the pandemic,' has severely impacted public health since its outbreak in early 2020 (Dryhurst et al., 2020). In addition to a large-scale health crisis, the pandemic resulted in global social and economic issues ranging from public education disruptions to supply chain delays. Given the worldwide implications of the pandemic and the socio-economic sectors affected, it is important to study its short-term impacts and projected long-term consequences in different contexts.

As a driving force in the global economy, the construction industry has faced multiple challenges due to the pandemic. National lockdowns have resulted in temporary stops to construction projects and supply chain issues. As a result, project schedules experienced significant delays. Furthermore, quarantine measures and social distancing requirements negatively impacted construction productivity and increased demands on the construction workforce. Since telecommuting is not an option for construction field work, the quarantine measures resulted in difficulties in ensuring safety and productivity while meeting the deadlines of the construction projects (Daniels et al., 2020).

The impacts of the pandemic have been evaluated in numerous academic studies focusing on different industries from varying social, economic, and environmental perspectives (Weir et al., 2021; Chowdhury et al., 2020; Maneenop et al., 2020; Uğur et al., 2020). Research investigating the pandemic and the construction industry has addressed implications from several perspectives, including workers' health and safety, supply chain issues and material price instabilities, project delays, and contractual and legal issues (Jeon et al., 2022; Alsharef et al., 2021; Assaad & El-adaway, 2021). While the macro-level effects of the pandemic are important to understand, there is also a need to focus on identifying regional impacts as various countries and geographic regions exhibit social, economic, governmental, and cultural differences in their own unique ways.

This study aims to investigate the preliminary impacts of COVID-19 in the U.S. construction industry across six U.S. regions classified according to the U.S. census bureau (Pacific West, Mountain West, Mid-West, Southwest, Southeast, and Northeast), as shown in Figure 1. A literature review provided four main categories of impact on the construction industry: canceled projects, forced layoffs, delayed schedules, and reduced productivity. In light of the literature review, an online survey was conducted with the members of a nationally recognized construction association to understand pandemic-specific impacts on construction firms. The preliminary results of this study indicate that every region was negatively impacted by the pandemic, which opens the door to future studies that could investigate the relations of these impacts to each region's geographical, political, and cultural characteristics. The findings of this study will help policymakers and construction firms develop strategies relevant to regional needs and circumstances caused by future outbreaks.

Background

COVID-19 has affected every aspect of the worldwide economy – including the construction industry – and despite its short history, numerous academic studies on the pandemic have been conducted. This background section will focus on research relating to COVID-19 and construction organizations which primarily focus on risk management and mitigation strategies.

Almost 10% of the U.S. workforce works in a construction-related occupation, and workforce health and safety is a principal objective for most construction organizations. Pamidimukkala et al. (2021) identified virus exposure as the most significant concern for construction field workers and, as expected, that social distancing measures lessened the risk of virus exposure. Additionally, remote workers at construction organizations identified isolation and the work environment as their most pressing concerns. The same study revealed strategies to cope with these challenges. These included redefining job site safety with physical distancing measures, regular temperature checks, flexible work schedules, implementing technology for meetings, and frequent interaction with other workers (Pamidimukkala et al., 2021).

Another study (Raoufi & Fayek, 2021) identified 177 actions to control and mitigate the effects of COVID-19 in construction organizations. These actions were then categorized into the following categories: health and public health directives, safety, workforce, workflow and productivity, communication, suppliers and subcontractors, economics and cost/budget issues, logistics and support, technology, regulations, disputes/claims, and contractual issues, insurance and bonds, suspension of work/project, restart/relaunch of work/project, new normal, and concerns about the welfare of employees. Routine health monitoring, workforce support, flexible communication and coordination among stakeholders, risk assessment of the supply chain, and resource issues were examples of the recommendations to mitigate the possible risks of the pandemic (Raoufi & Fayek, 2021).

Guidelines for responding to the pandemic with best practices were presented in Assaad and El-adaway (2021)'s study within four categories 1) workforce-related issues, 2) project and workplace considerations, 3) procurement and supply chain implications, and 4) contractual, legal, and insurance issues. Jeon et al. (2021) identified the relationships between the pandemic and the Purdue Index for Construction (Pi-C), which measures the health status of the construction industry in five dimensions: economy, stability, social, development, and quality. The impacts of the pandemic were most significant on the stability dimension of the Pi-C (Jeon et al., 2021). Alsharef et al. (2021)'s study revealed risk and safety management measures such as forming a task force to review the pandemic's impacts, additional organizational training, managing delays, and benefiting government relief programs.

Considering the ongoing impacts of the pandemic, it is clear that researchers will continue to focus on different aspects and measures of the pandemic on the construction industry. As one of the world's largest and most populous countries, the U.S. has several social, economic, and cultural variations across geographic regions. Therefore, the primary focus of this study is to identify regionally specific impacts of COVID-19 on the construction industry.

Methodology

Data for this study were collected through a Qualtrics survey distributed by a nonprofit national organization focused on serving and educating construction financial professionals. Prior to general distribution, a pilot survey was developed and distributed to 12 participants, and pilot survey feedback was incorporated into the final survey. Final surveys were distributed to general and associate members through the national organization list serve email. After the initial survey request, weekly reminders were sent to potential survey respondents, and regular reminders were posted on the national organization's web-based discussion forum that engages members on various construction related topics. Additionally, it was requested that survey recipients share the survey link with colleagues. The survey was available for 60 days between Sep 25, 2020, and Nov 25, 2020.

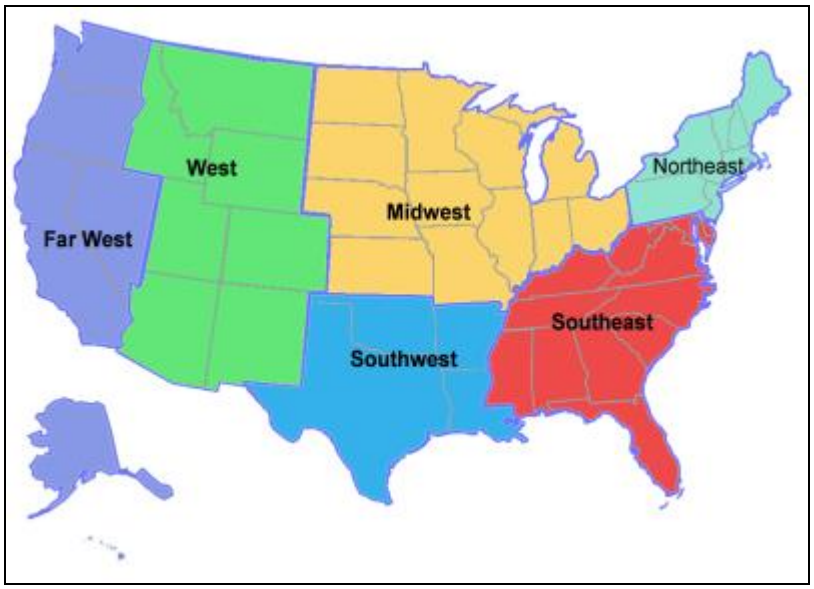


Figure 1: U.S. Regional classification of survey participants.

The survey measured the negative impacts of COVID-19 in four risk categories: 1) canceled projects, 2) forced layoffs, 3) delayed schedules, and 4) reduced productivity. Participants were given a sliding 100-point scale for rating the negative impact of COVID-19 (0-20 minimally impactful, 20-40 somewhat impactful, 40-60 moderately impactful, 60-80 significantly impactful, 80-100 substantially impactful). A 100-point scale was utilized to provide a high level of sensitivity in analysis.

Study participants were delimited to professionals that reported working for the following types of construction firms: 1) *General/Prime Contractors* (more than 20% of construction work self-performed) (n = 96) and 2) S*ubcontractors* (50% or more of construction work performed for another contractor) (n = 115). Participants reported annual revenues ranging from less than $36MM to more than $500MM. Participants reported the geographic region where their organization was headquartered as classified by the U.S. Census Bureau.

After the survey was closed, responses were grouped by firm type and geographic region, and mean scores were calculated. A total of 211 responses were evaluated for this study.

Results

Canceled or Delayed Projects

Figure 2 reports the average regional impact score for *Canceled or Delayed Projects* for general contractors (n = 87) and subcontractors (n = 115). On average, general contractors (M = 46) reported slightly higher impact scores than subcontractors (M = 43). Regionally, the general contractors in the Southwest reported the lowest impact scores (M = 29), while the Northeast (M = 54) and Southeast (M = 51) reported the highest impact scores. Regional impact scores for subcontractors varied less than for general contractors. Subcontractors in the West reported the lowest impact scores (M = 35), and participants in the Far West reported the highest (M = 47). Except for the Southwest, subcontractors in all regions reported lower impact scores than general contractors.

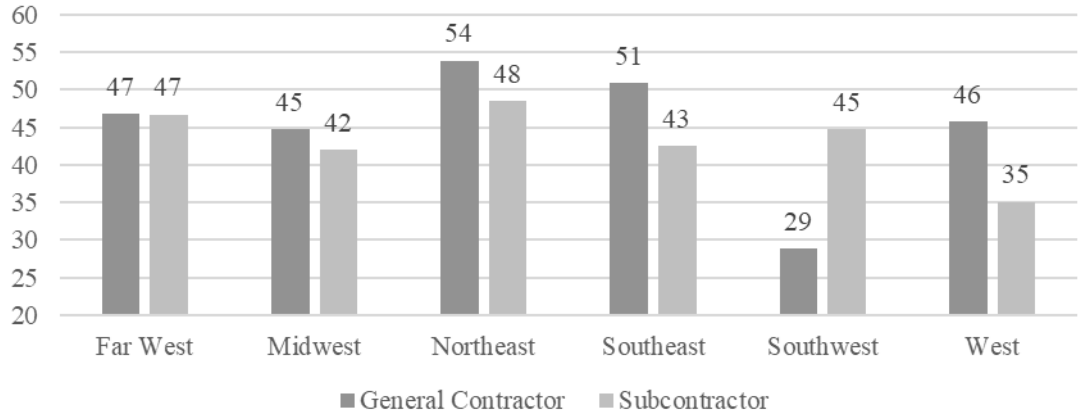


Figure : Impact of COVID-19 relating to cancelled or delayed projects.

Forced Layoffs

The average regional impact scores for *Forced Layoffs* for general contractors (n = 63) and subcontractors (n = 84) are reported in Figure 3. On average, general contractors (M = 24) reported lower mean impact scores than subcontractors (M = 27). General contractors in the Southwest reported an average impact score of only 5, while all other regions reported impact scores between 21 and 30. For subcontractors, regional impact scores ranged between 21 and 28 for five of the six regions. Subcontractors in the Far West reported the highest impact score at 38.

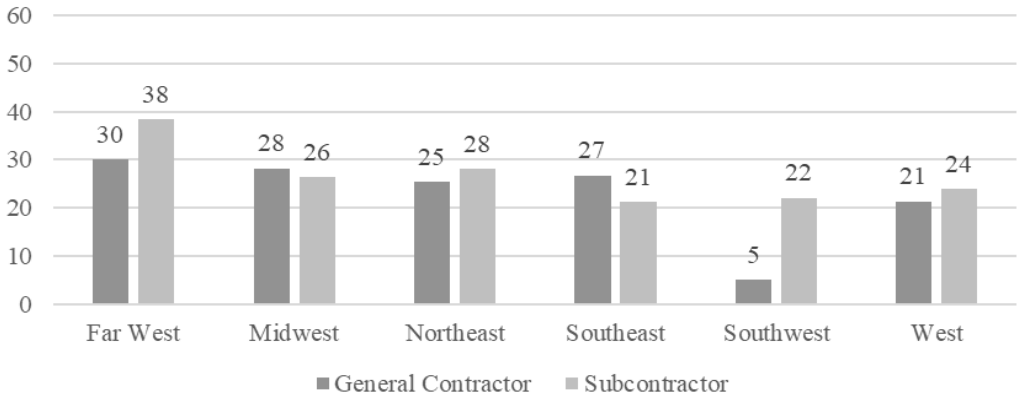


Figure 3: Impact of COVID-19 relating to forced layoffs.

Project Schedules

Figure 4 reports average impact scores for *Project Schedules* for general contractors (n = 83) and subcontractors (n = 113) by region. On average, general contractors (M = 43) reported ostensibly higher impact scores than subcontractors (M = 41). General contractors in the Northeast (M = 50) and Far West (M = 49) reported the highest impact scores, while their Southwest counterparts reported the lowest (M = 29). Similarly, subcontractors in the Northeast and Far West reported the highest mean impact scores at 50 and 46, respectively, with subcontractors in the West reporting the lowest at M = 32. Subcontractors and general contractors for all regions reported impact scores within 11 points.

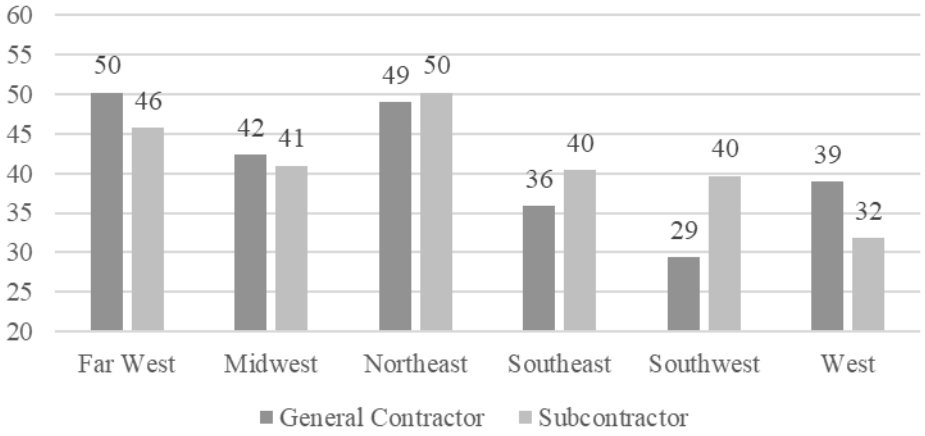


Figure 4: Impact of COVID-19 relating to project schedules.

Reduced Productivity

Regional impact scores relating to *Reduced Productivity* for general contractors (n = 89) and subcontractors (n = 110) are found in Figure 5. Overall, general contractors (M = 37) reported slightly lower impact scores than subcontractors (M = 40). General contractors in the Far West reported the highest impact scores (M = 50). Subcontractors in the Southeast (M = 48)

and Northeast (M = 47) reported the highest impact scores, while counterparts in the West (M = 36) reported the lowest.

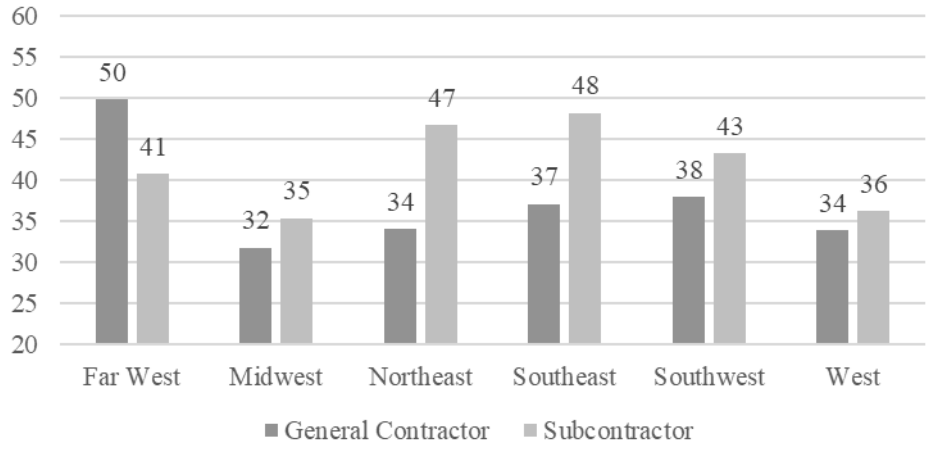


Figure 5: Impact of COVID-19 relating to reduced productivity.

Discussions and Future Research

While negative impact scores were reported in all four risk categories, disparities in impact scores across categories and geographic regions merit further discussion. For example, the impact scores of forced layoffs were notably smaller than those of the other risk categories in all six geographic regions. While beyond the scope of this study, future studies exploring the reasons for these impact scores are merited. Future research could focus on the correlation between an already tight construction labor market and low layoff impact scores. Additionally, potential studies could evaluate the effects of construction firms' financial health on forced layoffs and if construction firms perceived less risk (i.e., felt a greater sense of control) relating to internal layoffs compared to governmental quarantine mandates and owner-prescribed delays and cancelations (Franzese, 2020).

Regional differences in impact scores are also worth mentioning. Notably, general contractors and subcontractors in the Far West and Northeast regions reported higher than average impact scores in almost all categories. Conversely, general contractors and subcontractors in the West and Southwest reported lower than average impact scores in nearly all categories. These results suggest that regionally specific factors affected risk perceptions and therefore merit further exploration. Future studies exploring regional differences in governmental regulation along with regional social, economic, and cultural variations may shed light on the causes of disparate regional impact scores (Franzese, 2020).

Limitations and Conclusion

Evaluation of study results should take into account limitations and constraints. For example, study participants were solicited through –a national association that primarily serves construction finance professionals. While these professionals are likely involved in strategic decision-making and planning for construction firms, their perceptions of risk – particularly related to productivity and project delays – may differ from project-level professionals such as

project managers and superintendents. It should also be noted that this study only evaluated a small timeframe in a rapidly changing business and regulatory climate.

This study explored the negative impacts of the COVID-19 pandemic on construction firms as reported by construction finance professionals across six geographical regions of the U.S. General contracting and subcontracting professionals reported pandemic-specific impacts to 1) project cancelations and delays, 2) forced layoffs, 3) project schedules, and 4) reduced productivity. Across all four risk categories evaluated, general contractors and subcontractors reported pandemic-specific negative impacts with regional differences in the magnitude of these impacts. The results of this study are beneficial in understanding risks associated with future pandemics or other global economic disruptions and how the extent of these perceived risks differ across regions in the U.S.

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Integrated Risk Assessment Process (IRAP) for Mega Construction Projects: A Demonstrative Case Study

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Abstract

Risk, complexity, and uncertainty are inherent components of mega construction projects due to their characteristic features. A failure to synthesize these concepts within a structured approach leads to unrealistic risk assessments, ineffective management strategies, and poor project performance. The Integrated Risk Assessment Process (IRAP) could assist practitioners in identifying and quantifying the risks in their projects more realistically. This research, therefore, aims to demonstrate the practical benefits of IRAP. For this purpose, a case study was conducted with the retrospective analysis of a mega pipeline project in Turkey. IRAP was employed at the beginning, middle, and end of the project by analyzing the complexity and uncertainty factors, as well as strategies implemented to manage them. In order to clarify the role of management strategies, risks at the planning stage of the project were also assessed without considering the strategies. With the rating exercise, variations in the complexity, uncertainty, and risk levels at different project stages were observed. The findings from the demonstrative case study revealed the potential contributions of IRAP to risk management and monitoring in mega construction projects.

Keywords: *complexity, management strategies, mega construction projects, risk, uncertainty.*

Introduction

Risk assessment constitutes a critical phase of project risk management. It enables project managers to set project performance targets more realistically and allocate resources more effectively. For instance, risk assessment can be utilized during the bidding stage of a project to determine an appropriate contingency budget (Dikmen et al., 2022). It can also help monitor the risk levels during the execution of the project and learn from actual risks as a part of the post-project evaluation. However, in order to take full advantage of risk assessment, it is necessary to comprehend all factors that may affect project risks. Traditional risk assessment

methods, such as probability and impact rating, mainly focus on treating uncertainties in the project. Although widely used in practice, they usually fail to account for the interdependencies between different risk sources. Since they are not capable of reflecting the true nature of risks, especially under high complexity, new approaches are needed to assess complexity-induced risks (Taroun, 2014). This is particularly important for mega construction projects as they are characterized by risk, complexity, and uncertainty (Boateng et al., 2015; Erol et al., 2018; Hu et al., 2015). A failure to synthesize these concepts within a structured approach leads to unrealistic risk assessments, ineffective management strategies, and poor project performance. Hence, the success of a megaproject largely depends on how well risk-related concepts are addressed (Dimitriou et al., 2013; Giezen, 2013; Kardes et al., 2013).

With the increasing criticism of fragmented risk management approaches recently, new research efforts have emerged to incorporate complexity into risk management (Erol, 2020; Jensen & Aven, 2018; Thomé et al., 2016). Some risk models have also been developed specifically for this purpose (Qazi et al., 2016; Dikmen et al., 2021). However, the project management literature lacks studies reporting the practical benefits of implementing complexity-based thinking in risk management through real cases. From this point of view, this paper aims to demonstrate how an integrated risk assessment approach developed by the authors (Erol et al., 2020; Erol et al., 2022) can assist practitioners in identifying and quantifying the risks in their projects more realistically. For this purpose, a case study was conducted with the retrospective analysis of a mega pipeline project in Turkey.

The remainder of the paper is organized as follows. The next section gives some background information on the integrated risk assessment approach utilized in this study. Then, details are provided about the implementation of the risk assessment process in the demonstrative case study. Finally, the benefits of the proposed approach and possible future studies are discussed.

Integrated Risk Assessment Process (IRAP)

The Integrated Risk Assessment Process (IRAP) was developed as a result of an exploratory study involving interviews with 18 managers from 11 mega construction projects. Based on these interviews, the interrelations between risk-related concepts were identified, and a conceptual model linking the themes of risk, complexity, uncertainty, and management strategies was proposed. More information about this model, which forms the basis of IRAP, can be found in Erol et al. (2020).

IRAP is composed of four main steps. It starts with identifying the risk sources (complexity and uncertainty) of the project. Some complexity factors can be specified at the beginning of the project by analyzing features, such as size, number of stakeholders, and technical difficulty. These factors constitute the "static complexity" of the project. Similarly, some uncertainty factors can be identified at the front end of the project with the existing knowledge and experience of the project management team. The second step of IRAP is formulating management strategies for the identified risk sources. The purpose of these strategies is both to facilitate the management of complexity and uncertainty factors and reduce their magnitude in the project. However, strategies formulated to deal with the existing factors may trigger the emergence of new risk sources that leads to secondary risks. For this reason, there is an iterative process between the first two steps of IRAP. This iterative process is expected to result in a network in the third step, linking the risks to complexity and uncertainty factors, together with the strategies formulated to manage them. The last step of IRAP is analyzing the resulting risk

network. The network analysis is a crucial step of IRAP since it enables project managers to rate the risk sources by considering the interdependencies between various factors. Since the measures taken based on the network analysis may introduce new risk sources, there is a feedback loop to repeat the previous steps before the finalization of IRAP. In addition to "static complexity," "dynamic complexity" may arise as the project progresses due to the changes in the existing factors or the involvement of new ones. Similarly, initially identified uncertainties may decrease, or new factors may emerge. Furthermore, the dynamic nature of the projects may require updating the existing management strategies or formulating new plans. Therefore, IRAP should be repeated periodically throughout the project.

Although IRAP can be operationalized with different analytical techniques based on network analysis, the risk assessment of the case project was performed with the ANP model developed by Erol et al. (2022). According to this model, the overall risk of a mega construction project is calculated with eight risk factors. These risk factors are connected to three main clusters: complexity, uncertainty, and management strategies. The complexity cluster is composed of 17 factors under the technical, organizational, and environmental complexity categories. The uncertainty cluster contains two main categories, comprising uncertainty about the future and vagueness about the project. Management strategies cluster, on the other hand, include flexibility and control strategies, which are also linked to other clusters. Consequently, the overall risk of a mega construction project can be calculated using the parameters at the lowest level of the hierarchy. These parameters, consisting of 17 complexity factors and two uncertainty categories, are the risk sources of the project. The weights of the risk sources in the model were determined by the domain experts through a two-round Delphi study. For more detailed information about the ANP model, interested readers may consult Erol et al. (2022).

Implementation of IRAP to a Mega Pipeline Project

In order to exemplify the implementation of IRAP, a demonstrative case study was conducted with the retrospective analysis of a mega pipeline project (the name is withheld due to confidentiality concerns). As a transnational natural gas pipeline project, it has significant strategic importance for the countries involved due to its potential to improve their competitiveness in global energy markets. In Turkey, the project was divided into several lots. The construction works of each lot were awarded to different contractors as sub-projects. In this paper, IRAP has been applied to one of these projects. The investigated project has a total length of more than 400 kilometers. It was a design-bid-build project with a lump-sum contract. While the contract price was more than $400 million, the total project duration was approximately three years. The project's contractor was a joint venture of one international and two Turkish construction companies. The project was completed without any significant cost overrun or delay. Since the project has all the characteristic features of a mega construction project, it was an appropriate case example for demonstrating the assessment of risk-related factors through IRAP. The information used in the case analysis was provided by the planning and contracts manager of the project, who has 15 years of experience in large-scale construction projects. Due to the broad authority and responsibility he owned in the project, all managerial and technical issues could be elucidated.

During the case analysis, IRAP was applied to three project stages. In this respect, complexity and uncertainty factors, as well as strategies implemented to manage them, were analyzed at the beginning, middle, and end of the project. These stages correspond to the progress rates of approximately 10%, 50%, and 90%. Then, the ANP model was employed to calculate the risk

scores of the project at these three stages using the identified complexity and uncertainty factors. Furthermore, to clarify the role of management strategies in the assessment process, risks at the planning stage of the project were calculated without considering the strategies implemented for complexity and uncertainty factors. With the rating exercise, variations in the complexity, uncertainty, and risk levels were observed for different project stages. Consequently, the potential contributions of IRAP to risk management and monitoring in mega construction projects were evaluated with a real application. The following subsections elaborate on the implementation of IRAP in the case project.

Identification of the Risk Sources and Management Strategies

The risk assessment procedure started with the identification of the risk sources in the project. Since the weights of the ANP model were available for 17 complexity factors and two uncertainty categories (Erol et al., 2022), the risk sources in the case project were identified through these parameters. However, under each uncertainty category, three uncertainty factors were defined to analyze the risk sources of the project in more detail. Corresponding category weights of the ANP model were distributed to these factors equally. Thus, 17 complexity factors under the technical, organizational, and environmental categories, as well as six uncertainty factors that belong to the categories of the uncertainty about the future and vagueness about the project, were analyzed for the risk assessment of the project. Table 1 lists these risk sources.

Table 1. Risk sources assessed in the case project.

ID	Risk Source	Category
C1	Size of the Project	Organizational Complexity
C2	Strategic Importance of the Project	Environmental Complexity
C3	Political or Macroeconomic Instability	Environmental Complexity
C4	Variety of Financial Institutions or Sponsors	Organizational Complexity
C5	Interactions between the Stakeholders	Environmental Complexity
C6	Inadequacy of the Contract	Organizational Complexity
C7	Lack of Technical Experience	Technical Complexity
C8	Changes in the Project Scope	Technical Complexity
C9	Unrealistic Project Targets	Technical Complexity
C10	Unavailability of Resources	Organizational Complexity
C11	Interactions between the Project Disciplines	Organizational Complexity
C12	Cultural Diversity	Organizational Complexity
C13	Multiple Critical Paths (Parallel Activities)	Technical Complexity
C14	Staff and Equipment Mobility	Organizational Complexity
C15	Physical and Logistic Constraints	Environmental Complexity
C16	Technological Novelty of the Project	Technical Complexity
C17	Originality of the Project Design	Technical Complexity
U1.1	Weather Conditions	Uncertainty about the future
U1.2	Rental Cost of the Equipment	Uncertainty about the future
U1.3	Force Majeure Events	Uncertainty about the future
U2.1	Quality Performance of the Project	Vagueness about the project
U2.2	Health and Safety Performance of the Project	Vagueness about the project
U2.3	Public Opposition	Vagueness about the project

Each factor in Table 1 was evaluated with the project manager to draw a comprehensive picture of the risk sources in the project. Table 2 exemplifies how "Physical and Logistic Constraints" led to risk events at different project stages.

Table 2. Evaluation of a risk source.

Risk Source	General Evaluation
C15: Physical and Logistic Constraints	The project involved geographically dispersed construction areas where different physical constraints exist. Since each region has unique conditions, the project teams had to deal with various physical obstacles. In particular, problems were encountered due to the weather conditions of the high-altitude points. On the other hand, there were also logistic constraints as the construction was performed in a wide area. For example, although the pipes were supplied by the owner, transporting them to different construction locations was the responsibility of the contractor. The pipes procured from Chinese and Turkish suppliers required specific logistic arrangements. In the middle of the project, the pipes shipping from China landed at a different port, a far distance from the original port stated in the contract. For this reason, additional logistics difficulties arose in the project. Furthermore, the distance between the main camps and construction locations was increasing with the progress of the project. In later stages, it started to take a longer time to arrive at the construction area, which caused a reduction in effective working time. Thus, the contractor had to take different measures to cope with logistic problems throughout the project.

IRAP also requires determining strategies to manage identified risk sources. For instance, Table 3 tabulates the strategies implemented for the "Physical and Logistic Constraints" at three different project stages. Since a strategy implemented to manage a specific risk source may have a positive or negative impact on other sources, affected factors were also listed in the table. While some of these management strategies directly change the level of complexity or uncertainty in the project, others influence the manageability of the risk sources.

Table 3. Management strategies implemented for a risk source.

Project Stage	Implemented Strategy	Other Factors Affected by the Strategy
Beginning (≈ 10%)	In order to avoid physical constraints, seasonal conditions were considered when planning the works. Accordingly, the construction activities at high-altitude points were scheduled to be performed between April and September. On the other hand, in order to minimize logistical problems, the fly camps were utilized in addition to the main and intermediate camps. Furthermore, since each pipe at the stockyard had to be positioned in a specific location, their GPS coordinates were monitored through pipe tracking software.	Consideration of the seasonal conditions in the construction plan facilitated the management of U1.1 (weather conditions). On the other hand, precautions related to the logistic constraints facilitated the management of C14 (staff and equipment mobility).
Middle (≈ 50%)	The contractor had the right to request a change order in case the pipes landed at a different port. Accordingly, additional transportation expenses were covered with the change order issued by the owner.	Discussions for the issuance of the change order in the project have increased the complexity in C5 (interactions between the stakeholders).
End (≈ 90%)	In one of the construction locations, when the distance became too far from the main camp, the related teams were moved to a hotel in a nearby town. In order to get the approval of the owner, the contractor took additional safety precautions in the hotel. As a result, the time spent to arrive at the construction area was reduced considerably with this arrangement.	Moving the teams to a hotel made the management of U2.2 (health and safety performance of the project) more difficult. Moreover, the inspections made by the owner to ensure the hotel is suitable in terms of physical space and fire systems further increased the complexity in C5 (interactions between the stakeholders).

Rating the Risk Sources

Following the identification of the risk sources and strategies developed to manage them, a rating exercise was conducted for different project stages. There were three main issues required to be considered by the project manager while scoring a factor. First of all, its magnitude in the project during the stage of assessment should be determined. Second, the direct impact of the strategy implemented for this factor should be reflected in the rating. Third, the indirect impact of the other strategies affecting this factor should also be taken into account. For instance, while rating C5, strategies developed for C15 were also considered since they influenced this factor (see Table 3). Thus, instead of an isolated analysis, IRAP ensured the assessment of complexity and uncertainty factors within a network setting. Based on this procedure, all risk sources were rated on a five-point scale by considering their level at the beginning, middle, and end of the project. Besides these three stages, another rating was provided for the planning stage of the

project without considering any strategy. Table 4 presents the complexity and uncertainty scores assigned for these stages.

Table 4. Scores of the risk sources for different project stages

Risk Source	Planning (No Strategy)	Beginning (≈ 10%)	Middle (≈ 50%)	End (≈ 90%)
C1	5	5	5	5
C2	2	2	1	1
C3	4	3	1	1
C4	2	1	1	1
C5	5	3	4	4
C6	4	4	4	3
C7	2	1	1	1
C8	2	2	2	3
C9	4	3	1	1
C10	3	2	2	3
C11	2	2	2	3
C12	3	2	2	2
C13	2	2	4	4
C14	4	4	5	5
C15	5	4	5	4
C16	2	1	1	1
C17	2	2	1	1
U1.1	4	3	2	1
U1.2	3	3	3	1
U1.3	2	2	1	1
U2.1	5	4	3	2
U2.2	5	4	2	1
U2.3	2	2	2	1

Calculation of the Risk Assessment Scores

In order to calculate the risk assessment scores, the ratings given in Table 4 were multiplied by the corresponding weights of the ANP model (Erol et al., 2022). According to the ANP model, the score of each risk factor is estimated via three complexity and two uncertainty categories. Therefore, the first step was determining the category scores through corresponding complexity and uncertainty factors. To illustrate this operation, Figure 1 demonstrates the calculation of the "Environmental Complexity" at the beginning of the project using the scores of the related complexity factors and their weights. In Figure 1, scores that belong to C2, C3, C5, and C15 were multiplied by the weights written on the arrows. Then, the results obtained were summed up to determine the total category score (2.89). The same operation was repeated for other complexity and uncertainty categories to calculate their scores as well.

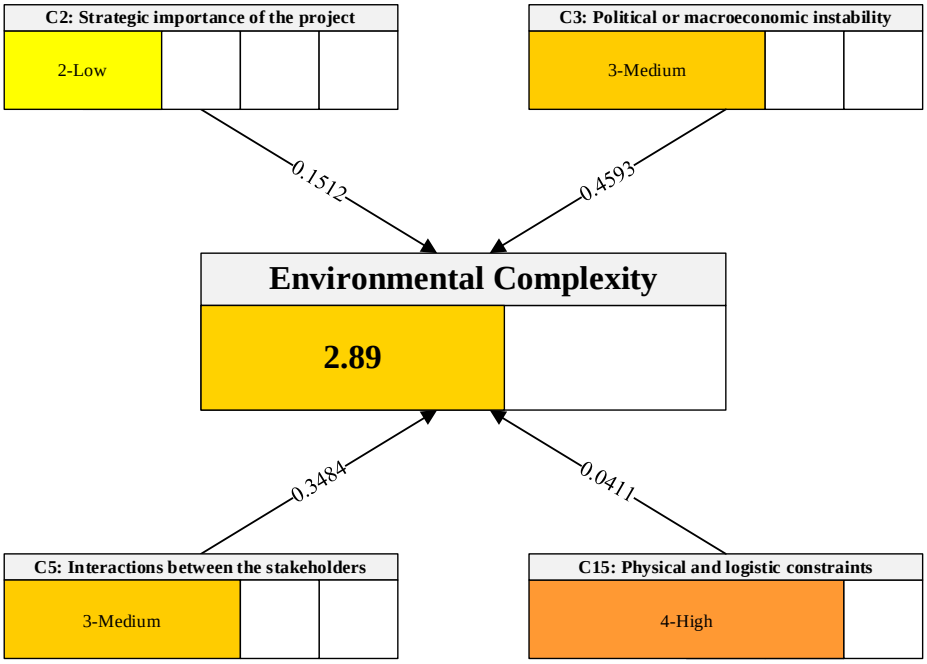


Figure 1: Calculation of a category score.

The next step was determining the scores of each risk factor via the five categories. In this respect, Figure 2 exemplifies the calculation of the "Contractual Risks" at the beginning of the project. In Figure 2, scores determined for three complexity and two uncertainty categories were multiplied by their total weights written on the arrows to calculate the total risk score (3.01). The same category scores were also multiplied by the weights of other risk factors so that all risk scores could be determined.

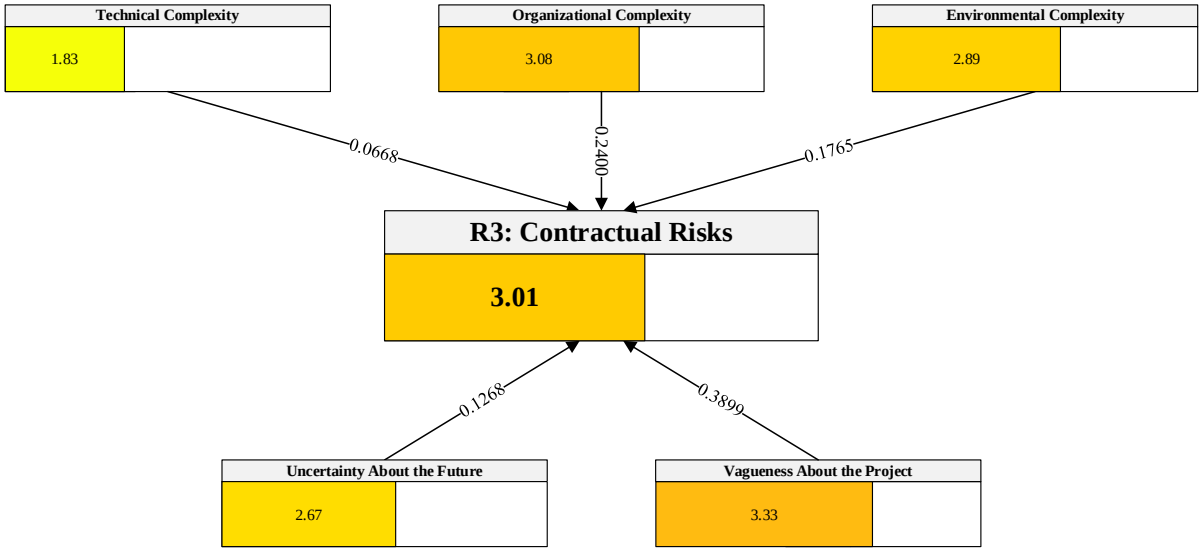


Figure 2: Calculation of a risk score.

The final step of the calculations was determining the overall risk of the project. For this purpose, the score of each risk factor was multiplied by the corresponding weights, and the results were summed up. Figure 3 illustrates the calculation of the overall risk score (2.86) at the beginning of the project.

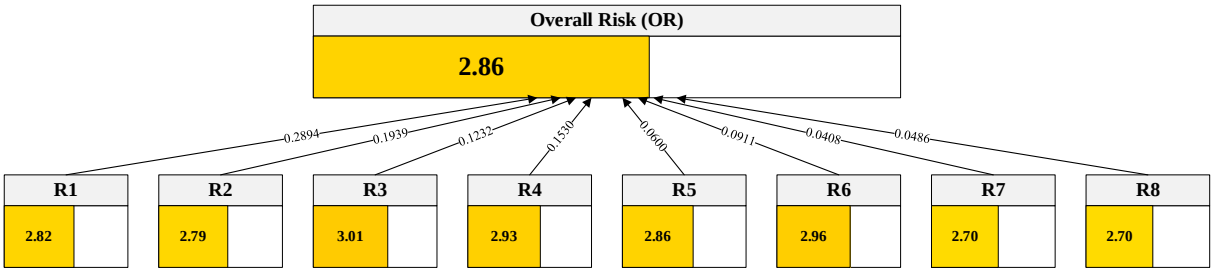


Figure 3: Calculation of the overall risk score.

Based on the calculation procedure explained above, the risk assessment scores of all factors were determined for four project stages. Table 5 presents the risk assessment scores calculated using the ratings given in Table 4. According to the results, R3 was the most significant risk factor during the planning stage of the project. Similarly, due to the unfavorable contract clauses, R3 was anticipated as the most crucial risk factor by the project manager at the beginning of the project. Hence, the result calculated by the model aligned with the perception of the manager. R6 was determined as the second-highest risk factor, followed closely by R4 and R1. These findings were also considered reliable. According to the project manager, the governance and coordination of the geographically dispersed project teams was the most challenging part of the project. Similarly, the owner was evaluated as an important risk factor because of not only the strict contractual obligations but also the extremely high standards set in the project. Furthermore, the volatile environment caused by the coup attempt at the beginning of the project has increased R1. Even though R3 has been among the top three risk factors throughout the project, its impact was mitigated after the contractual amendment made during the project. Therefore, R6 became the most significant risk factor after the middle of the project since the coordination issues continued to be a challenge over the course of the project. On the other hand, R7 and R8 were the least significant risk factors for most of the stages. According to the project manager, the project was not very challenging in terms of construction operations since the same activity types were repeated at different locations. Similarly, except for the changes in the alignment sheets at the beginning of the project, design-related issues were not considered a critical risk factor. Hence, the calculations of the model reflected the thoughts of the project manager. Apart from these two factors, R1 became the least significant risk factor at the last stage as the impact of the country-related problems has reduced towards the completion of the project.

Table 5. Risk assessment scores for different project stages.

Risk Factor	Planning (No Strategy)	Beginning (≈ 10%)	Middle (≈ 50%)	End (≈ 90%)
R1: Country-related Political and Economic	3.47	2.82	2.22	1.72
R2: Financial	3.35	2.79	2.26	1.80
R3: Contractual	3.63	3.01	2.42	1.96
R4: Owner-related	3.48	2.93	2.40	1.97
R5: Procurement	3.43	2.86	2.30	1.86
R6: Project Management and Organization	3.49	2.96	2.45	2.02
R7: Construction-related / Technological	3.26	2.70	2.15	1.77
R8: Design	3.27	2.70	2.14	1.76
OR: Overall Risk	3.45	2.86	2.30	1.84

The risk assessment scores in Table 5 demonstrate that all risk factors, as well as the overall risk, have decreased throughout the project. The results also revealed the critical role of management strategies in reducing project risks. For instance, strategies implemented at the beginning of the project enabled more than a 17% reduction in the overall risk. Nonetheless, the changes in the risk scores also depend on the factors affecting the magnitude of the source parameters. Figure 4 visualizes the changes in the scores calculated for three complexity and two uncertainty categories together with overall risk at different project stages. Accordingly, categories displayed different behaviors in terms of variations in the scores. Despite the existence of management strategies, organizational complexity continued to increase throughout the project. However, the results should not imply that the management strategies used in the project were ineffective. On the contrary, they helped keep the high organizational complexity of the project at an acceptable level. In contrast to organizational complexity, environmental complexity showed a declining trend over time. In terms of technical complexity, variations were inconsistent. Although there was a slight decrease until the middle of the project, it started to climb thereafter. On the other hand, the level of uncertainty declined continuously over the project duration. The decrease in vagueness about the project might be achieved by closing the information gap over time. Similarly, the impact of uncertainty about the future can be expected to decrease as the project progresses. For example, an increase in the rental cost of the equipment at the end of the project could be less significant as compared to the initial stages. Furthermore, management strategies contributed to decreasing the level of uncertainty in the project for both categories. As a result, the risk reduction in the case project was more closely associated with lowering the uncertainty level.

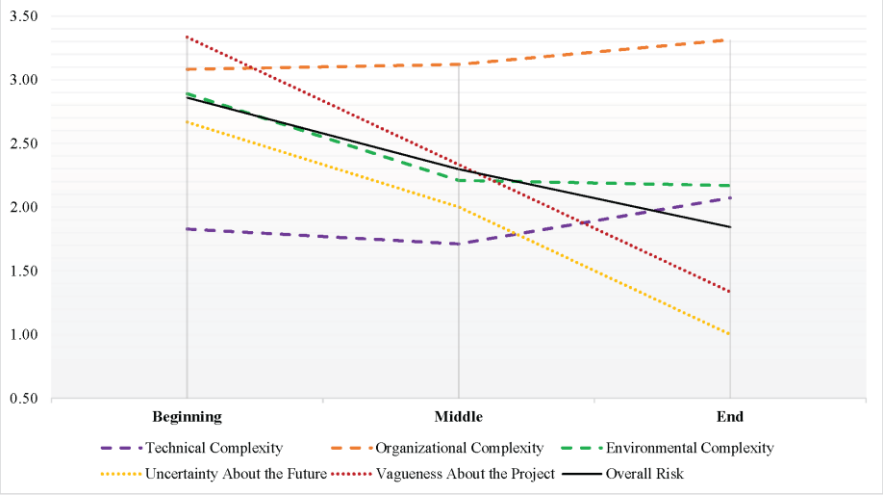


Figure 4: Changes in the category and overall risk scores.

It should be noted that despite the decreasing trend in the risk level of the case project, other projects may not show the same behavior. The emergence of a critical risk source during the project may cause sudden increases in the risk level. Similarly, a strategy developed for a risk factor may increase the risk level in other factors. For instance, hiring a subcontractor to reduce the technical risks in the project may amplify the coordination-related risks. Therefore, both the risk sources and the impact of management strategies should be assessed periodically, as promoted by IRAP.

Summary and Conclusions

In this paper, the implementation of an integrated risk assessment approach was demonstrated in a mega pipeline project. After a detailed analysis of complexity and uncertainty factors, risks of the project were calculated at different stages, and variations were observed. According to the findings from the demonstrative case study, the performance of the proposed risk assessment approach is promising in terms of unveiling the risk sources in the project and reflecting the risk perception of the project manager. Thus, IRAP has the potential to improve the risk management performance of mega construction projects. The following are the main takeaways from the demonstrative case study:

- The main benefit of the proposed risk assessment approach is that it integrates complexity-based thinking into risk management. While the traditional risk assessment techniques are based on estimating the probability and impact of unknowns, IRAP promotes analyzing the static and dynamic complexity factors, together with the uncertainty factors, as potential risk sources of the project. It facilitates the exploration of all possible risk causes in the assessment process.
- Another important aspect of IRAP is that management strategies are engaged in the risk assessment process. In traditional approaches, identification, analysis, and response are the successive phases of risk management. However, IRAP integrates the response strategies into both the identification and analysis of the risk sources. During the identification phase, they provide a feedback loop to uncover new risk sources resulting from their impact on the project. They are also taken into account during the analysis phase as their effects are reflected while rating the magnitude of the identified risk factors. Thus, management strategies constitute the cornerstone of the network-based approach in IRAP.
- IRAP also provides a practical risk monitoring approach for ongoing projects. It facilitates the assessment of the risk levels throughout different project stages and the evaluation of the fluctuations in the risk factors over the source parameters. Thus, the reasons for the increase in the risk level during a specific period of the project could be identified using IRAP.
- Although IRAP principally serves for risk assessment during the project lifecycle, it may also be used for other purposes. For example, as it can simulate the impact of different strategies on risk levels, scenario analysis may be performed with IRAP to select the most appropriate risk management strategies. Moreover, within a database setting, it may help record the lessons learned for the forthcoming projects.

Despite the reported benefits, it is evident that further studies are needed to test the validity of IRAP both in risk assessment and other applications. The risk sources and weights used in this paper have been based on the authors' previous studies. They can be customized for different projects to assess their unique conditions more realistically. Although IRAP was developed for mega construction projects, it can be applied to other project types for comparative purposes. It is also possible to compare IRAP with different risk assessment approaches to evaluate the performance or applicability. Moreover, other network-based quantitative methods, such as Bayesian networks, network theory, and system dynamics, can be utilized to operationalize IRAP. The advantages and disadvantages of these methods over ANP can be reported in future studies. On the other hand, the findings of the demonstrative case study were based on retrospective analysis and reflected the subjective views of the project manager. Longitudinal case studies that include more participants may better explain the sequence of risk events and their interactions with the complexity and uncertainty factors. They can also serve to test other potential benefits of IRAP, such as analyzing alternative risk scenarios for different

management strategies and recording the lessons learned for new projects. Finally, decision-support tools can be developed to facilitate the implementation of IRAP.

Acknowledgment

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Management of Risks Influenced by Information Asymmetry During Construction: Framework for Research

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Abstract

In construction projects a large part of the costs associated with risks fall on communication risks. Communication risks can occur at any time during the life of construction projects and can affect the activation of other risks. They are influenced by information asymmetry among project participants. Information asymmetry is a situation in which participants in the same project, although having the same goals, sometimes do not share information with other parties involved in the project because of self-interest. This is a typical principal-agent problem. Effective management of risks influenced by information asymmetry during the construction phase remains a challenge for project participants. The focus of this paper is on the risk management in construction projects to gain perspective on possible tools and methods for risk identification, analysis, and risk response. Also, basic concept of principal - agent theory and types of information asymmetries are introduced. Finally, the framework for research is proposed as a guidance for future work on the development of a comprehensive system for management of risks influenced by information asymmetry in construction projects.

Keywords: *communication, construction projects, information asymmetry, risk management.*

Introduction

The construction sector is of great importance for the world economy and the progress of society. Global construction output in 2020 was US$10.7 trillion and is expected to grow by 42% between 2020 and 2030 to reach US$15.2 trillion (Robinson et al., 2021). According to Robinson et al. (2021), "the global construction industry is set to be a global engine for economic growth and recovery from COVID-19". Investments in some large and complex projects, the so-called mega projects, with long duration and social importance, exceed as much as a billion dollars (Flyvbjerg, 2014). However, projects often face difficulties in terms of meeting deadlines, planned budget and quality. As a result, the entire construction sector has a bad reputation for being inflexible and unable to cope with the changes that occur during project implementation. A possible reason is the fact that risks and uncertainties are present in the construction sector much more than in other industries (Flanagan & Norman, 1993).

Throughout the process of conceptualizing, planning, designing, constructing, and commissioning buildings, it is easy to expect a large number of unforeseen or uncertain

events. The main sources of uncertainty and risk in projects include their uniqueness, complexity, large number of assumptions made during the planning process, limitations, large number of participants involved, and changes during implementation that are difficult to predict at the beginning of the project (Hillson, 2009). Also, there are external factors that include market, competing companies, changes in organizational, political, economic, technological, legal, international, environmental, and demographic factors (Hillson, 2009). It is impossible to expect a risk-free project, so managing risks is necessary for the successful implementation of projects.

Most common risks in construction projects are communication risks. The Project Management Institute (PMI, 2013) states that communication risks account for 56% of the total risk costs in projects. Communication risks can occur at any time during the life of the project. Their most important consequence is failure in meeting project objectives (Assaf et al., 2018; Choudhry et al., 2018; Berard & Karlshoej, 2012; Couto, 2012; Mephyans-Robinson, 2010; Schwalbe, 2010). According to Cerić and Ivić (2021) and Cerić (2014), communication risks are influenced by information asymmetry among project participants. Information asymmetry is grounded in principal-agent theory, defining a situation between two parties in which one is better informed than the other, and they do not share common interests (Jensen, 2000).

Effective communication risks management during the construction phase remains a challenge for project participants, mainly because of non-existing measurement tools. Therefore, a framework for research on management of risks influenced by information asymmetry during construction is presented in this paper. First, some basic terms of risk management process in construction projects are described in order to investigate possible tools and methods for risk analysis. Then, the implications of information asymmetry are explored, and risks influenced by information asymmetry are identified. The paper closes with the proposed framework for future research on risks influenced by information asymmetry during construction.

Risk Management

The purpose of risk management is to increase the likelihood that project objectives will be achieved through the management of threats, and by taking advantage of opportunities that may arise (Adelsberger, 2015). Therefore, the risk management process is one of the most important processes in project management. For many years, before the emergence of the risk management, construction projects ended with serious consequences on deadlines, budget, quality, and relationships among participants. Although participants were aware of the risks, they did not quantify them. Today, risk management is defined as "a system which aims to identify and quantify all risks to which the business or project is exposed so that a conscious decision can be taken on how to manage the risks" (Flanagan & Norman, 1993, p. 45). Risk management was enriched in the 1980s and 1990s by scientific publications related to the construction industry (Flanagan & Norman, 1993; Carter et al., 1994), various guidelines (CIRIA, 1996; APM, 1997; ICE & FIA, 1998), and also practically. Over the years, the process has evolved, and many models and methods have been developed designed to improve the decision-making process in an environment of uncertainty and risk.

In addition to scientific publications, international standards and norms are the broadest and most influential source of information on the risk management process, and the most famous

of them is the standard ISO 31000: 2018, Risk management – Guidelines. The International Standard Organization has issued another publication, which specifically explains the terminology related to risks (ISO 31073:2022, Risk management - Vocabulary), and another that discusses risk assessment techniques in more detail (IEC 31010: 2019, Risk management - Risk assessment techniques).

Different interpretations of risk-related concepts are available from different sources, and even the concept of risk itself has different interpretations, some of which are described below.

Sometimes the terms *uncertainty* and *risk* are equated and are often mentioned only in a negative context. However, they need to be distinguished. When we talk about uncertainty, it represents any event for which the outcome is unknown, and the outcome can be either positive or negative. On the other hand, according to Hillson (2009, pp. 6-7), risk is "uncertainty that matters", "risk is a type of uncertainty, but not every uncertainty is a risk". Risk is more specific than uncertainty and has a dual nature. It includes an *uncertainty* to which a certain number is assigned (in English language there are several terms for that number: likelihood, chance, probability, possibility), and *consequences* for something of importance. For example, a lottery game is an uncertain event because its outcome is unknown, and it can be either positive (cash gain) or negative (loss of money we paid for the ticket). On the other hand, that game does not pose a risk to us if we have not paid the ticket. The moment we decide how much we want to pay for a ticket, the event is assigned a probability of winning (it is higher if we pay more and less if we pay less). So, in order for that uncertainty to become a risk, the outcome of that event must have consequences for our goal to make money, and we must assign a number to that uncertainty. After drawing lottery numbers, this risky event will have either a positive (*opportunity*) or negative (*threat*) effect for us.

Numerous papers have tried to define risk. In one group of definitions, risk is presented as an event: "risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives" (PMI, 2017, p. 397); "risk is a situation or event where something of human value (including humans themselves) has been put at stake and where the outcome is uncertain" (Rosa, 1998, p. 28). In the second group, the risk is a consequence or effect: "risk is an uncertain consequence of an event or an activity with respect to something that humans value" (IRGC, 2005, p. 19); "risk is the effect of uncertainty on objectives" (ISO, 2018, p. 1). In the third group of definitions, risk is presented as a probability or chance: "risk is the chance of an adverse event, and it depends on circumstances" (CIRIA, 1996, p. 9); "risk is the probability of an adverse outcome" (Graham & Weiner, 1995, p. 30). Finally, the fourth group of authors argues that for a complete definition of risk it is necessary to take into account its dual nature, and define it not only as an event, consequence or probability, but comprehensively: "risk refers to uncertainty about and severity of the events and consequences (or outcomes) of an activity with respect to something that humans value" (Aven & Renn, 2009, p. 6); "risk refers to uncertainty of outcome, whether positive opportunity or negative threat, of actions and events. It is the combination of likelihood and impact, including perceived importance" (Cabinet Office, 2002, p. 7); "risk is a two-dimensional combination of events/consequences and associated uncertainties" (Aven, 2010, p. 624).

Many scientific publications have described the risk management process. The basic three steps of this process have remained the same for many years: risk identification, risk analysis, risk response (Flanagan et al. 1987; Crispin, 2020).

Risk Identification

Risk identification is a first step in every risk management process. It involves identifying any risks that could affect the project objectives. Identification includes naming and describing risks.

Important terms used to describe risk include *risk source*, *event*, *consequences*, and *likelihood*. Here we provide definitions from (ISO, 2018), which are internationally accepted and used. Risk source is defined as "element which alone or in combination has the potential to give rise to risk". It can be tangible or intangible. Event is an "occurrence or change of a particular set of circumstances". An event can have one or more occurrences, multiple causes, and multiple consequences. An event can also be something that is expected and does not happen, or something that is not expected and does happen. Therefore, the source of risk is a broader concept than the event. An event can be a source of risk, but the source of risk does not have to be an event. Consequence is defined as the "outcome of an event affecting objectives". The consequence can be certain or uncertain and can have a positive or negative direct or indirect effect on the goals. The consequences can be expressed qualitatively or quantitatively. Likelihood represents a "the chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency)". It should be differed from mathematical term *probability* that has a narrower meaning.

Other terms that often appear in risk identification process include *vulnerability*, *exposure*, and *hazard*. These terms describe the source of risk in more detail and do not have to be used in every context. Hazard is a "source of potential harm" (ISO, 2022). It is always associated with negative effects on goals. The hazard may be a substance (for example, oil), a site (for example, an oil refinery) or a situation (for example, an oil spill from an offshore plant). Vulnerability is "the property of something resulting in susceptibility to a risk source that can lead to an event with a consequence" (ISO, 2022). Exposure is defined as an extent to which an organization and/or stakeholder is subject to an event (Aven, 2011).

Methods that can be used to identify risks include expert opinions, participation in project meetings, surveys or interviews with relevant participants, brainstorming, the development of checklist, and SWOT analysis. Also, cause-and-effect diagrams can be formed, which graphically show risk factors and their possible causes, as well as other similar methods. Regardless of the chosen method, the correct identification of the risk requires the expertise of the participants in the process.

Depending on the nature of the risk, we distinguish two different types: *risks arising from an event* and *risks not preceded by any specific event*. The risks associated with the event are easier to identify. Their identification is based on the identification of the source of the risk, the event and its effect (Flanagan & Norman, 1993). Thus, one risk event can have several different sources, but also several different effects or consequences. The occurrence of some risky events can be influenced (such as the risk that two engineers will not coordinate

properly when working on a project), while the occurrence of some cannot be influenced (such as weather risks).

Risks that are not preceded by any specific event have in many cases not even been identified, and their importance has been particularly pronounced recently. There are two types of such risks, and these are variability and ambiguity risks (PMI, 2017, p. 398). *Variability risks* are related to the uncertainty that exists about some key characteristics of a planned event or activity or decision. Examples of such risks include: productivity may be above or below target, the number of errors found during testing may be higher or lower than expected, or unseasonal weather conditions may occur during the construction phase. *Ambiguity risks* are related to the uncertainty that exists about what might happen in the future. Some of the project areas where imperfect knowledge could have implications for project objectives include: elements of the requirement or technical solution, future developments in regulatory frameworks, or inherent systemic complexity in the project.

Thorough risk identification is the most important step in the entire risk management process. The result of the identification is the risk register, which is constantly updated during other phases of the risk management process, but also throughout the project, in order to provide the most accurate information about the risks at a given time.

Risk Analysis

Risk analysis is performed in order to describe the impact of identified risks, in as much detail as possible. Not all identified risks will be equally important, so the aim of the analysis is to prioritize them and obtain data with which to decide in the next step which risks need to be minimized and in what way. This is done by assessing the likelihood of occurrence of the risk and the strength of its consequences, which together represent its impact on the objectives.

The detail of the analysis and the methods used in this step depend on the purpose of the analysis, the availability of the information, and the resources available. The methods used can be divided into qualitative and quantitative, and a combination of them can be used. Qualitative methods are usually always applied, while quantitative methods are used only when greater detail is needed. The choice of the best method depends on various factors such as the availability of data and resources, the knowledge and skills of the analyst, and the required representation of the results. A qualitative approach to determining the list of priorities in risk management is applied when an appropriate database is not available (Cerić & Marić, 2011).

Risk matrices, influence diagrams and *event trees* are most often used to present the results of qualitative analysis. These tools use non-numerical data in describing risks, so called linguistic variables: weak, medium, strong (consequence or likelihood). To prioritize risks, multicriteria methods are also used, which use the ordinal scale to rank risks by impact*: multi-attribute utility theory* and *analytic hierarchy process* (Cerić, 2003). Research in construction (Marčić et al., 2013; Cerić & Marić, 2011) has shown that the most complete and adaptable method for qualitative risk analysis is the analytical hierarchical process because it can be used to determine solutions to otherwise complex problems using simple expert judgment. In cases where there is an interconnection of variables, instead of a hierarchical one, an *analytical network process* is used, which has also found application in construction (Cerić et al., 2013).

Risk Response

After conducting a risk analysis, experts have enough data to help them evaluate the risk and decide on mitigation measures. Risk evaluation involves making informed decisions about which risks need more attention and over which no action needs to be taken. In this step, it is necessary to pay attention to individual risks, but also to their interaction and the broader context of risk. Following the evaluation, the risk register is updated with information on the risks for which responses need to be planned.

General rules for designing risk mitigation strategies, according to the literature (CIRIA, 1996; Flanagan & Norman, 1993), include: risk avoidance, mitigation, absorption, and transfer. Combinations of these measures may also include risk sharing, which includes partial absorption, and partial risk transfer (Thakur et al., 2016).

If the risk is marked as unacceptable in the registry, the response may be risk avoidance or transfer. If undesirable, the response may be any of the above. If the risk is marked as acceptable, it can be absorbed with regular monitoring. If it is negligible, no risk response is required at that point.

Framework for Research

In the previous section some basic terms of risk management are defined. This enabled the classification of key processes, methods, and elements that need to be clarified in the case of risks influenced by information asymmetry. In order to apply the comprehensive management of risks influenced by information asymmetry in construction projects, new framework for research is developed in this paper.

From the field of behavioral economics, principal–agent theory can be applied to explain communication risks in construction projects. Principal-agent theory describes the relationship in which one party, designated as the principal, engages another party, designated as the agent, to perform a task on their behalf (Cerić, 2021). According to Liu and Ma (2020), there are information asymmetries and goal conflicts in the agency relationship. Information asymmetry considers that an agent possesses more or better information regarding the details of individual tasks assigned to him, his own actions, abilities, and preferences (see Akerlof, 1970). Goal conflicts refer to conditions in which the desires and interests of the principal and the agent are in conflict with each other (Kivisto, 2008). Information asymmetry and goal conflicts lead to opportunistic behaviors by participants and increasing agency costs (Kivisto, 2008).

According to Turner and Müller (2004), the project owner and contractor form the key relationship in construction projects. In extended principal-agent framework, the project owner is the overall principal and all the other participants (such as designer, project managers, supervisors) are agents directly or indirectly employed by the project owner. However, between some of the participants (for example, contractor’s and owner’s project managers) there is no direct contract. At best, their relationship is based on the guidelines provided by professional organizations concerned with project management and related field, but it remains non-contractual and difficult to control. According to the principal-agent theory, all the participants are guided by self-interest, as illustrated in Figure 1.

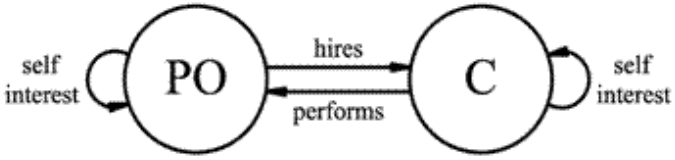


Figure 1: Basic principal–agent theory framework for construction projects (PO: Project owner, C: Contractor) (Cerić, 2016).

The principal hires an agent when he does not have the necessary knowledge and skills or the job is too complex and he lacks the knowledge to carry out certain phases of the job, and/or there is not enough available time. The reward to the agent is agreed in advance and the principal is obliged to pay it. The amount of agent's fee usually depends on the interest that the principal has in the realization of the set task. Thus, it can be said that the principal (project owner) depends on the agent (contractor) to undertake a task on the principal's behalf (Müller & Turner, 2005). In order to realize the interest of the principal, agent is ought to perform the task optimally. Nevertheless, the goals of the principal and the agent differ as each will seek to maximize its usefulness. The selfish action of the agent is consistent with the assumption that all individuals seek to maximize their own benefit, even when it may involve significant damage to the client (Schieg, 2008). Opportunistic behavior is possible because principal cannot (without compensation) supervise the agent. The greater the information asymmetry, the greater the likelihood of opportunistic agent behavior.

Due to characteristics of the principal-agent relationship and information asymmetry between the construction project participants, three types of risks arise: *adverse selection*, *moral hazard*, and *hold-up* (Schieg, 2008; Forsythe et al., 2015). *Adverse selection* occurs when the principal is not aware of the exact qualifications of the agent before the contract is signed. The agent hides its true characteristics in order to trick the principal and gain a contract. This is a situation where the agent has an advantage over the principal due to possessing and hiding relevant information that the principal cannot access on his own. In the case of *moral hazard*, the agent delivers below the quality specified by the contractual relationship. The principal cannot be sure whether the agent is doing his best because he sees only the result, while only the agent knows how much effort he has put in. *Hold-up* also occurs after the contract is signed. In this case the principal has already invested some resources in the belief that the agent will behave appropriately, but the agent acts opportunistically.

There are several possibilities for the mitigation of risks influenced by information asymmetry. Principal can apply *screening* of agent characteristics before contract is signed. During the tendering process, the principal can create multiple contracts and the agent should, by his choice of contract, reveal information about himself and how much effort he is willing to invest. On the other hand, agents can signal its true characteristics with their behavior on the market. Reputation also provides valuable information before signing the contract. After the contract is signed, in general, the relationship between project participants is controlled by means of contractual control (Bower & Skountzos, 2003). The contract expresses the intentions of the two parties, and so the roles and responsibilities of both sides are evident in the case any dispute arises (Simister & Turner, 2003). However, since multiple non-contractual relationships exist in every construction project, other means, such as relational control (trust) should be employed (Li et al., 2021; Marinho et al., 2021).

Considering all the acquired definitions in this paper, risk must include: (1) *Activity of importance* (construction of a building), (2) *Objectives at stake* (completion of a project within a defined deadline, budget or quality), (3) *Uncertainties about the outcome of that activity*. Adverse selection, moral hazard and hold-up all provide a threat to construction project objectives, but their emergence is very ambiguous. Investigation of these risks involves different areas of human sociology, psychology, and economy, therefore being a challenge to carry out. Qualitative methodology is selected as the most appropriate in this case, since risks influenced by information asymmetry cannot be quantitatively determined or measured. Framework for research shown in Figure 2. puts together two research areas – risk management and information asymmetry, in order to provide guidance in developing a management system for communication risks caused by information asymmetry in construction projects.

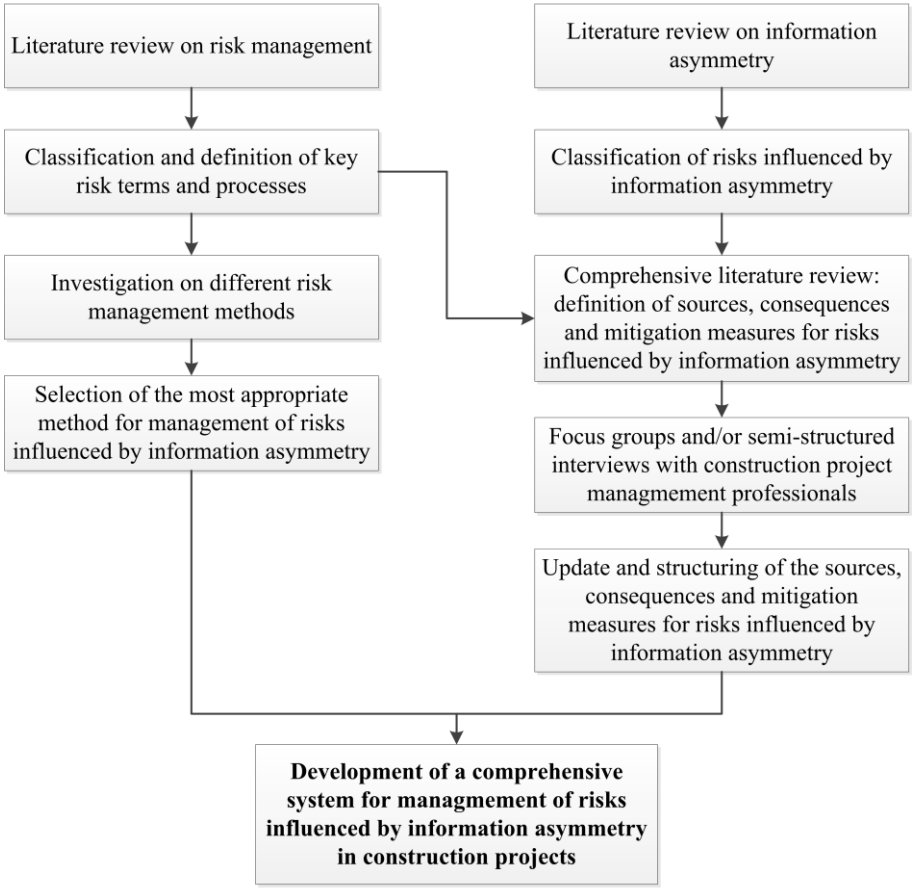


Figure 2: Framework for research on risks influenced by information asymmetry in construction projects.

The results of the first four steps of the proposed framework are presented in this paper. They include *literature review* in two areas (risk management and information asymmetry), *classification and definition of key risk terms and processes*, as well as the *classification of risks influenced by information asymmetry*. The following step will include a *comprehensive literature review* of key construction project management literature. The goal will be defining a list of *sources*, *consequences* and *mitigation measures* for risks influenced by information asymmetry.

To properly assess all the aspects of these risks in construction project environment, expert opinion of construction project professionals will be of great importance. Focus groups and/or semi-structured interviews will be carried out to evaluate, structure and update the list of risk sources, consequences and mitigation measures. The final steps will include an *investigation on available methods for risk management* and the *selection of the most appropriate method* to analyze risks influenced by information asymmetry. The research will result in the *development of comprehensive system for management of risks influenced by information asymmetry*. This will enable timely and precise identification, analysis and response on construction project risks influenced by information asymmetry between the main participants.

Conclusions

Risks influenced by information asymmetry are present in every phase of the construction project, before and after signing a contract between project participants. This paper provides a framework for research on management of risks influenced by information asymmetry in construction projects. A brief introduction into the concepts of risk management and information asymmetry is given, to provide an understanding of the main aspects that need to be studied. Framework presented in this paper shows the use of different qualitative methods with the goal of putting together two research areas – risk management and information asymmetry and providing guidance in developing a management system for communication risks in construction projects. The ambiguous nature of risks in questions requires exploration of different areas of human sociology, psychology, and economy. Expert opinions must be in focus to properly evaluate all the aspects of such risks. That type of research provides its challenges, but also offers a potential for comprehensively capture new ideas and possibilities for delivering successful and resilient construction projects.

Framework for research presented in this paper will provide the necessary guidance in developing the comprehensive system for management of risks influenced by information asymmetry in construction projects, which will be of great value for construction management professionals as well as for future researchers in the field.

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Risk Assessment Between Prefabricated and Traditional Residential

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Abstract

Tanzania's residential construction has been facing the most rapid and challenging growth in the construction industry. In global residential construction, many firms have tried to address challenges by introducing new methods of construction. However, most developing countries like Tanzania pose to be reluctant to the developing methods of construction due to a lack of knowledge and skills. Prefabricated construction (PFC) is one of these methods used around the world with a significant impact on the housing industry. Considering the growing risks in Tanzania's traditional method of construction (TMC), this research aims to provide knowledge on the prefabricated construction application. In this study, a comparative risk assessment between PFC and TMC is conducted by using Analytic Hierarchy Process (AHP). The findings showed that owner, economic and political related risks are the most significant factors for the PFC, whereas owner and nature-related risks are the most critical factors for the TMC in Tanzania. This study provides insight to the public, construction industry, and investors on the deployment of PFC in Tanzania's residential construction. These findings have important implications for understanding and enforcing PFC in Tanzania's residential construction industry.

Keywords: *Analytical Hierarchy Process, prefabricated construction, risk assessment, traditional method of construction.*

Introduction

The construction industry has been playing a significant role in determining the development and progress of a nation. The sector accounts for about 5% of total GDP in developed countries, while it tends to account for more than 8% of GDP in developing countries. Additionally, 100 million people are employed today in the construction sector worldwide (Global Construction Perspectives & Oxford Economics, 2013). In the industry, residential housing constitutes 38% of global construction volume; transport, energy, and water infrastructure 32%; institutional buildings 6%; commercial buildings 12%; and industrial sites 13% (World Economic Forum, 2016). However, the building and construction industry causes some challenges due to its high consumption of energy, water, and raw materials (Shan et al., 2017). As the European Union stated, the building sector is responsible for approximately 40% of primary energy use, 50% of all extracted materials, and 30% of carbon emissions; thus, adopting long-term efforts toward enforcing energy reduction is highly expected (Tsimplokoukou et al., 2014). According to the result of Jaillon and colleagues' study (2009),

the average construction waste can be reduced by 52% by using prefabrication rather than conventional construction methods. Moreover, the use of modern construction methods has a significant economic effect by reducing production hours by 31% (Nahmens & Ikuma, 2011). Besides, not only does the modern construction method such as prefabrication benefit the environment, but it also demonstrates significant advantages, such as improved quality control, reduction of construction time (20%), construction waste (56%), dust and noise on-site, and labor requirement on-site (9.5%) (Jaillon & Poon, 2008). However, most developing countries, including Tanzania, are reluctant to develop construction methods due to a lack of knowledge and skills.

Most of the innovation practices in Africa have been sluggish since not enough emphasis is implemented on the innovation practice. Narrowing down the construction industry to East Africa, Tanzania being precise, the construction industry accounted for 5% of the nation's GDP (Jason, 2008), which rose to 8.3% of the nation's GDP in 2013 (National Bureau of Statistics – NBS; Ministry of Works). In 2015, the Tanzania National Bureau of Statistics (NBS) enlisted the growth of the Tanzanian construction sector as 17.6%, followed by a decline in the growth to 6.9% in 2016 due to reduced investments in construction activities. This reduction in investment has led to the struggle of Tanzania's residential construction units in the industry. According to 2001 housing figures published by the Tanzanian Ministry of Lands and Habitat Development, there is a demand for 600,000 housing units in the major urban areas (Mehta & Bridwell, 2005). Since then, the country's population has risen from 35 million to 56.8 million (United Nations estimate July 1st, 2017), increasing the demand for housing units. Thus, innovations such as prefabrication in the construction sector contributed to the industrial practices in developing countries like Tanzania. However, the issues of such countries, including poor infrastructure, have resulted in a significant increase in the risks in the construction sector, and risks are different for every construction project depending on its size and nature (Subramanyan et al., 2012). Therefore, this study aims to evaluate the main risk factors of TMC and PFC in Tanzania's current construction era. Despite both methods being used globally, PFC has brought a substantial change in the worldwide development of construction industries over the last few decades (Wong et al., 2003).

Research Background

TMC dates to before 12000 BC. Since then, there have been various changes in both the construction materials and its methods of execution. As a result, the construction industry experienced many innovations in terms of materials and processes. Apart from the techniques and machinery innovation in the TMC, the PFC has also been developed. However, compared to other industries such as chemicals, electronics, and automobiles, the construction industry is the sector with the less innovation slope (Kulatilake, 2016).

PFC is one of the modern construction methods, and the UK government defines PFC as "the innovations in house-building from the construction site to the factory" (Pan et al., 2007). The Construction Industry Institute from the USA defined prefabrication "as a manufacturing process that takes place at a particular facility." Prefabrication is a manufacturing process in a specialized facility in which different materials are combined to establish a component of the final installation (Gibb, 1999). The prefab industry is the backbone for developing new ideas in the construction business (Dineshkumar & Kathirvel, 2015). In the construction field, prefabrication is regarded as the first level of industrialization, followed by mechanization, automation, robotics, and reproduction (Richard, 2005). The adoption of PFC was analyzed in

different literature on its benefits. Tam et al. (2007) define the seven benefits of PFC: (i) frozen design at the initial, (ii) enhanced controlling of quality improvement, (iii) construction cost reduction, (iv) less construction time, (v) incremental of environmental performance, (vi) integrity on the building design and finally (vii) construction, and artistic issues on the building. Similarly, Goodier and Gibb (2007) remarked on the benefits of PFC and highlighted its flexibility and sustainability. Moreover, Li et al. (2014) revealed how developed countries (e.g., USA, Sweden, and Australia) are the main contributors, whereas the contribution of developing countries (Turkey and China) is anticipated to increase (Li et al., 2014). However, both methods include some particular risks because of the difference between the approaches. For example, TMC involves construction on site, and PFC involves construction in a controlled environment. Therefore, to conduct proper risk management for PFC, the primary risk sources need to be identified and distinguished from the difference with TMC. Because the literature lacks a study that compares the risk sources in TMC and PFC in developing countries, this study aims to evaluate related in the Tanzanian construction industry to lead a better innovation development.

Methodology

This study aims to evaluate the risk factors of TMC and PFC in Tanzania's current construction era and provide insight to the parties in the construction sector and the public. After conducting a literature review to identify risk factors, an Analytical Hierarchy Process was performed using the data collected from experts to obtain the importance of each factor.

Selecting Critical Risk Factors

This research identified risk factors related to TMC and PFC through a detailed literature review. After eliminating studies, 23 peer-reviewed articles were selected. These studies are not limited to a particular country or region. Nineteen are related to the onsite construction, and four are on the offsite construction. Initially, the risk factors from all the selected studies are listed. Because different studies tend to have similar risks, a frequency column is formed to attain the similarity between the selected studies. The risk factors with a frequency of more than four are then separated, and groups are established to fit the relevant risks. As a result, a total of 32 risk factors exist in at least four academic papers. Finally, these risk factors are used to further evaluate to obtain the ranking of the very significant risk factors for the TCM and PFC.

Analytical Hierarchy Process (AHP)

AHP is a multi-criteria decision method introduced by Thomas Saaty in 1980. Saaty defined AHP as "a decision-making model that aids us in making decisions in our complex world" (Saaty, 1988). As the name states, it involves a hierarchy of the goal to the alternatives linking them. Fundamentally the AHP works by establishing priorities for alternatives and criteria used to judge the alternatives (Saaty, 2001). The AHP has various uses for the decision-maker (Saaty, 1988): (1) to assist in designing a form that represents a complex problem, (2) to measure priorities and choose among alternatives, (3) to measure consistency, (4) to predict a cost analysis, (5) to formulate a cost analysis, (6) to design forwards, and backward planning, (7) to analyze conflict resolution and (8) develop resource allocation.

The AHP arranges the selected factors in a hierarchy structure and first undergoes priority derivation for the performance of the alternatives. The priorities are then derived based on pairwise assessments using judgment. Finally, a weighting and adding process is used to attain the overall priority for the alternatives to the goal (Saaty, 2001). The pairwise assessments are normally conducted with the aid of a matrix. The matrix setup will contain a diagonal of 1's since when comparing similar criteria, so they will have the same importance. Since Saaty stated that AHP aids us in making decisions in our complex world, determining the weights is significant. The higher the criteria weight, the more important the criteria are considered to be. These criteria weights are calculated by the mean of the normalized criteria comparison matrix.

Shortly, the AHP generally has a trend in its procedure, starting with constructing a hierarchy of criteria from the available information and then integrating the information by normalization to obtain the relative rankings. Data from the qualitative and quantitative sections are then compared, and weights, in other words, priorities are acquired. In this method, the groups are considered independent of each other, as the factors in a single group are not to be thought to have any inter-relationship with another group. The goal node is only affected by the 2nd level of the hierarchy, whereas this level is only affected by the 3rd level, and subsequently, the alternatives are affected by the 3rd level (Vayvay et al., 2012). Thomas Saaty's team developed a software package called SUPERDECISION to conduct the ranking.

Data Collection

This study aims to evaluate the risk factors of TMC and PFC in Tanzania's current construction era. Since PFC is an unfamiliar technique in Tanzania, experts from the Turkish Prefabricated industry with international construction experiences in Africa, including Tanzania, are selected, while the TMC experts are from Tanzania. Table 1 and Table 2 show the experts' current position and their number of years of experience. Most professionals work in the production, planning, sales, and management sectors since these sectors are the crucial and most important ones in prefabricated construction. The prefabrication construction professionals were selected from four different privately-owned companies in Turkey. The traditional method of construction professionals has an average of 19 years of experience, most of whom are civil engineers in various companies. Similarly, the professionals also work in privately-owned construction companies in Tanzania.

The participants were asked to fill in pairwise comparison tables to rank sub-criteria and the alternatives. As Saaty (1977) suggested, a 1 to 9 Likert scale was used for the comparison. After modeling the hierarchical structure, the data is analyzed in SUPERDECISION software.

Table 1. Experts' information from PFC.

Professional	Position	Years of Experience
1	General Manager	18
2	General Manager	20
3	Factory Director	18
4	Production Manager	18
5	Project Manager	11
6	Planning Director	11
7	Civil Engineer	7
8	Senior Corporate Sales Manager	19
9	Corporate sales Manager	7
10	Sales Manager	3

Table 2. Experts' information from TMC.

Professional	Position	Years of Experience
1	Chief Engineer (Civil Eng.)	39
2	Managing Director (Architect)	35
3	Managing Director (Civil Eng.)	28
4	Managing Director (Civil Eng.)	33
5	Architect	20
6	Civil Engineer	20
7	Civil Engineer	20
8	Civil Engineer	6
9	Project Supervisor	4
10	Site Engineer	3

Findings

As a result of the AHP analysis, the importance of each risk factor is revealed. Table 3 and Table 4 show the ranking of factors for both TMC and PFC. The risk factors with the highest mean overall normalized weight in the external PFC are *sudden bankruptcy/ availability of finance* (0.0796) and *instability of political condition and war threat* (0.0759). These risk factors are from economic and political sub-categories. Further analysis is made for standard deviation, coefficient of variation, and variation degree.

The risk factor with the highest mean overall normalized weight in the internal PFC is *change or variation of orders* (0.0840) from the owner category, similar to the results obtained from the internal PFC risk factors. These levels of risk factors are grouped according to the mean overall normalized weights. The risk factors with normalized mean weight above 0.05 are considered Highly Significant (HS), mean weight between 0.03 and 0.05 are considered Moderately Significant (MS), mean weight between 0.01 and 0.03 are considered Somewhat Significant (SS), and below 0.01 are considered Not so Significant (NS).

Table 3. Importance weights of internal risk factors.

Category	**Internal Risk Factors**	**For TMC**		**For PFC**	
		Mean Overall Normalized weights	**RANK (Category)**	**Mean Overall Normalized weights**	**RANK (Category)**
Owner	Delayed payment	0.0470	4 (MS)	0.1187	1 (HS)
	Change or variation of orders	0.0840	1 (HS)	0.0749	4 (HS)
Designer	Changes in plan/design	0.0259	19 (SS)	0.0068	32 (LS)
	Defective/Poor design	0.0447	5 (MS)	0.0314	12 (MS)
	Project complexity	0.0395	8 (MS)	0.0077	31 (LS)
Contractor/ Company	Lack of training / skills	0.0352	10 (MS)	0.0243	15 (SS)
	Management & Communication problems	0.0317	14 (MS)	0.0200	19 (SS)
	Availability and condition of construction Equipment	0.0258	20 (SS)	0.0122	27 (SS)
	Inaccurate scheduling	0.0227	24 (SS)	0.0143	25 (SS)
	Labor disputes, strikes & fatigue	0.0203	25 (SS)	0.0080	30 (LS)
Suppliers	Availability of Materials	0.0193	27 (SS)	0.0315	11 (MS)
	Quality of Materials	0.0424	6 (MS)	0.0300	13 (MS)
	Slow delivery of Materials	0.0404	7 (MS)	0.0276	14 (SS)

Table 4. Importance weights of external risk factors.

Category	External Risk Factors	For TMC		For PFC	
		Mean Overall Normalized weights	RANK (Category)	Mean Overall Normalized weights	RANK (Category)
Political	Delays/Lack of formalities/permits	0.0126	31 (SS)	0.0182	23 (SS)
	Instability of political condition + War threat	0.0231	21 (SS)	0.0759	3 (HS)
	Government relations / stability	0.0185	29 (SS)	0.0499	5 (MS)
	Changes in laws and regulations	0.0124	32 (SS)	0.0229	16 (SS)
	Corrupt & Bribery practices	0.0275	16 (SS)	0.0198	20 (SS)
Social and Cultural	Attitudes and motivations	0.0274	17 (SS)	0.0108	29 (SS)
	Insecurity & Criminal acts	0.0231	23 (SS)	0.0202	18 (SS)
	Market conditions / culture	0.0231	22 (SS)	0.0154	24 (SS)
Economic	Inflation	0.0135	30 (SS)	0.0365	8 (MS)
	Sudden bankruptcy/ availability of Finance	0.0288	15 (SS)	0.0796	2 (HS)
	Exchange rate fluctuation	0.0261	18 (SS)	0.0467	6 (MS)
	Interest rate fluctuation	0.0192	28 (SS)	0.0436	7 (MS)
	Taxation changes	0.0326	13 (MS)	0.0221	17 (SS)
Natural	Weather/climate conditions	0.0517	3 (HS)	0.0195	21 (SS)
	Acts of God (Force Majeure)	0.0555	2 (HS)	0.0346	9 (MS)
Site	Accidents (safety)	0.0342	11 (MS)	0.0341	10 (MS)
	Site condition, constraints and access	0.0393	9 (MS)	0.0113	28 (SS)
	Work Scheduling (work boundaries)	0.0195	26 (SS)	0.0183	22 (SS)
	Geological / foundation conditions	0.0331	12 (MS)	0.0131	26 (SS)

Discussion and Conclusion

This study focuses on revealing the significant risk factors of the PFC and TMC. Therefore, this study evaluates 32 risk factors under nine categories and compares their significance in terms of TMC and PFC methods. The study results showed that in terms of internal risks, Change or variation of orders (0.0840), Acts of God (0.0555), and Weather/climate conditions (0.0517) are the three most important factors for TMC; while Delayed payment, Sudden bankruptcy/ availability of Finance, and Instability of political condition and War threat are the most significant ones for PFC. Considering that most of the critical risk factors are government-related, this makes it more manageable by close participation between the government with the investing companies in the PFC. Previous studies have also found similar TMC risks in developing countries such as Kenya and Tanzania. For instance, the study conducted in Uganda resulted in similar significant risks, including lack of training/skills and defective/poor design (Muhwezi et al., 2014).

Similarly, an investigation of factors causing construction project delays in Kenya was conducted, resulting in identical significant risks such as delayed payment, defective design, and management problems (Talukhaba, 1999). The East African countries are developing countries and highly need investors to steepen the growth slope. Considering the high population growth in (East African Community Facts and Figures – 2016 Report) Burundi (3%), Tanzania (2.7%), Uganda (3%), Kenya (1.3%), and Rwanda (2.4%), these population growths require a modern solution to enhance the construction quality, sustainability, and timesaving.

These results might provide insight into the East African countries since the countries share the same cultures and are all developing countries. This study also can be used for managing the risks and investments of the PFC in the East African countries since similar risks were witnessed in terms of TMC. The modernization of the construction sectors in East African countries can be highly accomplished by the collaborative cooperation between the government and the investors in the PFC. This study also helps to provide insight to other investors searching for international investments in East Africa. This study further helps the contractors bidding for projects in Tanzania and East Africa in general, providing them with information on what the local contractors and engineering companies put more emphasis on regarding risk assessment before accepting a project.

The method used in this study has some limitations as well. The AHP technique utilized in this study disregards the interrelationship between the risk factors of different groups. The possibility of having an interrelationship between some risk factors can be considered. Moreover, a few studies have been conducted on the causes of delays in Tanzania's construction industry. However, since the construction method used in Tanzania is the TMC, all the significant risk factor analyses are based on the TMC. This paper provides an insight into a modern method of construction, the PFC. The contribution to the literature is providing the significant risk factors of PFC and comparing it with the critical risk factors of the TMC in Tanzania's construction industry. This study further extends the literature showing the manageability of the significant risk factors in the PFC. Since the PFC combines the manufacturing industry and the construction industry, a manufacturing facility is required. Thus, the PFC can be further analyzed by considering its initial investments and the rate of Investment. These can also be used to countercheck the overall impact of the two methods on an actual project.

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Asbestos Free Demolition- Case Study in İzmir

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Abstract

Asbestos has been used extensively in construction industry for its superior insulation properties before its health hazards were discovered and eventually getting banned. It would not be wrong to assume all residential buildings built before the 1980s in Turkey contain asbestos. Therefore, it is important to raise awareness about the potential asbestos exposure hazard during demolition work. This article summarizes the efforts being made in the "Asbestos Free Demolition" EU project, which is executed to educate the construction industry and public with courses and seminars. The project also included field study to determine asbestos presence in the buildings that were damaged during the 2020 earthquake. 505 specimens were taken from 50 buildings that would go through demolition process. 11 buildings were found to contain asbestos. Eternite is the most common asbestos-containing

material type found in that 11 buildings. Results demonstrate the findings of asbestos-containing buildings and suggestions for prevention strategies before demolition work.

Keywords: *asbestos, demolition, EU project.*

Introduction

Asbestos is a carcinogen material that could kill humans when it is inhaled or digested in certain amounts (TWA: 0,1 fb/cm^3) (Toyokuni, 2019). Breathing in asbestos fibers could cause asbestosis, pleural disease, lung cancer and mesothelioma (O'Reilly et al., 2007). The risk of contracting these diseases increases with the number of fibers inhaled. Asbestosis is scarring in the lungs by asbestos fibers. Oxygen and carbon dioxide could not pass in and out of scarred lungs and causes difficulties in breathing. Asbestosis usually occurs in people who have had very high exposures of asbestos over a long time. Pleural disease is a non-cancerous lung condition that causes changes in the membrane surrounding the lungs and chest cavity (pleura) (Cugell et al., 2004). Mesothelioma is a rare cancer of the membrane that covers the lungs and chest cavity (pleura), the membrane lining the abdominal cavity (peritoneum), or membranes surrounding other internal organs (Bianchi & Bianchi, 2007). The symptoms of these diseases do not usually appear until about 20 to 30 years after the first exposure to asbestos (Prazakova et al., 2014).

On the other hand, asbestos is a great material choice in buildings due to its superior insulation and fireproofing properties (Craighead & Mossman, 1982). It was widely used in buildings before its fatal health effects was discovered in 20th century and prohibited from usage around the world. It was applied on steel beams and columns during construction of multi-story buildings as a fireproofing material. Due to its strength, asbestos was added to concrete, asphalt, vinyl materials in roof shingles, pipes, siding, wall board, floor tiles, joint compounds, and adhesives. Asbestos was also used for thermal insulation in acoustical plaster and as a component of a mixture sprayed on ceilings and walls.

The Directive adopted by the European Union in 1999 (1999/77/EC) prohibits the use and marketing of all types of asbestos in all European Union countries. With the entry into force of the Directive on 1 January 2005 for all member states, the European Union has started a ban on asbestos (Giannasi, 2007). Today, asbestos is completely or partially banned in more than 60 countries. However, asbestos will continue to cause deaths for more than twenty years, even in countries where asbestos is banned. Although asbestos products are not produced today, maintenance, repair, dismantling, demolition of structures containing asbestos products continue to pose hazard to workers and public health. According to European Union experts, by 2030, the predicted number of deaths caused by asbestos-related cancers in Western Europe will be around 500,000 (Marchwinska-Wyrwal et al., 2011).

In Turkey, the usage, extraction, and marketing of asbestos were prohibited by the date of December 31, 2010, with the council of ministers' decision. According to records, approximately 500,000 tons of asbestos was used in many products in Turkey before the asbestos ban (Güneş, et al., 2017).

The Law of "Transformation of Areas Under Disaster Risks No. 6306" was issued on 16 May 2012. The objective of the Law was to determine the principles and procedures concerning improvement, demolition, and renewal at areas under disaster risk (particularly earthquake),

as well as any other lands and plots which accommodate risk-bearing buildings, in order to establish suitable, healthy and safe living environments compatible with standards. For that purpose, the buildings which are deemed as “under disaster risk”, are being demolished. As a result, there has been an increasing amount of demolition work over the last 7 years. It is estimated that approximately 7 million buildings will be demolished in 20 years and transformed to a new one as a result of the law (Bozdoğan, 2020). In addition to this Law, in İzmir province of Turkey, 117 lives were lost, 1034 people injured, and 1846 residential buildings had damaged due to an earthquake that has 6.9 magnitude in 2020. It was decided by the government those 488 buildings will demolish in the first place (Ekizler, 2021).

It is highly possible to encounter asbestos in buildings, which are being demolished as part of the urban renewal process and due to the earthquake of Izmir. Unfortunately, many buildings are being demolished without considering the risk of asbestos exposure; despite regulations established on asbestos and construction/demolition work in Turkey dictate otherwise. However, the existing information in regulations lacks details and the current pre-demolition processes are not being followed properly by contractor firms probably due to unawareness and misinformation. Usually, building owners declare that there is no asbestos in the building and the demolition is carried out without attempting any survey or testing to check asbestos presence. As a result, workers who are engaged in demolition and other people in the vicinity are presumably being exposed to unhealthy amounts of asbestos. There have been a few academic studies in the past to address the dire situation (Kurt & Yıldırım, 2016; Üzmezoğlu & Ocaktan, 2017; Taşbaşı, et al., 2017) and even a roadmap to assist contractors complying with current legislation was proposed by Akboğa et al. (2016). However, contractors and building owners’ unwillingness to cooperate in dealing with asbestos hazard has been a challenge and a roadblock to any attempts and studies so far to remedy asbestos detection and removal process.

The current procedures mandated by the legislation are far from sufficient because standards have not been set on how to test asbestos presence and how to remove it based on the test results. Moreover, parties contractually involved in demolition work (contractor firms and building owners) are usually not willing to deal with asbestos removal because they are eager to demolish the building as soon as possible and proceed with the new construction. It is also known by contractors that determination of asbestos-containing materials and the abatement process significantly enhance the cost of demolition work (Franzblau et al., 2020). Contractor firms tend to finish their job as soon as possible and move on to their next project, while building owners want their renewed property without any delays due to asbestos removal. As a result, most of the demolition work in Turkey is being carried out without testing asbestos presence or just assuming that the building does not contain asbestos.

Nevertheless, it is unacceptable to simply deny the presence of asbestos in buildings to be demolished and proceed with the demolition/construction, because this puts many people at risk. Workers who are engaged in demolition, engineers, and other personnel in demolition site, and even civilians in the vicinity could be exposed to airborne asbestos fibers (Khadem et al., 2018) and get cancer (asbestosis, mesothelioma, and lung cancer) in the long term. Depending on the type of building (residential, industrial, etc) to be demolished, a detailed determination of asbestos fibers reveals the exact situation of the environment. (Obminski, 2020; Zhang et al., 2021). In terms of health perspective, it is vital to determine the amount and type of asbestos-containing materials and the status of airborne asbestos (Neitzel et al., 2020). It should also be noted that Turkey is only in the beginning stages of urban renewal process and thousands of buildings nationwide will be demolished over the years as part of

this renewal process. Many lives will be in danger as long as demolitions are carried out without asbestos testing and removal.

This paper aims to determine the asbestos-containing buildings in Izmir. For that reason, 505 specimens were taken from different locations of 50 buildings in İzmir as a part of the "Asbestos Free Demolition (AFDem)" EU project. According to the results, it was obtained that 11 buildings contain asbestos. This work also demonstrates the findings of asbestos-containing buildings and suggestions for prevention strategies before demolition work.

Asbestos Free Demolition (AFDem) Project

"Asbestos Free Demolition (AFDem)" is an EU-funded project which has started on 1st February 2021 by Ege University, Department of Civil Engineering with a budget of 150,000 Euro. The project stakeholders are Turkish Chamber of Civil Engineers (IMO), Dangerous Good Safety Advisory Association (TMGDK-DER), Association of Asbestos Removal Experts (ASUD), and The Municipalities of Izmir province.

AFDem project intends to improve occupational health and safety conditions in demolition work, which is listed under construction industry, one of the very hazardous sectors according to NACE Coding system. As stated before, most of the demolition work in Turkey is being carried out without making any attempts to eliminate asbestos exposure. Not only the demolition workers but also the public in the vicinity are in danger of getting exposed to asbestos. This will lead to many asbestos related health problems and even deaths in the future, unless demolition work is carried out entirely free of asbestos.

The intended outcome of the AFDem project is to raise awareness about asbestos hazards in demolition work, not only for parties involved in demolition but also for public at large. Turkey is quite unfamiliar with asbestos hazard and how threatening it can be to human life. The public, who is oblivious to the asbestos hazard during demolition, foremost needs to be informed about the hazards of asbestos, where asbestos can be found in existing buildings and why it needs to be removed. In addition, they need to know that asbestos fibers can be released into the air during demolition of buildings (mostly as part of urban renewal process). Even people and companies who are actively involved in demolition are not well trained in dealing with asbestos. Therefore, a series of training seminars is going to encounter to fulfil this objective along with a website to promote the project and inform the public on the reality of asbestos hazard in buildings. Training sessions is directed at contractors, building owners, municipality representatives and other stakeholders from construction industry. Training program consists of 5 training seminars and a workshop. The topics of the training sessions include but not limited to general asbestos information, asbestos health hazards, demolition operations in Turkey, asbestos presence in demolition work, asbestos testing, asbestos removal procedures and how to handle pre-demolition process in Turkey. This training session will be in 5 different cities (Ankara, İstanbul, İzmir, Adana and Erzurum) in Turkey with the aid of IMO (Turkish Chamber of Civil Engineers - İnşaat Mühendisleri Odası).

Website of the project is also an important asset to inform the public, since educational slides, educational modules about asbestos, findings from the project and other facts and statistics about asbestos hazard during demolition is shared on the website (https://afdem.eu/).

A well-informed public, who are sensitive to the asbestos exposure risk, should be an important driving force to establish asbestos free demolition work nationwide. If the public were knowledgeable enough about the hazards, most of the demolition work wouldn't have been carried out without asbestos testing and removal. Public would have been more sensitive to the demolition operations nearby their house or work locations, building owners wouldn't allow demolition of their buildings without dealing with asbestos first and workers would refuse to work in buildings with asbestos presence.

Increasing awareness is a major component in achieving the asbestos free demolition goal. However, proper procedures to remove asbestos needs to be established as well. Unfortunately, Turkish construction industry is rather unfamiliar with asbestos testing and removal techniques due to lack of standards or best practices regarding either how to test asbestos presence or how to remove asbestos from the buildings in Turkey. AFDem project fills this gap in the practices by taking samples from buildings to be demolished in Turkey and propose a removal process that involves different techniques based on different demolition conditions, such as age and type of building, location of asbestos, existence of construction materials that could typically contain asbestos and other technical factors.

Removal process also aims to focus on asbestos testing as part of removal procedures, particularly where to look for asbestos in the building, how to take samples, which equipment to use and other technical issues. Since there are varieties of techniques to remove asbestos based on the amount, type and location of asbestos in the building, developed procedures should be able to direct practitioners to select the right technique and how to apply it properly.

In addition to the lack of technical information, there are also uncertainties in the administrative side of things. Dealing with the existence of asbestos in buildings to be demolished and how to handle the administrative process is not an easy task for contractors and building owners because there are no proper guidelines established in Turkey. Such as, who building owners and contractors should contact regarding asbestos, where to get permits and other documentation, applicable regulations, and other administrative procedures. It is also difficult for municipalities to oversee this process. There are regulations concerning this matter, however they are not detailed enough to direct involved parties or not being followed as intended. Therefore, a sustainable mobile application is developed to form a roadmap and help practitioners make decisions on how to proceed in asbestos handling process.

Asbestos Measurement and Analysis

Sampling asbestos-containing materials (ACM) was executed according to "HSE 248 Asbestos: The Analyst's Guide". It is preferred guidance by many asbestos specialists as a sampling strategy. Also, it is important to take samples from the various locations of a building to detect all ACM. It is known that asbestos is mostly find in insulation boards, roofs, pipe laggings, floor tiles and window panels (HSE 248, 2012). In this study, to determine the ACM in 50 buildings that are going to be demolished, 505 bulk samples were collected in total. One of the building's views from the outside which is samples are taken is given in Figure 1. Besides, the inside of the part of the building is also shown in Figure 2 regarding the sampling strategy.



Figure 1: Outside of the building.



Figure 2: Inside of the building.

Samples were evaluated by Polarized Light Microscopy (PLM) according to "NIOSH 9002: Asbestos (Bulk) by PLM" guidance. PLM provides asbestos existence information and information of the type of asbestos fiber (İŞGÜM, 2019). It is known that other analysis methods such as Phase Contrast Microscope (PCM), Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM) can provide more information than PLM. For instance, SEM and TEM demonstrate the number of asbestos fibers and measures dimensions of them owing to their image amplification ability (Dodson et al., 2008). However, the reasons for employing PLM in this study are because it's easy to notice asbestos fibers, cheap in utilization and obtained information is sufficient. Sample results provide required data for depicting the ACM locations in buildings and guide to exhibit prevention strategies and removal processes. Therefore, many asbestos measurement firms prefer the PLM analysis method, especially in Turkey.

Results

The Asbestos measurements were executed by taking samples from 50 different buildings in different locations of Izmir. The number of bulk sample testing in buildings is 505. The

number of buildings with ACM is only 11. All the buildings are residential buildings with a reinforced-concrete structure. The detected asbestos type is chrysotile (white asbestos) with the percentage of 60%. The detailed information about these buildings is given in Table 1.

Table 1. Results of buildings with ACM.

No.	Location	Date of Construction	Floor area (m^2)	Number of Floors	Location of ACM (Eternite)	Amount of Asbestos (m^2)
1	Karabağlar	1995	300	5	Roofing	40
2	Bornova	1995	100	3	Roofing	15
3	Çiğli	1990	105	2	Basement	8
4	Bornova	1980	131.18	2	Roofing	20
5	Karşıyaka	1973	215	6	Basement & Roofing	30
6	Buca	1991	90	3	Roofing	30
7	Buca	1996	120	3	Roofing	30
8	Buca	1990	105	2	Roofing	10
9	Çiğli	1995	250	5	Garden	10
10	Bayraklı	1997	498	8	Roofing	25
11	Bayraklı	1997	198	10	Roofing	25

Asbestos removal operations are performed in 11 of the buildings which has detected with ACM. The detailed information about removal is given in Table 2.

Table 2. Asbestos removal from buildings.

No.	Location	Date of Construction	Location of ACM (Eternite)	Amount of Asbestos Removed (kg)
1	Karabağlar	1995	Roofing	250
2	Bornova	1995	Roofing	100
3	Çiğli	1990	Basement	100
4	Bornova	1980	Roofing	250
5	Karşıyaka	1973	Basement & Roofing	300
6	Buca	1991	Roofing	250
7	Buca	1996	Roofing	250
8	Buca	1990	Roofing	100
9	Çiğli	1995	Garden	400
10	Bayraklı	1997	Roofing	250
11	Bayraklı	1997	Roofing	250

Conclusion

Considering the existing building stock throughout the country, it is known that asbestos-containing materials are used in many buildings that were built in the past, continue to be used today and will be demolished within the scope of urban transformation. Therefore, those working in maintenance, repair, reinforcement and demolition works on the existing stock, their families and neighbors are at serious risk of exposure to asbestos. For this reason, within the scope of the study, it was aimed to determine the buildings containing asbestos in İzmir.

505 specimens were taken from different locations of 50 buildings in İzmir as a part of the "Asbestos Free Demolition (AFDem)" EU project. Results showed that, that 11 buildings contain asbestos. With the urban transformation process, the increase in the number of demolitions is quite high. During this transformation period, those around and those working in the demolition of buildings are exposed to dust containing asbestos.

In this study, the issue was discussed in detail to raise awareness about the hazards of asbestos presence in buildings. Demolishing the old or damaged buildings without testing asbestos presence is a high-risk operation. It threatens not only the workers health but also the people in the vicinity. The project discussed in this paper intend to address these problems and highlighted the importance of asbestos testing before demolition. If public is properly educated and companies follow regulations and procedures, it is expected that asbestos exposure hazard will be prevented and eliminated in the future.

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A Glance at Financial Risks in Construction Companies in Volatile Market

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Abstract

The construction, which is one of the locomotive sectors in the economy has risks similar to other sectors, as well as the additional risks it carries due to its complex structure and characteristics. Financial risk is the probability of actual deviation of expected return. In the globalizing world, especially in recent years, construction firms are taking more place in overseas tenders. In addition, various reasons such as the increase in importing construction materials, use of credit from abroad raises the financial risks which has existed for a long time but has increased dramatically in recent times. Increasing competition conditions have reduced profit margins compared to the past, which has made financial management more important because of the low profitability. Increasing and frequent economic crises have also increased sensitivity to the issue. All these conditions strengthen risk management, especially financial risk management for construction projects. Risk becomes more prominent on volatile conditions and the importance of financial management increases. This study is about financial risks in construction companies in volatile market.

Keywords: *construction, financial risk, project management, risk management*.

Introduction

It is known that the construction industry has a great contribution to the economy in Turkey as well as in the rest of the world, and Turkish construction companies have been constructing significant projects in foreign markets as well as in the domestic market in recent years. The size of the market emphasizes the importance of managing the risks, especially financial risks of the sector.

Construction companies undertake a significant risk in return for their expected profitability. Although the operational risks that are directly related to the execution of the work are taken into account, the financial risks that may not be seen from the construction side can gain great weight. For example, a construction company that has different credit currency and sales currency and works in two currencies carries exchange rate risk. In this case, the construction

company, which is in the opposite position, is at risk of losing all its profits, sometimes more, no matter how successful its production is.

Regardless of the size of the project, risk and uncertainty are inherent in construction work (Quayle, 1999). Considering the construction sector as one of the leading sectors of the country, and the increasing frequency of financial crises, increase the importance of financial risk in the sector. Sector carries high risk and low profit margin. Financial risks, such as operational risks, are among the most frequently encountered and risks to be managed in the construction sector. Financial risk appears to be the most effective risk when risk categories are ranked according to their loss effects. The integrated economy of the world creates many risks for the industries where financial risk is the most complex one especially for construction sector (Shibani et al., 2022)

This study aims to emphasize the importance of financial risks in the construction industry. The success of construction projects may depend on how well the project financial risks analysis and manages. In today's economy, effective financial risk management is a critical component of any winning management strategy.

Financial Risk

Financial risk can be defined in various ways;

• Financial risk is the probability that the expected return will deviate from the actual return (Hagin, 1979).
• Financial risk can be defined as the positive or negative difference between the expected value and the actual value. Risk can also be defined as the uncertainty of economic value (Bolgün & Akçay, 2005).
• Financial risk is the decrease in the solvency of the firm. The risk here arises depending on whether the firm finances its activities with equity or external resources. Financial risk is the danger that the firm's incomes will lose their continuity as a result of borrowing and fall below the income level that will make the interest and dividend payments by not keeping up with a special or general change in environmental conditions, especially in the economic (Sarıkamış, 2000).

Types of Financial Risk

Financial risk is examined in the literature under the subheadings of market, credit, liquidity and operational risk (Sevil, 2001).

Market Risk

Market risk is defined as the possibility of loss in positions held in on-balance sheet and off-balance sheet calculations due to price fluctuations in the financial market.

Market risk is the risk exposed as a result of price fluctuations in the market (Taş & İltüzer, 2008). There are 4 basic types of market risk: interest rate risk, exchange rate risk, stock position risk and commodity risk (Basel, 2004).

Liquidity Risk

Liquidity risk is the risks created by the difficulties encountered in converting a financial asset into cash on demand or the risk of disposing of this asset below its current market value.

Liquidity risk can be expressed as the sum of the following three definitions.
• Internal Liquidity Risk: As a result of the imbalance in cash flow, the firm does not have enough cash or cash inflows to meet the cash outflows fully and on time.
• Liquidity risk related to the market: It is the possibility of loss if the firm cannot enter the market properly, cannot close its positions at an affordable price, in sufficient amounts and quickly, or cannot exit positions due to the shallow market structure in some products and barriers and divisions in the markets.
• Liquidity risk related to funding: It is the possibility of not fulfilling the funding obligation at a reasonable cost due to the irregularities in cash inflows and outflows and maturity-related cash flow mismatches.

Operational Risk

Operational risk arises from oversight of errors and irregularities as a result of disruptions in internal controls, failure to act in accordance with time and conditions by management and personnel, errors in management, errors and disruptions in information technology systems, errors and disruptions in the conduct of business, and disasters such as earthquakes, fires and floods. It is defined as the possibility of loss or damage that may result from risks arising from human and technological errors or accidents can be defined as operational risk (Sevil, 2001).

Credit Risk

Credit risk is the possible change in net profit and fair value of equity due to non-payment or late payment (Mandacı, 2003). It refers to the risk that a business may be exposed to due to the failure of the counterparty to fulfill its obligations. Credit risk is the risk arising from the failure of the participant to fulfill their financial obligations according to the contractual time and circumstances (Sevil, 2001). It is defined as the situation faced by the institution due to the fact that the parties with which it has a credit relationship do not comply with the requirements of the contract and cannot fulfill its obligations partially or completely on time.

Other Financial Risks

In addition to the risks listed above, the following list can be given:

• The risk that the transaction cannot be concluded: The case where the institution cannot receive or obtain the financial instrument or cash subject to the transaction within the expected period from the counterparty,

• Risk occurring before the conclusion of the transaction: The situation where it is understood that one of the parties performing the transaction will not be able to fulfill its contractual obligations within the period of the transaction,
• Country risk: In international credit transactions, the possibility that the borrower or the institution may not be able to fulfill the obligation partially or completely on time due to the economic, social and political structure of the country in which it operates,
• Transfer risk: The possibility that the foreign currency debt cannot be repaid in the same type or another convertible currency due to the economic situation and legislation of the country where the borrower or institution is located,
• Risk of insufficient information regarding the legislation: As a result of the actions that can be taken by the Institution based on insufficient or incorrect legal information and documents, the possibility of lowering the rights and realizing the obligations above the expected,
• Reputation risk: Loss that may arise due to the loss of trust in the institution or damage to its reputation as a result of failures in its activities or non-compliance with current legal regulations,
• Risk of non-compliance with regulations: It is the loss that may arise as a result of non-compliance with the provisions of the legislation and legal obligations.

Risk is one of the inevitable facts of business life. There is no business that will carry out its commercial activities without risk. All of the above-mentioned risks are risks that need to be measured and managed.

Characteristics of the Construction Sector and Financial Risk

Although the size and importance of the share of the construction sector in the country's economy is known, it is a fact that it also faces risk factors that may arise from its structural features and other reasons. Most projects are done once, every project is new and has its own challenges and uncertainties. There are many presuppositions. Construction can take seasons. Job conditions can be very demanding. The use of resources is not uniform. Many environmental factors can change during the construction process, and they can all directly affect construction. Resolution of conflicts can take a long time and this can cause significant damage to all participants. When we look at the sector-specific risks in general, we can list the following elements;

• Widespread construction activity over the years
• Risks that occur depending on the contractor
• Rivalry
• Receiving the works through tender
• Deviations in the price given in the receipt of the works
• Inadequacy of the accounting system in the construction sector
• The construction industry is affected by climatic conditions
• Overseas construction activities
• Getting used to working in an insecure environment
• Other risk factors: In addition to the above-mentioned risk factors, there are many other situations that can be multiplied, such as the fact that the employers and institutions with which the construction companies are in contact do not make the payments on time, heavy conditions are imposed on the contracts, technical examinations of the works are not done carefully due to lack of time, ignorance or simply negligence may pose a risk in the industry (Tüz, 2013).

Financial Risk Perception in Construction Projects

The following determinations stand out regarding the risk perceptions, assessments and practices of construction companies in Turkey;

Firms perceive risk as the loss of money. The importance of planning and programming is recognized and it is widely believed that no problems will arise if they are done properly. Risk management is perceived as a problem related to planning, not a management element. It is considered important that the biggest risk is working without a program and that the program should reflect the truth.

When the risk categories are ranked according to the effects of material loss, the following order of importance emerges;
• Financial risks,
• Political risks,
• Construction manufacturing risks,
• Environmental risks

It has been determined that many companies do not have a special department dealing with risk management, but it is thought that teamwork should be done in this regard, and in some companies, risk management is carried out by different departments according to the nature of the risk. It is seen that firms add values between 5% and 25% to the offer, sometimes with intuition, sometimes with experience, and sometimes in order to put a price, without making any calculations against the risks that may occur in the contract price. The general prevention approach in the sector against risks is implemented by adding to the cost and time analyzes.

It is stated that there are traditionally four main ways of dealing with risk in the construction industry;
1. The umbrella approach, where every possible outcome is taken into account by adding a high risk premium to the price
2. The ostrich approach, where heads are buried in the sand and everything is assumed to be okay
3. Intuitive approach, which suggests relying on inner voice and intuition rather than relying on all the fancy analysis available
4. The brute force approach that focuses on out-of-control risk and states that everything can be controlled forcibly even though that is not the case in reality (Uğur, 2006).

These approaches can be seen as solutions in a narrow range that creates their own problems. However, their chances of winning against the prices and costs incurred in an effective risk analysis and management process are quite low. For example, it is almost impossible to price the currency risk by paying a very high premium and get the customer to accept it. Companies that analyze these risks correctly will reflect the risk premium correctly and will gain an advantage over other offers. The party that does not adopt risk analysis and management will have difficulty even understanding how the winning party creates this price. Those who bury their heads in the sand take their positions by chance unless market movements develop against them, they can continue but will have to pay for movements in the opposite direction. Those who take risks by relying on their intuition would get the same results if they tried their luck in the stock market. Brute force is useless in the markets, no speculator can significantly

change prices with brute force. If the business is left to a company that does not apply risk analysis and management, then profits or losses from market movements will be added directly to the profit and loss of the business. The profit or loss that occurs in this way does not arise from the business itself, it is no different from speculating in international markets, the firm is implicitly exposed to speculation. Positive results are perceived or reflected as a skill of management, and negatives as formed by market conditions that are impossible to resist and manage.

Results

Many organizations in the construction industry try to isolate themselves from risk. They think they can avoid risk by blaming unexpected costs on others. There may be examples where this approach has worked in the past. Although it seems to reduce the risk by reflecting the financial risk to the consumer as a price increase or transferring the risk to the subcontractor that can show the least resistance, it can either increase the existing risks or create new risks. The subcontractor's loss makes the continuation, quality, duration and prestige of the work difficult, and all these directly affect the construction company. Transferring risks to other parties by contract, or coaxing other parties to bear those risks, may seem like a skillful way at first, but it can turn into a game of clinging to false certainties. What matters is not who the risk is transferred to, but the actual capacity to bear the risk if the risk materializes.

The structure of the sector is very complex by nature, and in this case, it is exposed to a large number of risks of various sizes. It is extremely important to analyze and manage financial risks correctly.

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Currency Risk Analysis on Construction Cash Flows

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Abstract

Construction is one of the leading sectors in economy and the sector carries high risk and low profit margin. Currency risk, has a vital importance especially for the construction projects which have different currencies at their cash flows. The profit loss and cost changes of construction projects at volatile currency atmosphere, have made it important to measure the currency risk and to manage it rationally after determining the existence of this risk. İt is important to know how much the project's profitability can fluctuate with the effect of exchange rate risk to determine the budget to be protected from this risk effect. Currency risk management have to be done during the all project and construction phases to prevent the effects of currency changes on the costs.

Keywords: *construction, currency risk, financial risk, project management, risk management*.

Introduction

Turkish economy, which is opening up business abroad more than past and construction which is accepted its locomotive sector, has become to be influenced from the global crisis stronger in recent years by the unavoidable result of the globalization. At the last 50 years, the top sector of the list is construction which is being influenced faster by both the global scale changes and the local economic crisis in spite of having benefits at the latest.

Economic crisis caused risk management concept's appearance. Because of the influence of a crisis which appearance at anywhere of the world is being felt more than past, the sensibility to these risks and the importance of the risk management is enhanced. At the construction sector, financial crisis are conspicuous amongst the frequent and to be managed risks like operational crisis.

Currency risk has become one of the most important issues in international finance after the abandonment of the Bretton Woods System in the early 1970s. As a result of the end of the application of this system, countries left their currencies to fluctuate and the uncertainty of the future values of the currencies have become a risk factor in itself. Changing currency

inevitably affect the cash flows of companies. Currency risk is so important that it is in the top five in many countries in the construction sector (Sameh et al., 2021).

In this study, the impact of currency risks volatility on the cash flows and completion costs of the construction projects is studied. Matlab is used to calculate the currency effect and visualize the results. According to historical currency data, the project is floated over time and thus the effect of the currency risk that the project will be exposed to if it was constructed in the past is calculated. The results show how profits change with the effect of currency risks and can be used to establish the budget for hedging. The aim of this paper is to show the importance of impacts of currency risk to cash flow of construction companies.

Risk and Currency Risk

Currency risk is defined as the possibility of loss or profit that may arise in assets and liabilities depending on the fluctuations in the value of the currency. The importance of currency risk for construction projects is obvious. Various studies support that international construction companies are exposed to complex risks such as exchange rate, inflation, credit and other business risks (Lee & Waiters, 1989; Han, 1999). Today, construction companies have foreign currency assets, foreign currency receivables, foreign currency loan debts and other foreign currency debts in their liabilities, and all debts and receivables arising from foreign trade transactions. The fact that all these assets and liabilities are in different currencies is the source of currency risk. This risk, together with the increasing volume of international trade that emerged with the phenomenon of globalization, makes its impact more felt than before.

Conjuncture in Construction Sector

The successive economic crises have led to the emergence of the concept of risk management, and the fact that the effect of a crisis that has arisen anywhere in the world as a result of globalization is felt more than before has increased the importance of risk management. Financial risks, like operational risks, are among the most common risks that need to be managed in the construction industry. The increase in the diversity of financial risks and the frequency of global crises brought about by financial integration have further increased the need for asset liability management and risk management.

As Quayle points out, risk and uncertainty are inherent in construction work, regardless of the size of the project (Quayle, 1999). Construction projects begin in a complex and dynamic environment created by conditions of high uncertainty and risk factors combined with time limits demanded by the owner (Mulholland & Christian, 1999). For this reason, it is known that many issues foreseen in the planning process in the projects in the construction sector are realized differently than expected during the implementation phase and create the need for re-planning. Compared to other stages of planning, the need to be affected by uncertainties and to be monitored continuously is much more in financial planning. Because the disruption of financial planning will affect all other planning actors (finishing the project on time, construction at the planned quality, etc.) (Tüz, 2013).

Shin and Soenen (1999) argue that currency fluctuations can have a significant impact on the performance of firms with international activities by influencing the relative prices of

domestic and foreign products and their foreign currency-fixed liabilities (Shin and Soenen, 1999). Currency fluctuations were found to be one of the most critical factors causing budget overrun in East Asia (Chua et al., 2003). In some other studies, the risk arising from currency fluctuations has always been found to be significant for joint ventures at varying rates (Bing et al., 1999; Shen et al., 2001).

When Loderer and Pichler (2000) investigate possible reasons why firms do not take any action, it turns out that they have reason to believe that risk gaps are trivial and commonplace because they have difficulty understanding the importance of measuring the risk profiles of firms (Loderer & Pichler, 2000).

Construction Projects Cash Flow

Cash flow is the cash inflows and outflows that occur in the business as of a certain period. Cash flow statement is a statement that shows the cash flows of a business in a certain accounting period in terms of sources and places of use.

The cash inflow of the construction project includes progress payment income, employer advances, collateral deduction returns, and credit usage. In cash outflow, labor, equipment and material purchases, payments to subcontractors, transportation expenses, taxes, loan repayments and general expenses are seen.

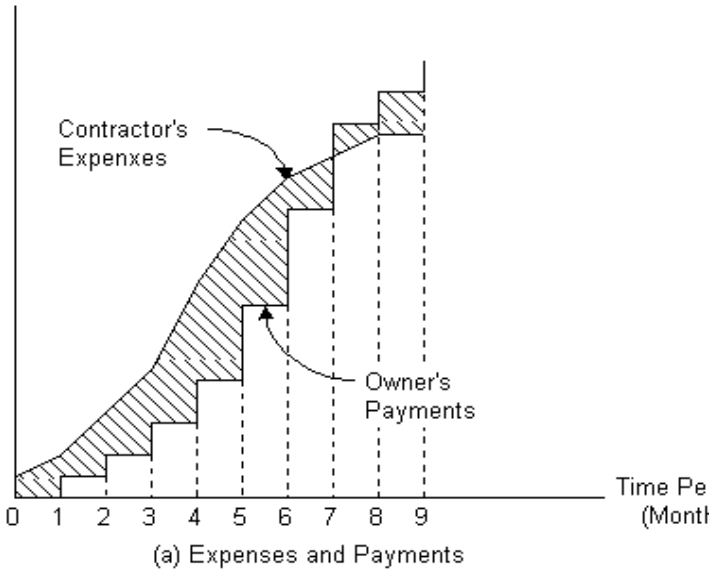


Figure 1: S curve (PMBOK, 2017).

The cost line used to measure, monitor, control and manage the overall cost performance of the project is the budget divided into time intervals. It is obtained by adding up the estimated costs for each period and is usually in the form of an S-curve (Figure 1). The S-curve is generally useful for a quick estimation of cash flow at any given moment (PMBOK, 2017).

Analysis

In this study, the effect of fluctuations in currency on the cash flow and project completion cost of a construction project is investigated. Matlab was used to calculate the exchange rate effect and visualize the results. According to historical currency data, the project is floated over time and thus the effect of the currency risk that the project will be exposed to if it was implemented in the past is calculated.

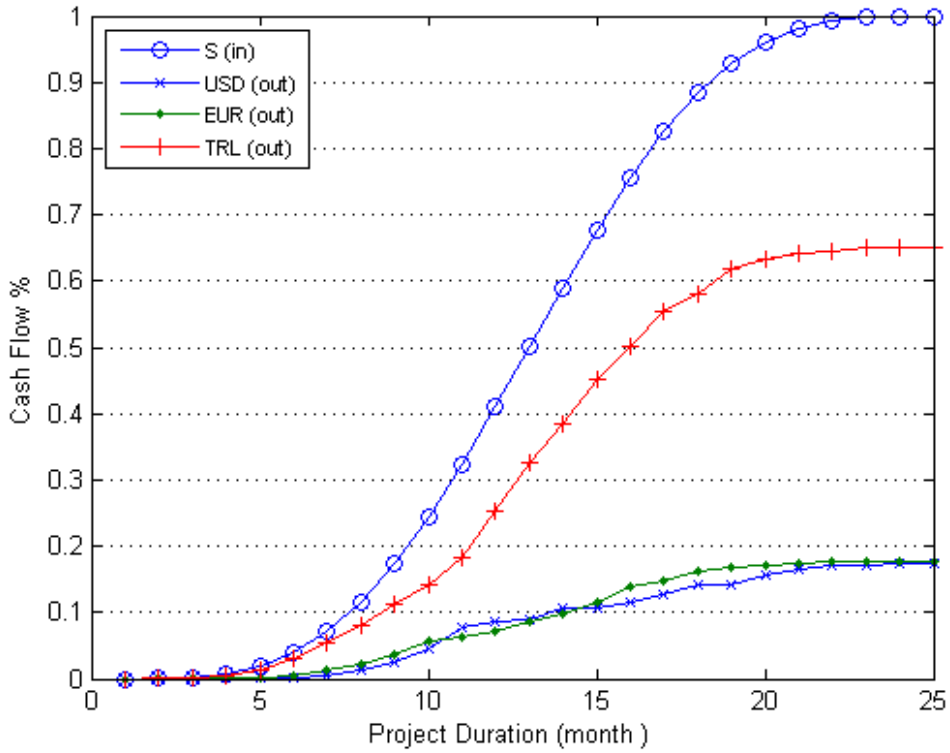


Figure 2: Example project cash flow.

The results found with the sample project data are shown in the histograms in Figure 3 and Figure 4.

As can be seen from the figures, the sample project can be completed between 0.97 times and 1.41 times the planned budget. The probability that the project will end at 1.08 times or less than the planned budget is 80%. There is a 20% probability that the project will be completed at a cost higher than 1.08 times the planned budget.

In the example project, the monthly cash flow fluctuation is between 1 and 2.21 times the planned one. The probability of project monthly cash flow fluctuation being 1.09 times or less than planned is 80%. There is a 20% probability that the project monthly cash flow fluctuation will be 1.09 times higher than planned.

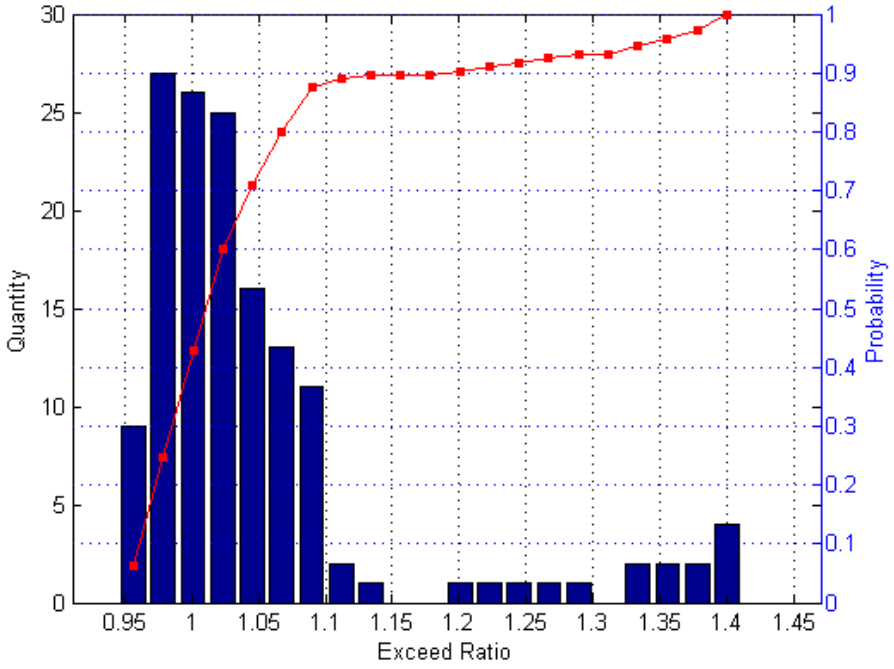


Figure 3: Sample project completion fee.

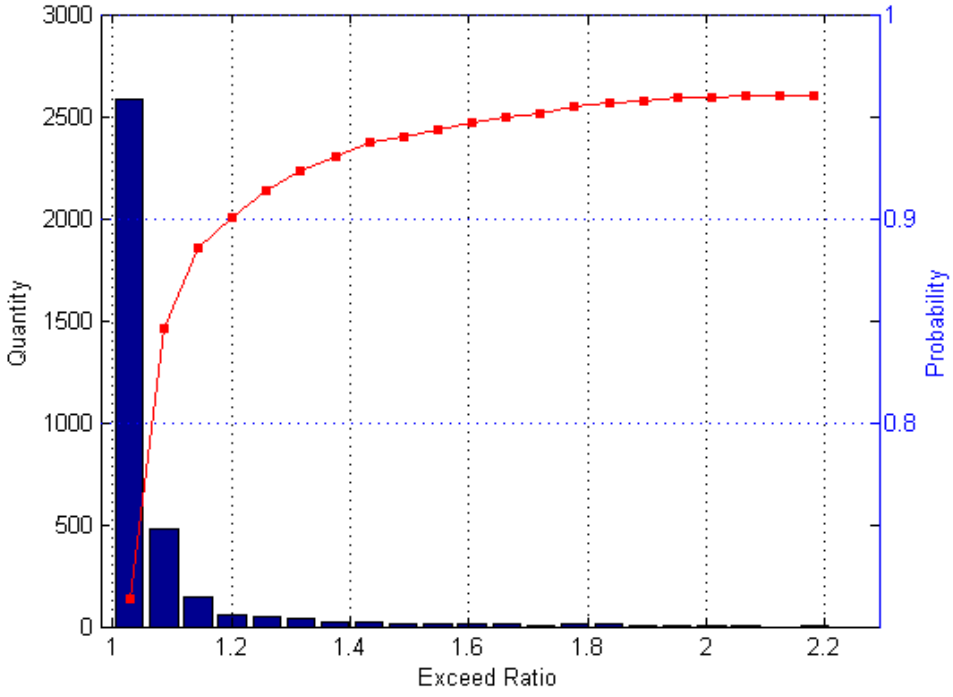


Figure 4: Example project monthly cash flow.

Results

The contractor can use cash flow forecasting techniques to understand his financial position and avoid the risk of bankruptcy. While this emphasizes the importance placed on cash flow, monitoring cash flow does not really eliminate the risk of bankruptcy. However, monitoring the cash flow and taking the right action on time will save the project from many risks.

The project completion cost may differ from the budgeted price depending on the cash inflows and outflows in different currencies and the effect of the volatility in the currencies. At the end of the project, although currency volatility did not make any difference in the completion cost, cash flows are under the influence of volatility. This situation can make great damage for construction companies that have not taken precautions by calculating their cash planning and financial risks, and it also puts the continuation of the business at risk. The firm fluctuates between raising additional resources and utilizing the surplus resources as cash flows remain volatile.

This budget overrun can destroy all the profits as well as cause losses. Fluctuating monthly cash flows and budget overruns can prevent work from being completed. On the contrary, when the currency supports the position in the cash flows, the tables that give the appearance of a very high profit are deceptive and are only speculative profits. This profitability has nothing to do with the business, so that the same profit can be obtained only by holding a foreign currency position.

The values obtained from the analysis show how sharply the profitability can fluctuate from time to time with the effect of currency risk and can be used to determine the budget to be created to protect from the effect of exchange rate risk. Currency Risk Management is a task that needs to be continuously monitored by analyzing the existing risk in all project processes.

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Carbon Footprint Reduction in Sustainable Earthen Buildings

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Abstract

Sustainable development addresses today's requirements without compromising future generations' ability to satisfy their needs. The construction industry is well-known for being a big consumer of materials with high emissions associated with their production. Cement manufacturing accounts for 5% of total carbon emissions, with each ton emitting around one ton of CO_2, which has a negative environmental impact. Modern construction materials that consume a lot of energy and emit a lot of CO_2 should be gradually phased out with sustainable building materials. Due to low carbon footprint in adobe, it has gained popularity as a method of utilizing more sustainable resources. However, these buildings are highly susceptible to environmental change, and their low resistance to water and earthquakes necessitates their improvement. Istanbul Technical University invented Alker technology in 1978 to improve the properties of earthen constructions. Alker consists of 10% gypsum, 2% lime and 20-22% water, based on the dry weight of the soil. Stabilizing Alker with waste marble dust, polypropylene fiber, and shredded plastic waste, has been demonstrated to increase its mechanical properties and can help restrict the growth of cracks. Alker enhanced with these wastes has been proven to be a more sustainable building material with low carbon footprint.

Keywords: *alker, carbon footprint, earth buildings, eco-friendly materials, sustainable development.*

Introduction

Due to environmental and economic considerations, the usage and fabrication of materials has grown increasingly in recent years. It is well known that the construction sector consumes large amounts of materials with high CO_2 emissions associated with their manufacturing, particularly concrete. One of the most significant issues in cement manufacturing is the high temperature required to manufacture this material, which results in considerable energy usage. Sustainable building is seen as a means for the construction sector to protect the environment. Construction companies worldwide are becoming more conscious of the need for

environmental conservation. In order to reduce construction's negative environmental effects while still achieving industrial sustainability, three new concepts have emerged: resource efficiency, cost efficiency, and design for human adaption (Akadiri et al., 2012). Sustainable development aims to improve people's lives by addressing their social, economic, and environmental needs. Cement production accounts for 5% of total carbon emissions, with each ton emitting around one ton of CO_2. Sustainable building is done by utilizing natural resources, such as adobe, in such a manner that they satisfy economic, social, and cultural demands while neither depleting or degrading these resources to the point that they cannot supply these needs for future generations. The built environment accounts for nearly 50% of annual worldwide CO_2 emissions. Building operations account for 27% of total emissions each year, while building materials and construction account for an additional 20 % as shown in Figure 1.

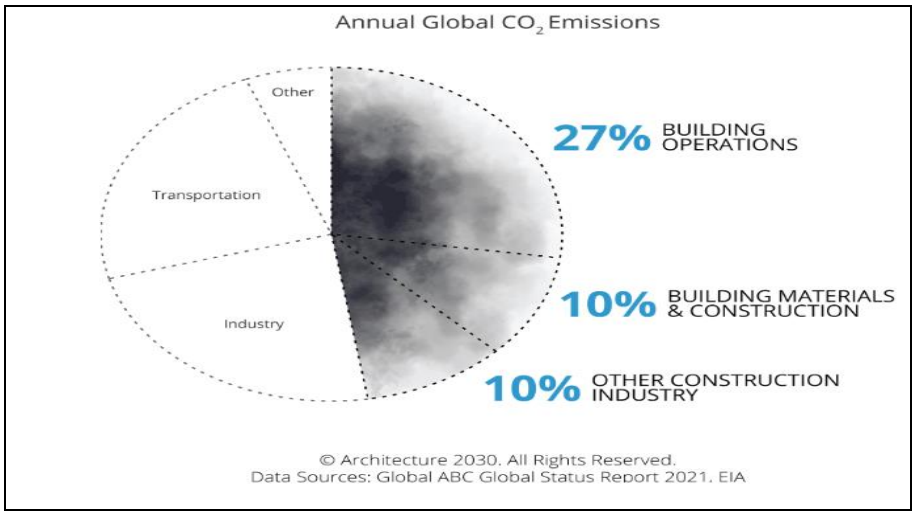


Figure 1: Annual global CO_2 emissions.

To achieve zero embodied emissions, the following principles must be followed:

- Reuse includes the renovation of existing buildings, the use of recycled materials, and the design for disassembly.
- Reduce by optimizing materials and specifying low- to zero-carbon materials.
- Carbon sequestration includes the design of carbon sequestering sites as well as the usage of carbon sequestering materials.

Figure 2 shows that only three materials (concrete, steel, and aluminum) account for 23% of total global emissions (the majority of which are used in the built environment).

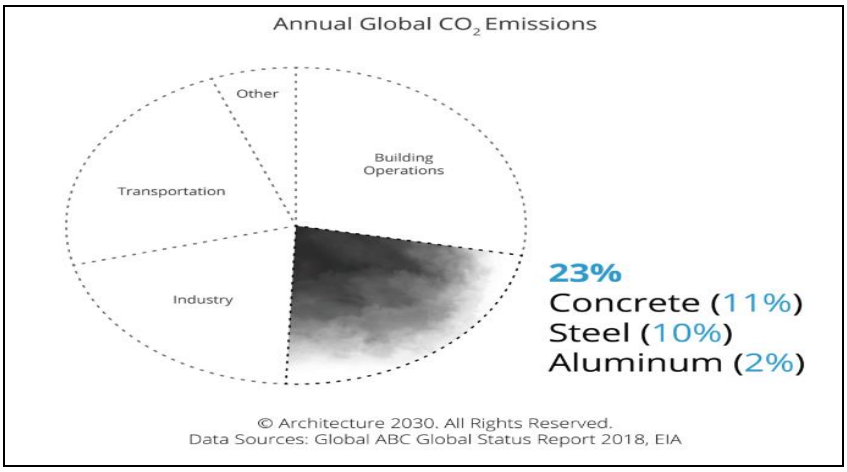


Figure 2: Annual global CO_2 emissions.

Characteristics of Adobe

Earth is an inexpensive, ecologically friendly, and abundant building material that has been widely employed in construction across the world. It is one of the oldest and most widely used building materials in the world. It is a natural building material made from sand, clay, water, and some kind of fibrous or organic material, such as sticks and straws. Earthen materials like stone and wood use less energy and require less resources. Some studies show that using earthen materials reduces the environmental impact of buildings (Hamard et al., 2016; Melià et al., 2014). Earthen structure, including rammed earth, adobe, and cob, that is warm in winter and cool in summer, is one of the oldest and most common structures in human history, and now about 30% of the world's population and 50% of the developing country population live in earthen shelters (Parisi et al., 2015; Silveira et al., 2012; Mateus et al., 2015; Silveira et al., 2018; Costa et al., 2019; Costa et al., 2016; Hoff, 2016; Varum et al., 2015). The affordability of new building materials and technologies makes earth construction a viable option for developing countries where modern building constituents and technologies are not readily accessible (Fratini et al., 2011). Adobe is a sustainable strategy having implications for social and cultural development. Costs are minimized due to the use of locally available materials and a straightforward construction technique. Earthen structures have a lower carbon footprint and embodied energy than structures composed of concrete, steel, or masonry (Bui et al., 2009). Because adobe does not require combustion before use as a building material, it eliminates the requirement for combustion.

The adobe building technique uses plastic earth and clay and is used mostly in locations with access to water. Using clay soil generates fissures upon drying due to shrinkage. To minimize cracking, adobe raw materials are typically mixed with straw or other plant fibers (Christoforo et al., 2016). To improve mechanical and thermal properties, adobe walls should be thick. Expert labor is required for specialized adobe making components. According to the literature, adobe soils must include 15–16% clay (Calatan et al., 2016). In order to achieve the best results, soils must be workable and malleable. Using fibers in adobes has caused controversy; some say it prevents cracking, others say it diminishes the mechanical strength of the earth bricks (Parisi et al., 2015; Sharma et al., 2015). Regardless of the weather, it can be claimed that adobe buildings have good energy management (Figure 3). Adobe buildings use less artificial heating and require less cooling in the winter. It is consequently

demonstrated that these buildings provide more comfortable interior areas in both winter and summer.

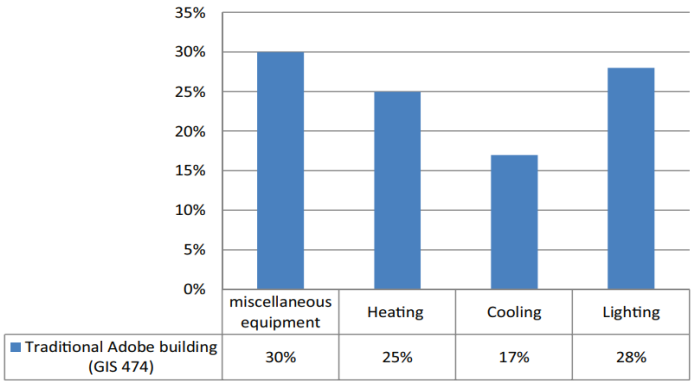


Figure 3: Yearly energy consumption in Adobe building (Obafemi & Kur, 2016).

Earthen Building Benefits and Limitations

Access to affordable housing for low-income people is linked to building materials and technologies (Adegun et al., 2017). According to Pacheco-Torgal and Jalali (2012), the use of traditional earth-based building materials has increased in recent decades due to their environmental friendliness. Earthen dwellings are eco-friendly due to limited manufacturing, recycling, and reuse. Earthen homes are thought to be healthy. The beneficial effect on health was unknown, but most people attributed it to a pleasant interior environment and the soil's ability to absorb toxins. Sanitation and rats were also mentioned. During the rainy season, moist feet enter the residence, polluting it and attracting parasites harmful to humans (Kulshreshtha et al., 2020).

While older building materials are considered "green", most current building materials are not recyclable (Pacheco-Torgal & Jalali, 2012). Manufacturing plastics, cement, and metals takes more energy. However, the building sector is now working hard to reduce embodied energy. It must be recyclable, reusable, have little embodied energy, and not emit dangerous particles to human health. Building materials have included stones, wood, earth, and plants. These are referred to as "conventional building materials". Materials derived from the earth or from biological sources (wood, fiber, and plant aggregates) that people have used for thousands of years are being reviewed as sustainable resources. Building materials and steel bars used in traditional construction need enormous amounts of extraction of raw material, this leads to resource depletion and environmental impact (Danso et al., 2015). It requires a lot of energy and generates pollutants like carbon dioxide and sulfur oxides. These pollutants are harmful to both the environment and human health. Traditional building materials like concrete, tiles, steel, bricks, solid blocks, hollow blocks, and pavement blocks have also become more expensive due to higher production energy costs, resource scarcity, and transportation costs. During the manufacturing process of those construction materials, different harmful chemicals such as high concentrations of carbon monoxide, sulfur oxides, nitrogen oxides, and suspended particulate matter are always released into the atmosphere. Emissions of harmful substances contaminate the air, water, soil, vegetation, and aquatic life, hence affecting human health and living conditions. Consequently, alternative building materials (such as earth blocks) and more sustainable construction procedures are being researched by Safiuddin et al.

(2010). Using earth saves energy (Costa et al., 2019), making it an eco-friendly material. In this environment, earth construction has increased in popularity as a way to create and use more sustainable resources (Laborel-Preneron et al., 2016).

Earthen materials, on the other hand, have weak mechanical properties, shrinkage, and low water resistance (Müller et al., 2016). Water movement (capillary action, rain, floods, etc.) causes clay particle swelling and shrinkage, finally resulting in cracks and material loss (Eires et al., 2017; Rainer, 2008). This mechanism has a stronger effect on montmorillonite clay (Lima et al., 2020; Minke, 2012). Although earth is one of the most often used building materials, it is also one of the most susceptible to moisture (Gomes et al., 2016). Water exposure reduces adobe's strength, resistance to erosion, dimensional stability, and durability. Additionally, long term exposure to water can cause adobe blocks to partially or entirely disintegrate (Murmu & Patel, 2018). The higher energy efficiency measures required to make on-site renewable energy sources possible, as well as the immediate awareness and greater understanding of energy consumption that they foster for its inhabitants, are major benefits of developing zero energy, zero carbon, or zero emission buildings. As long as onsite, near-site, and offsite renewable technologies are used, it is conceivable to reduce carbon emissions from energy use to zero in the majority of new non-domestic buildings (Hui, 2010).

Alker Technology: Proportions and Properties

Due to certain constraints, such as lower water resistance and earthquake resistance, Adobe does not satisfy today's needs. They are vulnerable to moisture and can be easily damaged by earthquake. Istanbul Technical University, which has been conducting research on earthen construction materials since 1978, discovered that earth may be stabilized with gypsum and lime, resulting in increased durability, physical and mechanical properties (Işık, 2011). This combination is known as "Alker" (an abbreviated form of the Turkish words for gypsum and adobe, meaning gypsum-stabilized adobe; gypsum = alçı, adobe = kerpic). The construction phase of the Alker Building, 1995, can be observed in Figure 4a, and the Urfa Pilot Building, 1999, can be seen in Figure 4b.

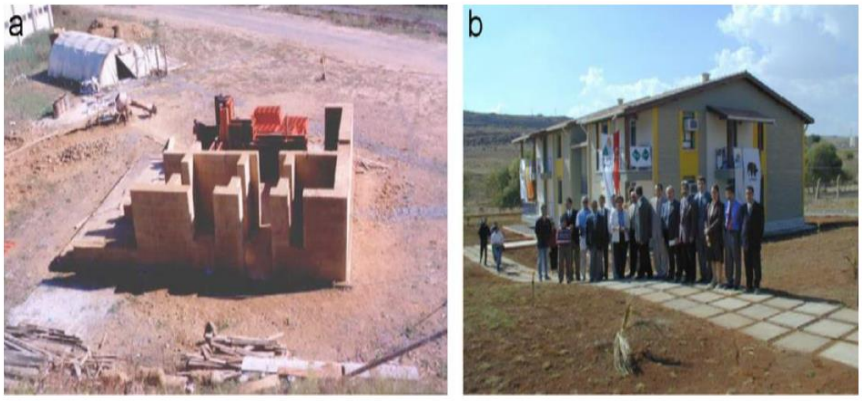


Figure 4: (a) Construction period of Alker building (b) Urfa pilot building (Işık, 2011).

The earth used in Alker technology is significantly more readily available than the earth required for traditional earthen construction due to its lower clay content. Alker is simply a soil that contains a large amount of clay and has been stabilized with lime and calcined

gypsum. It is composed of 10% gypsum, 2% lime, and 20% to 22% water, based on the dry weight of the soil (Balkis, 2017).

The binding property of the earth can be achieved with a clay content of about 30–50%. The addition of gypsum assists in this binding, and the earth's clay content of between 8% and 10% is sufficient to produce Alker (Isik, 2011). Table 1 displays the physical and mechanical properties of Alker.

Table 1. Physical and Mechanical properties of Alker (Işık et al., 1995).

Unit weight	**1.6 -1.7 kg/lt**
Shrinkage	%1.00 -1.50
Compressive strength	2- 4 N/ mm^2
Shear strength	0.9 - 1.3 N/ mm^2
Water absorption	Low
Long term water effect	Low
Thermal transfer coefficient	0.4 W/mK
Heat storage	1.0 kJ*/kgK

The use of lime and gypsum in mixes minimizes the time required for mixing, molding, compacting, and turning out of molds (Aydin & Balkis, 2017). Gypsum helps decreases the shrinkage of the building material, while Alker provides the durability required for load-bearing wall construction. Additionally, Alker is permeable and lighter than unstabilized earthen materials due to the fact that the gypsum hardens before the clay dries (Işık, 2011). Heat resistance and durability are particularly high in gypsum-stabilized earthy materials, especially in wet conditions. The manufacturing process is simple, and the energy usage in buildings constructed with this material is negligible. Buildings that are healthy also generate a healthy environment for people. The binding property of the earth can be achieved with a clay content of about 30–50%. The addition of gypsum assists in this binding, and the earth's clay content of between 8% and 10% is sufficient for the production of Alker. Isik (2011) discovered that a high clay content enhances shrinkage, whereas a low clay content reduces binding. The earth needed for Alker technology is much easier to obtain than the earth required for conventional buildings due to its low clay content. Although the earth's clay mineralogy has not been defined, a sufficient amount of clay is required in order to create a suitable bond (Onochie & Balkis, 2021). According to Balkis (2017), the use of Alker, a low-energy building material, helps achieve long-term sustainability in both indoor and outdoor construction.

Alker Stabilization

Onochie and Balkis (2021) investigated the effect of Polypropylene fiber alone on Alker. The results show that increasing the polypropylene fiber up to 0.5 % increased the 7-day compressive strength, but subsequent increases had no effect on the strength. The 28-day compressive strength increased by 0.5% as PPF content increased, however larger voids caused by increasing fiber content led in lower strength once the water in the pores dried. Moreover, Balkis (2017) investigated the mechanical properties of earth, polypropylene fiber, and waste marble dust (10% and 20% by dry weight of soil). PPF was found to reduce compressive strength by 0.5% while increasing flexural strength by 0.5%.

Plastic pollution is one of today's most pressing environmental challenges. Plastics are becoming more popular in construction due to a number of features such as their efficiency, strength and weather resistance, low maintenance, cost-effectiveness, light weight, and design flexibility (Akinwumi et al., 2019). Geotechnical applications, such as plastic stripes, can improve soil engineering qualities. According to the Statistical Service, the total municipal solid rubbish collected in Cyprus in 2017 was 547,000 tons, a 0.36% increase from 545,000 tons in 2016.

The use of plastic waste in the engineering sector for construction applications has a high potential for minimizing global environmental contamination and pollution. Innovative and sustainable use of plastic wastes in building applications will significantly reduce the amount of plastic waste disposed of into the marine environment while also providing alternative materials to meet the needs of the construction sector. The findings on the use of SPW-modified Alker as an alternative construction material for the sustainable manufacturing of earthen structures are based on the use of shredded plastic wastes in Alker (Ahmad et al.,2021).

Because of the use of shredded plastic waste, lime, and gypsum in the production of control and modified Alker samples, the compressive, flexural, and shrinkage properties of the design mixes had a positive effect on sustainability.

Alker's Housing Economy

When compared to other wall construction materials, the influence of gypsum stabilized adobe on construction costs or its part of the overall construction economics can be indicated. Figure 5 compares the cost and emissions of various outside wall materials with the same coefficient of heat transmission. These materials' heat transfer values U (W/ m2K) and wall thicknesses are also provided. Row 6 of Figure 5 illustrates the thermal insulation that is added to reduce both energy consumption and environmental pollution; row 7 illustrates the cost of one wall unit with insulation. Alker walls without insulation cost 1/3 the price of alternative material-based walls with insulation (Isik & Tulbentci, 2008).

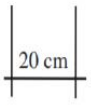
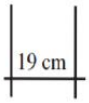
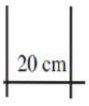
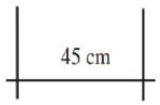
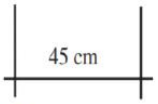
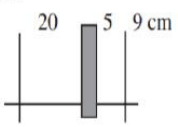
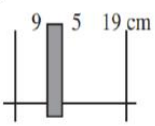
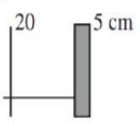
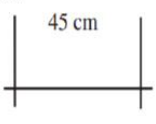
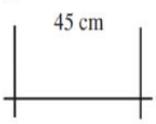
	Concrete wall	Burned rick	Lightweight concrete	Alker block	Compactedalker
1. Wall properties					
2. U Value (W/m^2 K)	3.23	1.25	0.95	0.7	0.7
3. Physical properties	λ = 2.090 W/m K; γ = 2.4 kg/m^3	λ = 0.580 W/m K; γ = 1400 kg/m^3	λ = 0.240 W/m K; γ = 600 kg/m^3	λ = 0.40 W/m K; γ = 1600 kg/m^3	λ = 0.40 W/m K; γ = 1600 kg/m^3
4. Pollution (kg/yr)		CO_2 = 7090; SO_2 = 40.5; CO = 35	CO_2 = 5675; SO_2 = 32; CO = 27.5	CO_2 = 5151; SO_2 = 29; CO = 25.5	CO_2 = 5751; SO_2 = 29; CO = 25.5
5. Cost without heat insulation	3.3	9	9	4.4	4.4
6. Insulation required for equal U value (U = 0.7 W/m^2 K)					
7. Total wall cost ($/m^2, 1995)	11	14	12.9	4.4	4.4

Figure 5: Comparison of external walls with similar heat transfer coefficients (Isik & Tulbentci, 2008).

Conclusion

The implementation of sustainable development has compelled all industries, including the construction industry, to adopt and apply environmentally friendly practices. Due to contemporary worldwide concerns about sustainable development prompted by widespread environmental problems such as climate change and resource depletion, as well as the high rate of technical innovation in the building sector, interest in alternative building materials such as earth has grown. The majority of construction laws contain increasingly stringent criteria for a building's thermal performance, as well as for its ecology and sustainability. When it comes to energy-efficient and environmentally friendly architecture, soil as a construction material has excellent physical characteristics and also meets all strength requirements. It is expected that 50-55% of greenhouse gas emissions are planned by 2030, which will increase the use of adobe structure, which is both environmentally and economically. It is anticipated that Alker wall material, with its low embodied energy, low heat transfer value, and considerable health benefits, has the potential to make a significant contribution to the region's transition to sustainable housing

Earthen structures are extremely sensitive to the destructive impact of earthquakes, as sadly demonstrated by the extensive damage and loss of life caused by earthquakes in regions where earthen construction is widespread. For thousands of years, earthen materials have been employed due to their ease of availability and economic efficiency. Earthen materials have gained popularity in recent years as the world has recognized the need for sustainability in all aspects of life. It is mostly utilized for its sustainability and has little influence on the environment.

Alker production is relatively simple and inexpensive compared to reinforced concrete buildings. This lowers carbon emissions and makes it a sustainable building production technique. The cost estimation demonstrated that Alker buildings are 13% cheaper than other building materials.

In construction, plastics are gaining popularity due to numerous aspects, such as their efficiency, strength, and weather resistance, low maintenance, cost-effectiveness, light weight, and flexibility in design. These features make plastics the ideal construction product and an integral part of a sustainable environment.

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Material Wastes and Management Strategies in the Building Construction Sites (BCS)

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Abstract

Waste is an important problem that should be handled due to the inadequacy of world sources. When the waste generation caused by economic activities are investigated, it is seen that construction industry (CI) has the largest share in waste generation with 35.9%. Therefore, taking precautions against to wastes and managing them should have the precedence in the CI as well as the other management facilities because of cost and source threats.

Material wastes, one of the physical wastes, have a strong impact on the waste generation. Being tangibility of material wastes makes them managed in sustainable way considering waste management strategies. Because of being material wastes are an urgent problem to be solved, in this paper it is aimed to investigate waste management strategies and material wastes which are occurred in the BCS. In this study, top material wastes, are produced in the BCS, are determined, and grouped whereas investigating the causes of material wastes and making suggestion for managing them during the construction process. Since it is thought that material waste could be minimized when it is known which material should be cared primarily and how they could be evaluated in the waste management process.

Keywords: *material wastes, waste management strategies, construction site waste management, building material wastes.*

Introduction

The construction industry is known for contributing development in many countries. As a result of playing a key role for economic growth, it needs to be improved in terms of managerial issues to control the building production processes. Waste management is one of the crucial parts that should be cared during the building life cycle since the construction industry generates immense amounts of wastes which are known as physical and non-physical (Can & Taş, 2020).

Construction industry has the largest share in waste generation with 35.9% (Eurostat, 2018). It is commonly acknowledged that the construction industry has a very high level of material wastes which are known one type of physical wastes. The generation of construction material wastes can cause economical, environmental and social problems in local and global scale as long as they are not managed well. Since the construction industry has a major influence on many other sub-industries by means of purchasing and providing products and services, managing material wastes can make a significiant contribution to circular economy (Agyekum et al., 2013).

Construction material wastes are mostly occurred during implementation and demolition sites of building and civil engineering structures (Ameh & Itodo, 2013; Dania et al., 2007). Building construction activities have been known to generate large and diverse quantities of waste (Dania et al., 2007). According to BigRentz's Construction Waste Statistics Research (2021), construction and demolition (C&D) material wastes such as concrete, asphalt, wood and other building wastes are estimated to be nearly one-quarter of national waste stream, which is the total material waste generated in the United States in one year. The research emphasizes that material waste generation is on the rise, and it is expected to skyrocket soon. In just United States, C&D waste generation increased by 342% from 1990 to 2018 and between 2005-2018, C&D waste generation levels grew more than 10 times faster than from 1990 to 2005 (EPA, 2022).

The United Kingdom generated 67.8 million tons od C&D material waste in 2018. In 2018, the Neherlands produced 25.12 million tons C&D material waste in 2018. Similarly, Germany generated 218.8 million tons material wastes in 2018 and this amount reached to 230.85 million tons in 2019. On the other hand, European Union are responsible for generating 850 million tons of C&D waste per year (Stone Cycling, 2021). Furthermore, Transparency Market Research (2022) states that annual construction waste is expected to reach 2.2 billion tons globally by 2025. This amount is expected to generate 2.59 billion tons of material waste annualy by 2030 and to rise further to 3.40 billion tons by 2050 (Stone Cycling, 2021). These statistics shows the importance of waste management in the BCS to manage the sources for circular economy and sustainability. Managing the material wastes brings not only sustainable construction sites but also new job opportunities in the near future.

Concrete and metals, relatively cost-effective to recycle, and brick, clay, gypsum boards, much less reusable, are the basic material wastes which ends up in landfills in plenty of quantities (BigRentz, 2021). EPA (2022)'s report emphasizes that more than 75% of all construction waste from wood, drywall, asphalt shingles, bricks and clay tiles ends up in landfills. BigRentz's Construction Waste Statistics Research (2021) combines some statistics about recycled construction materials. For instance, the research shows that over 95% of concrete and asphalt concrete waste, the largest contributors to total C&D waste, was recovered in United States in 2018 and a study in 2016 showed that in one year alone, C&D recycling oppotunities led to the creation of 175,000 United State jobs (EPA, 2022). In the United Kingdom, of the above amount, 62.6 million tons, recovery rate of 92.3%, were recovered from 2010 to 2018. This recovery rate is 88% in the European Union from 2018 and, 41% in the Netherlands while 88% in Germany in 2019 (Stone Cycling, 2021).

The challenge of material wastes in the BCS is a global problem which requires global solutions. Not only specific countries but also all countries should be aware of the waste problem for better source utilization.

Material Wastes

Construction wastes are the results of evitable and inevitable activities that do not create value, originate from different reasons such as stakeholders, building production processes, force majeure and occur in physical forms such as materials, labor, equipment or in non-physical forms such as cost, time, quality (Can, 2020). Can and Tas (2020) introduced a new construction Waste Classification System (WCS) according to the lean management approach with a holistic perspective considering current classifications. In this developed construction WCS, material wastes are evaluated as one type of the physical wastes which can be caused by stakeholders such as main contractor, sub-contractor, project team and by process like construction, post-construction and these wastes also can have environmental, economic, and social impacts.

Material wastes are evaluated as C&D wastes thanks to the highest resource usage level during the implementation process and the highest already used material production during the demoliton process. In the both process, material waste types can be evaluated in common perspective, but managing processes of them can be different due to resource usage and already used material production issues.

The actual course of waste management processes at the BCS can be produced on the basis of the observation of works (Sobotkaa & Sagan, 2016). Regarding to the observations and current researches, the material waste types substantially can be defined. Sobotkaa and Sagan (2016) states the BCS material waste types as concrete, bricks, tiles, ceramics, sawdust, shavings, cuttings, wood, particle boards and veneer other than tiles and ceramics, insulation materials, iron and steel. In the Nigerian BCS, material waste types are determined with their percentage compositon by Aboginije et al. (2021) as concrete (16.5%), wood (14.5%), reinforcement (12.1%), asbestos (10.5%), glass (9.4%), asphalt (7.3%), tile ceramics (6.1%), soil and stone (5.4%), plastic and packaging (5.2%), rubbles (4.4%), drywall (3.7%) and bitumen (2.8%). In addition to, Mahayuddin et al. (2010) state the material wastes and ratio in the Malaysian BCS as soil and aggregates, sand (44.3%), wood (12%), ceiling insulation materials (9.3%), concrete (7.2%), bricks (6.2%), tiles and ceramics (5.8%), lime (5.5%), cement (3.3%), metal (2.8%), glass (2.3%), gypsum board (1.2%).

Segregating waste into classes ensures more efficiency in the process of BCS to manage them. In Loch et al. (2019)'s research, the BCS material wastes are subdivided into four classes. These classes are named as A,B,C and D. These groups are:

- **Group A:** Reusable or recyclable wastes (metals, glass, cardboard etc.)
- **Group B:** Recyclable waste for other purposes (plastics, paper, cardboard, metals, glass, wood, empty packaging of paints etc.)
- **Group C:** Waste for no economically viable technologies or applications have been developed to enable its recycling (gypsum waste)
- **Group D:** Hazardous waste from the construction process (paints, solvents, oils and others, or those contaminated from demolitions, refurbishments etc.)

Similarly, C&D wastes have been classified with waste status and waste code by Government of United Kingdom (GOV.UK, 2022). Waste status has been defined as whether the material wastes are hazardous or not. In the each group, the material wastes' status has been defined with their own codes. The groups are:

- **Group 1:** Insulation and asbestos materials
- **Group 2:** Concrete, bricks, tiles, and ceramics
- **Group 3:** Wood, glass, and plastic
- **Group 4:** Bituminous mixtures, coal tar and tar
- **Group 5:** Metallic waste, including cable (copper, bronze and brass, aluminum, lead, iron and steel, tin, mixed metals etc.)
- **Group 6:** Soil, contaminated soil, stones, and dredging spoil
- **Group 7:** Gypsum
- **Group 8:** Cement
- **Group 9:** Paints and varnishes
- **Group 10:** Adhesives and sealants

There are many different categorisation in the literature for material wastes. Because of being many different materials and implemetation methods in today's construction, it is needed to control all the processes in an effective way. So, managing all the waste processes via basic steps makes whole the process more lean. Defining material wastes and categorisation is just one step of this waste management process as well as composing a lean and common categorisation of all the materials in basic way is extremely important preventing the information confusion.

Material Waste Management

Waste management is the collection, transport, processing, recycling or disposal and monitoring of waste materials and it deals with waste generated during construction and allied activities (Peddavenkatesu & Naik, 2016). According to Bilitewski et al. (1994), and Gilpin (1996), waste management encompasses collection, transporting, storage, treatment, recovery, and disposal of waste, and is defined as a comprehensive, integrated, and rational system approach towards achievement and maintenance of acceptable environmental quality and support of sustainable development.

Implementation of construction waste management can be one of the apparent solutions for the industry to minimize waste and waste disposal, ultimately reducing costs incurred during the process and contributing to the global "environmental-friendly" movement (Hwang & Yeo, 2011). Good practice in material waste management generate favorable results with various benefits such as cost savings, effective source usage, sustainability etc. Well organized and implemented material waste management in the construction industry provides reduced demand for landfill spaces, improved resource management, productivity, and quality improvement as well as economic benefits.

Given that the waste is a serious trouble for not only the construction industry sclae but also global scale, being aware of the wastes and managing them becomes mandotary day by day in terms of limited resources. The Construction & Site Waste Management Strategy has been improved by Hunt (2016) to manage the construction wastes in response both to existing legislation and rescinding of specific construction waste management regulations. The strategy sets out the responsibility for construction waste management and how the waste hierarchy can be applied. Three levels of construction work are identified, and these are covered in two processes which support this strategy, the Small Works Waste Process and the Construction Site Waste Management Process. Hunt (2016) evaluates the waste management strategy in three levels. First of them is defining responsibilities and drivers for the waste

management like external drivers, internal drivers, and responsibility for management of construction waste. Second of these steps is applying the waste hierarchy to construction works as reduce (designing out waste), reuse, recycle and recover. Last of these steps is defining levels (basic, minor, and major construction works) of site waste management which is tremendous management step.

Council (2017) prepared a vital report for construction waste management. In this report it is obviously seen that many countries such as United States, European Union, Japan, Singapore, Australia, Taiwan have started to take precautions against to construction wastes. In 2008 the Site Waste Management Plan (SWMP) Regulations were introduced which required construction works over £300K in value to have in place a Waste Management Plan, with the aim of reducing construction waste in United Kingdom (Hunt, 2016). In the United States (US), the government unit for supervising C&D waste management is the Environmental Protection Agency (EPA) which has a specific website for C&D waste management. EPA states implementation of source reduction given that it can be preventing waste before it is generated. In Europe, The Swedish Environmental Protection Agency (SEPA) is responsible for setting up the national plans and programmes for waste prevention for C&D waste management. Several regulations have been implemented for improving C&D waste management in the Netherlands. Similar with Sweden, there are two drivers for the successful C&D waste in the Netherlands: comprehensive regulatory framework and mature recycling market. The Japan Ministry of the Environment (JME) explained the main reason for the high recycling rate is the implementation of 'Construction Material Recycling Law', which was enacted in May 2000. According to this law, it is required that contractors should sort and recycle the demolition waste. In addition, some specific construction materials, such as concrete, asphalt/concrete and wood building materials are particularly suggested to be reused. Similarly, in Korea the Construction Waste Recycling Promotion Act, which was promulgated by the Ministry of Environment, has been put into effect in January 2005. The aim of this Act is to provide a legal basis for promoting construction waste management in an eco-friendly manner. Such as these samples, according to the Council (2017)'s detailed report, it is obviously seemed some successful experiences on C&D waste management in the countries including United States, European Union, the Netherlands, Japan, Singapore, Korea, Australia, and Taiwan as below:

- **United States:** Implementation of source reduction and development of mature waste trade market
- **European Union:** Implementation of Waste Framework Directive, mature reuse/recycling market, life cycle thinking, support for research projects
- **Sweden:** Implementation of legislative initiatives, improved and better controlled quality of C&D waste, implementation of landfill taxes and ban on landfilling of combustible waste fractions
- **The Netherlands:** Implementation of legislative initiatives, implementation of landfill and incineration taxes, development of mature secondary material market.
- **Japan:** Implementation of Construction Recycling Law, mature C&D waste recycling technologies and facilities
- **Singapore:** Efficient waste sorting, strict supervision on illegal dumping, mature waste recycling technologies and facilities
- **Korea:** Implementation of Construction Waste Recycling Promotion Act, quality certification system for recycled aggregates, construction waste information management system for waste exchange

- **Australia:** Implementation of legislative initiatives, implementation of landfill tax, supply chain management.
- **Taiwan:** Implementation of legislative initiatives, effective sorting.

The green building certificate systems also care the importance of waste management in the construction industry. One of popular green certificate systems, Leadership in Energy and Environmental Design (LEED), requests 13 credits from materials and resources category for new constructions in scope of LEED v4.1 for BD+C (USGBC, 2022). The prerequisite (P) and credits (C) in the materials and resources category are seen as below:

- **Materials And Resources Category**

P: Storage and collection of recyclables (required)
C: Building life cycle impact reduction (5 credits)
C: Building product declarations (2 credits)
C: Sourcing of raw materials (2 credits)
C: Material ingredients (2 credits)
C: Construction and demolition waste management (2 credits)

Another one of popular green certificate systems, Building Research Establishment Environmental Assessment Method (BREEAM), requests below assessments for material wastes in the latest version 6.0 (INC V6) (BREEAM, 2022):

- **Materials Category:**

Environmental impacts from construction products - building life cycle assessment (LCA) (up to 7 credits)
Environmental impacts from construction products - environmental product declarations (EPD) (1 credit)
Responsible sourcing of construction products (4 credit)
Designing for durability and resilience (1 credit)
Material efficiency (1 credit)

- **Waste Category:**

Construction waste management (5 credits)
Use of recycled and sustainably sourced aggregates (1 credit)
Operational waste (1 credit)
Speculative finishes (1 credit)
Adaptation to climate change (1 credit)
Design for disassembly and adaptability (2 credits)

The awareness of construction material wastes in terms of resources and circular economy is crucial step for all over the world. It is obviously seemed that rare of countries have started to take precautions for BCS waste management for recent years. Some legal regulations and related categories of green building certificate systems helps to improve the awareness and importance of managing the wastes regarding the very high level percentage of material wastes in the contruction industry as far as the other industries or waste sources. As a result of this, the material waste management should not be evaluated not only minimising them by means of waste hierarchy method (Council G. D., 2018). BCS material waste management

needs a holistic management steps at least as much the knowledge areas of project management.

Material Waste Management in the BCS

BCS material waste management is a vital principle to figure out and manage the wastes in the construction project. It involves a systematic approach to plan, identify, assess, response, implement and monitor process during the project that prevent the exposure waste using some the tools and techniques (Figure 1).



Figure 1: Material waste management.

"Plan material waste management" can be the first and tremendous step which the process of defining how to conduct material waste management activities for the BCS projects. The key benefit of this process is that it ensures that the degree, type, and visibility of material waste management are proportionate to both material waste procedures and the importance of the project to the organization and the stakeholders. This process is performed once or at predefined points in the project to define the material waste management strategy, methodology, roles and responsibilities, funding, timing, possible material waste categories. In this step different plan templates and guides can be used to improve and apply such cost-effective waste management plan, site waste management plan, material logistics plan, design out waste guide, procurement guide and demolition protocol (Akinade et al., 2016).

The second step is "identify material wastes" that is the process of identifying individual project material wastes as well as sources of overall project wastes and documenting their characteristics. The key benefit of this process is the documentation of existing individual project material wastes and the sources of overall project material wastes. It also brings together information so the project team can respond appropriately to identified material wastes. This process is performed throughout the project. In this process, expert judgement, data gathering like brainstorming, checklists, interviews, literature research, current categories, data analysis like root cause analysis can be used as tools and techniques for identifying material wastes. To illustrate, Construction Specifications Institute (CSI) Master Format divisions can be used for identifying material wastes in terms of applying and monitoring the wastes in common perspective. CSI codes describe 17 different divisions but one of them related to stakeholders and the other related to building types. So, 15 different divisions in 17 divisions are directly associated with construction materials for managing them (Url-1).

- **Site Construction** (site work supplier, aggregate manufacture supplier, demolition, hazardous material remover, off-site transportation and disposal, site preperation, landscaping, sewerage and drainage etc.)
- **Concrete** (concrete formwork, cast in place concrete, ready-mix concrete, precast concretei reinforcing steel, cement etc.)
- **Masonry** (mortar, washed sand & gravel, stone etc.)
- **Metals** (structural framing, structural steel, steel joists, metal decking, cold formed metal framing, load bearing metal studs, miscellaneous metal fabrications, metal handrails & railings etc.)
- **Wood & Plastics** (rough carpentry, wood and plastic fastenings, lumber, countertops, prefabricated structural wood, structural wood components etc.)
- **Thermal and Mositure Protection** (waterproofing/damp proofing, exterior insulation and finish systems, fireproofing, shingles, roofing tiles, preformed roofing and cladding/siding, skylights, firestopping, joint sealers etc.)
- **Doors and Windows** (metal doors and frames, special metal doors and frames, wood and plastic doors, folding doors and grilles, metal windows, wood and plastic windows, hardware etc.)
- **Finishes** (ceiling suspension, lath and plaster, drywall, tile and terrazzo, acoustical treatment, wood flooring, stone & masonry flooring, cultured marble, soft flooring, carpet, paint removal, wall coverings etc.)
- **Specialties** (chalkboards and tackboards, compartments and cubicles, specialty modules, lockers, protective covers, storage shelving, toilet and bath accessories, fireplaces, and stoves etc.)
- **Equipment** (maintenance equipment, air compressor, unit kitchens, laboratory equipment etc.)
- **Furnishing** (artwork, landscape partitions and components, multiple seating etc.)
- **Special Construction** (pools, solar energy systems, wind energy systems, building automation systems etc.)
- **Conveying Systems** (dumbwaiters, elevators, moving stairs and walks, lifts, scaffolding etc.)
- **Mechnaical** (mechanical insulation, fire protection, plumbing, heating, ventilating, and air conditioning (HVAC), process piping & equipment etc.)
- **Electrical** (lightning protection systems, communications, alarm systems, fiber optic cabling etc.)
- **ABC Miscellaneous** (lightning protection systems, communications, alarm systems, fiber optic cabling etc.)

The third step is “assess material wastes” that is the process of analyzing individual project material wastes and defining waste index. The key benefit of this process is that it quantifies overall project material wastes exposure, and it can also provide additional material wastes to support waste response planning. The quantities of waste can be estimated as one of techniques to assess the material wastes by the transportation records of waste disposed off from the construction sites (Poon et al., 2004) via (Mahayuddin et al., 2010) (Equation 1).

$$C = \frac{W}{GFA} \quad (1)$$

V = truck load (ton)
N = total no of truck for waste disposal

W = total waste generated from the project (ton) = V x N
GFA = gross floor area
C = waste index (construction of 1 m2 gross floor area generates C ton of waste)

Waste index, building waste assessment score (BWAS), environmental performance score (EPS), component-global indices, stock flow model, Spanish model, material flow analysis model, universal waste ratio, system analysis model are the some of waste quantification models. Similarly, Smart waste, net waste tool, design out waste tool for buildings, web-based estimation system, DeconRCM, demolition and renovation waste estimation system are defined as waste prediction tools while on-line waste control tool, waste management plan, CALIBRE, Webfill, Construct Clear, SmartStart, SmartAudit, true cost of waste calculater are known as the waste data collection and audit tools. Also, BREMap, GPS-GIS system, IRP-based barcode system, GIS-BIM supply chain management system are evaluates as GIS-enables waste tools (Akinade et al., 2016).



Figure 2: Waste hierarchy (Council G. D., 2018).

“Material waste response” is the fourth process to develop options, selecting strategies, and agreeing on actions to address overall project material waste exposure, as well as to treat material wastes. The key benefit of this process is that it identifies appropriate ways to address overall project material wastes. This process also allocates resources and inserts activities into project documents and the project management plan as needed. This process is performed throughout the project. This step is closely related to material waste management

plan step. In this step waste hierarchy, which has 6 steps (Reduce, Reuse, Recycling, Recovery, Treatment, Disposal) can be implemented as seen in Figure 2 (Council G. D., 2018). Reducing the material waste is the best option of waste hierachy while disposal is the worst. So, firstly (Reduce, Reuse, Recycling) 3R technique is one of lean management tools should be implemented then the other options should be cared.

The fifth step is "implement material waste responses" which is the process of implementing agreed-upon material waste response plans. The key benefit of this process is that it ensures that agreed-upon material waste responses are executed as planned to address overall project material waste exposure, minimize project material wastes, and maximize cost, quality, time opportunities. This process is performed throughout the project.

The last step of material waste management is "monitor material wastes". Monitor material wastes is the process of monitoring the implementation of agreed-upon material waste response plans, tracking identified material wastes, identifying, and analysing new material wastes, and evaluating material waste process effectiveness throughout the project. The key benefit of this process is that it enables project decisions to be based on current information about project material waste exposure. This process is performed throughout the project.

Conclusion

Because of being the biggest driver of waste generation, the construction industry should care wastes and manage them effectively to move resource usage from traditional linearity to a level of high circularity. Effective material waste management provides cost saving, reduced demand for landfill, improved resource management, profit and quality maximisation. As a result of the today's limited resources and sustainable development, it is believed that waste management in the construction industry should has needed priority.

Waste management closely associate with almost whole construction project stakeholders such as the client, the main contractor, design team, subcontractors, project employees, suppliers, government authorities and local residents. It is thought that improving legislative framework in each country will promote the sustainable resource management all over the world when the construction waste generation is taken into consideration.

In this study, it is recommended that waste management should not be evaluated just as waste hierarchy. Waste management is a process that should be cared during the construction project life cycle. In the BCS, material waste management can be implemented as one of the knowledge area of PMBOK. So, it is thought that waste management should has its own process groups while tools and techniques are improved for the construction waste management.

As a result of occuring large material wastes in the world, it is thought that each country also our country should manage wastes especially in the building construction sites because of having largest share of waste generation. Although it has started to be implemented with the standards and legal sanctions established in different countries in the management of construction material wastes, our country is at the very beginning of the road in this respect. This paper contributes the types of material wastes to manage them well while analyzing the current applications in the countries which they have already manage their contruction material wastes. So, with this paper it can be obviously seen the strategies, categories of the

construction material wastes and a material waste management proposal in scope of PMBOK knowledge areas. This paper can be a vital paper to start the manage construction material wastes in terms of classifying them and analyzing the steps of management to implement the management strategies basically for the countries which wants to manage their construction material wastes.

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Evaluation of the Impacts of Mega Sports Events in Cities with the Sustainability Indicator: The Case of İzmir Olympic Village

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Abstract

Large-scale events, which are called mega events in the international arena, are important activities in terms of ensuring intercultural interaction and communication, investing in cities, supporting the development of cities, and promoting them. In order to ensure the spatial, economic and social sustainability of mega sports events such as the Olympic Games and the Universiade, their utilization during and after the event should be planned. The aim of this study is to examine the effects and contributions of the Universiade event organized in İzmir and the Olympic Village, which was built for the event, to the city, citizens and sustainability during and after the event. In the study, the effects of the event on the city were evaluated with the sustainability indicator scale. As a result of the study, it was seen that the Olympic Village contributes to spatial sustainability in the long term, but the economic and social contribution was effective during the Olympics. This study contributes to the scientific and practical field in terms of analyzing the effects of mega sports events, which offer various interactions and opportunities on a global, national and urban scale, to the urban space, development and sustainability. It is aimed that the inferences obtained from this study will guide the cities where mega events will be held in the future.

Keywords: *İzmir olympic village, mega sports events, sustainability, sustainability indicator, Universiade.*

Introduction

Sports events are universal phenomenon for people who grew up in different cultures and speak different languages to meet in a common point and strengthen their social bonds (Yıldız & Bitirim, 2008). The Olympic Games, which have been organized since ancient times, have the goal of providing world peace through interaction with physical activity, reminding universal values such as equality and fraternity. Sports organizations that have an international impact are events that are demanded and given importance due to the development of intercultural relations and the economic, spatial and social contributions they provide to the country where the event is realized. Large-scale organizations appeal to a large part of the world's population

through their international feature and media, lead the development of cities by being carried out with the support of volunteers, institutions and states, and enable social, cultural and economic interaction among the citizens of the participating countries (Theodoraki, 2016).

Mega events are large-scale events that are organized periodically in different countries in a certain period, are realized with high costs, and appeal to large audiences on an international scale (Toksöz et al., 2014). After the Olympic Games, which are held every four years, the second largest sports organization in the world is the World University Games, known as the "Universiade". The University Games, which are organized by the "International Universities Sports Federation" (FISU), whose origins are based on the World University Games in 1923, are organized as summer and winter games every two years, with the participation of university athletes from different countries (Baydar, 2010).

Turkey applied to FISU for the Universiade 2005 to be organized in İzmir in 1999, and at the Federation meeting held in Beijing, it was decided to realize the 23rd World University Summer Sports Games (23rd Universiade) in İzmir (Baydar, 2010). This organization is the biggest international sports event in the city after the Mediterranean Games in İzmir in 1972 (Ekmekci, 2011). Mega events such as International İzmir Fair, Mediterranean Games and Universiade are important for the future and identity of the city and contribute to the city in the short and long term (İzmir Metropolitan Municipality, 2005). Within the scope of the Olympic preparations, one of the spatial legacies left by the event to İzmir was the Universiade 2005 İzmir Olympic Village. The Olympic Village (İzmir Games Village) was built on an area of 300 000 square meters in the Çetin Emeç Neighborhood of Limontepe, between Balçova and Karabağlar districts, for the athletes and officials who will participate to the event.

In 2005, 5372 athletes and 2512 officials from 131 countries in the five continents of the world participated to the University Games held in İzmir between 11-21 August. Competitions were arranged in 10 compulsory branches including athletics, tennis, basketball, artistic and rhythmic gymnastics, volleyball, football, water polo, fencing, jumping and swimming, and 4 optional branches such as sailing, wrestling, taekwondo and archery. A total of 274 260 visitors watched the 10-day event (İzmir Metropolitan Municipality, 2005; Aslan et al., 2019). In addition to the sportive activities, exhibitions were organized in galleries and cultural centers in the city, and traditional arts were promoted in the Olympic Village. (İzmir Metropolitan Municipality Communication Center, 2006, as cited from Yıldız & Bitirim, 2008)

Depending on the socio-economic and political conditions of countries and cities, their objectives and the results they will obtain from mega event vary. In this sense, the evaluation of the effects of mega events is very comprehensive and variable situation, including physical, economic, social and environmental at global, national and local scales. In the literature, there are studies evaluating Universiade 2005 İzmir in terms of socio-cultural, physical and economic conditions. Yıldız and Bitirim (2008) evaluated the Universiade İzmir through intercultural communication and made suggestions for sports games to be held in the future. Baydar (2010) examined the Universiade 2005 Olympic organization, the Olympic village and its facilities' settlement, according to the principles of landscape architecture design and planning. Ekmekci (2011) discussed the tangible and intangible benefits of the games for İzmir and Turkey five years after the Universiade 2005 Games. In these studies, information about the planning phase of Universiade 2005 and its effects were included, but the evaluation of the decisions taken in the planning of the event, the practices implemented during the event process and after, within the scope of sustainability was not mentioned. Therefore, in this study, it is aimed to examine the short and long-term effects and contributions of the Universiade İzmir and the Olympic

Village to the city, citizens and sustainability during and after the event. The originality of this study is the analysis of the İzmir Olympic Village, which was built as part of a mega sports event, with a sustainability indicator.

Background Information

Universiade 2005 İzmir and Olympic Village

In line with the scope and goal of Universiade 2005 İzmir, accommodation and sports areas were planned, and physical and social arrangements were made in different areas of the city. Before the event, 59 facilities in İzmir were maintained and repaired for competitions and training sessions in line with the criteria of the FISU and brought into compliance with international standards. Halkapınar Sports Hall, Karşıyaka Sports Hall and Karşıyaka Tennis Courts were brought to the city as new facilities. (İzmir Metropolitan Municipality, 2005; Saf, 2012). In addition to the renovation of existing facilities and the construction of new facilities, access roads, parking lots, landscaping and infrastructure works have been carried out around these facilities, contributing to urban development (Saf, 2012).

In mega sports events such as Universiade, many details such as accommodation, transportation, meeting participants' needs, ensuring their safety (Yıldız & Bitirim, 2008) need to be planned before the event. Olympic villages are residential areas that provide accommodation for the athletes and officials participating to the competitions, and contain various facilities for food, beverage and other needs. An olympic village was needed for the Universiade 2005 because the dormitories where university students stay in İzmir are scattered in the city and do not have sufficient physical and social infrastructure (Saf, 2012). Universiade 2005 İzmir Olympic Village was planned considering its use during and after the event, and the construction of the village, whose contract was made in 2002, started in 2003 (Figure 1).



Figure 1: Left: The Olympic Village built by terracing on a sloping land; Right: Olympic Village in 2004 (Baydar, 2010).

Olympic Village's architectural project was prepared by Merih Karaaslan, Şükrü Kocagöz and Mürşit Günday, 934 apartments were built in 64 blocks with an accommodation capacity of 9952 people for the athletes and officials who would participate to the event. The apartments, built in six different plan types as A, B, C, D, E and F, were offered to people living in İzmir as residences after the event was over (İzmir Olympic Village). There are 3+1 apartments in the terraced houses built on two slopes facing each other, and 2+1 apartments in the buildings behind the terraced houses (Figure 2). In the central area at the foot of the two slopes, there are

common and social areas such as sports and playgrounds, and swimming pool (Figure 3). In the area, transportation is provided from the main street called Universiade Street through side streets that provide access to the terraced residential blocks and buildings between the two slopes. Side streets are named with sports branches such as Athletics, Basketball, Football (Figure 3).



Figure 2. Left: Terraced houses; Right: View of terraced houses and apartments from the street (Personal Archive, May 2022).



Figure 3. Left: Terraced houses and swimming pool in the center; Right: Street signs (Personal Archive, May 2022).

Sustainability

The concept of sustainability emerged with the idea of reducing and preventing problems such as environmental situations and pollution caused by economic and technological developments, and protecting the ecosystem (Karakurt Tosun, 2009). In the national and international platforms organized after the 1980s, the concept of sustainability began to be discussed together with the urban space and urban life issues. World Commission on Environment and Development (WCED) published “Our Common Future” report in 1987, and sustainable development was defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. In the Brundlant Report, it was stated that sustainable development should be provided holistically in political, economic, social, technological systems and production systems, and after this report, the phenomenon of sustainable development began to be seen as a value system accepted all over the world (Karakurt Tosun, 2009).

In order to achieve sustainable development in cities, "architectural and urban design projects should be developed that will ensure that the environment is protected and developed together with its values, providing spaces suitable for present and future uses, and that will increase the physical quality of the environment and the quality of life" (Çahantimur & Turgut Yıldız, 2008). In this direction, for sustainability to be effective in the long term, sustainability criteria must be considered in each of the processes of planning, implementation, use, maintenance and repair, and re-functioning after use. In relation to these goals, various performance evaluation and indicator criteria have been established to measure the effects of sustainability in urban space (Couch & Dennemann, 2000; Hemphill et al., 2004; Yiğitcanlar & Dur, 2010). The reason for the creation of these measurements is to evaluate the concept of sustainability, which is becoming increasingly important, in line with spatial, social, cultural, economic, ecological and environmental criteria and to develop awareness in these issues.

Material and Method

Evaluating the effects of mega sports events is quite difficult due to the diversity and content of the effects. In general, these effects can be analyzed thematically in economic, social, environmental, and political framework, as well as their local and global effects, their effects before, during and after the event, and the effects of the actors involved (Theodoraki, 2016) (Figure 4). In this study, the effects of the mega sport event in the Olympic Village built for the Universiade 2005 were examined with the evaluation criteria adapted from the sustainability indicator scale developed by Couch and Dennemann (2000) to measure the sustainability in the urban renewal area in Liverpool, England. The scale consists of eight key assessment criteria and sustainability is evaluated with different statements in each evaluation criterion. The sustainability indicator scale developed by Couch and Dennemann has been discussed and used in different academic studies (Evans & Jones, 2009; Lombardi et al., 2010; Korkmaz, 2015; Gençer Özdemir, 2019). In this study, the statements in the sustainability indicator scale were adapted and developed in order to evaluate the planning, event and post-event processes of the mega event in line with the subject and content of this research.

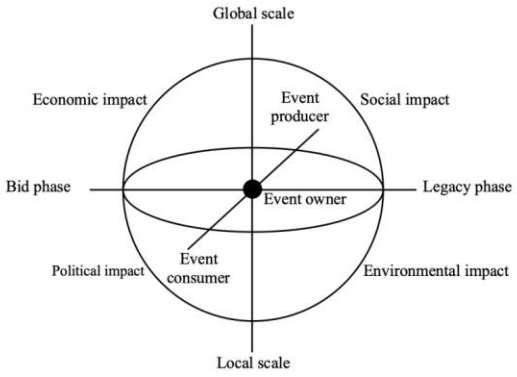


Figure 4. Effects of mega sports events (Theodoraki, 2016).

Evaluation of Universiade 2005 İzmir Olympic Village with the Sustainability Indicator Scale

In this study, the physical, social, economic and environmental sustainability of the Olympic Village, which was left to İzmir as the event legacy, was analyzed with the sustainability indicator scale adapted from the study of Couch and Dennemann (2000) (Table 1). Within the scope of the study, the subjects of community participation, economy and work, transport, pollution, energy, waste and resources, buildings and land use, wildlife and open spaces are evaluated as positive, neutral/mixed and negative impacts of the Olympic Village on the city, citizens, natural and built environment.

Table 1. Evaluation of Universiade 2005 İzmir Olympic Village with the sustainability indicator scale.

Sustainability Indicator	Positive Impact (+)	Neutral / Mixed Impact (*)	Negative Impact (-)
1 Community Participation			
(a) encourage local action and decision making in the planning and execution of the event			-
(b) involve the community in the development of the proposal/plan in the planning and execution of the event			-
(c) take into account under-represented groups		*	
(d) ensure the participation of local/foreign visitors during the event process.	+		
(e) ensure participation of local/foreign visitors after the event			-
2 Economy and Work			
(a) link local production with local and global consumption during the event process	+		
(b) link local production with local and global consumption after the event process			-
(c) increase employment during the event process		*	
(d) maintain/increase employment after the event			-
3 Transport			
(a) proximity of the event area to the city center		*	
(b) access from the event area to the city center (diversity of roads and transportation vehicles)			-
(c) encourage walking and cycling			-
(d) encourage use of public transport		*	
(e) discourage use of cars or lorries			-
4 Pollution			
(a) reduce local pollution (noise, air, water, soil)	+		
5 Energy			
(a) maximise energy efficiency			-
(b) generate energy from renewable reources or waste			-

6 Waste and Resources			
(a) reduce waste			-
(b) encourage reuse and/or repair			-
(c) encourage recycling or recycled products		*	
7 Buildings and Land Use			
(a) provide local materials and methods			-
(b) improve access for disabled			-
(c) reuse/conserve buildings	+		
(d) reuse of buildings after the event	+		
8 Wildlife and Open Spaces			
(a) encourage use of open space for community benefit	+		
(b) offer different possibilities like outdoor sports, cultural, social activities, etc.	+		
(c) encourage natural plant and animal life		*	
(d) protect and promote the use of the built environment and green space	+		

Community Participation

In the UN Environment and Development Conference organized in Rio de Janeiro in 1992, it was emphasized that sustainable development should be realized with the participation and cooperation of different actors, including central governments, local governments, non-governmental organizations, private sector and individuals (Karakurt Tosun, 2009). The planning and realization of the İzmir Olympic Village were determined by the central and local government, and the community was not included in the development of the plan. The Olympic Village served for the accommodation of foreign athletes between August 3-23 (Baydar, 2010) and hosted volunteers, local and foreign athletes during this time. After the event, with the settlement of the residents, it continues to be used as a closed and secure site, allowing foreigners to enter in a controlled manner. The lack of community participation in the planning of the Olympic Village and the transformation of the area into a closed site after the event negatively affect social sustainability.

Economy and Work

Hosting mega events, developing international relations, providing economic growth, and creating short and long-term benefits that will be effective in the city and the life of the citizens are considered as opportunities (Er & Güzel, 2019). When Universiade 2005 İzmir is evaluated in economic terms, the games and the arrangements made in the city cost 100 million dollars (Ekmekci, 2011), economic activity was created with the ticket revenues of the event and the expenditures of the visitors. (Saf, 2012). In this direction, when the economic sustainability in the Olympic Village is evaluated, it is seen that the economy was stimulated with production and consumption activities before and during the event, but after the event, the commercial activity in the region was limited to a few shops and restaurants.

A volunteer team of 18.753 people from 77 universities and 75 cities in Turkey, 84% of whom are from İzmir, was gathered to work in the Olympics and the Village (Ekmekci, 2011). During the event, jobs were provided by the assignment of volunteers and public service providers, and no direct contribution was made to employment. After the event, although a certain population

settled in the region, it did not have a positive effect on employment due to the limited commercial areas.

Transport

The distance of the Olympic Village to the city center is approximately 12 kilometers (Figure 5). Since the location of the Olympic Village is far from the facilities where the competitions were held, the athletes have had problems with distance and time (Baydar, 2010). In this sense, in determining the locations of the Olympic Villages, it is important to choose the closest point to the city center, which will not be far from the facilities during the event and will serve the citizens after the event. There is İzmir Freeway near the area and the city center can be reached by private vehicle and public transportation. Due to the location of the region, there are no regulations that encourage walking or cycling or discourage the use of large vehicles, which negatively affects economic and environmental sustainability.

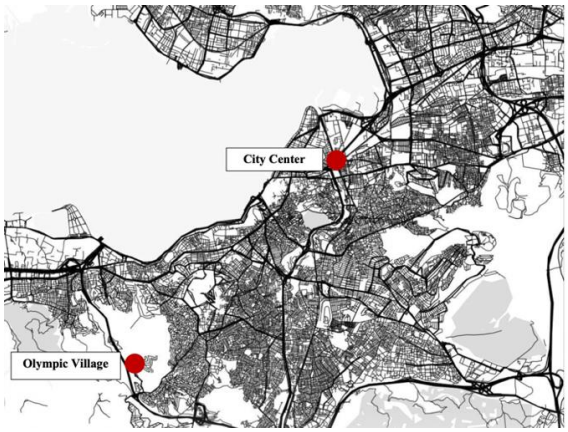


Figure 5. Location of Olympic Village in the city (URL 1).

Pollution

In İzmir Olympic Village, a large green area has been brought to the region with landscaping works, and air and noise pollution has been greatly reduced since motor vehicle use is not intense in the site. Maintenance and cleaning works are carried out by the site management on the roads and common areas, and these works help to prevent environmental pollution. In this respect, it can be interpreted that the impact of İzmir Olympic Village on sustainability is positive in terms of pollution criteria.

Energy

In today's conditions, where energy resources are rapidly depleted and energy efficiency has become an important issue, it is important to research and apply alternative energy sources for sustainable urban development and to ensure energy efficiency. In İzmir Olympic Village, blocks were built to meet the need for shelter during and after the Olympics, but no application was made in this project to increase energy efficiency in the settlement or houses, or to generate energy from renewable resources or waste. Therefore, the impact of İzmir Olympic Village on environmental sustainability is negative.

Waste and Resources

The protection of limited resources, the separation or recycling of wastes and their reuse contribute to sustainability economically and environmentally. On the streets of İzmir Olympic Village, there are waste collecting and recycling bins placed by the Balçova Municipality in order to separate the wastes and ensure their recycling (Figure 6). Glass, composite, cardboard, metal and plastic wastes are collected in these boxes. In addition, there are second-hand clothes, shoes and textile boxes placed by the Balçova Municipality on the streets. The products collected in these boxes are delivered to people in need by the municipality. Despite these practices, there is no information on what actions are taken to reduce waste or after waste collection.



Figure 6: Left: Waste and textile collection bins; Right: Recycle bin (Personal Archive, May 2022).

Buildings and Land Use

While planning the İzmir Olympic Village, the aim was stated that "it will be presented to the city as a part of it whose social and technical infrastructure has been completed with the transformation project after the games as an environmentally sensitive and city-related settlement", and it was aimed to hand over the residences to their owners after the event (İzmir Metropolitan Municipality, 2003). 934 residences in the Olympic Village, which were built for the athletes and officials participating in the event, were re-functionalized as a housing area where the people lived after the event. There are 742 3+1 flats of types A, B, C and D in the terraced blocks and 192 2+1 flats of types E and F in the buildings. The size and plan of each type of flat varies, and users can choose according to their needs.

Regarding the buildings and land use, the maintenance of the sports facilities in the city for Universiade 2005, the low number of newly built sports facilities, the active use of the sports facilities by the citizens after the event, the re-functioning of the Olympic Village as housing after the event, positively affects physical sustainability and the event legacy. However, it is seen that the use of local materials and methods is not included in the planning and implementation of the project, which negatively affects environmental sustainability. In addition, although the Awareness Center was opened in the Olympic Village to draw attention to the problems of disabled people and to organize educational and social activities for them (İzmir Metropolitan Municipality, 2018), there is no regulation to improve access for the disabled due to the sloping land structure and terraced houses.

Wildlife and Open Spaces

In the project of the Olympic Village, the planning of green areas in the open areas and common social areas between the terraced houses spread over the land, and the effort to establish a balance between the built environment and the green area affect social and environmental sustainability in a positive way. As each flat offers the opportunity to use open space on its own terrace, the presence of spaces such as playground, activity square, open sports fields and swimming pool in the village encourages the use of open space and offers the opportunity to socialize (Figure 7).



Figure 7: Left: Children's playground in the village; Right: Outdoor sports field (Personal Archive, May 2022).

Conclusion and Recommendations

Mega events, including sports activities, contribute to the country and city where they are organized, by making investments, improving political and social relations, increasing economic activity and making spatial arrangements. These organizations, which appeal to large audiences around the world, are also important tools for the promotion of countries, becoming touristic and cultural centers of attraction, and the realization of international interaction. However, in order to realize the impact of these organizations on the environment, city and citizens in a long-term beneficial way, it is necessary to make plans and practices based on physical, economic, social and environmental sustainability.

The University Games organized in İzmir became a mega event where incoming university athletes competed in sports competitions for 10 days and stayed in the Olympic Village. The effects of mega events on the city can be examined in the short and long term. The short-term effects of Universiade 2005 on the city can be expressed as the press members from all over the world introducing the country and the city to the world during the event, the visitors contributing to tourism by staying in hotels, the transportation of athletes, officials and visitors, and the creation of employment and economic mobility for their needs. The long-term effects of Universiade 2005 on the city can be expressed as the maintenance and repair of the existing sports facilities and the construction of new sports facilities, the construction of the Olympic Village, and the acquisition of the Olympic Village as a residential settlement addressing different economic and social needs. In this sense, it is seen that there is a spatial contribution to İzmir in the long term, but the effect of the economic and social contribution is short-lived.

In this study, the Olympic Village built for the Universiade 2005 in İzmir was evaluated with the sustainability indicator scale. According to the data obtained from the evaluation, although there are positive features in the event process, it is seen that the impact on social and economic sustainability in relation to community participation, economy and work is negative before and after the event. It might be said that environmental and economic sustainability are negatively affected in relation to transportation, energy use, waste and resources. On the other hand, the positive features of the project are the reduction of local pollution due to the built and natural environment balance created in the settlement area, the re-functioning of the accommodation areas built for the event as housing after the event, and the creation of social areas by encouraging the use of open space and green space. This situation positively affects physical, economic, environmental and social sustainability. In this sense, it is seen that the decisions taken during the planning and design of the event affect and direct the life and sustainability in the Olympic Village. According to the information obtained from the study, the recommendations for ensuring sustainable urban development that will be effective and efficient in the long term for the cities hosting mega events and their citizens are as follows:

- Organizing the events in developed regions in terms of physical and social infrastructure, quality and number of facilities,
- Determining the sustainability goals and practices in the planning, implementation, use and post-use processes of the event,
- Establishment of network and common studies between different actors such as international collaborations, central and local government, experts, private sector,
- Consulting the public about the project, assessing their needs and expectations, informing them about the implementations and ensuring their participation,
- Determining the needs and investments that will provide urban development and,
- Making budget, cost and income estimations,
- Organizing infrastructure works and building facilities that will contribute to the city in the long term,
- Determining the spatial uses during and after the event,
- Implementation of practices for the protection of natural resources and the environment,
- Making spatial and social arrangements for sharing of cultural and social values,
- Creating a good impression by promoting the country on an international scale

In this direction, planning should be done by evaluating the short-term and long-term effects of mega events on cities, and mega events should be made a tool of urban development. This study contributes to the scientific and practical field in terms of evaluating the effects of mega sports events, which offer various interactions and opportunities on a global, national and urban scale, on urban space, urban development and their contribution to sustainability and presenting suggestions. It is expected that the results of the study will guide the policymakers, and event organizers who would play a major act in mega events organized in the future.

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Effect of Solar Shade Elements on Heating and Cooling Loads in Houses and Cost Relationship

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Abstract

The world's population is growing rapidly, increasing the demand for energy in many sectors, such as industry, housing, transportation, etc. The high energy consumption in buildings has made efforts necessary for the effective use of energy. Energy efficient building design efforts are usually based on a building, floor, or apartment over the building envelope thermal insulation. What distinguishes this study from others is that it used shading elements in a block-based compound, taking into account the location, orientation, and distances between buildings. In addition, it performed energy analyses for the case where electrical energy, as well as natural gas, is used for heating buildings. This study focused on base buildings in a block-based compound in Antalya in the Mediterranean Climate Region. The study examined the effect of fixed sunshade systems on the energy performance of the building. Design Building Models were developed by applying sunshade systems to the Base Building Models. Energy consumption data of heating, cooling and ventilation systems were analyzed with the DesignBuilder simulation program. As a result of the analysis; It has been observed that the total annual energy savings of the Design Building Models reached 8.4%, and the building cost increase was 1.4 $/m² on average.

Keywords: *building energy simulation, cost analysis, energy efficient design, sunshade design.*

Introduction

One in every two people lives in urban areas worldwide, which is projected to increase to 75% by 2050 (European Commission, 2020). The world's population is growing rapidly. Therefore, cities are expanding at an unprecedented rate, with new residential areas and houses under construction. Due to rapid urbanization, millions of people are moving into cities, causing an increase in energy demand. People are consuming natural resources excessively to meet their energy needs. However, this trend is turning into a global disaster. Over the last decades, energy has become a critical issue for countries due to the increasing demand for energy and rising energy costs.

The European Union (EU) has set energy and climate targets within the scope of its 2030 strategy. The EU has aimed to reduce greenhouse gas emissions by 2030 by at least 40% (compared to 1990), increase the share of renewable energy sources in energy consumption to at least 32%, and provide at least a 32.5% improvement in energy efficiency (European

Commission, 2014). According to the Energy Efficiency 2021 Report by the International Energy Agency (IEA), the public and private sectors spent $188 billion in 2021 on energy efficiency in buildings, industrial structures, and transportation. In addition, annual clean energy investment worldwide is projected to increase to $4 trillion by 2030 to reach net-zero emissions by 2050 (IEA, 2021).

According to the Turkish Statistical Institute, less than a quarter of the residences in Turkey have thermal insulation on the wall (15%) and the roof (16%) (Kobalas, 2015). Most of the energy used in residences in Turkey is for heating (81%), indicating low energy efficiency. Turkey's energy-saving potential reaches 50% in buildings (Pamir, 2017). According to the Final Declaration of Combating Climate Change published by the Ministry of Environment and Urbanization of the Republic of Turkey (2021), Turkey will make smart city practices more common and build energy-efficient and eco-friendly residential areas.

Design decisions determine the amount of energy a building will likely consume throughout its service life. Every building needs energy for heating, cooling, ventilation, and lighting. We must apply energy-efficient construction criteria (zoning plans, plot location, situations with neighboring plots, setback distance, building envelope, user demand, etc.) to keep energy consumption to a minimum. Designers are most involved in the design of building envelopes.

Opaque components and glasses consist of wall elements and insulation materials. Transparent components consist of joinery. A building envelope is an energy-efficient building criterion that consists of transparent and opaque components. There is a large body of research focusing on opaque and transparent components to achieve energy efficiency in buildings (Vincelas & Ghislain, 2017; Koyun & Koç, 2017; Kon, 2018; Cüce et al., 2019; Aydin & Biyikoglu, 2020; Motlagh et al., 2021; Sayadi et al., 2021). Researchers address building envelope designs and consider building heating loads to make calculations.

This study investigated the effect of fixed sunshade systems on energy performance. Earlier research has examined energy efficiency based on a building, floor, or site. However, this study looked into energy efficiency based on a "block-based settlement" in buildings in Antalya, which is located in the Mediterranean Climate Region. People in Antalya widely use electricity for heating. Therefore, this study also developed scenarios where electricity, as well as natural gas, is used for heating to compare energy efficiency by fuel type.

Solar Control in Energy Efficient Building Design

We must develop “solar-friendly” designs to reduce energy consumption, energy costs, and carbon emissions in buildings. Integrating solar technology into buildings can ensure that they generate renewable energy and consume less energy through natural lighting depending on sunshine hours and daylight (Kazaz et al., 2019). Natural lighting depends on the climatic conditions, exterior barriers, orientation, shape, frame and glass properties and size of windows, and light reflectance factor of interior surfaces (Yüksel, 2019).

It is necessary to control the amount of solar radiation to prevent unnecessary heat gain in buildings in hot climate regions (Figure 1). Excessive heat gain increases cooling loads and thus the amount of energy consumed (Koca, 2006). Shading elements are part of energy-efficient building designs. Shading elements are artificial environmental variables that can be controlled according to window position and indoor solar radiation. Overheating due to solar radiation has adverse effects on users. Therefore, we should ensure as low heat gain as

possible to prevent this. We can reduce the thermal effect of the sun by placing shading devices in front of windows and opaque surfaces (Balcıoğlu, 2013).

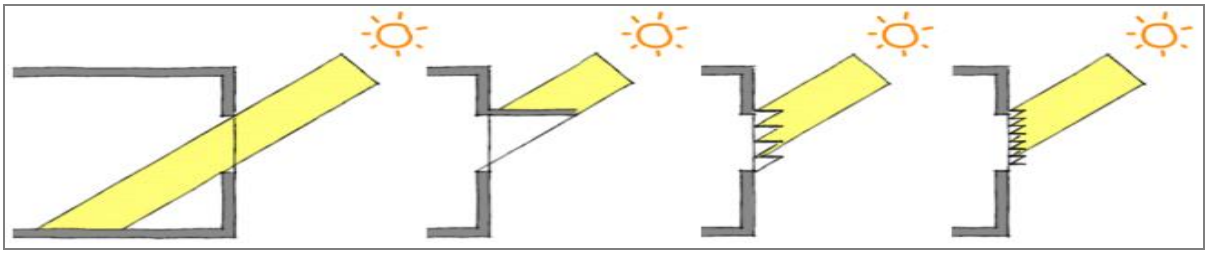


Figure 1: Solar shading design and solar radiation (Url-1, 2022).

The most common sunshade systems are consoles, shutters, and vertical-horizontal bars. These systems can be fixed or adjusted manually or mechanically. Sunshades are positioned outside buildings to prevent the thermal effect of daylight from penetrating the interior. These systems are designed according to the angle of light in summer (the sun is at its highest) and winter (the sun is at its lowest). While vertical bars are used on the east and west façades, horizontal bars are used on the south façades to prevent low-angle solar radiation in the morning and afternoon (Ofluoğlu, 2018) (Figure 2).

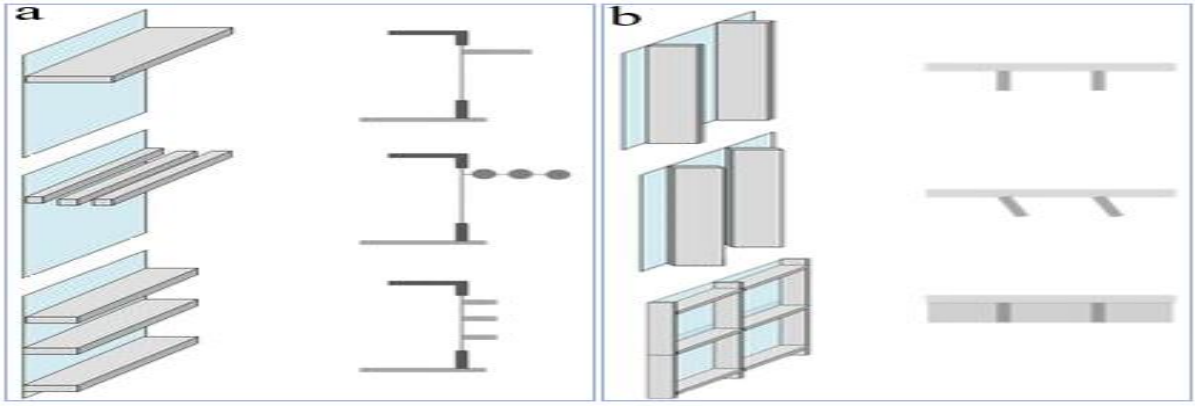


Figure 2: Horizontal and vertical sunshade design; a) south facade application, b) east and west facade application (Url-2, 2022).

Method

The sample consisted of a block-based urban transformation project in Antalya. The city has a hot-humid climate because it is located in the Mediterranean Climate Region. The study investigated how much solar shading systems could reduce the energy needs of buildings in block-based residential complexes.

This study had six stages. First, the buildings in the block-based settlement were determined as Block B, Block D, and Block F "Based Buildings" according to orientation, location, facade area, number of floors, and transparent surface ratio. Second, "Base Building Models" were developed modeling Block B, Block D, and Block F according to the current design parameters. Third, "Design Building Models" were developed by applying sunshade systems to the Base Building Models. The sunshade systems are recommended by the American

Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) according to climate zones. Fourth, the Base Building Models and Design Building Models were compared in terms of energy consumption to achieve energy cost, emission, and saving rates. Fifth, data were analyzed using the DesignBuilder dynamic thermal simulation program with a meteorological database and 3D modeling. Sixth, a cost analysis was made by calculating the investment cost of the solar shading systems.

Two Base Building models were developed according to the type of energy (natural gas and electricity) for heating. The "Design Building-1" model was developed by applying the sunshade systems to the "Base Building-1" (natural gas for heating; electricity for cooling) model, where natural gas is used for heating. The "Design Building-2" model was developed by applying the sunshade systems to the "Base Building-2" (electricity for heating; electricity for cooling) model, where electricity is used for heating.

Findings and Discussion

The research setting was a block-based urban transformation project consisting of six blocks and 317 residences on a 37,647 m^2 construction area (Figure 3). Block A consisted of 10 floors and 41 independent sections. Block B consisted of ten floors and 76 independent sections. Block C consisted of eight floors and 36 independent sections. Block D consisted of 11 floors and 41 independent sections. Block E consisted of nine floors and 72 independent sections. Block F consisted of 9 floors and 51 independent sections.

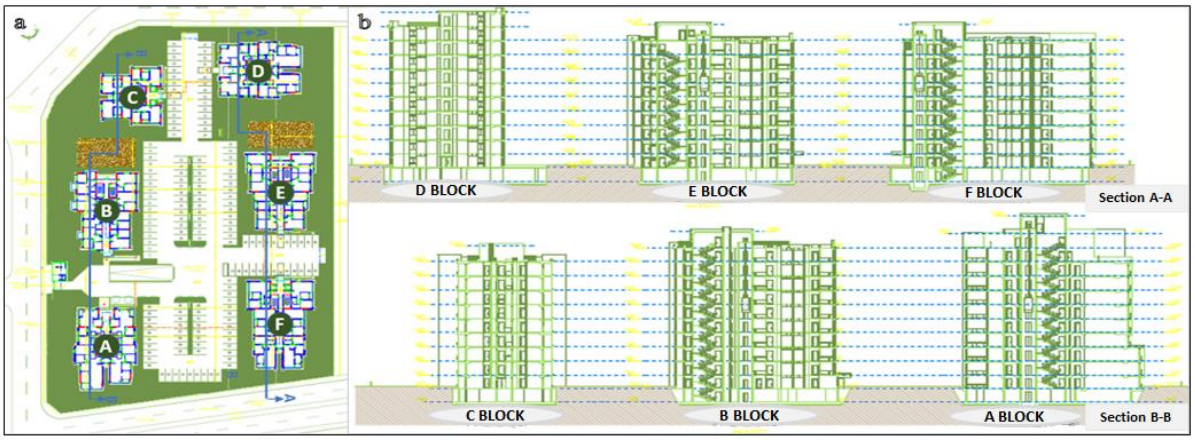


Figure 3: Urban transformation project; a) layout plan, b) sections.

The buildings were determined as Block B, Block D, and Block F "Based Buildings" according to orientation, location, facade area, number of floors, and transparent surface ratio. The base buildings were individually modeled according to the current design parameters (Figure 4).

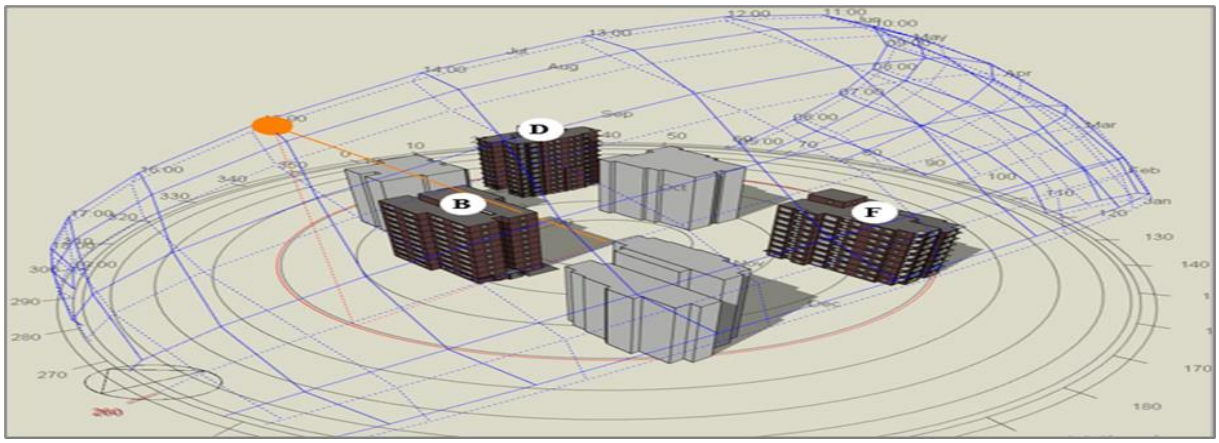


Figure 4: Model image.

The total area of the windows of Block B was 894.70 m^2 (60.60 m^2 south facade, 51.70 m^2 north facade, 388.30 m^2 east facade, and 394.10 m^2 west facade). The ratio of opaque surfaces to transparent surfaces on the exterior was 30% (Figures 5 and 6).

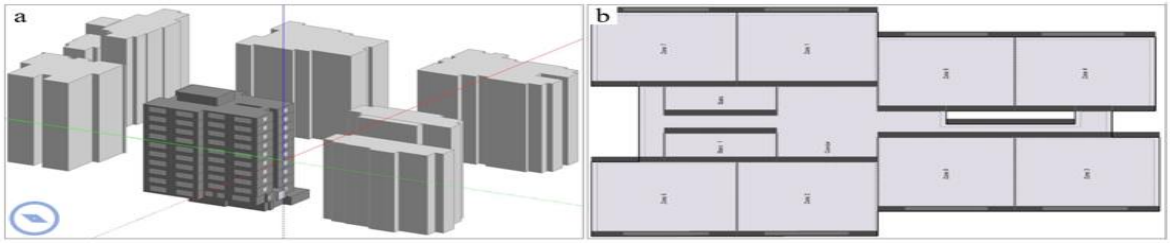


Figure 5: Block B model image; a) layout plan, b) floor plan.

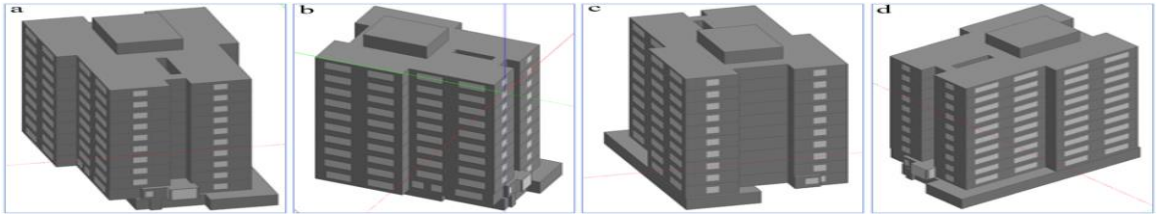


Figure 6: Block B model image; a) south facade, b) west facade, c) north facade, d) east facade.

The total area of the windows of Block D was 953.20 m^2 (278.70 m^2 south facade, 229.10 m^2 north facade, 309.70 m^2 east facade, and 135.70 m^2 west facade). The ratio of opaque surfaces to transparent surfaces on the exterior was 32.25% (Figures 7 and 8).

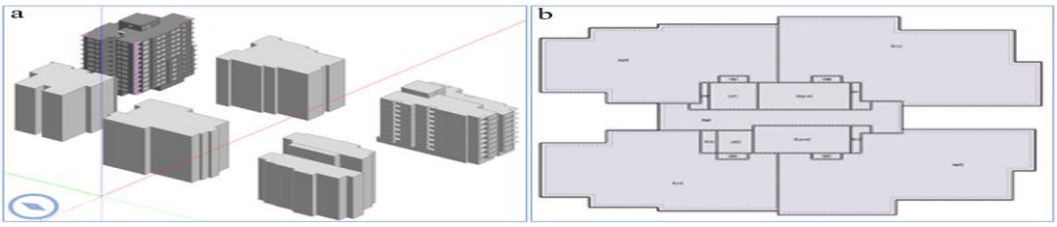


Figure 7: Block D model image; a) layout plan, b) floor plan.

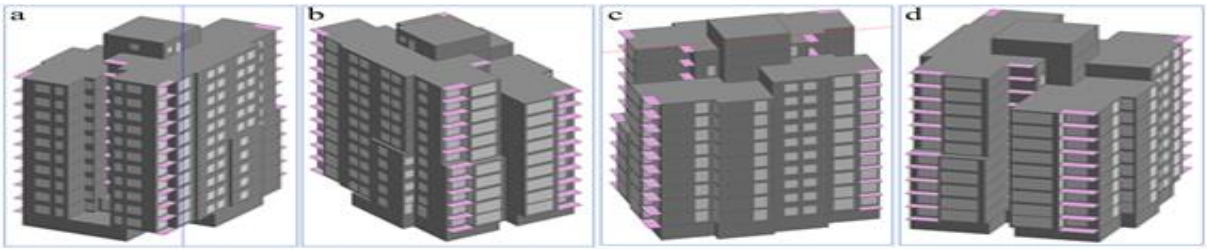


Figure 8: Block D model image; a) south facade, b) west facade, c) north facade, d) east facade.

The total area of the windows of Block F was 1023 m^2 (193.80 m^2 south facade, 24.05 m^2 north facade, 402.10 m^2 east facade, and 402.10 m^2 west facade). The ratio of opaque surfaces to transparent surfaces on the exterior was 39.41% (Figures 9 and 10).

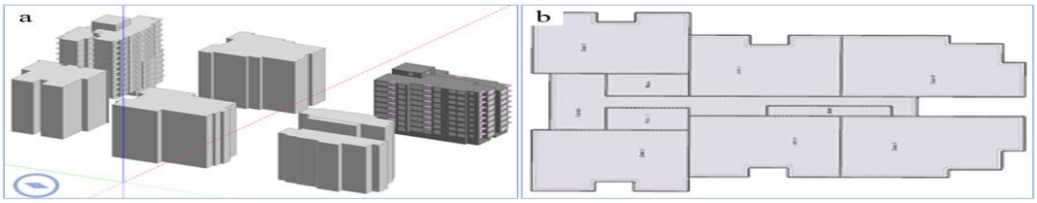


Figure 9: Block F model image; a) layout plan, b) floor plan.

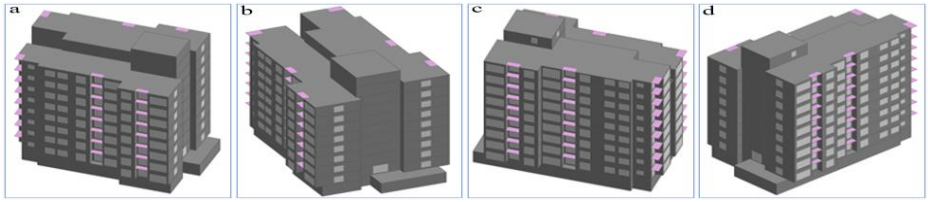


Figure 10: Block F model image; a) south facade, b) west facade, c) north facade, d) east facade.

The climate data of the ASHRAE Climate Zone 3A (Turkey's 1st Climate Zone) were used to calculate the heating and cooling loads for Antalya. The Base Buildings and Design Buildings were modeled according to the ASHRAE standard residential use profile.

The climate data of the ASHRAE Climate Zone 3A (Turkey's 1st Climate Zone) were used to calculate the heating and cooling loads for the Base buildings according to the ASHRAE 90.1-2010 standard recommended by ASHRAE. According to the ASHRAE Standard residential use profile, the Base Buildings and Design Buildings were modeled according to the number of occupants (20 m^2/person) and the operating hours/days (7/24).

Buildings can act as solar radiation barriers for each other according to distance, density, height, orientation, and positioning. This study examined the effects of these basic choices on energy efficiency. Figures 11, 12, 13 and 14 show the shadow effect of the buildings on equinox days.

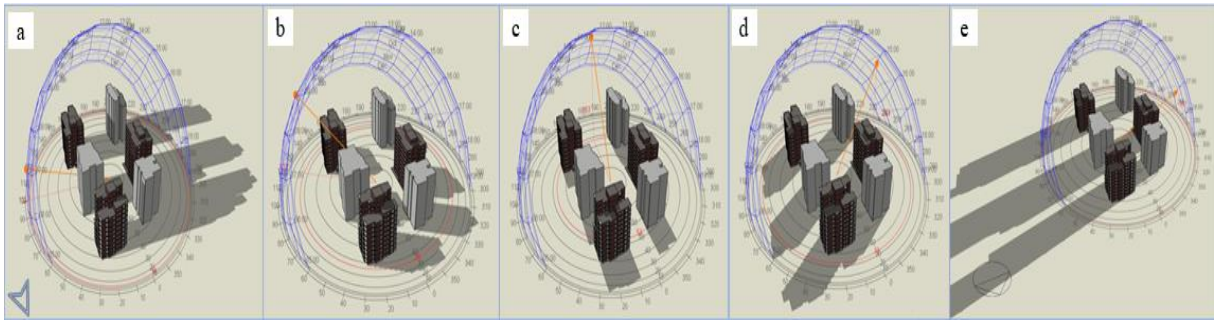


Figure 11: Shadow lengths formed by buildings on March 21; a) 7:00 am, b) 9:00 am, c) 12:00 pm, d) 15:00 pm, e) 17:00 pm.

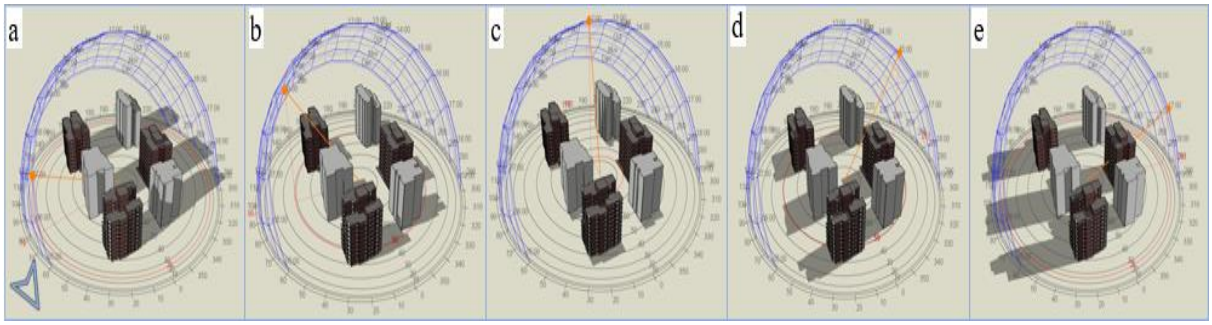


Figure 12: Shadow lengths formed by buildings on June 21; a) 7:00 am, b) 9:00 am, c) 12:00 pm, d) 15:00 pm, e) 17:00 pm.

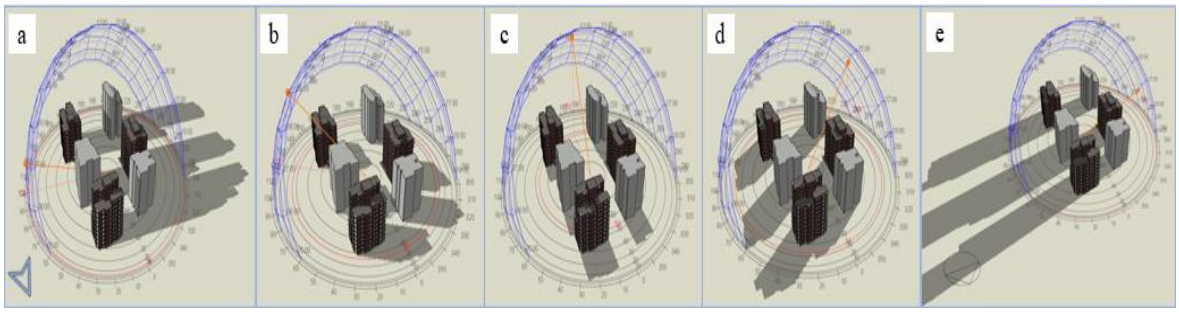


Figure 13: Shadow lengths formed by buildings on September 23; a) 7:00 am, b) 9:00 am, c) 12:00 pm, d) 15:00 pm, e) 17:00 pm.

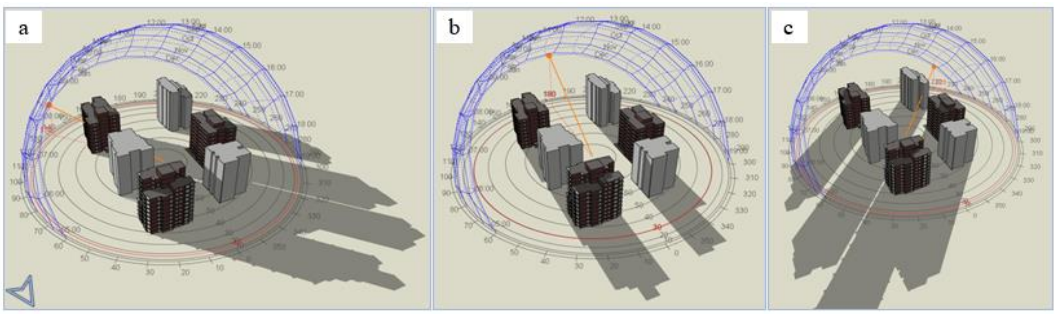


Figure 14: Shadow lengths formed by buildings on December 21; a) 9:00 am, b) 12:00 am, c) 15:00 pm.

Antalya is located in the First Region, according to TS 825. Horizontal sunshade systems on the south facades and vertical sun shading systems on the east and west facades were applied to the Base Building Models according to the ASHRAE criteria to reduce the cooling need of the building in line with the energy-efficient building criteria. The study investigated the effect of sunshade systems on energy performance. Vertical and horizontal sunshades were designed by taking the shadow element parameters as projection (60 cm), height (15 cm), depth (15 cm), and overflow (15 cm) (Figure 15). The investment cost of the solar shading systems was calculated based on the price of aluminum sunshade products (16.31$/m-12.01.2021) (Table 1).

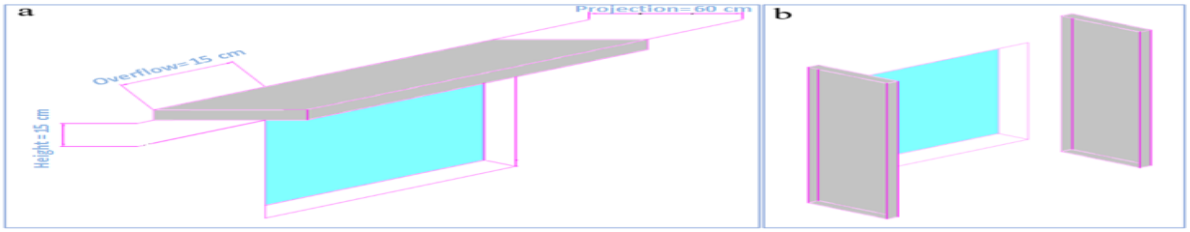


Figure 15: Sunshades applied to Base Building models; a) horizontal sunshade, b) vertical sunshade.

Table 1. Solar shading system cost analysis applied to base buildings.

Sunshade Design	Length (m)	Solar Shade Cost ($)		Cost Increase Rate ($)
		Current Status	Improved Status	
Block B				
South Facade Sunshades	35	–	570.82	
East-West Facade Sunshades	602	–	9818.08	
Total Cost		–	10388.90	100.00%
Cost Per Flat		–	136.70	
Unit Area Cost		–	2.19	
Block D				
South Facade Sunshades	125	–	2038.64	
East-West Facade Sunshades	162	–	2642.08	
Total Cost		–	4680.71	100.00%
Cost Per Flat		–	114.16	
Unit Area Cost		–	0.92	
Block F				
South Facade Sunshades	66	–	1076.40	
East-West Facade Sunshades	248	–	4044.66	
Total Cost		–	5121.06	100.00%
Cost Per Flat		–	100.41	
Unit Area Cost		–	0.98	

The Base Building Models did not have shading systems. Therefore, the cost increase rate of integrating horizontal and vertical sunshade systems was 100% (Table 1). The effect of the sunshade system cost on the cost increase of the building was 1.4 $/m² on average. Hourly analyses were performed on the Base Building and Design Building Models using the Design-

Builder simulation program. Table 2 shows the heating and cooling energy consumption amounts of the buildings. Table 3 shows the total energy consumption, cost, emission, and energy-saving rates.

Table 2. Heating and cooling energy analysis of the solar shading system.

System/Usage (kWh)	Base Building-1	Design Building-1	Savings Rate-1	Base Building-2	Design Building-2	Savings Rate-2
Block B						
Heating	70880.81	75298.20	-6.2%	29031.42	30811.29	-6.1%
Cooling	106702.31	78940.34	26.0%	106687.51	78929.92	26.0%
Block D						
Heating	81871.82	88202.90	-7.7%	31645.58	34080.07	-7.7%
Cooling	85321.87	74630.76	12.5%	85313.44	74624.28	12.5%
Block F						
Heating	71083.82	78909.70	-11.0%	27957.26	31003.82	-10.9%
Cooling	105454.20	96763.70	8.2%	105441.45	96752.08	8.2%

Table 3. Comparison of total energy consumption of base buildings and design buildings.

Account Items	Base Building-1	Design Building-1	Base Building-2	Design Building-2
Block B				
Consumption (kW)	351880.65	328530.61	311385.92	285319.86
Cost ($)	0.00	10388.90	0.00	10388.90
Energy Savings (kW)	6.6%		8.4%	
Emissions Savings (kg)	2.3%		8.4%	
Cost Increase Rate ($)	100.00%		100.00%	
Block D				
Consumption (kW)	325667.92	321796.41	275640.13	267210.76
Cost ($)	0.00	4680.71	0.00	4680.71
Energy Savings (kW)	1.2%		3.1%	
Emissions Savings (kg)	-2.3%		3.1%	
Cost Increase Rate ($)	100.00%		100.00%	
Block F				
Consumption (kW)	343797.43	342939.69	301847.08	296008.96
Cost ($)	0.00	5121.06	0.00	5121.06
Energy Savings (kW)	0.2%		1.9%	
Emissions Savings (kg)	-3.6%		1.9%	
Cost Increase Rate ($)	100.00%		100.00%	

The sunshade system increased the energy consumption for heating between 6.2% and 11.0%, while it provided annual energy savings between 8.2% and 26.0% in energy consumption for cooling (Table 2). We should use mechanical adjustable sunshade systems instead of fixed sunshade systems in order to make optimum use of solar energy and keep the increase in energy consumption for heating to a minimum in the Design Building Models. The Mediterranean Climate Region has more cooling degree-days (CDD) than heating-degree-

days (HDD). Therefore, we must create energy-efficient building designs that will keep energy consumption for cooling to a minimum. The sunshade system reduced total energy consumption in the Design Building Models (Table 3). Block B, Block D, and Block F Design Buildings achieved total energy savings of 6.6%, 1.2%, and 0.2%, respectively, when natural gas was used for heating. On the other hand, they achieved total energy savings of 8.4%, 3.1%, and 1.9%, respectively, when electricity was used for heating. The smaller the ratio of opaque surfaces to transparent surfaces in Base Buildings, the more energy the solar shading system saved.

Electricity allowed the buildings to save more energy than natural gas (Table 3). This can be explained by the fact that the electricity efficiency (Ƞh,s=0.99) is higher than the natural gas efficiency (Ƞh,s=0.93). In terms of energy cost comparison, natural gas should be used for heating for energy cost savings in buildings because the electricity unit price ($0.0790352/kWh, Ck Akdeniz Electric Inc.-Domestic-April 2021) is higher than the natural gas unit price (0.0241020$/kWh, Enerya Energy Inc.-Residential-April 2021).

Conclusion

This study examined the effect of a sunshade system on energy performance in buildings in a block-based settlement in Antalya, which is located in the Mediterranean Climate Region. The results showed that the solar shading system reduced annual energy consumption by up to 8.4%. The energy-saving rates indicate that costs are not obstacles to installing solar shading systems.

This study is important for two reasons. First, it took into account design parameters (location and orientation of buildings and distance between buildings) to evaluate energy efficiency on a block basis. Second, it performed energy analyses on scenarios where electricity replaced natural gas for heating.

In conclusion, solar shading systems provide energy savings in buildings in the block-based settlements in Antalya. We think our results will guide municipalities, academia, and the construction industry because this study focused on sustainable energy and examined the relationship between solar shading systems and energy costs.

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Investigation of the Effect of Building Orientation on Building Energy Performance in the Mediterranean Climate Region

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Abstract

The world's population is growing rapidly, resulting in urban sprawl, increased demand for energy, and environmental pollution. This has promoted efforts to construct energy efficient buildings. Energy efficient building design efforts are usually based on a building, floor, or location through the building envelope design. What distinguishes this study from others is that it calculated energy efficiency in a block-based compound, taking into account the location, orientation, and distances between buildings. It also performed energy analyses for the case where electrical energy, as well as natural gas, is used for heating buildings. This study focused on three-block base buildings in a block-based compound in Antalya in the Mediterranean Climate Region. The study examined the effect of different orientation scenarios on the energy performance of the building. The energy cost, emission, and savings rates between the base building and design building models were obtained by performing hourly analyses using the DesignBuilder simulation program with the EnergyPlus dynamic thermal simulation engine. The results showed that the Design Building Models with south-east orientation, 90° angle to south, and about 90° angle provided annual total energy savings of 0.3%, 3.7%, and 4.3%.

Keywords: *building energy simulation, building orientation analysis, energy efficient design.*

Introduction

Urbanization increases energy demand worldwide. People consume natural resources excessively to meet their energy needs. However, excessive energy production and consumption causes environmental pollution and exacerbates global warming, affecting all living things and future generations. Over the past decades, "green building" has been a critical concept for minimizing environmental problems and leaving a better world for future generations.

The world's population has reached 7.8 billion as of 2021. China's population stood at 1.4 billion, equivalent to 18% of the total world population (UN.ESCAP, 2021). By 2030, only China and Indonesia will add 342 million and 80 million more people to the world population, respectively. Irregular population growth has led to environmental pollution and outbreaks, resulting in climate change and natural disasters (Erçoşkun, 2018). One in every two people lives in urban areas worldwide, which is projected to increase to 75% by 2050 (European Commission, 2020). The European Union (EU) biodiversity strategy for 2030 has set targets

for reducing greenhouse gas emissions by 2030 by at least 40% (compared to 1990), increasing the share of renewable energy sources in energy consumption to at least 32%, and providing at least a 32.5% improvement in energy efficiency (European Commission, 2014).

A building envelope is an energy-efficient building criterion that consists of transparent and opaque components. There is a large body of research on improving the thermos-physical properties of transparent and opaque components for energy efficiency in buildings in different climatic zones (Mahlia & İqbal, 2010; Kon, 2018; Çetintaş & Yılmaz, 2019; Alsayed & Tayeh, 2019; Aydin & Biyikoglu, 2020; Urbikain, 2020; Rosti et al., 2020; Aktemur et al., 2021). Most research focuses on building envelope design and calculates energy efficiency over building heating load.

Building orientation is a fundamental design choice defined as the method of setting the direction of a building in such a way that it derives maximum benefit from the elements of nature. This study investigated the effect of building orientation on energy efficiency. Earlier research has examined energy efficiency based on a building, floor, or site. However, this study looked into energy efficiency based on a "block-based settlement" in buildings in Antalya, which is located in the Mediterranean Climate Region. People in Antalya widely use electricity for heating. Therefore, this study also developed scenarios where electricity and natural gas are used for heating to compare energy efficiency by fuel type.

Building Orientation in Energy Efficient Building Design

The characteristics of the external climate elements (the angle and amount of sunlight and the direction and strength of the wind) of a plot of land depend on its direction. The heat transfer rate per unit area (a building envelope element) depends on building orientation (Tatar, 2015). The southern surfaces of buildings between 32º and 56º north latitude receive approximately three times as much sunlight in winter as the east and west surfaces. However, they receive approximately half as much sunlight in summer as the east and west surfaces depending on the direction and duration of sunlight (Karaaslan, 2011).

Buildings should be less fragmented and closed to the north and have wide south facades and compact forms to minimize heat loss depending on solar radiation (Erçin, 2005). Solar radiation and prevailing wind direction are critical for energy conservation in the positioning of buildings. Figure 1 shows that B and C experience 50% and 60% more heat loss than A, whereas D experiences 25% less heat loss than A (Soysal, 2008).

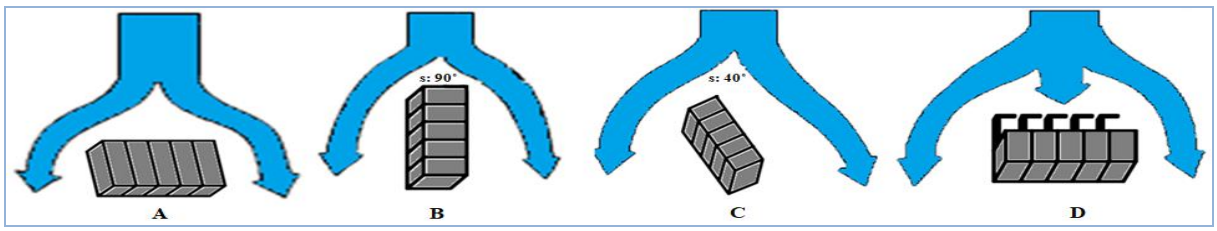


Figure 1: Building orientation according to the prevailing wind direction.

Research on energy-efficient building design addresses such parameters as optimum building location, shape, size, and distance between buildings in different climates. Figure 2 shows optimum orientations depending on climates (Tatar, 2015).

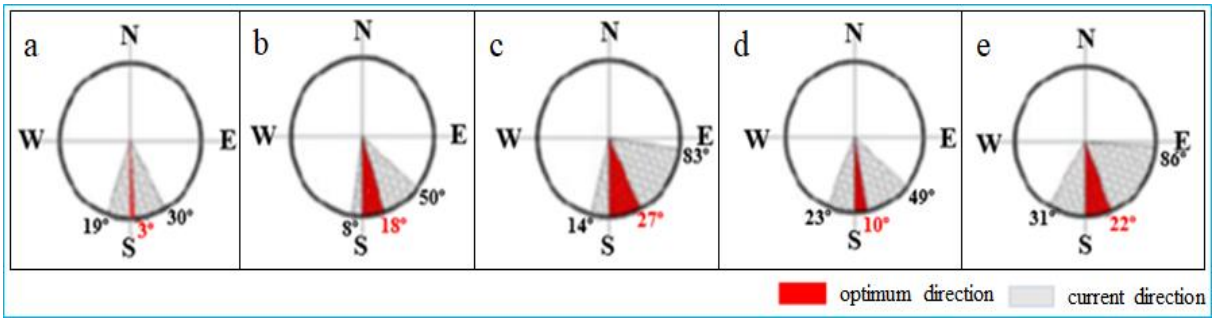


Figure 2: Optimum orientations depending on different climates; a) hot-humid climate, b) hot-dry climate, c) moderate-dry climate, d) moderate-humid climate, e) cold climate.

Method

The sample consisted of a block-based urban transformation project in Antalya. The city has a hot-humid climate because it is located in the Mediterranean Climate Region. It is classified in the first-degree day zone according to the Turkish Standards Institute (TSI). The study investigated how much optimal orientation could reduce the energy needs of buildings in block-based residential complexes.

This study had six stages. First, the buildings in the block-based settlement were determined as Block B, Block D, and Block F "Based Buildings" according to orientation, location, facade area, number of floors, and transparent surface ratio. Second, "Base Building Models" were developed modeling Block B, Block D, and Block F according to the current situations. Third, 19° (south-west) and 30º (south-east) reference ranges were determined for hot-humid climatic regions. Fourth, orientation scenarios of about 5° were applied to the Base Building Models according to the reference range to develop "Design Building Models." Fifth, the Base Building Models and Design Building Models were compared in terms of energy consumption to achieve energy cost, emission, and saving rates. Sixth, data were analyzed using a meteorological database, which is a dynamic thermal simulation program, and DesignBuilder and EnergyPlus dynamic simulation, which are capable of 3D modeling.

For each orientation scenario, natural gas and electricity were used as heating energy. For each block, two Base Building models were developed according to the energy type for heating. Orientation scenarios were applied to the "Base Building-1" (natural gas for heating; electricity for cooling) model based on natural gas for heating in order to obtain the "Design Building-1" model. Orientation scenarios were applied to the "Base Building-2" (natural gas for cooling; electricity for heating) model based on electricity for heating in order to obtain the "Design Building-2" model.

Findings and Discussion

The research setting was a block-based urban transformation project consisting of six blocks and 317 residences on a 37,647 m^2 construction area (Figure 3). Block A consisted of 10

floors and 41 independent sections. Block B consisted of ten floors, 76 independent sections, and a 4743.7 m^2 net usage area. Block C consisted of eight floors and 36 independent sections. Block D consisted of 11 floors, 41 independent sections, and a 5102.4 m^2 net usage area. Block E consisted of nine floors and 72 independent sections. Block F consisted of 9 floors, 51 independent sections, and a 5201.3 m^2 net usage area.

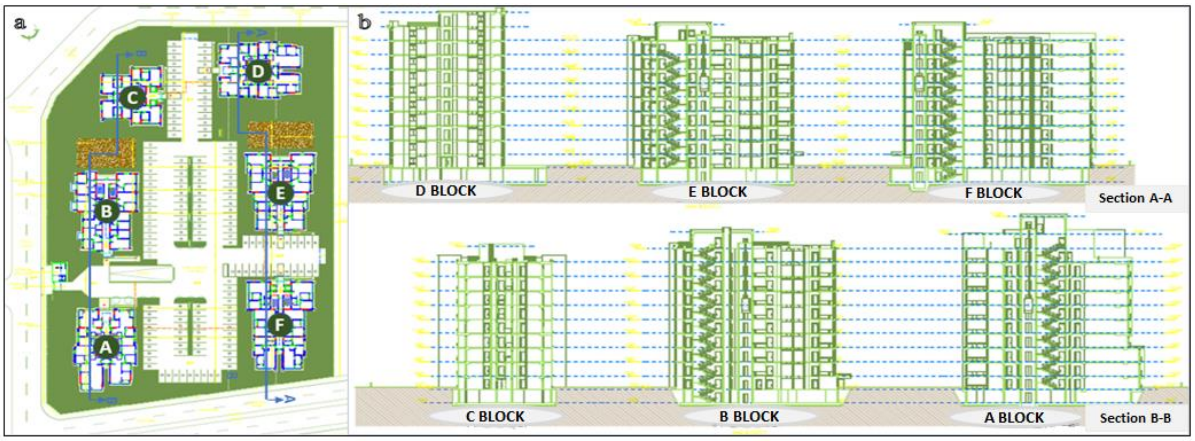


Figure 3: Urban transformation project; a) layout plan, b) sections.

The buildings were determined as Block B, Block D, and Block F "Based Buildings" according to orientation, location, facade area, number of floors, and transparent surface ratio. The block-based settlement representing the energy consumption behavior of the base buildings was modeled (Figure 4).

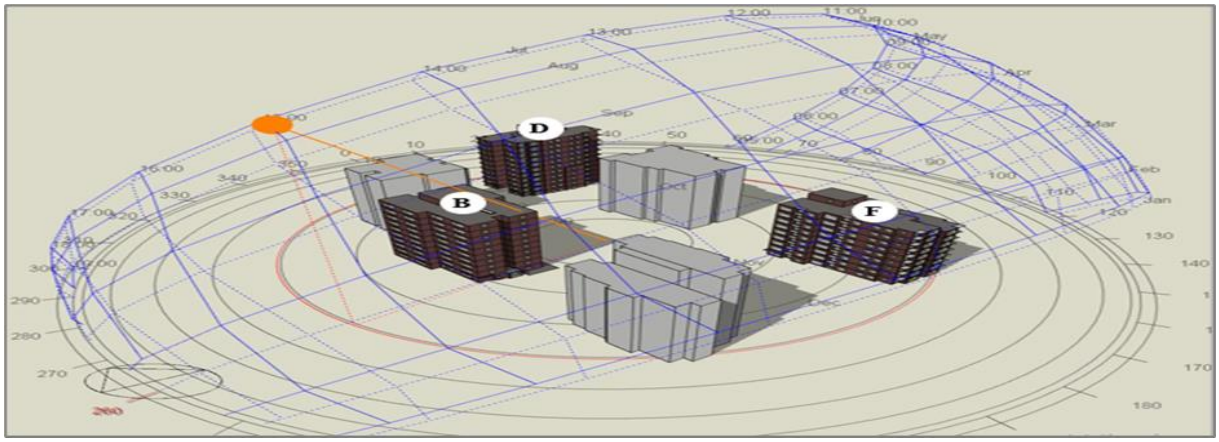


Figure 4: Model image.

The climate data of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Climate Zone 3A (Turkey's 1st Climate Zone) were used to calculate the heating and cooling loads for Antalya according to the ASHRAE 90.1-2010 standard recommended by ASHRAE. The Base Buildings and Design Buildings were modeled according to the ASHRAE standard residential use profile.

Buildings can act as solar radiation barriers for each other according to distance, density, height, orientation, and positioning. This study examined the effects of these basic choices on energy efficiency. Figures 5 and 6 show the shadow effect of the buildings on each other on equinox days.

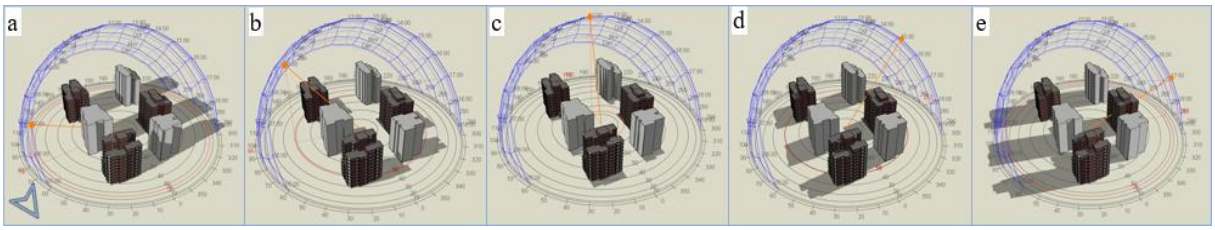


Figure 5: 21 Shadow lengths formed by buildings in June; a) 7:00 am, b) 9:00 am, c) 12:00 pm, d) 3:00 pm, e) 5:00 pm.

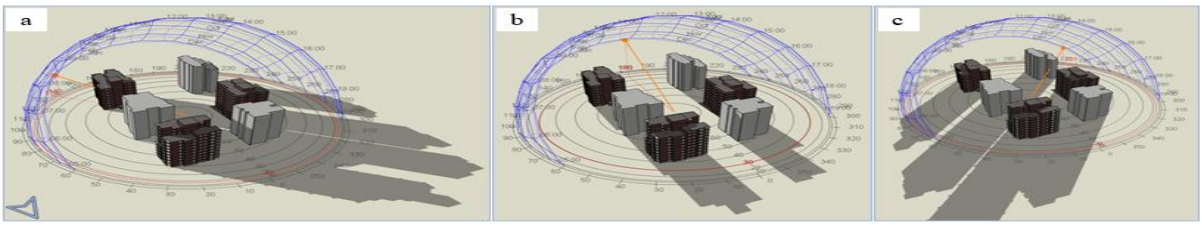


Figure 6: 21 Shadow lengths formed by buildings in December; a) 7:00 am, b) 9:00 am, c) 12:00 pm, d) 3:00 pm, e) 5:00 pm.

The most suitable orientation range is between 19° (south-west) and 30º (south-east) for energy efficiency in hot-humid climatic regions, where Antalya is located. The optimum orientation is 3° to the southeast (Figure 7). Design Building Models were developed, orienting the Base Buildings approximately 5 degrees in the reference range. The orientation scenarios in the Base Building Models were applied considering the plot boundary drawing distances and distances between buildings specified in the regulations.

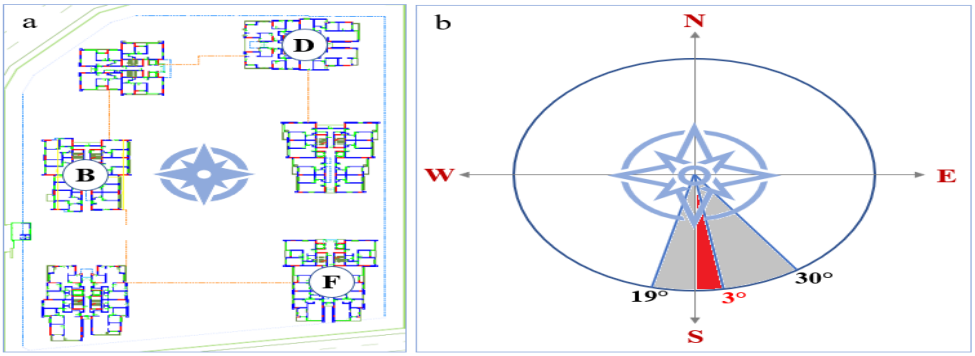


Figure 7: Optimum orientation analysis criteria; a) current orientation of base buildings, b) Optimum orientation range in hot-humid climate zone.

Table 1 shows the scenarios. The living spaces were predominantly in an east-west orientation in Block B and F Base Buildings. "Scenario 8" was developed outside the reference range so that the buildings formed an angle of 90º with the south to examine how their energy consumption was affected if the living spaces in those blocks had a north and south orientation. Figures 8, 9, 10, 11, 12, and 13 show the current orientations of the Base Buildings and the Design Building orientations after each scenario, respectively.

Table 1. Orientation scenarios applied to the base buildings.

Scenarios	Block B Orientation		Block D Orientation		Block F Orientation	
	South-West	South-East	South-West	South-East	South-West	South-East
Current Situation	0º		0º		0º	
Scenario-1	3º	3º	3º	3º	3º	3º
Scenario-2	5º	5º	5º	5º	5º	5º
Scenario-3	10º	10º	10º	10º	10º	10º
Scenario-4	15º	15º	15º	15º	15º	15º
Scenario-5	19º	20º	19º	20º	19º	20º
Scenario-6	-	25º	-	25º	-	25º
Scenario-7	-	30º	-	30º	-	30º
Scenario-8	-	90º	-	-	-	90º

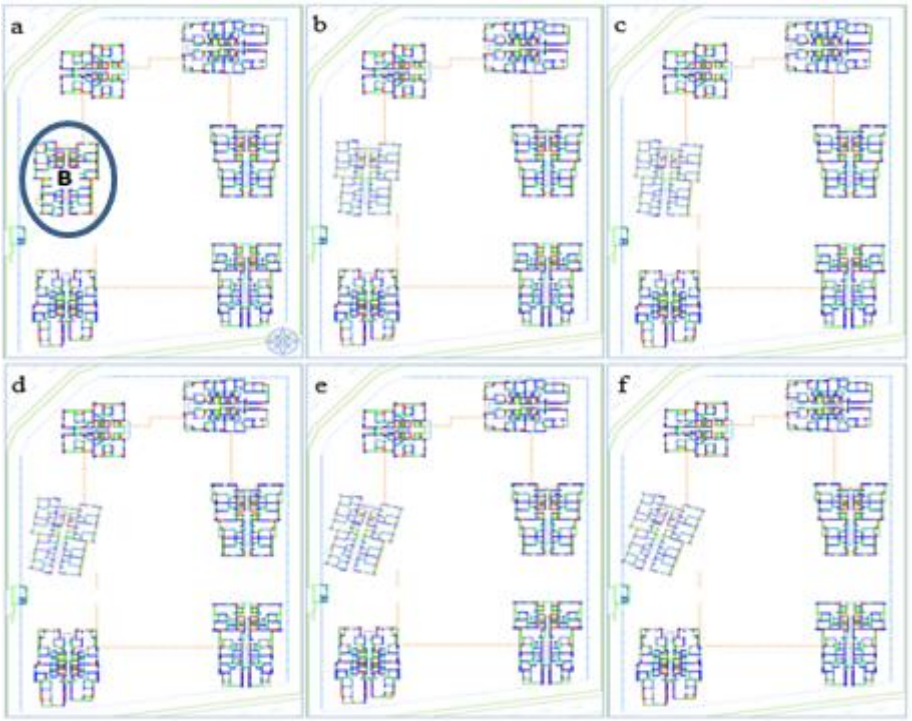


Figure 8: Block B south-west oriented design building models; a) current situation-south 0º, b) south-west 3º, c) south-west 5º, d) south-west 10º, e) south-west 15º, f) south-west 19º.

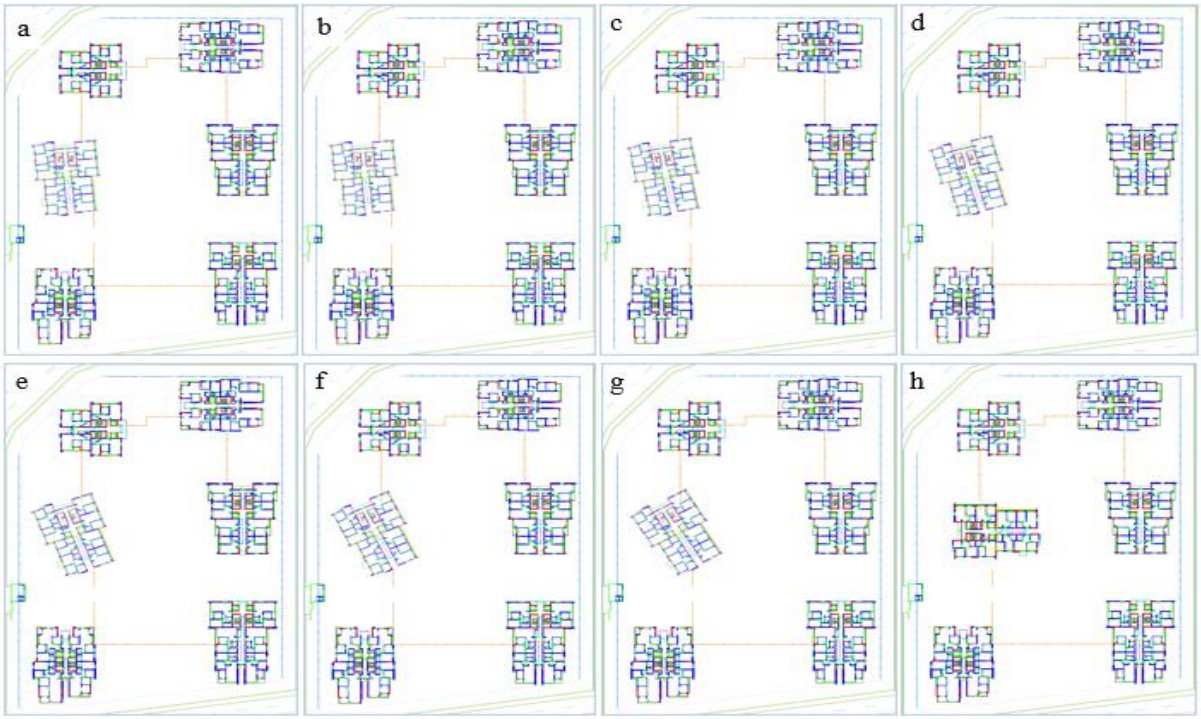


Figure 9: Block B south- east oriented design building models; a) south- east 3º, b) south-east 5º, c) south- east 10º, d) south- east 15º, e) south- east 20º, f) south- east 25º, g) south-east 30º, h) south- east 90º.



Figure 10: Block D south-west oriented design building models; a) current situation-south 0º, b) south-west 3º, c) south-west 5º, d) south-west 10º, e) south-west 15º, f) south-west 19º.

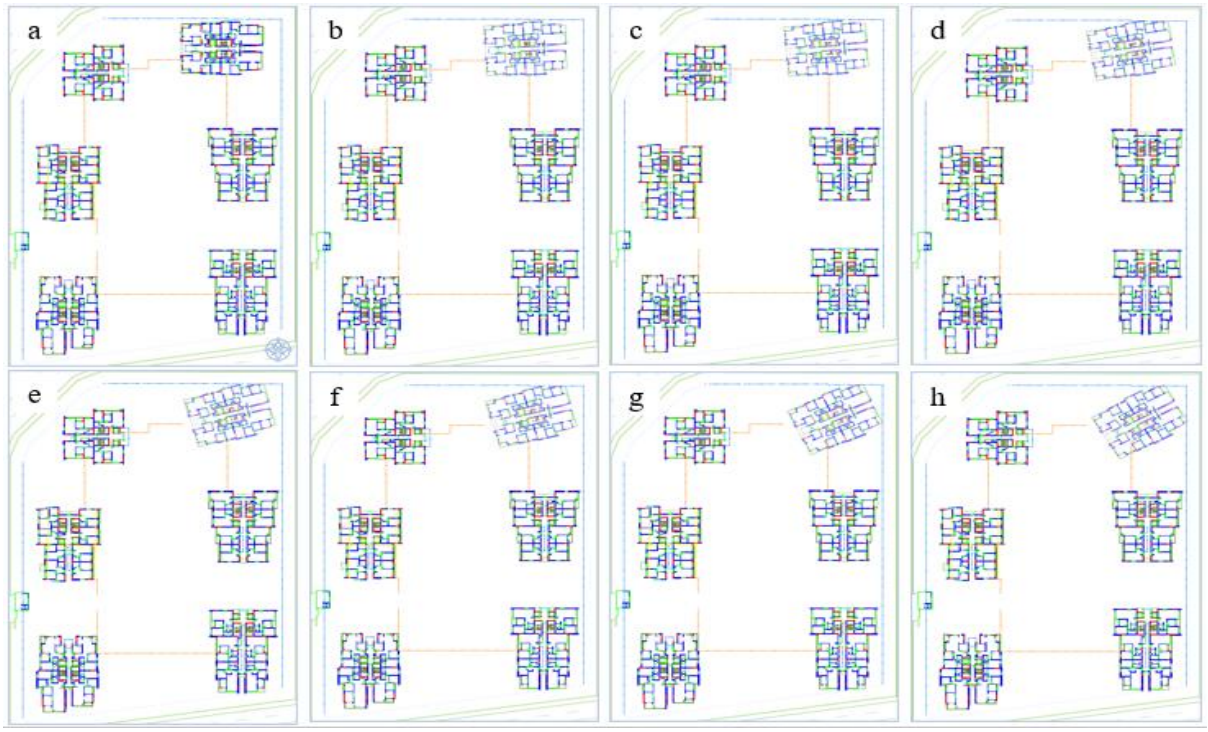


Figure 11: Block D south- east oriented design building models; a) current situation-south 0º, b) south- east 3º, c) south- east 5º, d) south- east 10º, e) south- east 15º, f) south- east 20º, g) south- east 25º, h) south- east 30º.



Figure 12: Block F south-west oriented design building models; a) current situation-south 0º, b) south-west 3º, c) south-west 5º, d) south-west 10º, e) south-west 15º, f) south-west 19º

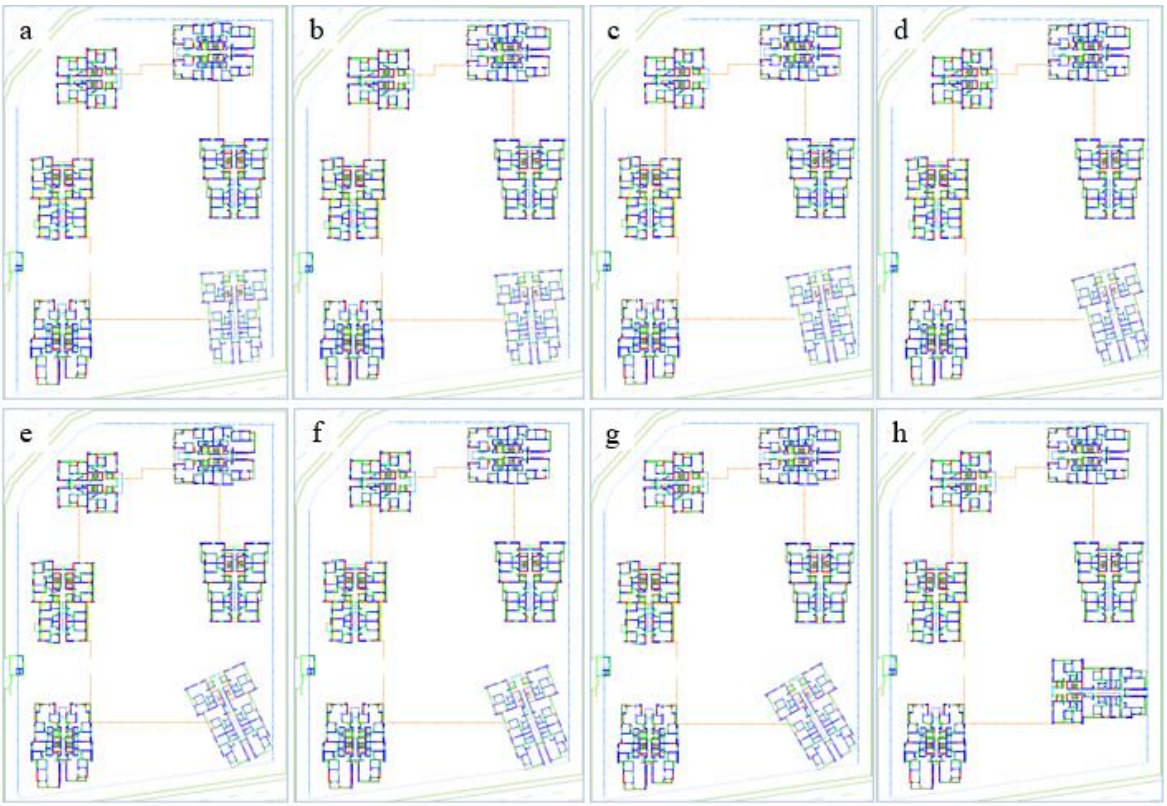


Figure 13: Block F south- east oriented design building models; a) south- east 3º, b) south- east 5º, c) south- east 10º, d) south- east 15º, e) south- east 20º, f) south- east 25º, g) south- east 30º, h) south- east 90º.

The energy consumption of heating, cooling, and ventilation systems between the Base Buildings and Post-Scenario Design Buildings were compared to obtain optimum orientation scenarios using DesignBuilder and EnergyPlus dynamic simulation programs. Table 2 shows the annual energy consumption and energy and emission saving rates of the Base Buildings and Post-Optimum Orientation Scenario Design Buildings.

Table 2. Energy and emission saving rates after the optimum orientation of the base buildings.

Account Items	Base Building-1	Design Building-1	Base Building-2	Design Building-2
Block B				
South-west Optimal orientation	10º		19º	
Consumption (kW)	351880.75	351178.51	311386.42	310545.81
Energy Saving (kW)	0.20%		0.27%	
Emission Saving (kg)	0.21%		0.27%	
South-east Optimal orientation	90º		90º	
Consumption (kW)	351880.75	340011.49	311386.42	298130.67
Energy Saving (kW)	3.37%		4.26%	
Emission Saving (kg)	1.22%		4.26%	
Block D				

South-west Optimal orientation	10º		5º	
Consumption (kW)	325667.92	325034.41	275640.13	274758.00
Energy Saving (kW)	0.19%		0.32%	
Emission Saving (kg)	0.58%		0.32%	
South-east Optimal orientation	3º		30º	
Consumption (kW)	325667.92	326091.18	275640.13	275322.89
Energy Saving (kW)	-0.13%		0.12%	
Emission Saving (kg)	-0.13%		0.12%	
Block F				
South-west Optimal orientation	5º		5º	
Consumption (kW)	343797.47	343437.53	301847.12	301630.45
Energy Saving (kW)	0.10%		0.07%	
Emission Saving (kg)	0.18%		0.07%	
South-east Optimal orientation	90º		90º	
Consumption (kW)	343797.47	339479.26	301847.12	290695.18
Energy Saving (kW)	1.26%		3.69%	
Emission Saving (kg)	-4.32%		3.69%	

Block B and F Design Buildings (oriented 90º with south) had a total energy saving of 3.37% and 1.26%, respectively, when natural gas was used for heating. They had a total energy saving of 4.26% and 3.69%, respectively, when electricity was used for heating. The Design Buildings save energy for two reasons. First, the living areas in the Base Buildings, which have an east-west orientation, are exposed to the sun throughout the day. Second, other buildings act as sunshades for the Design Buildings. The optimal orientation angle of Block D varied according to east/west directions and the type of energy for heating. Block D had the highest energy saving when the building formed a 5º angle with the south in the south-west direction and when electricity was used for heating. Blok D Design Building-1 had an energy increase of 0.13% when it formed a 3º angle with the south in the south-west direction, while Design Building-2 had a maximum saving (0.32%) because Blok D Base Building had approximately optimal orientation. This can be explained by the north-south orientation of the living areas in Block D.

Electricity provided more energy savings than natural gas (Table 2). This can be explained by the electrical efficiency being higher than the natural gas efficiency. However, natural gas is an ideal choice for heating in terms of energy cost savings because the unit price of electricity is higher than that of natural gas.

Conclusion

This study investigated the effect of optimal orientation practices on the energy performance of buildings in a block-based settlement in Antalya in the Mediterranean Climate Region. The results showed that building designs based on optimal orientation reduced annual energy consumption by up to 4.3%. Optimal orientation is a critical design parameter because it has

no investment costs and keeps the energy consumption required in artificial air conditioning to a minimum throughout the service life of buildings.

This study is critical because it considered design parameters, such as the location of buildings and the distance between them in block-based settlements. Another essential feature of this study is that it analyzed scenarios where electricity, as well as natural gas, is used for heating because buildings in Antalya widely use electricity for heating.

In conclusion, the optimal orientation for the buildings in the block-based settlement in Antalya in the Mediterranean Climate Zone is 90º or about 90º south to south-east. When buildings with optimal orientation use electricity for heating, they achieve maximum energy savings. We think our results will guide municipalities, academia, and the construction industry because this study focused on sustainable energy to examine the relationship between energy and cost through energy-efficient optimal orientation applications.

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Evaluation of Smart Sustainable Building-City Integration Level: An Analysis for Criteria in Building-City Intersection

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Abstract

City and building labels such as sustainable and smart have gained popularity in politics and academia for nearly 40 years since the world urban population demanding more facilities is increasing rapidly. Currently, since ICT (Information Communication Technologies) supports urbanism, the concept of a smart city, which increases the welfare of citizens, is popular. Moreover, buildings that are the inseparable components of cities contribute to environmental sustainability and improve occupants' well-being by providing personalized comfort conditions via ICT. Smart sustainable building-city integration can provide social, economic, and ecological sustainability with mutual resource use beyond the sum-up of smartness and sustainability of buildings and cities individually. In this paper, firstly, frequency analysis takes place on the tool's criteria in the literature that measure the smartness and sustainability levels of cities for the last 8 years and buildings over the previous 28 years published in refereed journals and institutional works. Secondly, researchers used the content analysis technique to define the intersection area for the buildings and cities. Research findings underline the importance of thirteen criteria in resources, technology and innovation, mobility, security and safety, welfare, and management. The determined intersection criteria can establish a scientific model for evaluating the building-city integration level.

Keywords: *evaluation, ICT, integration, interoperability, smart building, smart sustainable building, smart sustainable city.*

Introduction

A smart city aims to ensure sustainability, increase efficiency, and improve the quality of life in many important aspects of city life such as governance, mobility, health, and safety (Mosannenzadeh & Vettorato, 2014). The emergence of smart cities and similar city improvement activities has created the need not only to evaluate the city's development over time but also to make performance comparisons between different cities of a country or cities of different countries (ISB & SEF, 2017). A generally accepted smart city evaluation model to evaluate smart city initiatives makes it possible to compare results from one sample to another (Hemment et al., 2016). Such a benchmarking encourages cities to be more smart and sustainable through competition. There are over 200 city evaluation tools worldwide (ISB & SEF, 2017). Literature review, expert opinion, and stakeholder consultation determine smart city indicators in a smart city evaluation (Sharifi, 2019).

Although a smart city aims for sustainability, all smart city solutions do not include sustainability, and thus the smart sustainable city (SSC) concept derived (Ahvenniemi et al., 2017). In order to measure the realization level of SSC goals, there is a need for new evaluation tools that meet the requirements of the two concepts together. Institutional standards can be a measure of evaluation. ETSI, ITU-T, ISO, and UN are SSC standards.

Like in cities, the concepts such as smart, intelligent, and sustainable describe buildings. Buildings are responsible for 36% of world energy consumption and approximately 40% of CO2 emissions, according to 2019 data (European Commission, 2021). Rapid consumption of sources has been the driving force in designing sustainable and smart buildings. The characteristics of sustainable or green building terms take place in building evaluation tools and it is obvious that intelligent and smart buildings evaluation criteria are less prominent in the literature (Ghaffarianhoseini et al., 2018). In certificate systems of some countries (such as Japan and Hong Kong), while there are criteria that provide smart and green building features together, in some countries (like Korea) have completely different (Ghaffarianhoseini et al., 2015). Buildings that meet the characteristics of being smart and sustainable are based on advanced technologies and efficient use of ICT (Zhuang et al., 2020).

A building can meet the requirements of smart or sustainable building evaluation criteria, but this is not enough to achieve the sustainable city goal. Stieninger (2016) defines the relationship of the smart building with the city as follows:

A smart building should interact with other sustainable components/systems of the city while supporting reuse and recycling; it should use its inputs and outputs (what they take from nature and what it can give back to nature) in a balanced exchange of giving and receiving. A smart city can operate in a healthy and environmentally friendly manner only if it benefits from a constant flow of change while providing information and feedback loops on all system components, required inputs, and outputs.

Although there are evaluation tools for smart and sustainable buildings and cities, the issue of defining building city intersection criteria and evaluating SSB-C integration is a potential gap in the literature. Only one research has proposed a framework for evaluating smart building city integration (Apanaviciene et al., 2020). This paper firstly touches on smart and sustainable buildings-cities main criteria. Frequency analysis is an effective study in determining the main criteria most used in evaluating smart and sustainable buildings and cities. Combining the frequency analysis results creates the new main criteria for evaluating SSB and SSC. The criteria set will be specific to this study for the new evaluation model. The study based on determining intersection criteria is the final analysis. SSB main criteria and related SSC evaluation criteria are combined for the intersection criteria.

Literature Review

Smart and Sustainable City Evaluation Studies

Academic, public, and private institutions prepare smart and sustainable city evaluation tools. A smart city evaluation tool consists of main criteria and indicators. Research that present these evaluation tools and analyzed them according to related the concept (Patrão et al., 2020; Sharifi, 2019). The smart city criteria developed by (Giffinger et al., 2007) to rank European

cities constitute the most cited, used, and most applied evaluation framework in this field (Bibri & Krogstie, 2017). The model as follows:

Smart economy. Innovative spirit, entrepreneurship, economic image and trademark, productivity, flexibility of the labour market, international residency, ability to convert.

Smart mobility. Local accessibility, International accessibility, Availability of ICT infrastructure, Sustainable, innovative, and safe transportation systems.

Smart environment. The attractiveness of natural conditions, Pollution, Environmental protection, Sustainable resource management.

Smart people. Proficiency level, proximity to lifelong learning, social and ethnic pluralism, flexibility, creativity, cosmopolitanism-open-mindedness, participation in public life.

Smart living. Cultural opportunities, health conditions, individual security, housing quality educational opportunities, tourist attraction, social solidarity.

Smart governance. Participation in decision making, public and social services, transparent governance, political strategies and perspectives.

The standards developed by ITU-T in evaluating a SSC provide a basis for cities and communities to create an integrated IoT environment, use collected data, and deploy reliable technology (ITU, 2021). The contents of these standards as follows: the use of information and communication technologies in SSC and the impact of sustainability, KPIs on the evaluation of achievements in achieving sustainable development goals, maturity model, impact evaluation, a guide for city leaders, master plan, increasing innovation and participation in SSC, master plan, setting the stage for stakeholder engagement (ITU, 2021).

Smart and Sustainable Building Evaluation Studies

LEED (Leadership Energy and Environmental Design) Certificate (USGBC) for evaluation of sustainable building and SRI (EU) are widespread systems. SRI has nine technical domain: Heating, domestic hot water, cooling, ventilation, lighting, electricity, electric vehicles, dynamic facade, monitoring and control headers (Verbeke et al., 2018). LEED has nine credit category: Integrative process management, location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, regional priority (USGBC). SSB studies are a relatively new compared to smart and sustainable building studies, and there are fewer studies in the literature.

Methodology

The increase in the number of SSB-C evaluation tools necessitated the determination of the limitations of the research. This paper analysis includes 15 cities (previous eight years) and 15 buildings (previous twenty-eight years) evaluation tools that have been the research subject in the last years. Selection criteria as follows: The most up-to-date, 2. The oldest and most accepted, 3. Developed technical standards by institutions, 4. Presented research in article, 5. Tools that evaluate cities in different geographies (continent, country), 6. Evaluation tools that

evaluate cities with multiple goals such as sustainability and happiness as well as smartness, 7. Different qualities such as standard, index, model, methodology, and guide. This paper has three-stage findings and discussion sections for the defining SSB-C integration necessities: 1. Main criteria frequency analysis for smart and sustainable city evaluation tools, 2. Main criteria frequency analysis for smart and sustainable building evaluation tools, 3. Defining SSB-C intersection main criteria.

Findings and Discussion

The main criteria in the evaluation tools selected by literature review on SSB-C in Table 1 and Table 2. The common main criteria of SSB-C evaluation tools are in Figure 1 and Figure 2. In tables, while the black-colored tics are the criteria found directly in the main headings, the red ticks express the criteria closely related to the scope of the main headings.

Smart and Sustainable City Evaluation Tools: Main Criteria

The selected evaluation tool's titles are closely related to the subtitles in the research by (Giffinger et al., 2007) or the indicators of some tools are the main criteria for other tools. The evaluation tools' main criteria most frequently used are economy (Ec), environment (En), governance (Go), people (Pe), mobility (Mo), and life (Li), followed by technology and infrastructure.

Table 1. The relationship of the main criteria of the selected smart and/or sustainable building assessment tools with the 6 main criteria.

No	Title	Ec	En	Go	Pe	Mo	Li	Other Criteria
1	Happiness Driven Smart City (Zhu et al., 2022)	✓	✓	✓	✓	✓	✓	Efficient and green physical infrastructure, Labour-friendly and innovative economy, inclusive and attractive society, sustainable and eco-friendly natural environment
2	U4SSC (ITU, 2021)	✓	✓	✓	✓	✓	✓	Society, culture
3	Global Power City Index (GPCI) (Norio Yamato et. al, 2020)	✓	✓	✓	✓	✓	✓	Research and development, cultural interaction, liveability, accessibility
4	LRSC (Akande et al., 2019)	✓	✓	✓	✓	✓	✓	Society
5	SSCC (Li et al., 2019)	✓	✓	✓	✓	✓	✓	Technological innovation, smart infrastructure, smart services.
6	Cities in Motion Index (Handa Gustiawan, 2019)	✓	✓	✓	✓	✓	✓	Human capital, social cohesion, transportation, urban planning, international outreach, technology, city/country cluster
7	CSC (Smart Cities Council, 2018)	✓	✓	✓	✓	✓	✓	Strategic, connected, aware, responsive, innovative

8	CSCP (Shen et al., 2018)	✓	✓	✓	✓	✓	✓	Infrastructure
9	ASCIMR (Velazquez-Romera et al., 2017)	✓	✓	✓	✓	✓	✓	No difference
10	Smart Cities Index- A Tool for Evaluating Cities (ISB & SEF, 2017)	✓	✓	✓	✓	✓	✓	No difference
11	A methodology for Northern Italy (O et al., 2017)	✓	✓	✓	✓	✓	✓	Energy
12	CITYkeys (Bosch & Jongeneel, 2017)	✓	✓	✓	✓	✓	✓	Planet, prosperity, propagation
13	CKPI (Hemment et al., 2016)	✓	✓	✓	✓	✓	✓	Transport, culture, health, energy
14	Smart Cities Readiness Guides (Smart Cities Council, 2015)	✓	✓	✓	✓	✓	✓	Built environment, telecommunications, energy, health and human services, payments and finance, public safety, waste management, water and wastewater, transportation.
15	Boyd Cohen Wheel (Cohen, 2014)	✓	✓	✓	✓	✓	✓	Government

*U4SSC: United 4 Smart Sustainable Cities, CKPI: Community KPIs for the IoT and Smart Cities, CSCP: China Smart City Performance, LRSC: Lisbon Ranking for Smart, Sustainable Cities, CSC: Code for Smart Communities, SSCC: Smart sustainable cities China, ASCIMR Assessing Smart City Initiatives for the Mediterranean Region.

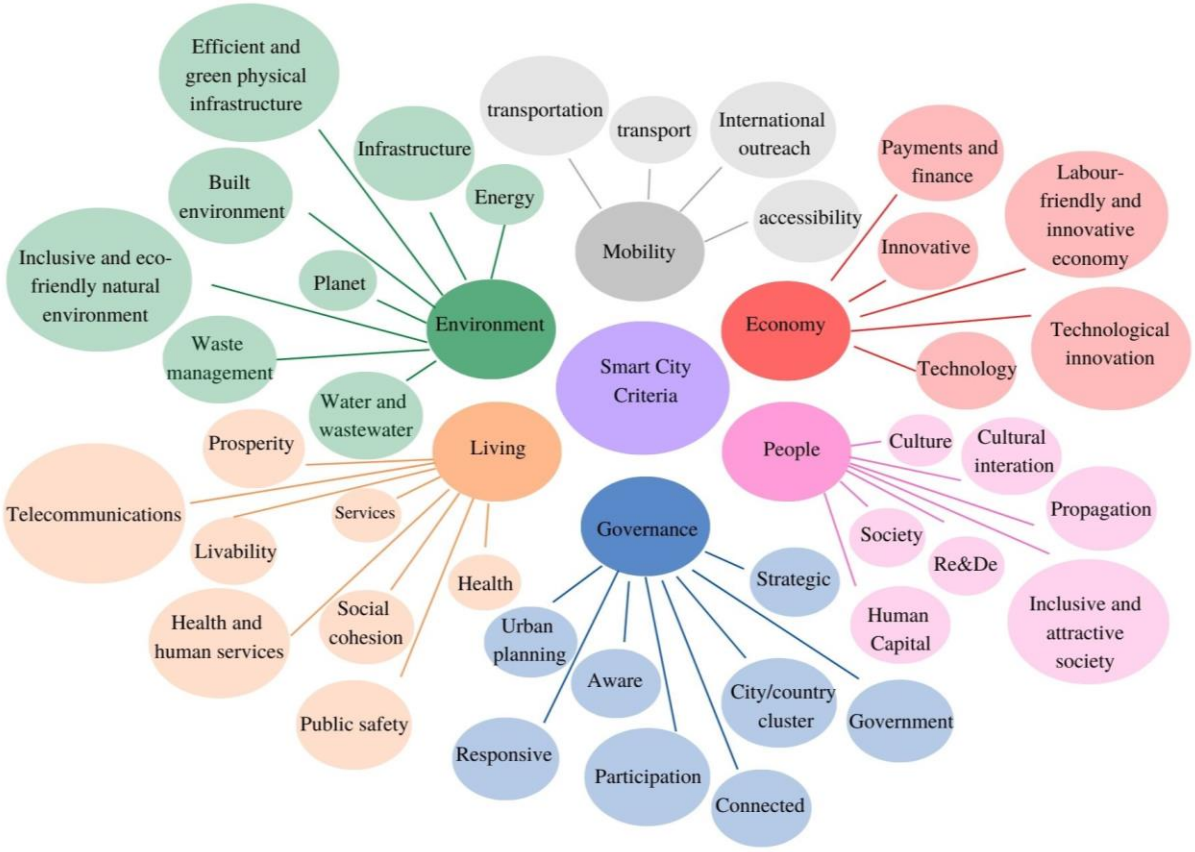


Figure 1: Main smart city criteria and other related criteria in literature (criteria in Table 1).

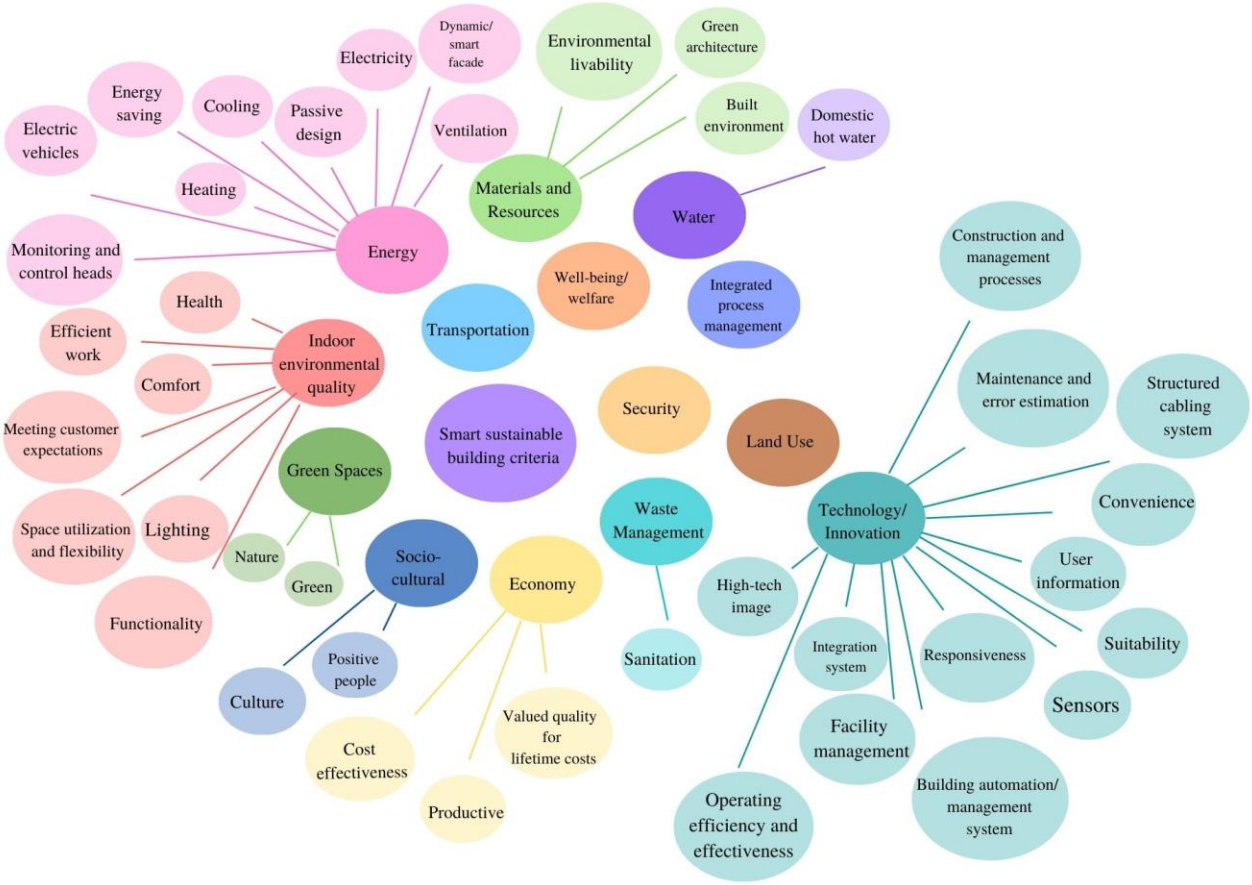
Smart and Sustainable Building Evaluation Tools: Main Criteria

According to selected 15 smart/intelligent and sustainable building evaluation tools, frequency analysis is 1-Energy 2-Material and Resources 3-Water 4-Waste Management 5-Technology/Innovation/integration process management 6-Transportation 7- Security 8-Indoor environmental quality, well-being, welfare are most used criteria. The renovation criterion is not included because the research investigates new construction projects and infrastructure especially ICT is related and included all of criteria. In table 2, Criteria 1-8 are based on LEED certification system credit categories (USGBC) because of includes Table 2 criteria mostly. IPM requires the use of BIM (Building Information Modeling) in a SSB, and it is appropriate to be evaluated under the technology title. After the frequency analysis, SSB main criteria will become obsolete.

Table 2. The relationship of the main criteria of the selected smart and/or sustainable building assessment tools with the 8 main criteria.

No	Title	1	2	3	4	5	6	7	8	Other Criteria
1	MIASBP (Meryem et al., 2018)	✓	✓	✓	✓	✓			✓	Socio-cultural, economic
2	The evaluation for smart	✓	✓	✓	✓	✓		✓	✓	Smart facades, passive design, sensors, building automation

	buildings (Omar, 2018)									system, building management system
3	The EU Smart Readiness Indicator (SRI) scheme (Verbeke et al., 2018)	✓	✓	✓	✓	✓	✓		✓	Heating, domestic hot water, cooling, ventilation, lighting, electricity, electric vehicles, dynamic façade, monitoring and control heads, energy saving, maintenance and error estimation, comfort, convenience, user information
4	MATOOL(Fantana, 2013)	✓	✓	✓	✓	✓			✓	Built environment, responsiveness, functionality, economic, suitability
5	HSBS	✓	✓	✓	✓	✓	✓	✓	✓	Green, productive
6	The intelligence of IBs (Huang, 2014)					✓			✓	Function, economy
7	TIBA (Show-Ling, 2014)	✓				✓		✓	✓	Structured cabling system, compliance, facility management, integration system,
8	The intelligence of IBs (So et al., 2011)	✓	✓	✓	✓	✓		✓		Space utilization and flexibility, valued quality for lifetime costs, operating efficiency and effectiveness, culture (meeting customer expectations), construction and management processes, health and sanitation
9	BiQ (Katz & Skopek, 2009)	✓	✓	✓	✓				✓	More brown space instead of green space (green architecture)
10	IBI (Chow & Leung, 2005)	✓			✓	✓		✓	✓	Working efficiency, culture, management practice& security, cost effectiveness, health and sanitation, space, green, safety& structure, high-tech image
11	Green Mark (BCA)	✓	✓			✓			✓	No difference
12	ASGB (Wang, 2019)		✓					✓	✓	Environmental livability
13	CASBEE (IBEC, 2018)	✓	✓						✓	Land
14	Green Star (GBCA)	✓	✓	✓	✓	✓	✓	✓	✓	Management, land use and ecology, emissions
15	(BREEAM, 1990)	✓	✓	✓	✓	✓	✓		✓	No difference



*BCA: The Building and Construction Authority, BREEAM: Building Research Establishment Environmental Assesment Method, CASBEE: Comprehensive Assessment System for Built Environment Efficiency, TIBA: (Taiwan Intelligent Building Association) ABRI (The Architecture and Building Research Institute), IBI: Intelligent Building Index, BiQ: The Building Intelligent Quotient, HSBS: The Honeywell Smart Building Score 2.0, ASGB: Assessment Standard for Green Building, MIASBP: The Main Indicators For The Assessment Of Smart Buildings Performance.

Figure 2: Main smart and sustainable building criteria and other related criteria.

Some criteria are related to main criteria more than one. Such as dynamic façade is connected both energy, indoor environmental quality, well-being and technology main criteria. In the figure, each title is shown associated with a single title.

Main Criteria for SSB-C Integration Evaluation: "Intersection"

Table 4 and Figure 3 show that SSB-C intersection criteria analysis and integration process. C1. Economy C2. Environment C3. Governance C4. People C5. Mobility C6. Living C7. Infrastructure C8. Technology, B1. Energy B2. Material and Resources B3. Water B4. Waste Management B5. Green Spaces B6. Technology/Innovation B7. Transportation B8. Security B9. Indoor environmental quality and wellbeing B10. Welfare B11. Socio-cultural B12. Economy B13. Integrated Process Management B14. Land Use.

Table 4. SSB and SSC intersection criteria.

SSC Main Criteria		SSB Main Criteria													
		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
	C1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	C2	✓	✓	✓	✓	✓	✓	✓		✓			✓		✓
	C3														
	C4											✓			
	C5	✓	✓				✓	✓							
	C6					✓	✓		✓		✓	✓	✓		
	C7	✓	✓		✓		✓						✓		✓
	C8	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓

Conclusions

Although the evaluation tools are based on main criteria in general; they also include criteria with other names related to these criteria. The intersection area of smart sustainable cities and smart sustainable buildings mainly covers thirteen criteria in six main areas namely; (1) resources, (2) mobility, (3) security and safety, (4) technology and innovation, (5) welfare and (6) management. Since the initial investment cost is required to establish smart sustainable buildings and cities, the economy title forms the basis of all criteria.

Resources (energy, material, water, land). It focuses on using clean energy resources throughout the building lifecycle, recycling and reusing building materials, and environmental livability to effectively and efficiently use limited planetary resources. The building can meet the resources (water, energy, material) it needs from the city capacity with the help of ICT and give the resources it produces to the city network.

Mobility. It is positioning the buildings as close as possible to buildings containing business, education, health, culture, arts, recreation, and trade services, providing a multimodal (bicycle, cable car, subway, electric vehicle) transportation system in cities that uses clean energy sources, and multimodal buildings according to their locations. It is sharing real-time transportation information (time, occupancy, and route) between transportation systems with ICT.

Security and safety. The location and resilience design of the buildings according to the site of the city in the disaster area, the use of detectors in case of disaster, and the establishment of a system that provides 24/7 monitoring with cameras and information flow to the city system.

Technology and innovation. With the ICT infrastructure established in cities and buildings, it is to inform building users, provide building-specific services, to develop advanced green systems for energy and water needs in building operation.

Welfare (socio cultural, indoor environmental quality and well-being, green space). It is related to the fact that the buildings have socio-cultural activities and green areas, and they bring these areas to the city, as well as benefit the city residents from the city equipment—moreover, housing prices and the purchasing power of city dwellers.

Management (waste management, integrated process management). It links managerial activities (such as integrated process management, building operation, building waste

management, and demolition management) between building and city throughout the building lifecycle with the help of ICT.

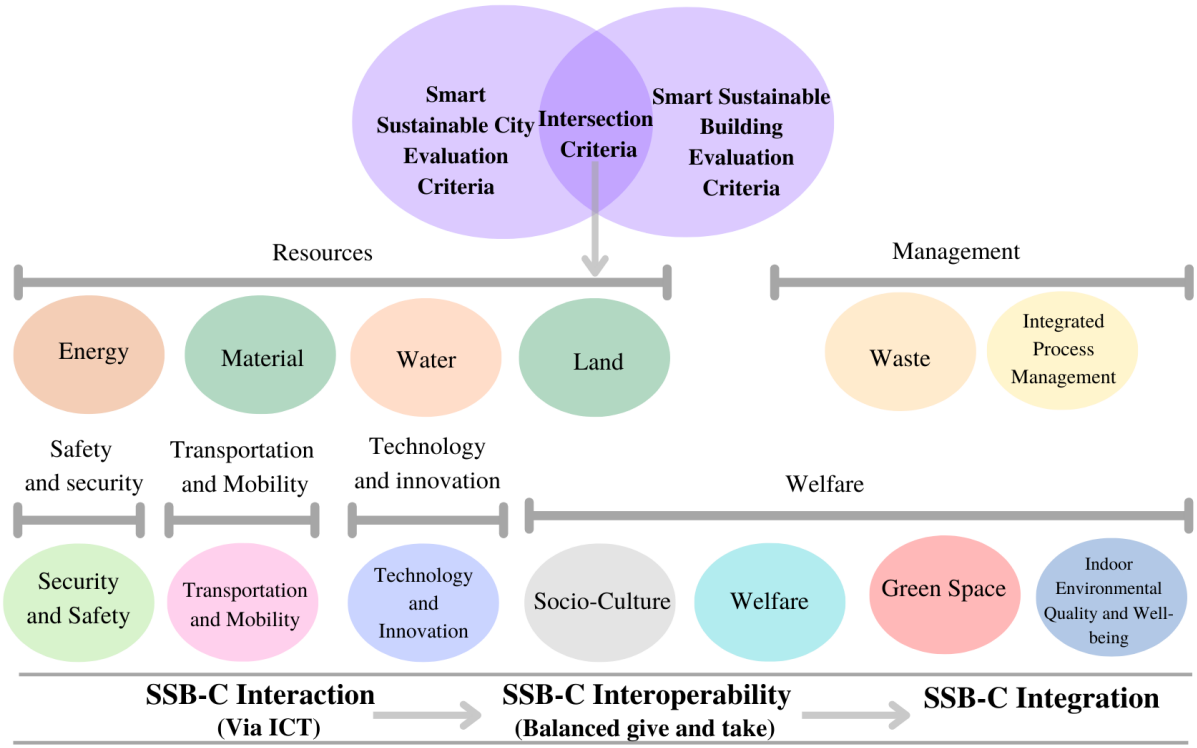


Figure 3: SSB-C intersection criteria and process of SSB-C integration.

This paper is limited to the specified method and analyzed selected smart sustainable city and building relevant criteria. Future research may address the identification of new intersection criteria through additional evaluation tools, analysis of key criteria, and indicators that change in line with advancing technologies and current needs. SSB-C integration evaluation tools that include these main criteria have significant benefits for solution providers and policy makers such as city managers, citizen welfare, and industrial stakeholders. The determined intersection criteria can establish a scientific model for the evaluation of building-city integration with the indicators to be determined later.

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A Multi-Attribute Decision-Support System for Site Selection of Wave Energy Converters

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Abstract

Renewable energy generation grew at its fastest rate in recent years due to the various benefits that renewable energy has over traditional fossil fuel sources. However, not selecting the appropriate location for renewable energy projects may weaken these benefits. Wave energy is one of the important renewable energy sources in coastal areas. Therefore, the selection of the most appropriate location where wave energy converters can be situated is a critical endeavor. Indeed, the most appropriate location is expected to maximize the energy that can be generated by wave energy. This study proposes a multi-attribute decision-support system to determine the most appropriate location where wave energy converters can be installed. A total of 4 main criteria and 17 corresponding sub-criteria are considered in the proposed model, which integrates the critic method to calculate the weights of the criteria and the complex proportional assessment (COPRAS) method to rank the alternatives. The value of the proposed model is demonstrated through an example. Armed with such a decision support tool, decision-makers should be able to maximize their energy production by locating wave energy converters in the most favorable sites.

Keywords*: decision-making, site selection, wave energy, wave energy converter*.

Introduction

Energy is key to development and economic growth. However, development comes with growing populations that demand more energy. Global organizations, which are deeply concerned by the increasing energy demand, set their goals by taking this need into consideration. For example, one of the United Nation's Sustainable Development Goals is ensuring global access to affordable and clean energy by 2030. These goals bring us to the use of renewable energy. There are several renewable energy sources, namely, solar energy, wave

energy (a.k.a. ocean energy), wind energy, hydropower, bioenergy, geothermal energy. Wave energy stands prominent among these renewable energy sources for having a lower environmental impact, a higher energy intensity and being more predictable (Chakraborty, 2019; Bertram et al., 2020). In addition, it is claimed that 10% of the global energy demand can be satisfied by using wave energy (Iglesias et al., 2010). Even though wave energy has a great potential to satisfy the growing demand, this potential depends on selecting the appropriate location for wave energy converters (Wang et al., 2019). Therefore, the selection of the right location for the installation of wave energy converters is one of the crucial decisions to ensure the maximum utilization of wave power potential (Carballo et al., 2014). Nevertheless, it is not an easy task since several conflicting criteria should be considered simultaneously. Hence, the site selection for wave energy converters should be considered as a multi-criteria decision-making problem (Cavallaro, 2009).

The main objective of this study is to develop a decision-making model that can be used in the selection of the most appropriate location for the installation of wave energy converters. To achieve this objective, first, an extensive literature review was performed. Even though the current literature reveals that there are existing decision-making models proposed to solve the selection problem, there is still a need to extend the existing research by proposing models developed via using different multi-attribute decision-making (MADM) methods. For this purpose, this study aims to improve Turkoglu et al.'s (2020) integrated MADM approach via using methods that may provide more benefits to decision makers in determining the right location for the installation of wave energy converters. The proposed model uses Criteria Importance Through Intercriteria Correlation (CRITIC) and Complex Proportional Assessment (COPRAS) methods. CRITIC method is used to calculate the weights of the criteria, while COPRAS is used to rank the alternatives. A case study was carried out to illustrate how the proposed model can be applied in a real-life case. Results showed that this tool can be helpful in the selection of the most appropriate location for the installation of wave energy converters.

The Proposed Model

The proposed model is developed in two stages. In the first stage, the process starts by defining the wave energy site selection problem. Then, the evaluation matrix is constructed. The previous step is followed by the organization of the decision-makers who are associated with the wave energy site selection process. The decision-makers are also involved in the identification of the criteria (main and sub-criteria) that have impact on the selection of wave energy site. The final step of the first stage includes the calculation of the weights of the main and sub-criteria using the CRITIC method.

CRITIC method is proposed by Diakoulaki et al. in 1994 with the purpose of determining the weights of the criteria in MADM problems. This method is based on the analytical examination of the evaluation matrix. The first of the two important features that CRITIC method offers to decision-makers is that there is no need for the independence of attributes. The second feature is that the qualitative attributes can be transformed into quantitative attributes (Diakoulaki et al., 1995; Alinezhad & Khalili, 2019). Its calculation steps are presented below (Vujicic et al., 2016):

- Step 1: Constructing the decision matrix;
- Step 2: Determining the normalized the decision matrix;

- Step 3: Computing the standard deviation for each criterion;
- Step 4: Constructing the symmetric matrix;
- Step 5: Calculating the value that represents the measure of conflict;
- Step 6: Using the multiplicative aggregation formula to compute the amount of information (C_j);
- Step 7: Determining the weights.

In the second stage, the computation steps of COPRAS method are followed to develop the model. First, the initial decision matrix is constructed. After the normalization of the initial decision matrix elements, the weighted normalized decision matrix is generated. Then, the sums of weighted normalized values for both the beneficial and non-beneficial criteria are calculated. In the next step, the relative significances of the alternatives are calculated which is followed by the computation of the quantitative utility for each alternative. In the final step, alternatives are ranked according to their quantitative utility values.

COPRAS was introduced by Zavadskas et al. in 1994 as a MADM method. It is employed in the ranking process of alternatives according to their associated weights. COPRAS method evaluates these alternatives in terms of significance and utility degree (Stefano et al., 2015). COPRAS has been used in many studies due to its ease of understanding and application (Zavadskas et al., 2007; Bardauskienë, 2007; Malinauskas & Kalibatas, 2005). The calculation steps of COPRAS method are listed below (Organ, 2016):

- Step 1: Constructing the initial decision matrix;
- Step 2: Normalization of the initial decision matrix;
- Step 3: Constructing the weighted normalized decision matrix;
- Step 4: Computing the sums of weighted normalized values for beneficial and non-beneficial criteria;
- Step 5: Calculating the relative significances;
- Step 6: Calculating the quantitative utility for each alternative;
- Step 7: Ranking the alternatives.

Case Study: Wave Energy Site Selection Using the Proposed Model

The illustration of the proposed model can be best demonstrated by a real-life problem. For this purpose, the case presented by Turkoglu et al. (2020) is also used in this study for the selection problem of the most appropriate site to install wave energy converters. The case consists of two different locations (i.e., Kefken (A1) 41.25° N, 30.20° E and Karaburun (A2) 41.50° N, 28.70° E) in the Black Sea. There is a reason for choosing two different locations in the Black Sea. It is one of the coastal regions of Turkey that offers a great wave energy potential (Sağlam et al., 2010). Furthermore, the criteria identified in Turkoglu et al.'s study (2020) after performing a literature review and conducting interviews with decision makers are also used in this study. There are four main criteria that have been considered in the proposed model, namely, (1) locational aspects factors (LF), (2) efficiency of the wave energy converter factors (EF), (3) cost factors (CF), and (4) environmental aspects factors (EA). Each main criterion has different sub-criteria. The first main criterion (i.e., locational aspects factors) has nine sub-criteria, namely, incident wave power (LF_1), incident significant wave height (LF_2), incident

wave period (LF_3), water depth (LF_4), maritime transportation density (LF_5), extreme wave height (LF_6), time variation of incident wave power (LF_7), shape parameter of incident wave spectrum (LF_8), and currents (LF_9). On the other hand, the second main criterion does not have any sub-criteria. The third main criterion (i.e., cost factors) has four sub-criteria, namely, material cost (CF_1), installation cost (CF_2), operation and maintenance costs (CF_3), and accessibility (CF_4). Finally, the fourth main criterion (i.e., environmental aspects factors) has three sub-criteria, namely, water quality (EA_1), endemic species (EA_2), and migration routes (EA_3). Figure 1 shows the decision hierarchy of the wave energy site selection problem.

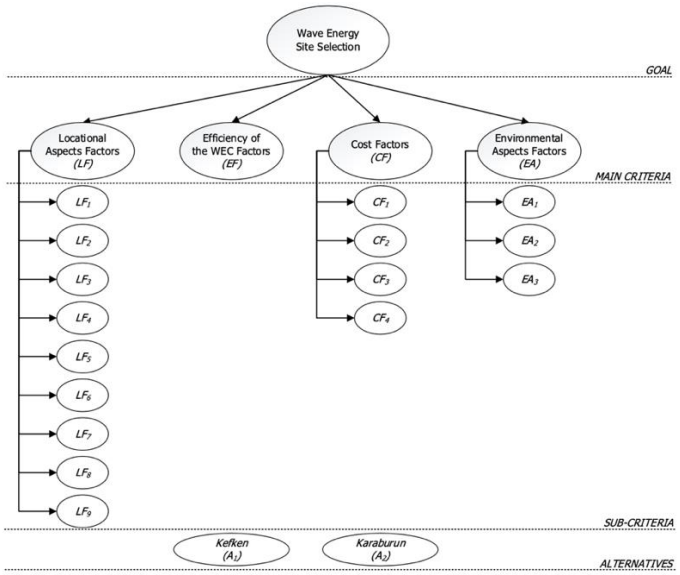


Figure 1: Decision hierarchy of the wave energy site selection problem.

In order to use CRITIC and COPRAS methods, the first step is constructing the initial decision matrix. Table 1 shows the initial decision matrix and data used for performance evaluation of alternatives. The data for water quality (EA_1), and migration routes (EA_3) criteria are qualitative. Water quality (EA_1) criterion is measured on a scale of 1 to 5 (i.e., 1: Very Bad; 5: Very Good). Besides, migration routes (EA_3) criterion is measured on a scale of 0 to 1.5 (i.e., 0: not on the migration route, 0.5: only on the migration route of birds of prey, 1: only on the migration route of marine animals; 1.5: on the migration route of both). On the other hand, the criteria other than water quality (EA_1) and migration routes (EA_3) are quantitative. Furthermore, LF_5, LF_6, LF_7, LF_9, CF_1, CF_2, CF_3, CF_4, EA_1, EA_2, and EA_3 are non-beneficial criteria for which lower values are desirable, while greater values are desirable for the rest of the criteria considered in this study. Stated in other way, LF_5, LF_6, LF_7, LF_9, CF_1, CF_2, CF_3, CF_4, EA_1, EA_2, and EA_3 criteria should be minimized, while the rest of the criteria are being maximized.

Table 1. Initial decision matrix of evaluation criteria for two wave energy sites.

Criterion	Measurement Unit	A_1 (Kefken)	A_2 (Karaburun)	Best	Worst
LF_1	kW	3,198.69	4140.54	4,140.54	3,198.69
LF_2	m	3.05	3.42	3.42	3.05
LF_3	s	7	7.2	7.2	7
LF_4	m	20	20	20	20
LF_5	point	1	0.17	0.17	1
LF_6	m	9.2	6.4	6.4	9.2
LF_7	m	0.84	1.01	0.84	1.01
LF_8	s	0.28	0.33	0.33	0.28
LF_9	cm/s	10	10	10	10
EF	%	70	70	70	70
CF_1	$	3,882,403	4,696,916	3,882,403	4,696,916
CF_2	$	685,130	828,867	685,130	828,867
CF_3	$/year	280,204.91	362,711.51	280,204.91	362,711.51
CF_4	km	1.4	0.6	0.6	1.4
EA_1	1-5 scale	4	3	3	4
EA_2	point	30	15	15	30
EA_3	0-0.5 scale	1	1.5	1	1.5

In this study, Özhan and Abdalla's (2002) metocean model is used to obtain the data for the For LF_2, LF_3, LF_4, LF_6, LF_7 and LF_8 criteria. The value of LF_5 criterion was computed using Eq. 1. On the other hand, Eq. 2 was used to measure EA_3 criterion. The value of LF_1 criterion was calculated by employing Eq. 3 (Chakraborty et al., 2019).

$$P_{LF_5} = \sum_{i=1}^{N} \frac{1}{d_i} \tag{1}$$

where d_i is the distance of any maritime facility which may cause potential interference to the point where the wave energy converter will be installed, and N is the total number of facilities ($i=1, 2, \ldots, N$) within a 10 km radius of the specified point.

$$P_{EA_3} = (a + b) \times 0.2 + c \times 1 + d \times 0.6 \tag{2}$$

where a, b, c, and d are the number of plant species unique to the region in question, the number of animal species unique to the region in question, the number of marine species unique to the region in question, and the number of amphibians unique to the region in question, respectively.

$$P_w = \left(\frac{\rho \times g^2}{64\pi}\right) \times T_p \times H_s^2 \tag{3}$$

where P_w is the average wave power, H_s is the incident significant wave height, T_p is peak period, ρ is the density of water, and g is the gravitational acceleration.

In this study, CRITIC method is used to determine the weights of the criteria. First the initial decision matrix is normalized (Table 2) to compute the correlation coefficient of the criteria. Lastly, the weights of the criteria are determined (Table 3). In Table 3, W_j is the weight of the j^{th} criterion and C_j is the quantity of information contained in j^{th} criterion.

Table 2. Normalized decision matrix.

	A_1 (Kefken)	A_2 (Karaburun)	σ_j
LF_1	0.000	1.000	0.707
LF_2	0.000	1.000	0.707
LF_3	0.000	1.000	0.707
LF_4	0.000	0.000	0.000
LF_5	0.000	1.000	0.707
LF_6	0.000	1.000	0.707
LF_7	1.000	0.000	0.707
LF_8	0.000	1.000	0.707
LF_9	0.000	0.000	0.000
EF	0.000	0.000	0.000
CF_1	1.000	0.000	0.707
CF_2	1.000	0.000	0.707
CF_3	1.000	0.000	0.707
CF_4	0.000	1.000	0.707
EA_1	0.000	1.000	0.707
EA_2	0.000	1.000	0.707
EA_3	1.000	0.000	0.707

Table 3. Criteria weights.

Criteria	C_j	W_j
LF_1	9.192	0.059
LF_2	9.192	0.059
LF_3	9.192	0.059
LF_4	0.000	0.000
LF_5	9.192	0.059
LF_6	9.192	0.059
LF_7	14.849	0.095
LF_8	9.192	0.059
LF_9	0.000	0.000
EF	0.000	0.000
CF_1	14.849	0.095
CF_2	14.849	0.095
CF_3	14.849	0.095
CF_4	9.192	0.059
EA_1	9.192	0.059
EA_2	9.192	0.059
EA_3	14.849	0.095

The findings of the CRITIC method reveal that material cost (CF_1), installation cost (CF_2), operation, maintenance costs (CF_3), time variation of incident wave power (LF7), and migration routes (EA_3) have the highest weight among all criteria. They are followed by the incident wave power (LF_1), incident significant wave height (LF_2), incident wave period (LF_3), maritime transportation density (LF5), extreme wave height (LF6), time variation of incident wave power (LF7), shape parameter of incident wave spectrum (LF8), accessibility (CF_4), water quality (EA_1), endemic species (EA_2) which have the second highest weight.

After determining the weights of the criteria via CRITIC method, COPRAS method is used to determine the ranking of the location alternatives where wave energy converters can be installed. The method starts by constructing the initial decision matrix (Table 1). Then, elements of the initial decision matrix are normalized (Table 4) to construct the weighted normalized decision matrix (Table 5).

Table 4. Normalized decision matrix.

	A_1 (Kefken)	A_2 (Karaburun)
LF_1	0.436	0.564
LF_2	0.471	0.529
LF_3	0.493	0.507
LF_4	0.500	0.500
LF_5	0.855	0.145
LF_6	0.590	0.410
LF_7	0.454	0.546
LF_8	0.459	0.541
LF_9	0.500	0.500
EF	0.500	0.500
CF_1	0.453	0.547
CF_2	0.453	0.547
CF_3	0.436	0.564
CF_4	0.700	0.300
EA_1	0.571	0.429
EA_2	0.667	0.333
EA_3	0.400	0.600

Then, the sums of weighted normalized values for both beneficial and non-beneficial criteria are computed to determine the relative significances of the alternative locations. Finally, the ranking of the alternatives is obtained after calculating the quantitative utility for each alternative. The results obtained via COPRAS method (Table 6) show that A_2 (Karaburun) is the most appropriate alternative as it has a greater utility value when compared to the utility value of A_1 (Kefken).

Table 5. Weighted normalized decision matrix.

	A_1 (Kefken)	A_2 (Karaburun)
LF_1	0.026	0.033
LF_2	0.028	0.031
LF_3	0.029	0.030
LF_4	0.000	0.000
LF_5	0.050	0.009
LF_6	0.035	0.024
LF_7	0.043	0.052
LF_8	0.027	0.032
LF_9	0.000	0.000
EF	0.000	0.000
CF_1	0.043	0.052
CF_2	0.043	0.052
CF_3	0.041	0.053
CF_4	0.041	0.018
EA_1	0.033	0.025
EA_2	0.039	0.020
EA_3	0.038	0.057

Table 6. Results of COPRAS method.

Relative significance of alternatives					Utility values and ranking of the candidate alternatives	
	P_j	R_j	$1/R_j$	Q_j	N_j	Ranking
A_1 (Kefken)	0.109	0.406	2.465	0.428	88.258	2.000
A_2 (Karaburun)	0.125	0.360	2.777	0.485	100.000	1.000

The findings of this study are consistent with the findings of the authors' previous study (i.e., Turkoglu et al., 2020). Even though the same location is favored in both studies, studies (e.g., Polat et al., 2019) exist revealing the fact that using different MADM methods for the very same problem may end up with different results. Therefore, this study gives decision-makers the opportunity to use the proposed model in different locations which allows them comparing the results to make sure that the most appropriate location is selected.

Conclusion

Renewable energy generation grew at its fastest rate in recent years. Wave energy is one of the important renewable energy sources in coastal areas. But, not selecting the appropriate location for a renewable energy project may weaken its benefits. Therefore, the selection of the most appropriate site for the installation of wave energy converters is very important to get the maximum utilization of wave power potential. In this study, a multi-attribute decision-support system to determine the most appropriate location where wave energy converters can be installed has been proposed. The proposed multi-attribute decision-support system integrates

CRITIC and COPRAS methods. The weights are calculated via CRITIC method and the alternatives are ranked via COPRAS. The findings of this study show that Karaburun is the most appropriate alternative as it has the greatest utility degree. It should be also noted that the finding of this study is consistent with the findings of the authors' previous study. However, decision-makers should be aware that studies exist revealing that the use of different MADM methods may give different results for the very same problem. Discussion with decision makers reveals that this method is reliable and usable in any wave energy site selection as it provides a reasonable and rational results. An in-depth study that includes additional criteria and different locations my shed further light to the site selection of wave energy converters.

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Evaluation of Construction and Demolition Wastes in the Context of the Waste Framework Directive of the European Union Member States

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Abstract

Construction and demolition wastes (CDW) accounts for nearly 40% of total waste in the European Union (EU) in recent years. EU with the Waste Framework Directive (WFD), which is the basic law of the waste policy, has set various targets for the member countries to reduce CDW. However, this directive does not specify a common definition or approach for CDW and the application does not clearly define the evaluation categories. This has led to various strategic differences in CDW management among member states. Therefore, in this study, the correlation of CDW generation with national construction turnover, gross domestic product, and number of people in EU MS are examined and compared. These data were evaluated to analyze the relationship between landfill tax, CDW recovery rates, and landfill bans. However, according to the obtained correlation graphs, there is no particularly significant relationship between landfill or recovered CDW rates and CDW tax. Finally, the current situation in Turkey was analyzed, and the processes and strategies to be followed according to the important gaps and concerns regarding the credibility of the CDW definition and data specified in the EU were determined.

Keywords: *construction and demolition waste, European Union, Turkey, waste management.*

Introduction

Construction and demolition wastes (CDW) have increased significantly as a result of urbanization (Saez & Osmani, 2019). This has made CDW a global issue (Shi & Xu, 2021). CDW accounts for nearly 30-40% of total waste globally (Chen et al., 2002). When CDW generated by natural disasters is added to these, this rate rises to 50% (Öztürk, 2005). China, the United States of America (USA), and the European Union (EU) are the top three CDW producers, as well as the three largest economies (Kabirifar et al., 2020). China nearly 400 million tonnes (CABR, 2014); the USA nearly 700 million tonnes (Wu et al., 2019) and the EU 850 million tonnes (Saez & Osmani, 2019) are responsible for generating construction and demolition waste per year. The recovery rate of CDW in 2018 was 5%, 76%, and 88% in China, the USA, and the EU, respectively. In China, although 95% of these wastes are

recyclable, they reach landfills without any waste separation (Wang et al., 2021). Worse still, most of them are disposed of in illegal landfills (Xu et al., 2018). In the USA, the recycling rate is nearly 25% (Yu et al., 2021). Eurostat (EU statistics website) (Eurostat, 2018) according to 2016 data, nearly 71% in the EU; while the Netherlands, one of the EU member states (MS), reached 100%, Italy and Slovenia exceeded 97%; Ireland, Croatia, Cyprus, Malta, Portugal, and Romania have a recycling rate of less than 50%.

CDW threatens many countries as it constitutes a large part of solid waste (Elgizawy et al., 2016). CDW, by EU definition, are the wastes with the highest volume and weight. The percentage of CDW in total waste are 36% in the EU (Eurostat, 2018), 36% in Japan (Tam & Tam, 2008), 38% in Hong Kong (Tam & Tam, 2008), nearly 40% in China (Huang et al., 2021) and 44% in Australia (Tam & Tam, 2008); from EU MS, Austria, Malta and Luxembourg have percentages of 75%, 79% and 81.2%, respectively (European Commission, 2022). In this case, CDW determined by the EU as a priority waste stream due to its significant generation level and high recycling potential (Borghi et al., 2018). This study explores the practice of CDW management in the EU. Due to the uncertainties and gaps in the Waste Framework Directive (WFD), there is no common definition and approach for CDW in MS. There are differences in implements and evaluations. To compare these differences in EU-27 MS, CDW generated with 2018 data from Eurostat has been analyzed by taking into account factors such as construction turnover, GDP, and population. The study, considering the per person CDW rate generated in each MS examines the relationship between CDW bans and taxes, CDW landfill, or recovery rates in MS. The current situation in Turkey was analyzed and the process to be followed was briefly stated.

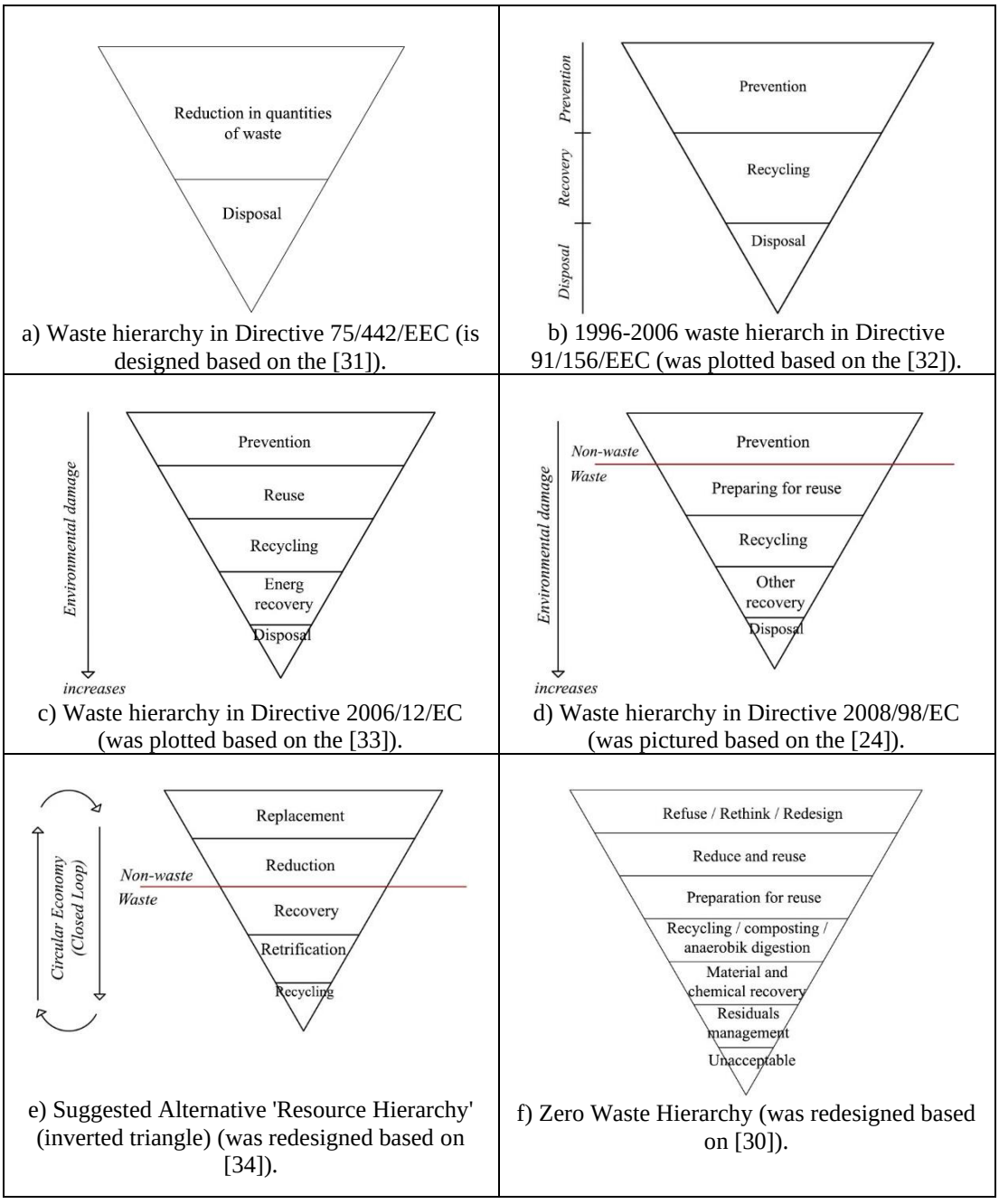
Waste Framework Directive

This stage adopts the EU Waste Framework Directive (WFD) and the waste hierarchy and uncertainties in the WFD.

Waste Framework Directive and Waste Hierarchy

In the European Union, waste management policies first started in 1975 with the WFD (SOER, 2015). With this directive, waste has been recognized as an environmental problem for the first time. However, waste prevention and recycling have been defined as an intention rather than an attainable goal (SOER, 2015). The WFD has served as an important harmonization tool for nearly 30 years without significant change (Elni review, 2010). After 1975, the Directive was changed to 2006/12/EC in 2006 (Neubauer, 2007) and 2008/98/EC in 2008 (Wang & Xie, 2021). WFD is the basic law of the EU Waste Policy. The WFD determines waste-related definitions for the EU-27 MS (European Commission, 2008) and provides a general framework for waste prevention and management (Römph & Cramer, 2020). Article 4 of the WFD requires the MS to define a waste management hierarchy incentived by law and policy (European Commission, 2012). WFD is implemented taking into account the waste management hierarchy (European Commission, 2008). The waste management hierarchy in the EU is prevention, reuse, recycling, energy recovery, landfill, and disposal (European Commission, 2008). In addition, the EU's action plan adopted in 2015 was revised and adopted the circular economy with the WFD No. 2008/98/EC in 2018 (European Commission, 2014). The main goals of the 2008 WFD are to transform the EU into a 'recycling society', prevent waste generation, use waste as a resource, reduce the negative

environmental and health impacts of waste and provide resource efficiency towards the creation of a circular economy (Ponce del Castillo, 2014). Despite these goals, the current waste hierarchy still allows disposal, not reflecting a circular economy framework (Zhang et al., 2022). The proposed hierarchy is a closed-loop, resource-use hierarchy, which is identified with the concept of the circular economy. Along with this concept, the Zero Waste Hierarchy was formed (Figure 1). The zero waste hierarchy proposed by Zero Waste Europe (ZeroWaste Europe, 2019) proposes to preserve value by designing wastes outside the system.



a) Waste hierarchy in Directive 75/442/EEC (is designed based on the [31]).

b) 1996-2006 waste hierarch in Directive 91/156/EEC (was plotted based on the [32]).

c) Waste hierarchy in Directive 2006/12/EC (was plotted based on the [33]).

d) Waste hierarchy in Directive 2008/98/EC (was pictured based on the [24]).

e) Suggested Alternative 'Resource Hierarchy' (inverted triangle) (was redesigned based on [34]).

f) Zero Waste Hierarchy (was redesigned based on [30]).

Figure 1: Waste management hierarchy development framework.

Uncertainties of Waste Framework Directive

WFD adopted by the EU; A common definition for CDW does not specify an approach and the application does not clearly define evaluation categories. Previously, construction wastes were simply debris from construction sites (Taylor, 2011). However, there is currently no consensus on the definition of CDW (Yuan, 2017; Wang & Xie, 2021). For example, in CDW report data provided by EU MS include: Germany excavated/non-excavated soil (Deloitte, 2015a); Finland (Deloitte, 2015b), Spain (Deloitte, 2015c), and the Netherlands (Deloitte, 2015d) with/without hazardous waste; Finland (Deloitte, 2015b), Spain (Deloitte, 2015c), Sweden (Deloitte, 2015e), Austria (Deloitte, 2015f), Belgium (Deloitte, 2015g), Bulgaria (Deloitte, 2015h) and Romania (Deloitte, 2015i) with/without excavation or soil and stone. Since illegal disposals are not included in these reports, there is a great variation in reported values between countries (Saez & Osmani, 2019). Also, the CDW group may or may not be dangerous. However, Eurostat only analyses non-hazardous CDW. The non-hazardous category has a higher volume, increasing the chance of reuse (Carcel-Carrasco et al., 2021). However, it does not give the total amount of CDW generated. In this case, there are problems with the accuracy and completeness of the recorded data collected and summarized by the MS. In addition, quantitative data CDW of illegally disposed of are not available. In addition, while the WFD does not provide a definition for backfilling, the term backfilling is evaluated differently between MS as recovery or disposal (Deloitte, 2017). According to Eurostat 2018 data (EEA, 2020), the including or excluding backfill of amounts reported affects the calculation of the recovery rate and causes large differences between some MS. Furthermore, the Directive indicates a shift from a policy based on waste disposal to a policy that prioritizes its use through recycling to conserve natural resources (Malia et al., 2013). The 2008/98/EC WFD includes the option to set end-of-waste (EoW) criteria for recycling waste-derived materials. However, the criteria have not yet been defined (Carcel-Carrasco et al., 2021). Only five MS (Austria, Belgium, France, the Netherlands, and Romania) have end-of-waste criteria in their national legislation (Deloitte, 2017). In this case, the targets set do not directly contribute to recycling.

Management Performance of CDW in EU-27 MS

The analytical methodology of this research comprises five stages corresponding to the third part (Figure 2): CDW data framework, CDW Data reliability, analysis of CDW generation rates, analysis of CDW recovery rates, and CDW policy framework.

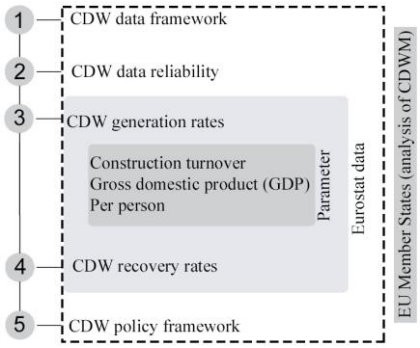


Figure 2: Framework of this study.

CDW Data Framework

EU adopted waste data for the first time in 2002 with regulation 2150/2002/EC on waste statistics. The regulation obliges EU MS to provide data on waste generation, recovery, and disposal every two years since 2004. As of this year, data on waste generation and treatment are available. However, CDW landfill data has been included in Eurostat since 2010 (Wang & Xie, 2021). In 2010, statistics on CDW generation were calculated using data sources such as surveys and interviews. As of 2011, CDW data is transferred directly to a central database by collection and processing companies (Deloitte, 2015f).

CDW Data Reliability

Data in this stage are from Deloitte, which provides source data to the EU. The European Commission (Deloitte, 2017) assesses the data quality of the MS and divides it into three parts (Table 1).

Table 1. CDW data quality levels and data collection (is designed based on the (Deloitte, 2017) source).

Good	Modest	Poor
Germany [1]	Belgium [2]	Bulgaria [3]
Austria [1]	Estonia [1]	Finland [3]
Czechia [2]	France [2]	Ireland [3]
Denmark [1]	Croatia [1]	Sweden [3]
Netherlands [1]	Spain [3]	Cyprus [3]
Poland [1]	Italy [1]	Latvia [1]
Portugal [2]	Lithuania [1]	Malta [1]
Slovakia [3]	Luxembourg [3]	Romania [2]
Slovenia [3]	Hungary [3]	Greece [3]

Data collection: [1] ADS: Administrative data sources; [2] S: Survey; [3] ADS and S

Analysis of CDW Generation Rates

Large amounts of CDW are generated in the EU, but there are significant differences between MS (Iacoboaea et al., 2020). In EU MS, the highest and lowest rates were 81.2% in Luxembourg and 0.1% in Bulgaria in 2018 (Figure 3).

In Table 2, Germany and France generated more than 60 million tonnes of CDW in 2018. These countries are followed by Italy, Belgium, and the Netherlands, respectively. However, it will not be an accurate and quality measurement to evaluate only by considering the amount of CDW generated. Factors such as construction turnover, Gross domestic product (GDP), and population are very important as that affect the amount of CDW generated. Table 2 was created with data on these parameters in each MS.

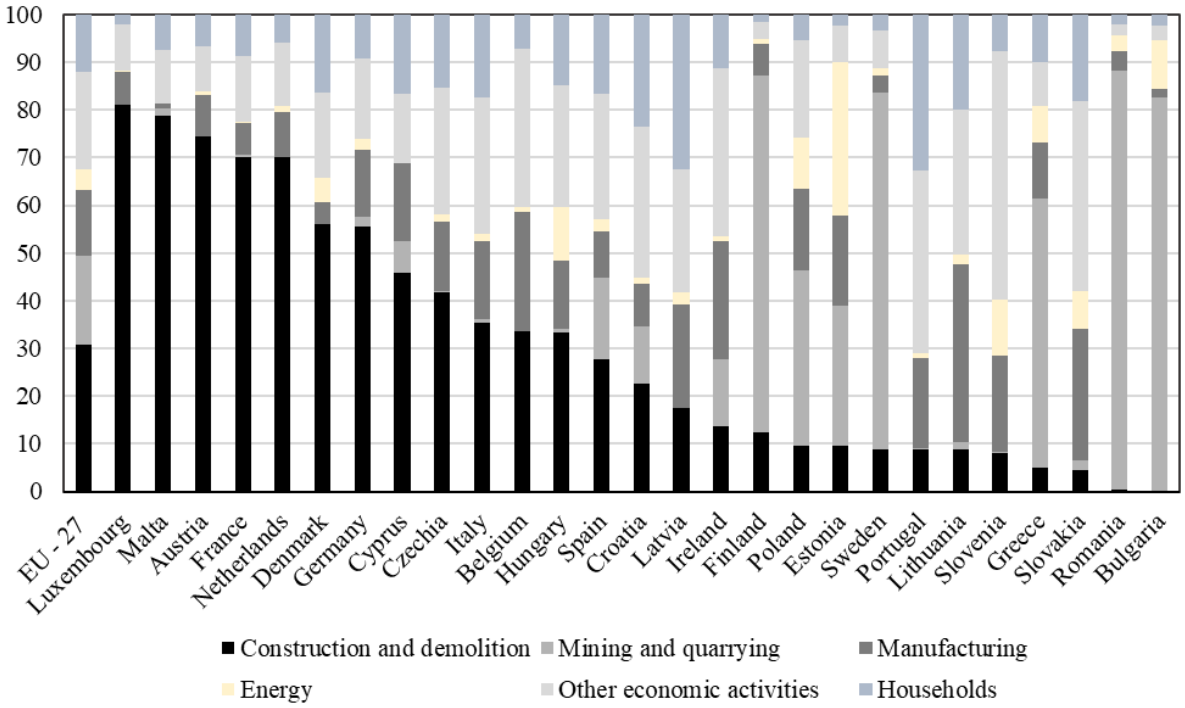


Figure 3: Waste generation (total waste percentage of CDW) by activities of EU MS in 2018 (Neubauer, 2007).

Table 2. Amount of CDW, analysis of construction turnover, GDP, and per person of each MS during 2018 (data from Eurostat, 2022).

MS	CDW (Mt)	Parameters analysed			Tonnes of CDW per parameter		
		CDW turnover (M€)	GDP	Person	t/M€	t/GDP	t/person
EU - 27	303.17	1.584.448	13.531.537,0	446.834.500	191,34	22,40	0,68
Belgium	21.76	68.495,8	460.091,7	11.467.900	317,71	47,30	1,90
Bulgaria	0.15	8.051,8	56.224,7	7.000.000	18,76	2,69	0,02
Czechia	7.50	32.958,4	210.970,5	10.649.800	227,44	35,53	0,70
Denmark	4.13	38.048,0	302.328,7	5.806.100	108,47	13,65	0,71
Germany	86.41	311.194,9	3.367.860,0	83.019.200	277,68	25,66	1,04
Estonia	1.21	3.890,8	25.817,7	1.324.800	309,72	46,68	0,91
Ireland	0,71	29.639,8	326.631,3	4.904.200	23,89	2,17	0,14
Greece	1.15	9.308,6	179.557,7	10.722.300	123,01	6,38	0,11
Spain	14.50	150.361,1	1.203.259,0	46.934.600	96,41	12,05	0,31
France	68.98	309.259,1	2.363.306,0	67.028.000	223,04	29,19	1,03
Croatia	0.50	6.519,2	52.688,8	4.076.200	75,22	9,31	0,12
Italy	41.27	166.843,7	1.771.391,2	60.359.500	247,33	23,30	0,68
Cyprus	0.32	3.578,0	21.612,6	875.900	90,74	15,02	0,37
Latvia	0.39	4.707,8	29.153,6	1.920.000	81,86	13,22	0,20
Lithuania	0.80	6.172,0	45.514,8	2.794.200	129,22	17,52	0,29
Luxembourg	0.64	6.251,4	60.362,2	613.900	102,16	10,58	1,04
Hungary	3.47	14.065,0	136.073,4	9.772.800	246,60	25,49	0,35
Malta	1.88	1.251,6	12.954,8	493.600	1500,1	144,93	3,80
Netherlands	21.20	105.000,5	773.987,0	17.282.200	201,91	27,39	1,23
Austria	11.16	52.893,8	385.424,0	8.858.800	211,02	28,96	1,26
Poland	6.76	78.186,1	497.842.3	37.972.800	86,41	13,57	0,18
Portugal	1.56	20.150,7	205.184,1	10.276.600	77,33	7,59	0,15

Romania	0.73	20.458,2	204.496,9	19.401.700	35,56	3,56	0,04
Slovenia	1.07	5.580,2	45.864,2	2.080.900	190,87	23,22	0,51
Slovakia	0.85	11.078,3	89.430,0	5.450.400	76,64	9,49	0,16
Finland	1.25	38.638,7	233.462,0	5.517.900	32,36	5,35	0,23
Sweden	2.88	81.864,7	470.673,1	10.230.200	35,14	6,11	0,28

For each parameter analyzed according to Table 2, values higher than the EU mean are shown in gray (Table 3). In Table 3, Belgium and Estonia have the highest; Bulgaria and Ireland have the lowest construction turnover. Belgium and Estonia exceed 300 tonnes/M€; Ireland generated at such a low level that it could not exceed 20 tonnes/M€. The average CDW/GDP rate in the EU-27 MS were 22.4 tonnes in 2018. Belgium, Estonia, Czechia, France, Austria, Netherlands, Germany, Hungary, Italy, and Slovenia were the MS exceeding the average. In contrast, Ireland and Bulgaria have the lowest CDW/GDP ratios.

Table 3. Ranking of EU MS by the amount of CDW generated per parameter analyzed for 2018 (data from Table 2).

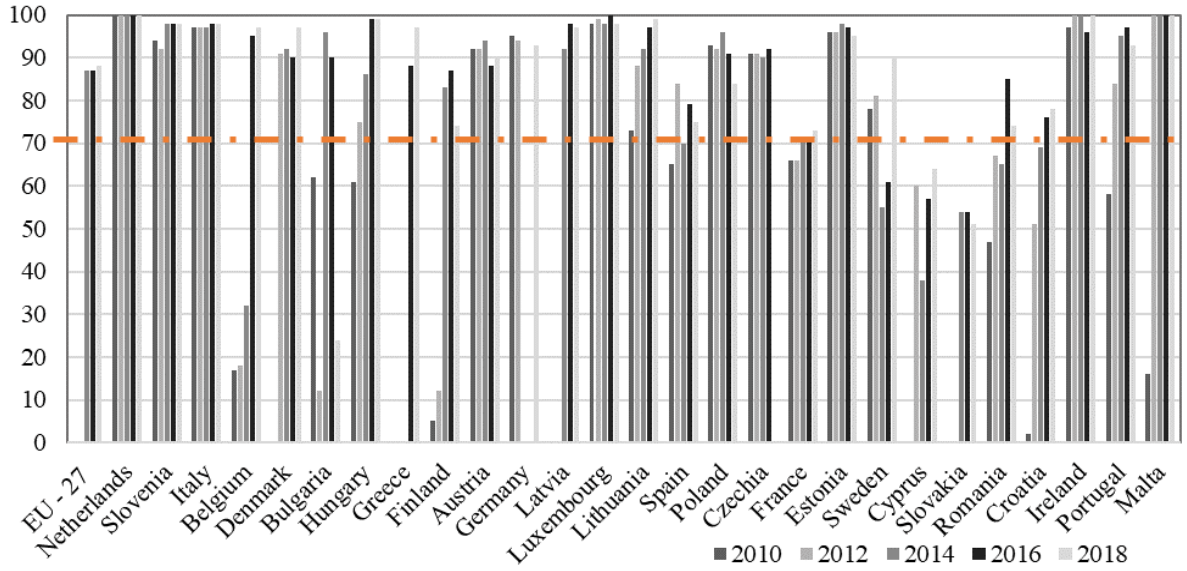
	CDW and Turnover		CDW and GDP		CDW and Person	
	MS	t / M€	MS	t / GDP	MS	t / Person
1	Belgium	317,71	Belgium	47,30	Belgium	1,90
2	Estonia	309,72	Estonia	46,68	Austria	1,26
3	Germany	277,68	Czechia	35,53	Netherlands	1,23
4	Italy	247,33	France	29,19	Germany	1,04
5	Hungary	246,60	Austria	28,96	Luxembourg	1,04
6	Czechia	227,44	Netherlands	27,39	France	1,03
7	France	223,04	Germany	25,66	Estonia	0,91
8	Austria	211,02	Hungary	25,49	Denmark	0,71
9	Netherlands	201,91	Italy	23,30	Czechia	0,70
10	EU - 27	191,34	Slovenia	23,22	Italy	0,68
11	Slovenia	190,87	EU - 27	22,40	EU - 27	0,68
12	Lithuania	129,22	Lithuania	17,52	Slovenia	0,51
13	Greece	123,01	Cyprus	15,02	Cyprus	0,37
14	Denmark	108,47	Denmark	13,65	Hungary	0,35
15	Luxembourg	102,16	Poland	13,57	Spain	0,31
16	Spain	96,41	Latvia	13,22	Lithuania	0,29
17	Cyprus	90,74	Spain	12,05	Sweden	0,28
18	Poland	86,41	Luxembourg	10,58	Finland	0,23
19	Latvia	81,86	Slovakia	9,49	Latvia	0,20
20	Portugal	77,33	Croatia	9,31	Poland	0,18
21	Slovakia	76,64	Portugal	7,59	Slovakia	0,16
22	Croatia	75,22	Greece	6,38	Portugal	0,15
23	Romania	35,56	Sweden	6,11	Ireland	0,14
24	Sweden	35,14	Finland	5,35	Croatia	0,12
25	Finland	32,36	Romania	3,56	Greece	0,11
26	Ireland	23,89	Bulgaria	2,69	Romania	0,04
27	Bulgaria	18,76	Ireland	2,17	Bulgaria	0,02
*	Malta	1500,10	Malta	144,93	Malta	3,80

* Malta has been excluded due to data quality as data rates are too high.

Analysis of CDW Recovery Rates

The WFD has set a target of at least 70% non-hazardous CDW (excluding soils) recovery by 2020 (European Commission, 2008). Figure 4 shows the recovery rates of EU-27 MS from

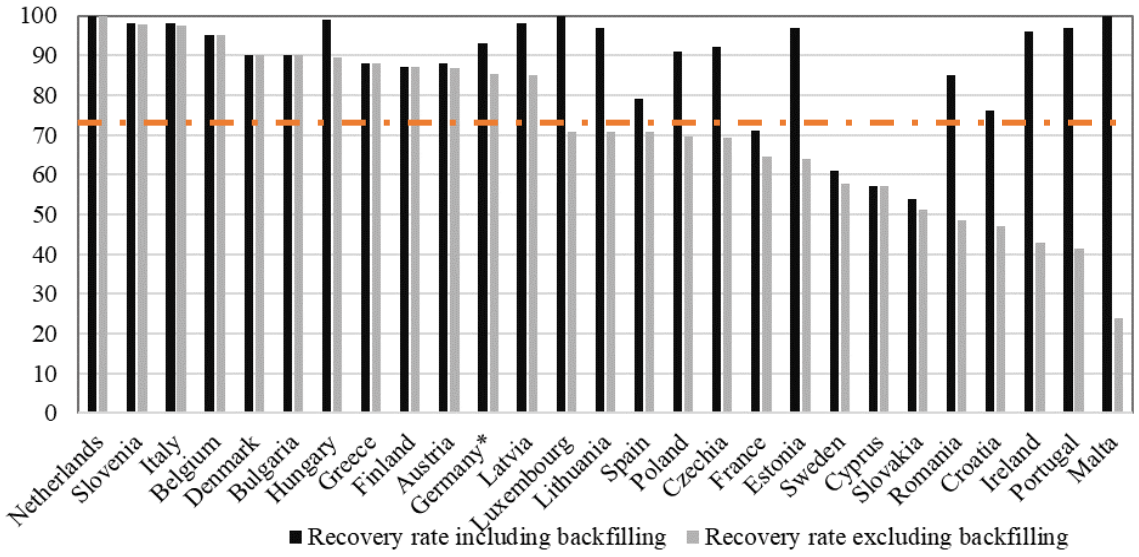
2010 to 2018, with data from Eurostat (2022). In Figure 4, recovery data is very volatile in some MS (such as Bulgaria, Cyprus, and Romania).



Data is confidential (Czechia –2018; Germany -2014 and 2016)
Data not available (Denmark –2010; Latvia – 2010 and 2012; Slovakia -2010 and 2012).

Figure 4: Recovery rate of construction and demolition waste.

In Figure 4, nearly 88% of total CDW was recovered in the EU in 2018. However, this rate also includes the filling rate, which is called backfilling. Most of MS accept backfilling as recovery. However, backfilling is a disposal method and refers to a process that cannot be recovered even if disposal results in the recovery of materials or energy (Deloitte, 2017). In Figure 5, Malta has a 100% recovery including backfill, while it has a recovery rate of 24% excluding backfill. In addition to the country of Malta, similarly, MS failed to exceed the EU 2020 70% recovery target excluding backfilling; Poland, Czechia, France, Estonia, Romania, Croatia, Ireland and Portugal. The MS of Sweden, Cyprus, and Slovakia failed to achieve this target in both cases, with or without backfill.



*Recovery rate including backfilling data was not available for the year 2016, so data from 2018 was used.

Figure 5: Recovery rates of CDW including and excluding backfilling in EU MS in 2016 (the figure (EEA, 2020) was created from the data in the source).

CDW Policy Framework

Through the WFD, EU MS has established different waste management implements and policies. Combined with the increase in CDW and the lack of local government policies for CDW management, the problems associated with the collection, transportation, and disposal of waste increase (Nunes & Mahler, 2020). These problems cause significant adverse effects on the environment, increased energy consumption, and consume finite landfill resources (Brandao et al., 2021). In this case, a lack of landfill will be inevitable over the years (Doan & Chinda, 2016). Although all MS have adopted the WFD into their national regulations, only Portugal, Slovenia, Spain in 2008 and in 2019 France developed national regulations for CDW management (Saez & Osmani, 2019). Because of the remaining MS rely on waste management plans; they do not have specific national CDW regulations (Saez & Osmani, 2019). Deloitte (2017) has divided EU MS into 3 categories according to their CDW legal framework (Figure 6).

The level of CDW management varies considerably in EU MS. For example, the landfill rate for CDW ranges from 0% for the Netherlands, Ireland and, Malta to 76% for Bulgaria Eurostat, 2022). Table 4 shows the member states' classification of CDW landfill bans and landfill taxes according to the high and low CDW generated per person identified in Table 3.

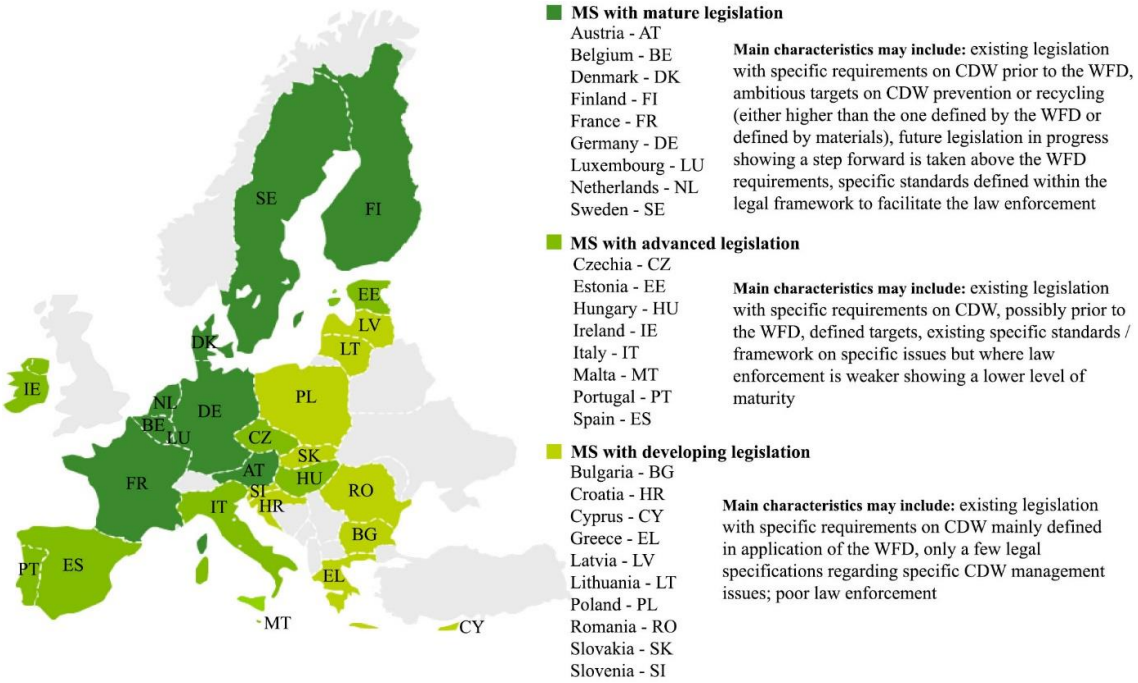
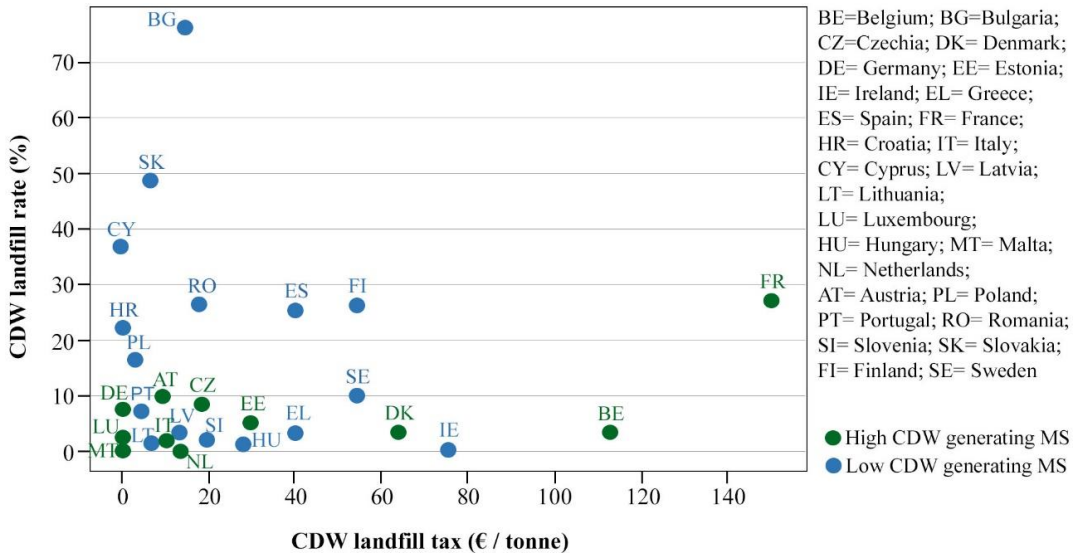


Figure 6: Level of maturity of the legal framework in MS (was redesigned based on Deloitte, 2017).

Table 4. Landfill ban and landfill taxes for high and low CDW generating per person in EU MS (the table (Saez & Osmani, 2019; Eurostat, 2018; Deloitte, 2015a,b,c,d,e,h,j,k,l,m,n,o; Deloitte, 2017; European Commission, 2018; CEWEP, 2017) was created from the data in the sources).

High CDW generating				Low CDW generating			
MS	Ban	Tax	€ /ton	MS	Ban	Tax	€ /ton
Belgium	✓	✓	56,05-113,01	Slovenia	✓	✓	19,2
Austria	✓	✓	9,20	Cyprus	-	-	-
Netherlands	✓	✓	13,07	Hungary	✓	✓	28
Germany	✓	-	-	Spain	-	✓	5-40
Luxembourg	✓	-	-	Lithuania	✓	✓	7,14
France	✓	✓	40-150	Sweden	✓	✓	54
Estonia	✓	✓	29,84	Finland	✓	✓	55
Denmark	✓	✓	49-64	Latvia	-	✓	13
Czechia	-	✓	18,50	Poland	✓	✓	2,7
Italy	-	✓	1,03-10,33	Slovakia	✓	✓	0,33-6,64
Malta	-	-	-	Portugal	-	✓	4,27
				Ireland	-	✓	75
				Croatia	✓	-	-
				Greece	-	✓	40
				Romania	-	✓	18
				Bulgaria	-	✓	14,3

In Table 4, according to the data in Table 3, the ones that are above the EU-27 average of the MS according to the amount of CDW generated per person (0.68 tonnes/person) are high; others are defined as low CDW producers. Figure 7 was created to classify the analyzed CDW policy framework for EU MS by per person CDW rates and analyze the relationship of these rates to CDW landfill tax and landfill rates. In MS, CDW landfill taxes differ by region or province, or by type of construction waste. The highest of the different CDW landfill taxes applied for countries such as Belgium, Denmark, France, Italy, Spain, and Slovenia were taken.



Data were not available for Czechia's CDW landfill rate in 2018, so data from 2016 were used.

Figure 7: Relationship between CDW landfill rate and landfill tax in EU MS in 2018.

Landfill taxes and bans may be two of the most effective practices for increasing CDW recovery rates (Deloitte, 2017). However, in this correlation graph, no direct relationship was found between the CDW landfill tax and the CDW landfill rate, or recovery rate (Figure 7).

Turkey

In Turkey, the first study on CDW was in 2004. There are four regulations for CDW conducted by the Ministry of Environment, Urbanization, and Climate Change:

- Excavated Soil, Construction, and Demolition Waste Control Regulation – 2004 (Official Journal of the Republic of Turkey, 2004)
- Regulation on Landfilling of Wastes – 2010 (Official Journal of the Republic of Turkey, 2010)
- Waste Management Regulation – 2015 (Official Journal of the Republic of Turkey, 2015)
- Zero Waste Regulation – 2019 (Official Journal of the Republic of Turkey, 2019)

Turkey has not yet adopted the Waste Framework Directive (2008/98/EC) into its national legislation and current regulations are not enough for CDW management. Available regulations are only theoretical and are not implemented. In Turkey, for the implementation of these regulations, first of all, CDW data must be available. However, there are currently no legal or economic mechanisms in Turkey to assist in reducing the amount of disposal and landfill of CDW. In Table 5, CDW management comparison chart between Turkey and the EU is given.

In Table 5, in the 2016-2023 Action Plan (European Commission, 2018), the only target for CDW as the future target are to promote the importance and management of CDW and excavated soil. This action plan is not a policy that contains or proposes specific solutions for CDW. When we compare it with the EU; EU MS have much better policies and practices than Turkey (Table 5). However, according to Table 5, this situation differs between MS.

Table 5. Comparison of CDW management in Turkey and the EU.

Indicators	European Union (EU-27)	Turkey
Waste Framework Directive	Available in all 27 MS	No
CDW Management Plan	Available in all 27 MS	No
Specific Regulations for CDWM	Available in 4 of 27 MS	No
CDW data	Available in all 27 MS, although the quality of data varies	No
CDW landfill ban	Application in 16 of 27 MS	No
CDW landfill tax	Application in 22 of 27 MS	No
CDW recovery rate	88%	No data
CDW recycling rate	71%	No data
Backfill definition	Available in 12 of 27 MS	No
End of waste criteria (EoW)	Available in 5 of 27 MS	No
Distribution of CDW recycling facilities	Available in all 27 MS, although their number may differ	In some developed cities, facilities for aggregates have been operation
National/regional sorting obligation	Application in 16 of 27 MS	No
National/regional separate collection obligation for different materials	Application in 13 of 27 MS	No
Obligation separate collection and management of hazardous CDWs	Application in all 27 MS	No
Pre-demolition audits	Application in 16 of 27 MS	No
Green Public Procurement	Application in 11 of 27 MS	No
Future target	70% recovery	To disseminate the importance and management

Results

This study presents an analysis of firstly WFD's uncertainties about CDW then the EU member states' CDW generation and recovery rates, policy frameworks, and the situation in Turkey. The study reached the following conclusions:

- The CDW defined by the EU's WFD demonstrated the lack/inadequacy of existing legislation and policies (significant uncertainties and gaps in the definition, scope, standards, policies, and data quality of the CDW).
- The study shows that current strategies are diverse and fragmented among MS and are not equally promoted. This case prevents MS from developing models to help estimate the amount of CDW and each MS from constitute an efficient infrastructure for CDW in line with the 'Circular Economy'.
- Belgium, Germany, and Estonia were found to be the highest ranked according to parameter analyses such as CDW-construction turnover, CDW-GDP, and CDW-person, and Bulgaria, Ireland, and Romania were the lowest.
- No correlation was found between CDW landfill tax and CDW landfill rate or recovery rate in EU MS. This may be due to the different quality levels of CDW data provided by MS or the main goal in taxation.
- European Union target of recovery rate for the year 2020 has not achieved, including backfilling three MS and excluding the backfilling of twelve MS.
- Turkey is very deficient in CDW management, practices, and policies.

Recommendations for this study should include a quantitative recycling target rather than an EU CDW recovery target. To achieve this goal, effective recycling facilities will be needed. EU CDW management protocol; It has already stated (Elshaboury & Marzouk, 2021) that the identification, separation, and collection of CDW will assist in the improvement of reverse logistics of CDW, CDW processing and quality, and management of recycled products from CDW, and appropriate policies. Solving the CDW management problem will lead to better strategic development with the application of new technologies (such as BIM, artificial intelligence, big data, internet of things). Using these technologies that automatically identify different materials, on-site waste separation has the potential to aid CDW classification and reduce costs (Davis et al, 2021). Appropriate policies should be implemented for these. In particular, more effective and coordinated actions and policies should be encouraged for the definition of waste end criteria, traceability guidelines, pre-demolition inspections, and the development of harmonized supporting guidelines for material (such as the taxation of raw materials) and tools. Turkey should immediately begin initiatives to develop prevention, reduction, and recovery programs for CDW in national, regional, and local policies. Regional planning and policies would be more beneficial because of the amount of CDW generated and the type of waste generated are different in each region.

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How to Measure the Social Sustainability? Measurement Criteria for Architectural Design

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Abstract

Social sustainability requires a multifaceted understanding of the relationship between structure and human. Social interactions between people and the nature of their interactions are regulated through structures. On the other hand, structure also plays an important role in facilitating or preventing the development of actions in social life. The promotion and development of social sustainability through the structure depends on the creation of appropriate physical conditions within the structure by addressing the issues of social sustainability and the opportunities offered to the users of the structure in the architectural design process. Although the social sustainability criteria were mentioned in the content of the articles in the examined literature, the issue of determining the measurement criteria of social sustainability was found to be insufficient. Based on this analysis, the potential of the social sustainability approach to provide data support to the architectural design process has been analyzed and the measurability part has been presented to designers according to the criteria determined from the literature. According to the data obtained as a result of this analysis, a list of criteria has been created according to the social sustainability criteria that will shed light on the designers and are of primary importance in the construction process. Social sustainability is an approach aimed at defining, regulating and improving social life based on human and human relationships and interactions in public life. In this context, the aim of this study is to shed light on future social sustainability studies and to provide data support.

Keywords: *measurement criteria, principles of social sustainable architecture, social sustainability, social sustainability literature.*

Introduction

It is possible that many of the issues addressed in the architectural design process are directly or indirectly related to social sustainability due to the fact that people are the focus of architecture. The architectural design action, which is the decenter of the interaction between the environment and man, is very important because it is a process of creating and developing criteria that will determine the quality of settlements. Architectural design is a process that is staged as defining the problem, collecting data, revealing the first thoughts about the solution, creating alternative designs, choosing the most optimal model/design and evaluating the result by re-comparing the final model with the initial data. It is inconceivable that at every point in this process, this discipline, which has a human being at its center and has lost all meaning in

the absence of its user, lacks social sustainability. Human being, which has been forming and regulating its relations with the built and natural environment using many principles it has acquired from nature for hundreds of years, has maintained its mutual interaction with nature accompanied by the excellent teaching of nature. However, a number of global disasters have arisen due to the weakening of relations with nature for a wide range of reasons, the dominance of the point of view that sees nature as a resource in life. This situation has brought about a mental awakening and efforts to make life sustainable. The beginning of this effort dates back to 1972, when the issue of the environment was discussed for the first time at the Stockholm Conference (Boudes, 2014). However, the meeting of the Brundlant Commission in 1987 was remarkable because it was the first time that the concept of sustainability was defined. With the report published by the Commission, the concept of sustainability has settled in the world literature. According to the report, also known as the "Our Common Future Report", sustainable development is defined as "Development that meets today's needs without compromising the ability of future generations to meet their own needs (WCED, 1987)". The concept of sustainability has thus become a concept that has been discussed in almost every field from the moment it was first defined to the present day. While these concepts are being developed on the basis of, the evaluation criteria in the literature on behalf of social sustainability, which is the sub-heading of sustainability in architecture, stand out. In this context, the aim of this study is to shed light on future generations and architectural discipline in the construction process by converting these criteria into an evaluation criterion.

Literature Review

Social Sustainability

Indicators of social sustainability in architecture should be discussed in order to provide people with the highest quality living standards and liveable conditions for future generations. The principle of equality and accessibility should not be ignored for this discussion. In declaration on social sustainability, it is necessary to understand that the relationship between structures and society is multifaceted. All kinds of social interactions between people, the quantity and nature of these interactions are provided through these structures located in the environment. On the other hand, it is possible to achieve or prevent social interaction of people through these structures. Since this interaction between people and structures is continuous, the most important factor in the evaluation of spaces should be social sustainability indicators. In this context, a guide that can help architects in the social sustainability dimension of design should be examined. Determination of appropriate sustainable design strategies in sustainable design and social design as a tool to determine the performance criteria to guide decision-making processes involved in the design process from the first phase and sustainable architectural design, architectural and social priorities and objectives should be used.

In social sustainability indicators, the spatial quality of the architectural structure to be examined is first examined in order to determine the elements that need to be adapted to architecture and that require the design of the design in this context through a specific guide. Social sustainability, as a conceptual definition, includes the definition of a quality of life standard, as well as social sustainability in architecture should include the concept of quality of space. Words image within the concept of spatial quality, accessibility, identity, accessibility and parking facilities can be sorted in the following manner, imagination,

productivity, spatial orientation, flexibility, privacy, security, meaning, health, construction, health, physical and mental relaxation, comfort, status, etc. it could belong.

A sustainable building is defined as designing quality living conditions that are ecologically compatible with its environment, economically feasible, and prioritize user needs. In other words, a sustainable structure should have positive effects on the environment, its economic effects should be minimized and it should have sociocultural factors (such as quality and healthy space). At this point, it can be said that social sustainability has been left in the background as a result of not studying it much in the theoretical field. Berardi (2013), who works in the field of architecture, has determined a number of indicators of social sustainability. Substances can be listed as follows:

- Ethical standards should be followed throughout the supply chain with ethical trade and by providing healthy and safe working environments.
- Spaces should be designed according to user needs and provide flexibility in spaces.
- It should preserve the local heritage and culture.
- It should be integrated into the local context and ensure users' access to infrastructure services.

At this point, Berardi (2013) mentioned the keywords of social sustainability such as **flexibility** and **adaptability** when talking about sustainability.

In order to determine the architectural criteria of social sustainability, it is first necessary to analyse the relationship of space with people and society well. Man has tried to shape the place where he is located according to himself for ages. Initially, people made the cave where they lived a shelter for themselves, and over time they built their own unique structures. As the process of building this structure progresses, it has also been learned that spaces affect people. This bilateral interaction and its consequences have revealed the concept of social sustainability. In other words, spaces have the capacity to guide society and social relations. One of the concepts included in the concept of social sustainability, "quality of life", is a measurable level of well-being while receiving high-level efficiency in the space where a person is a user. It is a requirement of social sustainability with the concept of equality that all people achieve this "**quality of life**" equally. With the concept of "the right to life that should be passed on to future generations" contained in the definition of the concept of sustainability, it is one of the main goals of social sustainability to be able to leave and achieve this level of well-being equally to future generations. Prosperity includes the place where people are located and includes their daily lives in this place and their satisfaction arising from this life (Bacon et al., 2013). Since prosperity is shaped according to needs, space must have a flexible design in order to be socially sustainable in the face of changing needs. A definition of social sustainability made by Palich and Edmonds (2013) describes it as "a process aimed at designing sustainable and successful spaces to increase people's well-being by understanding what they need where they live". Another important concept that social sustainability includes is health. In the ISO 21929-1:2011 document submitted by the International Organization for Standardization, it is explained that social sustainability is the right of all mankind to benefit equally within the scope of health. Human health, both physically and spiritually, is affected by the design of the structure. Factors such as material quality, the amount of light the space receives, and the designs of the energy production-consumption relationship, directly affect human health. As it can be seen from this, human health is one of the factors affecting the "quality of life". In the ISO 21929-1:2011 document submitted by the International Organization for Standardization, another concept mentioned is security. Aside from the importance of security for human life, security also provides a person

with the feeling of "belonging" necessary for a "quality life". As it can be seen from here, security is one of the indicators of social sustainability in architecture. Another of the indicators of social sustainability in architecture is social equality.

Quality of life is conceptually directly related to the well-being of people. Human-centred quality of life, “human well-being", nature-cantered "environmental well-being" and it refers to the situation of “having a good place” based on space. The department, which is based on space, stands out in this research (Ministry of Development, Eleventh Development Report).

Methodology

In order for the systematic analysis to cover a sufficient number of articles, the research databases “Web of Science”, “Scopus”, “EBSCOhost” were used. In order to contribute to the development of the concept of social sustainability and to fully its measurability, the articles published between 1972 and 2020 were examined. The reason why 1987 was chosen as the starting date is that the concept of sustainability and the concept of social sustainability, which is the subject of the study as a subheading, were first included in the Brundtland Report in 1987 (WCED, 1987). In this direction, the data mentioned in the study were reached by means of a literature review in such a way that the date 1987 was the starting point. As a research term, the keywords “social sustainability”, “social sustainability indicators”, and “measurement criteria” were searched in the entire article, publication titles and/or keywords. In this context, the whole of the study reveals a comprehensive and important approach to the promotion and development of social sustainability through structure.

Social Sustainability Indicators in Architectural Design

Space is not something that can be expressed only by physical forms. When it is considered that its subject is a person, space, physical forms and social relations become a whole. In this whole, there is a structure of space that shapes, regulates, develops social life and relationships, and is also affected by relationships in social life. It is obvious that the designers who founded this two-way design should act with an emphasis on social sustainability. Within the scope of social sustainability of a structure, space has a stimulating and developing quality of social interaction (Talen, 1999), a sense of place (Relph, 1976), a sense of trust and confidence (Newman, 1972) and a sense of comfort (Carr, 1992). However, in order to develop a space encourage social, flexible and adaptive qualities to occur in the desired place as supporting activities in an effective and efficient manner (Wegen, 2005; Mzoori, 2014), it is important to visualize the interactions of social life. The perception of security in the structure is also important for the development of community ties and the formation of a sense of community. By Bramley (2009), one of the indicators of social sustainability has been the element of security, as it was revealed that the sense of security in the structure strengthens social ties.

In this context, the titles in the literature that stand out with social sustainability and structure design are listed in Table 1.

Table 1. Social sustainability indicators in architectural design (source: authors).

SOCIAL SUSTAINABILITY INDICATORS IN ARCHITECTURAL DESIGN
Accessibility
Reachability/Parking Facilities
Space Efficiency
Flexibility
Security
Spatial Orientation

Accessibility

On the axis of social sustainability information, accessibility is at the top of maintaining the principles of social sustainability in architecture, as it emphasizes the principle of "**equality**" for all users. When referring to the phenomenon of accessibility in the context of social sustainability in architecture, 21542-2011 ISO standard (building construction: accessibility and usability of the Built Environment-Building Construction: built environment accessibility and availability) has defined accessibility of construction with the following ingredients:

- accessibility in the use of certain buildings
- outdoor accessibility
- indoor accessibility
- accessibility of traffic and transport services.

The first priority in building accessibility belongs to outdoor accessibility. Because no matter how flawlessly the structure is designed as spatial accessibility, if users or visitors cannot reach the structure, this will start to create chaos before the structure is used. Therefore, disabled access to the group structure should be pioneered within the scope of outdoor accessibility.

Reachability/Parking Facilities

Feitelson and Salomon (2000) establish relationship between the location of the structure and accessibility. Accordingly, the spatial patterns formed depending on the location choices of the uses in the built environment are influenced by a number of qualities such as ease of access to the transport network, speed of movement in the transport network, reliability and cost of access and movement on the network. These qualities vary depending on the location of the land and the type of transport network. In this context, the relationship of the location of the structure with the transportation network is important because it indicates the ease of access to the structure. In terms of accessibility, the presence of public transportation facilities and the provision of access to these facilities have an important place in promoting and developing social sustainability through the structure. Because transportation facilities and accessibility play a fundamental role in terms of human rights and equal opportunities. The fact that the structure has a location that can allow physical activities directly affects the availability and livability of the structure and the built environment. Therefore, in terms of social sustainability, location and orientation decisions should be made taking into account transportation facilities and ease of access to these facilities.

Space Efficiency

According to Hillier et al. (1984), the function is a characteristic spatial pattern and a characteristic part of the general spatial pattern. It is possible to express the concept of spatial pattern in this definition as the organization of the ways of decoupling of spaces and relations between spaces. Hillier et al. (1984) questioned the relationship between the form and function of the building, and on the overall structure of the spatial organization of the relations between the various spaces indicate that it has an effective role. Preiser (1983) states that user needs arise together with the built environment and user interaction, stating that user needs are actually indicators that reveal the performance and quality of the built environment. The performance levels that it considers in three groups as ”health, safety and security level“, ”functionality and efficiency level“ and ”psychological comfort and satisfaction level", in other words, reflect the needs of users in the physical environment. These three performance levels are also indicators of the liveability level of the spaces.

Flexibility

Flexibility is basically the ability of a place to adapt to new situations/relationships. According to Sinclair (2012), static spaces that are physically arranged according to very specific parameters show resistance to adaptation to other uses that may occur in space over time. Because fixed spaces usually have a single function and therefore exhibit an overly rigid behavior. According to Blakstad (2001), flexibility covers only one aspect of the change in buildings. Flexibility here is considered as a way to provide technical solutions by changing, moving, relocating elements such as walls, movable panels, and furniture within the basic structure of the building. Blakstad (2001) states that flexibility is a method for providing physical adaptability.

Security

According to Maas (2009), a sense of security is a prerequisite for health, well-being and quality of life. Promoting and developing social sustainability through a built environment is associated with the ability to use the structure without being threatened or experiencing a sense of fear. The perception of security in the built environment and in the structure is important for the development of community ties. According to Kent and Thompson (Jul, 2014), safe, clean and interesting areas in the structure can support the development of community ties and the strengthening of the community.

Spatial Orientation

The organization of space is important spatial information that supports in terms of an individual's understanding of the relationship between spaces and forming an image of this relationship. The fact that the relationships between horizontal and vertical spaces cannot be deciphered by users is an element that makes it difficult to find direction in the structure. It can be said that it is possible to direct human movements by determining the main axis of space and the direction of movement in the structure. According to Passini (1998), who drew attention to the importance of the circulation system in terms of direction finding, horizontal and vertical circulation systems are part of the architectural sense of direction finding.

How to Measure the Social Sustainability Indicators

In the articles containing the social sustainability indicators examined, the lack of the measurability part is noticeable in the literature. The fact that the determined indicators are grouped one by one or two and included in the articles and not made into the main headings makes the measurement standard difficult. Assessing the impact of structure on social sustainability, Bramley (2009) states that social sustainability includes two important dimensions, namely “social equality” and “sustainability of society”. In this case, the measurement criterion of social sustainability within the scope of the subtitle "Equality and justice for all" is the presence of Pedestrian Path, Use of Green Space, Accessibility and Parking Facilities. Hami and Emani (2015) state that planting has a negative relationship with total crimes in neighbourhoods, crimes against property, and violent crimes. In this context, Hami and Emani (2015) state that green areas in residential areas are positively related to increasing social security and draw attention to the nature of vegetation. Schulz (1980), in his work Geniuc Loci, stated the identity of the place as a prerequisite for human identity. The feeling of living in a residential building with local architecture is the measurement criterion because the buildings contribute to the identity creation process with their mass and superficial shapes. Subheadings such as the use of local materials, giving direction to the design by taking into account local typologies can be created. To Mclntyre (2006), according to the exterior view, fresh air circulation, access to sunlight, user-centred design and an interior that encourages interaction to allow, aesthetic and high-quality social structures are structures that can be design driven. Here, these issues are collected under the heading of Quality of Life/Health Compliance. In the Maslow hierarchy of needs, which are listed as physiological, security, social, self, realization needs, the need for security constitutes the most basic requirements that come after physical needs. The security element is one of the most important measurement criteria of social sustainability. In this context, the security indicator is examined under security measurement criteria : presence of security guards inside or outside the building, whether there are surveillance systems at the entrance to the structure of education, urban safety features such as pedestrian paths, in the area of the school gates.

Results

In the light of the information obtained from the literature, the characteristics and measurability levels that a structure must have in order to be socially sustainable are indicated in the Table 2.

Table 2. The characteristics and measurability in social sustainability (source: authors).

SUSTAINABILITY CRITERIA	MEASUREMENT CRITERIA
Equality/Justice/Social Justice	Pedestrian Path / Use of Green Space / Accessibility / Need for parking / Use of public transport
Social Sustainability/ Social Gain	Neighbourhood Relations / Public Use of Community Areas / Garden Use / Park Use
Liveability/ Social Sustainability	Positive-Negative Features of the Use of Living Space/
Quality of Life/Health Compliance	The desire to move to another dwelling/ The problem with housing/The level of income/ownership/The network of social relations
Perception of the City and Sense of Belonging	Social exclusion status / sense of belonging / Urban activities in which he can participate in public life/
Identity	The feeling of living in a residential building with local architecture
Aesthetic Perception	Satisfaction with the Facade of the Dwelling, Its Colour, Appearance
Security	Presence of security guards inside or outside the building / Whether there are surveillance systems at the entrance to the structure / Examination of urban security features such as pedestrian paths, school gates in the area
Accessibility	The presence and transportation of elevators in the structure for the convenience of transportation of disabled people / Examination of disabled roads and access facilities in the current region/
Flexibility	Evaluation of the suitability of housing for changes in user requests / Evaluation of the ability to shape environmental urban furniture on an urban scale in the inhabited area according to user requests
Economic Equality	Property status / Income status of persons / Finding out if there are energy-efficient uses of the structure in which they live/

In order to promote and improve the social sustainability of the structure, it is necessary to understand the effects of the structure on social sustainability with awareness of social sustainability. In this context, the whole of this study has revealed a comprehensive and important approach to the promotion and development of social sustainability through structure. Within the scope of this approach, the principles set out in the measurability criteria in Table 2 are the priority items encountered in the literature review.

Conclusion

Social sustainability is one of the most important indicators that reveal the quality of life and well-being of people and communities. In a structure where social sustainability is promoted and developed, the physical conditions related to the structure and the facilities offered by the structure to its users are very important. In this study, these possibilities have been collected under six main headings in the light of the results of the literature review:

- Accessibility
- Reachability/Parking Facilities
- Security
- Spatial Orientation
- Space Efficiency
- Flexibility

Due to the fact that the spatial requirements related to social sustainability, which should be taken into account decently in the architectural design process, are scattered in the literature, the evaluation criteria in this study have been collected from the literature and presented to the reader. Social sustainability in the construction sector in our country to be considered for the development of awareness of all stakeholders, universities, local governments, professional associations and cooperation between civil society organizations must be. Based on this, it is necessary to create social sustainability and awareness in society. In this context, this study has been prepared in order to shed light on future studies and to determine the measurement criteria of social sustainability criteria in the construction process.

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An Investigation into the Sustainable and Green Building Certifications to Enhance Sustainability and Lean Performance of the Construction Supply Chain Management

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Abstract

Construction project management is experiencing challenges with respect to sustainability and competitiveness. Supply chains and supply chain management in the construction industry (CI) can influence footprint and sustainability of this industry. Furthermore, lean and sustainable construction supply chain management (LSCSCM) can have impact on the competitiveness and core competencies of the construction companies. For this reason, application of effective strategies and principles in the supply chain management to enhance lean and sustainability performance of the entire supply chain need to be fostered. Based on the literature review, this paper aims to investigate sustainable and green building certifications (the BREEAM, CASBEE, DGNB and Greenstar certifications) and their potential contribution to the LSCSCM. This paper emphasizes that all four sustainable and green building certifications can have potential to provide a method for delivering information on the leanness and sustainability of construction activities and supply chains in CI. This paper is expected to provide valuable input to the stakeholders of the supply chains in the CI.

Keywords: *construction supply chain, supply chain management, lean, sustainability, sustainable and green building certification.*

Introduction

For construction companies to stand out in the market, it is important that they target useful utilization of their resources and creation of unique abilities so that product quality, and novelty and effectiveness, client gratification and client reaction can be enhanced (Racela, 2014). Companies need to search for innovative ways to deal with intensified competition in the global CI market. At this stage, supply chain (SC) plays an integral part as SC is vital for construction projects and has impacts on the circular economy (Tatlici & Sertyesilisik, 2019). While managing the SC, one has to make sense of the breakdown and traceability of a range of factors such as services and products, logistics, people, information, activities and

resources (Designing Buildings, 2014). To effectively manage the SC, it is important to offer an approach that suits the project program (Designing Buildings, 2014).

In the last decade, companies and academics have focused on new trends in construction management at the SC level due to advances in technologies and increasing importance of environmentalist approach and information systems (Ghadge et al., 2020). Competitive advantage factors at the SC level can be supported through the lean and sustainable approach (Tatlici & Sertyesilisik, 2019). Adaption of the sustainable and green building certifications criteria to SC at relatively early stages of projects can have potential to improve process and achieve lean and sustainable SC. This can result in an association of lean and sustainable construction supply chain management (LSCSCM) among contractors and designers to benefit all parties to outperform their competitors. This study focuses on green building certifications that can contribute to the lean and sustainable SC.

Research Method

This paper aims to investigate sustainable and green building certifications (the BREEAM, CASBEE, DGNB and Greenstar certifications) and their potential contribution to the LSCSCM. The research objectives are to determine the criteria by certification, and the way of collaborative use of lean and sustainable approaches and certifications at the SC level. A systematic literature review (SLR) has been applied within the scope of this research. In this study, based on the literature findings, the factors that are important for the success of supply chain management (SCM) practices and SC relations in the CI were investigated. In line with the research aim and objectives, Sustainable and Green Building Certifications were examined to determine the factors for contractor companies to achieve lean and sustainable SC in the CI. The study is to determine the criteria that can be used/considered in supplier selection for contractor companies in the CI to support achievement of lean and sustainable SC. 4 certificates have been examined within the scope of this research. These 4 certificates are: BREEAM, DGNB, Greenstar and CASBEE.

Construction Supply Chain Management

CI is affected by the competitive environment in the world. In order to be successful in compelling competition conditions; supply, design, production, marketing and logistics need to be managed effectively and companies need to control their product efficiency, costs and prices (Salami et al., 2016). Ability to control the construction process from the beginning to the end can influence ability to compete in the CI (PYM, n.d.). CSCM is an approach inspired by manufacturing SCs and in recent years has attracted attention of academics and professionals in the CI (O'Brien et al., 2008). SCM can eliminate costs and timeouts in the CI and improve performance in the construction process (Egan, 1998).

The fundamental differences between processes of construction and of other industries as well as the nature of these processes challenge application of manufacturing SCM practices directly to the CI (Young et al., 2011). For this reason, the CI needs different SCM solutions from other industries such as manufacturing and retail (Segerstedt & Olofsson, 2010). According to Sullivan et al. (2011), the established relationships and processes carried out are not seen as a SC connection for each project. This makes it difficult to optimize construction SCs over the long term (Garcia & You, 2015). As SC complexity increases, it becomes more

difficult to balance the needs of all members in the SC (Dunakin, 2022). Monitoring and measurement activities are critical success factors in ensuring mutual trust among members (Tan, 2001). In the development of SCM in the CI and in the success in relations, factors such as mutual trust between the parties, senior management support, consideration of mutual interests, manpower development, uninterrupted information flow and frequent meetings are the most important factors (Akintoye et al., 2000).

Sustainable and lean approaches are important in SC. Sustainable SC is expressed as a SC that ensures that the leading companies continue to protect their brand integrity, and that the entire SC communicates more easily with each other and constantly shares product details (Gedik, 2021). Furthermore, protecting and improving the environmental and economic values are among the objectives of the sustainable SC (Wu & Pagell, 2010). In this way, the long-term plans of the companies can be protected, and the company's earnings can be guaranteed (Sheffi, 2001). Sustainable SC, which enables the development of social skills of companies, is one of the most fundamental points that can affect long-term earnings (Gedik, 2021). In a sustainable SC, it is necessary for the company to be in constant communication with all other companies and customers (Sisman, 2018). Weakening of communication in certain periods can prevent the efforts for achieving the desired success (Sisman, 2018).

Sustainable and Green Building Certifications

As the world is changing-over towards a more sustainable economy, it is important to anticipate a continued increase in green building certifications in CI (Kurnaz, 2021). The construction SC should be checked whether it complies with the certification principles.

In the CI, triggering the SC with lean and sustainability can be obtained through the integration of the principles of sustainable and green building certifications into the SC. There are a range of green building certifications, which are global or being offered in specific countries (Yun et al., 2018). Within the scope of the research, the principles/criteria of the following 4 certificate programs were examined to be integrated into the construction SC.

BREEAM: In 1990, BREEAM was created in the United Kingdom and turned out to be the world's first technique through which buildings could be assessed for sustainability (BREEAM, 2009). BREEAM is a global initiative measuring the infrastructure projects and sustainability of buildings (BREEAM new construction technical manual, 2018). The BREEAM certification measures sustainability in a series of categories including transport, energy, innovation, health and well-being, materials, pollution, land use, waste, water and management (Parker, 2012). It includes new construction, existing buildings, and refurbishment projects (BREEAM, 2022). BREEAM has a specific BES 5058 standard called BRE Environmental & Sustainability Standard focuses on the sustainability (BREEAM, 2009). In BES 5058, environmental problems, which leave an impact on buildings all through their functioning life, are addressed (BREEAM, 2009).

CASBEE: The certification involves urban advancement, city administration, housing, and commercial building (SharpLaunch, 2022). CASBEE's aim is to offer a good lifestyle to people and minimize the life-cycle resource usage and environmental masses linked with the built environment, ranging from single home to an entire city (CASBEE, n.d.). Hence, it is easy for the system to conduct evaluation in every step of the building's design and

construction (CASBEE for building technical manual, 2014). The evaluation offers enhancement in all phases (CASBEE for building technical manual, 2014).

DGNB: DGNB has been constantly improved since its inception and it is considered not just the most progressive system in the world but is also globally renowned as the Global Benchmark for sustainability (DGNB System, n.d.). Different stages are involved in every building from its planning to deconstruction (Bertino et al., 2021). The DGNB certification system might accompany these stages with regards to an all-inclusive sustainable construction technique (DGNB System, n.d.). DGNB produces two certificates (Uruk & Islamoglu, 2019). The first certificate is awarded in the initial assessment phase, which is known as the design phase, whereas the main certificate is awarded once the construction is completed (Uruk & Islamoglu, 2019).

Greenstar: Green Star is an initiative that was developed in Australia and covers building design, energy performance, interiors and complete societies (Illankoon, et al., 2019). Through Greenstar, a building's design, construction and management procedures are measured under the optimal conditions (Anbarcı et al., 2012). Greenstar includes nine categories covering the environmental impacts that result directly from the site selection, design phase, construction phase and maintenance phase of a project (Greenstar, 2013a). These are; energy, materials, management, water, indoor environment quality (IEQ), ecology and land use, transportation, innovation and emissions (Green star, 2018).

Results and Discussion

Green building approaches are more easily adopted by increasing the performance more tangibly during the construction (Hwang & Tan, 2012). The construction SC is one of the most critical processes in terms of time and cost performance (Salami et al., 2016). Therefore, focusing on the construction SC based on the sustainable and green certificates, and lean and sustainability approaches can have potential to provide a competitive advantage and make a positive contribution.

The standards can offer a technique for the CI through which information is provided on the leanness and sustainability of tasks (Aristizábal-Monsalve et al., 2022). In general, they can be implemented on the evaluation of incorporated performance of works throughout the life cycle of a structure (BSI, 2021). For this reason, within the scope of current research, the four sustainable and green building certifications (i.e., BREEAM, CASBEE, DGNB and Greenstar) were examined in detail for CSCM.

The objectives and principles of these certificates were examined one by one under the filter of leanness and sustainability. Criteria that can work together with the construction SC and that can contribute to both economic, social and environmental impacts at the SC level have been determined. The most important point in the criteria obtained is to receive a positive answer to the given question; Does it add value to the project in terms of sustainability dimensions when integrated into the construction supply chain process?

Table 1. Criteria obtained through BREEAM, CASBEE, DGNB and Greenstar.

BREEAM criteria as follows:		**Reference**
1	Consideration of environmental criteria in the management of the site and use of the building.	BREEAM (2018)
2	Minimizing the energy consumption of buildings.	BREEAM (2009)
3	Encouraging designs to increase human health and comfort of building users.	BREEAM (2018)
4	Paying attention to the ease of transportation and location is important.	BREEAM (2018)
5	Using systems that reduce water consumption.	BREEAM (2009)
6	Paying attention to the selection of the building materials used in our company and our suppliers from materials whose environmental effects are approved.	BREEAM (2018)
7	Paying attention to the recycling of wastes generated during the building production process and the evaluation of the wastes generated during the building operation and use process is important.	BREEAM (2018)
8	Protection of uncontaminated lands and biodiversity is aimed.	BREEAM (2009)
9	Encouraging designs that prevent harmful fluids, light-noise pollution, soil and water resources pollution that have an impact on global warming.	BREEAM (2018)
10	Taking risks into account.	BREEAM (2009)
11	Encouraging contributions to innovative ideas, designs, management processes or technological development in the field of sustainability.	BREEAM (2009)
DGNB criteria as follows:		
1	Measuring global warming potential in the materials used.	DGNB (2020)
2	Measuring the ozone layer depletion potential in the materials used.	DGNB (2020)
3	Measuring the photochemical ozone creation potential in the materials.	DGNB (2020)
4	Measuring the risks to the local environment in the materials used.	DGNB (2009)
5	Measuring sustainable use of resources.	DGNB (2018b)
6	Measuring the use of non-renewable resources.	DGNB (2018b)
7	Organizing the wastes according to their categories.	DGNB (2009)
8	Evaluation of building-related life-cycle costs.	DGNB (2018b)
9	Evaluation of materials for their suitability for use by third parties.	DGNB (2009)
10	Paying attention to thermal comfort in the materials in winter.	DGNB (2019)
11	Paying attention to thermal comfort in the materials in summer.	DGNB (2019)
12	Paying attention to the safety and risk of dangerous accidents in the materials used.	DGNB (2009)
13	Paying attention to the accessibility of the disabled.	DGNB (2018a)
14	Paying attention to field efficiency.	DGNB (2009)
15	Paying attention to the suitability of the materials used in our company and our suppliers for translation.	DGNB (2009)
16	Consideration is given to design assurance in the materials.	DGNB (2009)
17	Paying attention to the adaptability of technical systems in the materials used.	DGNB (2009)
18	Paying attention to the ease of use of building services.	DGNB (2009)
19	Paying attention to the durability of the materials used.	DGNB (2009)
20	Paying attention to the ease of cleaning and maintenance in the materials used.	DGNB (2019)
21	Consideration given to the ease of recycling and separation of the materials used.	DGNB (2019)
22	Paying attention to the design concept in the materials.	DGNB (2019)
23	Consideration of sustainability aspects at the tender stage for the materials used.	DGNB (2009)
24	Paying attention to the quality/pre-screening of the contracts.	DGNB (2009)
25	Paying attention to the quality assurance for construction in the materials used in our company and our suppliers.	DGNB (2009)
26	Paying attention to the state of the micro-environment.	DGNB (2018a)
27	Paying attention to the proximity to transportation and their connections.	DGNB (2019)
28	Paying attention to the proximity to the use of basic services.	DGNB (2018a)
29	Paying attention to the proximity to public services.	DGNB (2018a)
Greenstar criteria as follows:		
1	The use of practices and procedures of sustainability throughout all stages of	Green star (2018)

	design, building and continuing procedure.	
2	Promoting initiatives that increase the comfort and well-being of users.	Green star (2013b)
3	Reducing greenhouse gas emissions from production from alternative sources such as reducing energy demand, efficiency and use in various phases of design, construction and ongoing operation.	Green star (2018)
4	Reducing greenhouse gas emissions (e.g., reducing the dependence on the use of personal private vehicles).	Green star (2013b)
5	Paying attention to the environmental impacts of 'point source' pollution from projects on the atmosphere.	Green star (2013b)
6	Openness to recognizing innovative practices that promote sustainability.	Green star (2013b)
7	Improving the sustainability performance of the project.	Green star (2013a)
CASBEE criterion as follows:		
1	Improving the environmental quality.	CASBEE (2014)

11 criteria in BREEAM, 1 in CASBEE, 29 in DGNB and 7 criteria in Greenstar have been identified (Table 1). The BREEAM criteria generally focus on environmental factors of projects under construction and waste management (Table 1). When the documents published in BREEAM (2009) and BREEAM (2018) are compared, it is seen that the focal points of BREEAM (2018) are detailed to respond to new trends. BREEAM (2009) examined general environmental factors such as energy and water consumption of buildings whereas BREEAM (2018) has expanded and detailed its point of view and explained the issues with statements that include the solution along with the problem in its criteria (Table 1). BREEAM's focus is on green material selection, waste material management, transportation and location, and promoting designs that take into account environmental factors (Table 1).

DGNB criteria were obtained from 5 different documents (Table 1). 13 criteria from DGNB (2009), 7 criteria from DGNB (2018a) and DGNB (2018b), 6 criteria from DGNB (2019) and 3 criteria from DGNB (2020) were determined. The focus of DGNB (2009) has been the materials and materials used and among the most striking criteria are the environmental effects, efficiency, durability, sustainability and quality control of materials (Table 1). DGNB (2018a) and DGNB (2018b) focus on 3 main issues (Table 1), where: the first of them is the sustainable use of resources and the measurement of and monitoring the rate of use of non-renewable resources; the second issue is to pay attention to define the factors of their micro-environment well; and the final issue is proximity to public services or ease-of-use access to essential services. The ease of recycling and separation of the materials used in DGNB (2019) comes to the fore. By looking at this environmental approach more holistically, attention should also be paid to logistics and transportation. Logistics must be carefully planned, both in the procurement process of the materials and in the distribution of the wastes to the relevant companies. This multiple logistic circulation will significantly increase the carbon footprint. In order to minimize the carbon footprint, proximity and ease of transportation should not be disregarded in the supplier's selection. In DGNB (2020), there is a particular focus on construction materials.

Greenstar criteria were obtained from 3 different documents and five of the criteria out of seven are Greenstar (2013a) and Greenstar (2013b) (Table 1). Environmental impacts, sustainability and performance were the focus points of Greenstar (Table 1). Greenstar (2018) focuses on sustainability and energy efficiency in various phases of design, construction and ongoing operation.

CASBEE, on the other hand, has the least criteria compared to the other 3 certificates as only one criterion was obtained when considered with the LSCSCM filter (Table 1). CASBEE's main focus is on improving the environmental quality of construction (Table 1).

As with the increase in the importance given to the CSCM, the search for and application of new techniques has increased, the importance given to lean and sustainability approaches in the SC has increased. Within the scope of this study, the 4 main green building certifications were reviewed in the SC filter to identify potential criteria suitable to be used to support achievement of a lean and sustainable SC. It is also important to determine the implementation way of obtained criteria to make a maximum contribution to the construction SC. In order to achieve a lean and sustainable SC and to meet the certification principles more holistically, the focus should be on the beginning of the chain. Lambert et al. (1998) emphasized the need to focus on the supply chain organizational structure and construction process components in the SC management implementation process. With the accurate subcontractors and the accurate system, the SC can take the burden of management and make the construction process more fluid. The criteria identified based on certifications can be used in the selection phase of suppliers. Working with the suitable supplier plays an important role in achieving company goals, maintaining and strengthening their competitive level in the long run. For this reason, the supplier selection process, which is a strategic decision for businesses, should be done in a more scientific and systematic way, not based on intuition and experience (Çakın & Özdemir, 2013). The 48 criteria provided systematically in Table 1 can be considered as input to supplier selection and establishment of LSCSCM.

Conclusion

This research investigated sustainable and green building certifications (the BREEAM, CASBEE, DGNB and Greenstar certifications) and their potential contribution to the LSCSCM. Main contractor and supplier relationships are critical to improve the coordination between the parties in the construction SC (Salami et al., 2016). Relationships with suppliers can lead to higher productivity, higher profits and a reliable environment (Singh et al., 2017). To improve the coordination and obtain those benefits, some approaches should be integrated to the CSCM. In this study, primarily importance of the construction supply chain management was examined. In addition, the concept of green building, which gained importance with the reflection of this concept on architecture, was investigated. General information about the certification systems and legal regulations developed to assess the performance of green building applications was given. In this direction, literature review was carried out. The 4 main certificates (i.e., BREEAM, CASBEE, DGNB and Greenstar) that can contribute to obtain a lean and sustainable SC have been examined. A total of 48 criteria have been identified as the basic principles to be used in the creation of a LSCSCM. The criteria were obtained by passing through multidimensional filters where the first of them is to have a contribution of economic, social and environmental impacts on the SC and the second is including same targets in line with lean and sustainability approaches. Adaptation of the identified preliminary criteria (Table 1) to the supplier selection process can have potential to support the LSCSCM establishment.

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Bio-Based Construction Materials for Bio-Circular Transition: A Brief Bibliometric Analysis

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Abstract

Society faces many global problems due to the Anthropocene era, where human activity is the dominant force on the planet's climate and environment. Continuation of current behaviors will cause the failure of many significant life support systems that affect society. Therefore, resource flows must be balanced with the ecological system. At this point, how materials are produced, used, and consumed is very important in terms of lasting sustainability. Production, consumption, and the functioning of the economic system must change to survive the worst or adverse anthropogenic effects. For the construction industry to avoid anthropogenic impacts, it must integrate minimally harmful solutions to the environment, even carbon positive. Adapting naturally biodegradable materials to the construction industry will be a solution. The increasing use of bio-based building materials is important as it will improve the circular economy in terms of bioeconomy and shape the transition to a bio-based circular economy. The main aim of this study is to investigate the potential of bio-based materials, especially agro-materials, and the circular economy in the construction industry based on a bibliometric analysis of literature. It is anticipated supporting bio-based materials will inevitably contribute to the environment, support local production, and create new job opportunities.

Keywords: *Bio-based construction materials, bioeconomy, circular economy, construction industry, sustainability.*

Introduction

Global problems due to the Anthropocene era create economic and ecological crises due to increased energy consumption, abused natural resources, and released greenhouse gases (GHG). The need to implement sustainable solutions in many industries has arisen to handle these problems. Due to the adverse environmental consequences of the construction industry, the reflection of sustainability has peaked in this sector as well. Minimizing waste and CO_2 emissions, increasing energy optimization, saving natural sources, reducing the impact of climate change and preventing it have become a priority to create a more sustainable built environment. Therefore, each process has been reconceptualized from design and construction to operation and demolition. Within this context, the circular economy (CE) concept has gained importance as a sustainable, innovative paradigm among researchers, scholars, and policy-makers (Kirchherr et al., 2017), and has become popular in the construction industry. Adopting CE principles will promote an important contribution to reducing GHG emissions

by implementing circular strategies. The circular transition of the construction industry focuses more on waste and material recycling. For the construction industry to avoid anthropogenic impacts, it must integrate minimally harmful solutions to the environment, even carbon positive. Within this framework, this study seeks to investigate the potential of bio-based materials, particularly agro-materials, and CE in the building sector using a brief bibliometric analysis of literature. The adoption of bio-based materials could empower the local suppliers as well as national development. By enhancing the efficient flow of information and materials among the construction stakeholders, environmental, economic, and social development could ensure in the construction industry. It is anticipated supporting bio-based materials will inevitably contribute to the environment, support local production, and create new job opportunities.

Circular Economy vs. Bioeconomy

The circular economy (CE) concept is a promising approach to changing how the economy works. It offers a systemic perspective on how resources (materials, energy, information) flow and cycle within systems. The core principle of CE is to expand the use of valuable resources brought into the system through the renewal of circular designs (EMF, 2013b). CE helps to increase resource efficiency by separating economic growth from resource utilization (van Stijn & Gruis, 2020). Originating from various schools of thought (Weigend Rodríguez et al., 2020), it aims to develop the current production model by altering consumption patterns (Leising et al., 2018) and optimizing efficient resource use. In this way, CE focuses on the underlying causes of global issues like contamination, habitat destruction, and climate change, seeks to prevent waste generation by creating a regenerative economy, and provides opportunities for better growth (EMF, 2021). *The technical cycle*, that includes the recovery of technical materials and the management of finite stocks of materials, and *biological cycles*, that covers the flow of renewable materials, are indicated in the framework of CE (EMF, 2013a). It is stated that the basic rules of the restorative CE will be complemented by the cycle of materials based on technological and biological ingredients throughout the economic system (EMF, 2013a).

On the other side, European Commission (EC) (2012) defined the bioeconomy as "*the bioeconomy encompasses the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy*" (EC, 2012). Furthermore, EC has pointed out the importance of the bioeconomy as being part of CE by setting up five-bioeconomy strategies for Europe to achieve a carbon-neutral world in accordance with the Paris Agreement's climate goals: "(i) *ensuring food and nutrition security,* (ii) *managing natural resources sustainably,* (iii) *reducing dependence on non-renewable, unsustainable resources whether sourced domestically or from abroad,* (iv) *mitigating and adapting to climate change,* and (v) *strengthening European competitiveness and creating jobs*" (EC, 2018). In the publication (2018) prepared by EC, it was introduced that "*The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. To be successful, the European bioeconomy needs to have sustainability and circularity at its heart. This will drive the*

renewal of our industries, the modernisation of our primary production systems, the protection of the environment and will enhance biodiversity." (EC, 2018).

Alongside the EC, the Organisation for Economic Co-operation and Development (OECD) (2009) also emphasized the bioeconomy's importance. Highlighting the great contribution of biotechnology to the development of the bioeconomy, three sectors with great potential in biotechnology have been identified: agriculture, health, and industry. On the other hand, it is thought that without proper local, national, and global policies to promote its development and use, biotechnology cannot fulfill its full potential. The need for a multi-layered policy framework that fosters knowledge diffusion across sectors and addresses application-specific technological, economic, and institutional challenges are noted to come through the obstacles for the bioeconomy to succeed (OECD, 2009).

Since biowaste, surpluses, and discards may be converted into useful resources, the bioeconomy is viewed as the regenerative part of CE. It is considered that by creating innovations and incentives, food waste can be reduced by 50% by 2030, and the strengthening of European Union (EU) industries will be promoted through the creation of new value chains, and more eco-friendly and economic processes. Furthermore, the creation of one-million new jobs in rural and coastal areas for the growth of local bioeconomies could be achieved by installing bio-based industries. Thus, cities can become a major circular bioeconomy hub by reinforcing environmental, social, and economic development as the strengthening of the biocycle of CE would support both environmental and economic and social development by providing many new job opportunities (EC, 2018).

Bio-based Materials in the Construction Industry

Bio-based materials offer numerous positive impacts and other beneficial qualities in the environment, economy, and social well-being compared to many fuel-based materials. Bio-based materials are organic resources either forest products or agriculture/animal products and are naturally breathable and regulate moisture (Yadav & Agarwal, 2021). They also have the potential to reduce global GHG emissions due to the low amount of energy required for production. Since the current trends in the construction industry cause detrimental problems, researchers, practitioners, and policymakers have turned their attention to bio-based alternatives having more benefits than conventional materials. These benefits are: "(i) *renewable,* (ii) *long-term use,* (iii) *absorbing carbon during cultivation,* (iv) *moisture absorption and breathability,* (v) *less harmful pollutant emissions,* (vi) *disposed easily at the end of their life*" (Varriale, 2021), "(vii) *abundance,* (viii) *ease of use,* (ix) *globally distributed in a variety of forms,* (x) *easily sourced,* (xi) *readily adapted to the needs,* (xii) *hygroscopic,* (xiii) *versatile,* (xiv) *porous and nonabrasive,* (xv) *biodegradable,* (xvi) *compostable* and (xvii) *reactive*" (Jones, 2017). Along with these benefits, energy savings, life-cycle objectives, global warming, and climate change mitigation contribute to the rapid evolvement of bio-based materials in the construction industry (Jones, 2017). Carcassi *et al.* (2022) pointed out those benefits in their recent study by confirming that bio-based insulations could achieve climate goals at the building level before 2050 (Carcassi et al., 2022).

Bio-based materials and components have a great potential for a lower-impact building. Furthermore, they are light and easy to work with that makes them suitable for prefabrication and fast installation (Yadav & Agarwal, 2021). Therefore, many bio-based materials inspired from nature are explored to be adapted to the construction industry. Agriculture-generated

materials such as flax, hemp, lignin-based fibers, mycelium, sunflower, wood wastes, corn cob, bamboo, rice husk, cork, coconut, and timber (Yadav & Agarwal, 2021) might be used to gain bio-based construction materials by enhancing the ecological benefits (Amziane & Sonebi, 2016). These materials might compete for farmland against the food and bio-energy industries. More sustainable rural growth could be achieved, especially in less developed countries, when agricultural wastes are treated properly (Varriale, 2021).

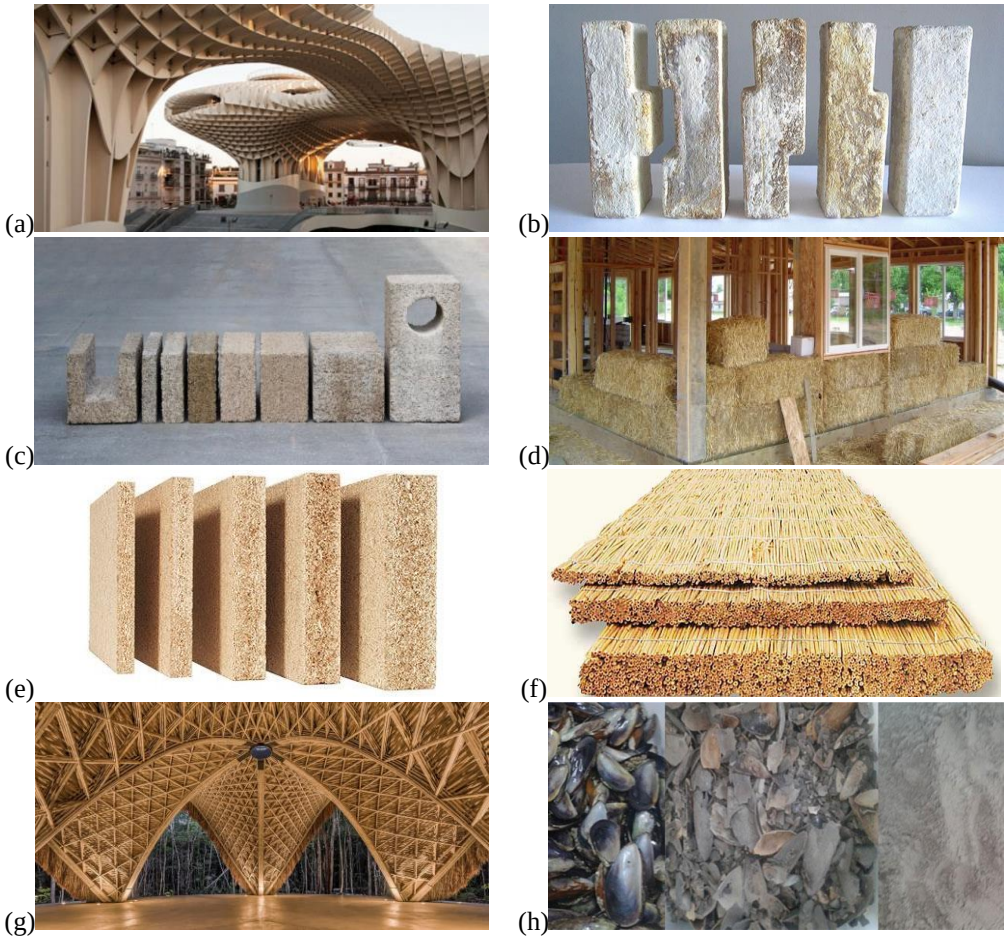


Figure 1. Bio-based materials: (a) Wood structure, Metropol Parasol in Seville, Spain, (b) Mycelium brick, (c) Hempcrete blocks, (d) Strawbale in construction, (e) Flax boards, (f) Reed material, (g) Bamboo structure, Luum Temple in Tulum, Mexico, (h) Mussel shell

Timber-Wood

The most common bio-based material used in building projects is wood/timber. After discarding the conventional passion for steel and concrete, new-wave architects frequently started to choose wood for iconic architectural landmarks, like the Metropol Parasol (Figure 1a). Although the usage of timber structures was not limited to landmarks (Varriale, 2021), its installation was restricted to low-rise buildings depending on a variety of factors, including structural performance and fire protection concerns (Blok et al., 2019). However, the focus on high-rise timber buildings is progressing in the last few years thanks to technological breakthroughs (Ijeh, 2019).

Mycelium

Mycelium (Figure 1b) is a promising material as a vegetative part of fungi. Mycelium-based composites have many enablers thanks to their low cost, energy consumption, density, regenerative features, low environmental impact, and carbon footprint when these materials are compared to traditional materials (Jones et al., 2020). Therefore, they promise sustainable and biodegradable design and fabrication processes. Fungal-based biotechnology can speed the shift from a linear economy towards a bio-based CE. This advancement enables to produce more sustainable resources for the transportation, automotive, and construction industries that are more robust in terms of fuels, food, textiles, chemicals, and other materials (Meyer et al., 2020). Although the potential area of this promising material ranges from food production to medical biotechnology, the research in the construction industry is still underexplored (Modanloo et al., 2021) because using fungal-based materials as an alternative to conventional construction materials could be an inherent problem (Campbell et al., 2017) due to weaknesses in load capacity, unfavorable water affinity, and unknown reliability (Sydor et al., 2022). On the other side, some researchers studied how to install mycelium into architecture and construction projects by exploring various design and fabrication methods such as additive manufacturing (Modanloo et al., 2021), multi-scalar assembly system (Campbell et al., 2017), and conventional growing process (Bruin, 2018). Besides these, Cerimi *et al.* (2019) concluded that fungal-based materials are an excellent choice for the future due to its enormous potential for innovation and ability to be both renewable and biodegradable (Cerimi et al., 2019). Jones et al. (2020) concluded that fungal-based substances are environmentally sustainable alternatives compared to wood, foam, and plastic insulation for panels, flooring, door cores, and furnishings thanks to their thermal conductivity, low density, fire safety, and strong acoustic absorption (Jones et al., 2020). It is a general belief that innovative breakthroughs depending on the transdisciplinary studies with stronger collaboration between researchers, designers, industrial stakeholders, the public, and policymakers on fungal-based materials facilitate the shift to a bio-based CE (Meyer et al., 2020).

Hempcrete

One of the fastest-growing biomasses in the world, hempcrete (Figure 1c) is a combination of hemp, water, and lime, and weights one-eighth as much as typical concrete. Used in France as non-bearing infill walls, the lightweight nature of this bio-based material can reduce a building's energy by reducing the embodied emissions. Hemp-based panels and structural blocks can replace many old wood frames and cement blocks thanks to their rapid growth. Thus, it supports the reduction of deforestation, so of increasing carbon sequestration (Yadav & Agarwal, 2021). In addition to its biological properties, such as breathing and allowing evaporation, its non-toxic and lightweight properties ease movement on the construction site (Roberts, 2020). Although hempcrete-based materials cannot be installed as load-bearing, they can be used to create screeds, roofing, and self-insulating walls as finishing plasters, insulators for roof and floor (BCB Tradical, n.d.). As long as they are shielded from moisture and water, hempcrete walls, which can be created on-site or through a manufacturing process, can be left uncovered or coated with plasters. These materials have a negative carbon footprint and serve as carbon sinks as a result of biogenic CO_2 absorption during hemp growth and via carbonation (Arrigoni et al., 2017). Thanks to the environmental advantages and ease of use, the interest in these promising bio-based materials is gaining momentum.

Strawbale

With its durability, longevity, high load carrying capacity, and insulating qualities, straw (Figure 1d) is a material with potential for enhancing building energy performance (Yadav & Agarwal, 2021). This material demonstrates versatile usage since it could be used in a variety of industries such as for soil productivity in agriculture, insulating the existing structures or constructing new structures in the construction. It can also be used to transform biomass into usable chemicals or alternative energy sources through pyrolysis processes (Tlaiji et al., 2022). Contrary to conventional construction materials, the use of straw made from agricultural waste promotes sustainable development since it has a very low embodied energy over its whole life cycle. It also has a direct bearing on the preservation of natural resources and land use (Gupta et al., 2019). Furthermore, It is emphasized that due to the possibility of prefabrication, it can contribute to the production of low-cost social and affordable housing (Gupta et al., 2019).

Flax boards

Flax board (Figure 1e) is an engineered and non-bearing sheet material. It is lightweight and fire resistant. For this reason, they are used in door sections, fire resistant doors, cores and partition walls in dry conditions (GreenSpec, n.d.; Yadav & Agarwal, 2021).

Reed

Reed (Figure 1f) is one of the most common wetland plants in the world, mostly used for roof construction thanks to its high productivity. Its rapid growth and widespread availability make the reed an inexpensive and durable option for natural building material. Reed contains the highest silicon concentration among all plants, responsible for water resistance and high flammability. However, the thermal conductivity of the reed makes it suitable as an insulating material compared to timber shingles and clay. In addition, the reed's thermal conductivity optimizes indoor temperature in all seasons by providing good moisture conduction together with large air content (Critical Concrete, 2017; Yadav & Agarwal, 2021). However, they are suitable for hot and humid climates. Reed is widely used because it is inexpensive and readily available, easy to maintain, highly ventilated, has thermal insulation capabilities, and requires a low-tech construction technique. It is also resistant to seismic effects. It has the potential to be a performance efficient and natural low-carbon material, as it requires minimum amount of energy during the whole life cycle (Dabaieh & Sakr, 2015).

Bamboo

Bamboo is a promotive material to avoid the deforestation of tropical forests. It is widely known as a sustainable building material because it can be easily grown, harvested in a short time, and reusable (Nurdiah, 2016). Due to their ability to absorb carbon and to require low life-cycle emissions, herbaceous and fast-growing materials like bamboo and straw are considered an efficient alternative. Selecting these biomasses is advantageous as they exhibit a shorter regrowth period, thus higher yields. They are often the by-products of cropland that could be converted into high-value products, preventing competition in land usage between construction and agriculture (Carcassi et al., 2022). It also makes possible more complex and organically shaped architectural structures (Figure 1g) because they bend easily (Nurdiah, 2016).

Mussel shell

It has been determined that the mussel shell has thermal and acoustic properties that make them suitable for use as a building insulation material. Contained in a closed space, the mussel shell (Figure 1h) can be regarded as a substance with low thermal conductivity (Martínez-García et al., 2019). It can potentially be used as a concrete filler, reducing the porosity in the concrete microstructure, thereby reducing the amount of water used to maintain concrete workability (Wang et al., 2021). Several acoustic tests, however, have proven that a portion of the closed shell behaves in a manner that is comparable to that of the widely used insulating material. The mussel shell has a similar amount of embodied energy to other bio-based insulating substances when used as loose infill material, however, it has a significant advantage over other bio-based insulation substance for being resistant to biological attacks and fire. It can be used on the walls in a wooden frame, on roofs as a heat and sound insulation material, and on the ground instead of traditional drainage materials (Martínez-García et al., 2019).

The increasing usage of bio-based building materials is important as it will improve CE in terms of bioeconomy and shape the shift towards a bio-based CE depending on the features: (i) renewable source of agricultural or forest material, (ii) land management in life cycles of the materials, (iii) supported by renewable energy for harvesting and other processes (iv) enabling process flow from cradle to cradle. Considering that building materials account for a significant portion of harmful emissions that are generated and utilized, bio-based construction materials can be regarded as a fundamental part of the bioeconomy. In addition, it is a fact that these materials cannot be considered independent from CE, as bio-based construction materials contain a low amount of carbon in the production and operation processes compared to conventional materials (Suttie et al., 2017). As a result, supporting bio-based materials will inevitably contribute to the environment. Since it is stated that the bioeconomy will support local production and create new job opportunities, it is also clear that the bioeconomy is completely sustainable development.

Bibliometric Analysis Regarding Bioeconomy and Bio-based Materials

Method

Based on the literature research, it has been realized that the research on the circular transition of the built environment mostly focuses on waste management and material recycling. In addition, it has been observed that traditional materials in the technical cycle, such as concrete, brick, steel, and others, are more often considered within the scope of the circular economy. Since the business models in the construction industry are based on traditional materials, bioeconomy and the bio-based materials in this sector is not at the expected level. A bibliometric analysis was conducted in the Scopus database to prove this claim. The two-step analysis contained the journal articles in the English language. The phrases below were employed for corresponding steps (data update time August 14, 2022):

The first step:

- (“bioeconomy” OR “bio economy”) AND (“built environment” OR “construction industry” OR “construction sector”),

The second step:

- ("bio-based materials" OR "biobased materials") AND ("built environment" OR "construction industry" OR "construction sector")

Firstly, the identified phrases were searched within "Article Title, Abstract, and Keyword". As a further step, the obtained data were exported in .csv file format from the Scopus database and analyzed in VOSviewer. The focus of the bibliometric analysis was the co-occurrence of author keywords thanks to employing the most prominent terms to understand the methodological structure of a research domain. The "Full counting" technique was employed in VOSviewer.

Findings

As a result of the analysis on the Scopus, the following results were gained for the steps:

The first step:

- 22 documents were resulted in the Scopus (16 articles, 3 conference papers, 2 book chapters, and 1 review).
- The minimum frequency distribution of a term was adjusted as two in VOSviewer.
- 5 out of 81 keywords met the threshold and 5 keywords were mapped (Figure 2a).

The second step:

- 54 documents were resulted in the Scopus (26 articles, 14 conference papers, 10 book chapters, 3 review, and 1 book).
- The minimum frequency distribution of a term was adjusted as two in VOSviewer.
- 9 out of 122 keywords met the threshold and 9 keywords were mapped (Figure 2b).

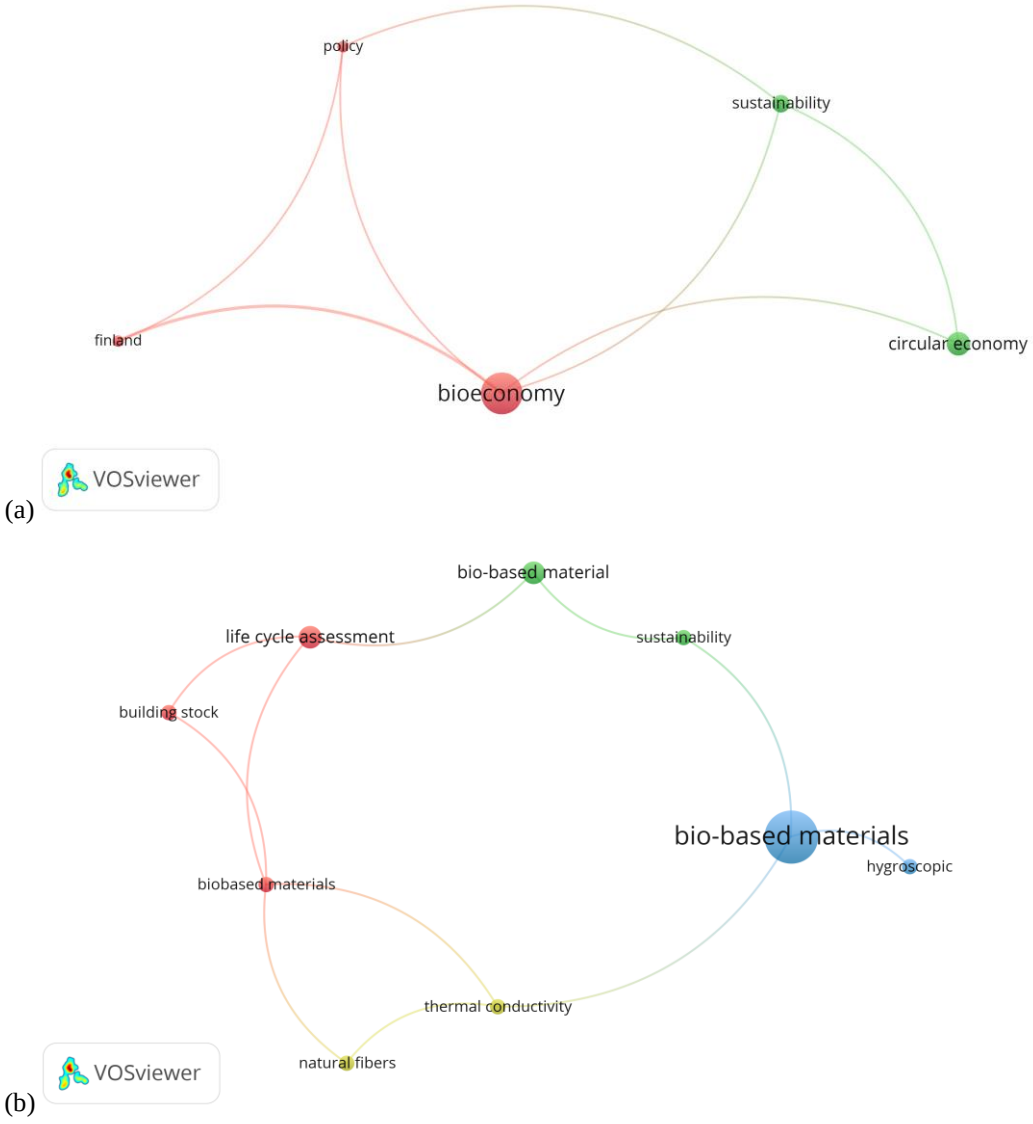


Figure 2. Keywords map of bibliometric analysis:
(a) Result of the first step, (b) Result of the second step.

As seen in Figure 2a and 2b, the outcomes of the first step contain the most core keywords such as “bioeconomy, circular economy, sustainability, policy, and Finland”, the results of the second step contain similar keywords as “bio-based materials, bio-based material, biobased materials” because of the different understandings for the term. The other keywords regarding the second step are related to the fundamental terms of the industry such as “hygroscopic, life cycle assessment, thermal conductivity, and natural fibers”. Based on the bibliometric analysis conducted by VOSviewer, it can be considered that the reflections of bioeconomy and bio-based materials on the construction industry and the built environment are still in their infancy.

Conclusion

Advances in the construction industry, which play a pivotal role worldwide, are strongly linked to the economic strength of the global community. The construction industry has a societal impact as it also employs many people and is responsible for supplying basic human needs and shaping the built environment. The depletion of natural resources has led designers, practitioners, and governments to seek new materials within this industry as well. For this reason, bio-based materials, which are also encouraged by the EU, have started to be applied in various sectors. These completely natural materials without creating waste are compatible with the conceptual framework of CE. However, since the business models in the construction industry lean on traditional materials, the employment of bio-based materials in this sector is not at the expected level. Besides, the reflections of these promising concepts, bio-based materials and bioeconomy, are still underexplored within the construction industry. Within these claims, it is anticipated that promoting bio-based materials will give broad meaning to the transition to bio-CE in the construction industry, and the harmful environmental impacts of the construction industry can be reduced thanks to the use of bio-based materials. Furthermore, the production of bio-based materials will boost the local economy by supporting the local producer, and thus environmental, economic, and social development can be achieved.

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Transitioning to a Circular Economy in the Construction Industry: Enablers and Barriers

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Abstract

Considering the increasing population and building demand, the construction industry has become one of the leading causes of waste production and resource consumption. Accordingly, the construction industry's impact on the economy and the environment is increasing. Contrary to the traditional linear economy, adopting the circular economy model can help cope with such issues, reducing the environmental impact of buildings and the consumption of natural resources. Research on the circular economy in the built environment has been increasing in recent years, with varying focuses and scopes on strategies (e.g., design for deconstruction), indicators (e.g., amount of construction and demolition waste), and requirements (e.g., regulations). For successfully transitioning into a circular economy, especially for developing countries, it is necessary to understand how to apply circularity in the construction industry, to identify the barriers to its integration into the sector, and the enablers to eliminate such barriers. This study aims to accumulate and demonstrate the existing knowledge by identifying, categorizing, and mapping the enablers (e.g., integrating circularity into education) and barriers (e.g., lack of awareness) to the construction industry. This study is planned to guide future research on facilitating a circular economy in the construction sector more effectively.

Keywords: *barriers, built environment, circular economy, construction sector, enablers.*

Introduction

With the development of conditions and technology in developing countries, the overall population, infrastructure needs, and the demand for consumption of materials in the construction industry are increasing. Considering the emerging needs, the construction industry is one of the largest raw material consumers and waste producers. Accordingly, problems related to climate change and resource scarcity are increasing. The linear economy model, which is based on high natural resource consumption and neglects resource recovery, is being questioned; therefore, there is a need for a new practice to reduce this consumption and the amount of waste (Cruz Rios et al., 2021). The increase in the demand for recycling within the sector worldwide and the desire to reduce carbon emissions and material consumption facilitated the use of the circular economy (CE) model to come to the fore and be investigated in the last few years.

Circular economy (CE) offers a comprehensive strategy model for sustainability to minimize environmental and economic costs for construction projects (Shooshtarian et al., 2022). Three

main stages where the strategies identified for CE can be beneficial are design and planning (e.g., design for disassembly, specifying recyclable materials), material and component manufacture (e.g., use of secondary material), and end-of-life stages (e.g., selective demolition, closed-loop recycling) (Sáez-de-Guinoa et al., 2022). Decisions made in the design phase are influential in determining the factors that affect the buildings until the end-of-life. Circular design principles aim to design structures that use fewer resources, protect and expand natural and man-made resources, adopt designs for long-term use and recycling, taking into account technical and biological cycles (Cruz Rios et al., 2021). The manufacturing and production phase is significant to ensure that materials and components are recyclable and the life span can be extended. The end-of-life stage is essential for implementing strategies, as it determines the demolition techniques and recovery percentages necessary for the materials to be reused with the highest possible value to be reintegrated into the chain (Sáez-de-Guinoa et al., 2022). Additionally, innovative systems can create scenarios and strategies to reduce the impact of traditional systems by improving circularity (Tirado et al., 2022). CE is thought to increase competitiveness and help create new job opportunities by protecting businesses against resource scarcity and volatile prices (Kanters, 2020). CE facilitates cities reduce their ecological footprints and improve the economy by reducing the amount of waste and imported raw materials to be processed, incorporating secondary materials into the cycle, and creating local employment (Tirado et al., 2022). Although there is a general incentive for the development and use of CE strategies, it is necessary to continue studies on developing criteria and determining strategies to support urban sustainability to measure resource flow, resource use and associated environmental impacts (Hossain et al., 2020). The local awareness level of CE principles is generally in line with the global level, but the understanding of CE application in construction is insufficient worldwide compared to other industries (Torgautov et al., 2021).

In transitioning into a circular economy in the construction sector, interventions of different stakeholders are needed because the circular economy requires collaborative, interdisciplinary work in terms of strategies for better consumption and waste management (Tirado et al., 2022). For the process to be properly controlled and maintained, it is necessary to review the existing knowledge, understand the roles of the stakeholders in this practice, and understand the main indicators, barriers, and enablers of adopting circular economy strategies in construction projects (Guerra & Leite, 2021). Such barriers and enablers vary according to the needs of countries/regions. Existing studies in the literature have generally focused on specific countries. For example, Cruz Rios et al. (2021) identified barriers in the USA, Charef et al. (2021) in the UK, and Shooshtarian et al. (2022) in Australia. Variations in these studies reflect the differences in the level of understanding and adoption in different countries. In addition, the literature generally focused on specific strategies (e.g., construction and waste demolition, circular design), limiting the observation of the general understanding of CE, especially in developing countries, where CE has been practiced in a limited capacity. Moreover, for transitioning into CE, the enablers and barriers should be linked with the related stakeholders to better understand their roles and responsibilities. However, such an exploration is scarce in the literature. Hence, the aim of this study is to analyze the current literature to identify the barriers and enablers of CE, and to map these factors to related stakeholders. Such an understanding will be used to map and prioritize the enablers and barriers of CE in connection with the relevant stakeholders in Turkey, with the participation of practitioners in the following stages of this study. At this stage, this conference paper presents the results of the preliminary study on the synthesized literature on enablers, barriers, and stakeholders.

Methodology

This study adopts a literature review method using the Web of Science database to identify barriers and enablers for integrating CE into the construction industry. The most prominent fifteen articles, which did not specialize on specific CE strategy (e.g., construction and demolition waste management, demolition for deconstruction) or specific materials but instead addressed CE in general, were used to identify and group barriers and enablers. Although it did not comply with the set limitations and was not within the scope of this research, Adams' research was included in the scope of the research due to its high number of citations. Sources have followed many different methods while identifying the barriers. In general, each barrier and enabler was listed by evaluating the literature where there were articles that used both qualitative and quantitative methods within their study. Some studies incorporated practitioners' perspectives. For instance, Bilal et al. (2020) eliminated and listed barriers based on the overall cumulative scores obtained for the barriers through the evaluation of the literature and expert opinions. Following the review of the literature, barriers and enablers were identified, synthesized, and presented in a tabular format.

Circular Economy in the Construction Industry

In a recent study, Cruz Rios et al. (2021) stated the existence of limited literature on identifying barriers and facilitators of CE strategies that can be used in buildings and the construction sector. However, research on this topic is accelerating, considering both general CE findings and strategies. Identifying the main barriers to the integration of CE is based on the interplay of many factors and indicators that influence the adaptation of CE in the construction sector (Bilal et al., 2020). The identified barriers can be attributed to the characteristics of the construction industry. The recent literature mainly focuses on two aspects of CE; the level of awareness on CE, and enabling strategies (Torgautov et al., 2021). Considering the integration of the CE into the construction industry, practices, such as the reuse of existing components (e.g., doors, windows) and the use of salvaged materials can be counted as CE strategies (Cruz Rios et al., 2021). Strategies within the built environment may include the design for disassembly (DfD) and adaptability, reuse of building components, adaptive reuse, and use of biodegradable building materials. Charef et al. (2021) identified and classified the barriers associated with strategies such as prefabrication, design for change, design for demolition, reverse logistics, waste management, and closed-loop systems to assess the sustainable management of an asset's lifecycle and adopt CE in the AEC sector. Giorgi et al. (2022), on the other hand, grouped the strategies to implement CE at the building level in three main application areas: business and stakeholder networks, resource and waste management, and reversible building design. In addition, one of the strategies affecting the development of CE is waste management. The inability to reach a sustainable solution due to unspecified rules and guidelines on waste management is also a situation that should be taken into consideration. In addition to the necessary policy implications, it should also be considered that companies would not want to abandon the current practice of landfilling waste not to increase their costs. Besides, it is possible to state that the construction and demolishing waste management could not develop due to the poor performance of the contractors and the lack of appropriate infrastructure and facilities (Torgautov et al., 2021).

In this study, the barriers obtained as a result of literature review were identified and grouped under five main categories: economic, behavioral, technical, political, and environmental. The importance of the economic benefit was emphasized when considering the use of

environmentally friendly technologies and the reuse of construction materials (Torgautov et al., 2021). Table 1 presents the synthesized economic barriers for CE, along with the related stakeholders stated in previous studies. Implementing certain circular strategies may require upfront costs to enable future reuse of materials and components. In addition, the expertise of the people working for these strategies can be cited as a potential additional cost (Guerra & Leite, 2021). The project constraints may make it difficult to adopt circular strategies for the contractor. Similarly, the consequences that may arise due to constraints may affect the owner's willingness to implement other strategies, such as selective destruction or deconstruction (Guerra & Leite, 2021).

Table 1. Economic barriers.

Code	*Economical Barriers*	*A 1*	*A 2*	*A 3*	*A 4*	*A 5*	*A 6*	*A 7*	*A 8*	*A 10*	*A 11*	*A 12*	*A 13*	*A 14*	*A 15*	*St**
E1	Lack or underdevelopment of the market mechanism for recovery	*	*			*	*									S, M
E2	Schedule constraints					*	*	*	*	*	*	*			*	C, RE
E3	Cost constraints			*		*	*	*	*	*	*	*	*		*	C
E4	Limited applicability of circular business management for the construction industry						*									C, O
E5	Uncertain financial situation for CE	*	*				*		*			*	*			RE
E6	The customer's willingness or readiness to pay for the new concept			*			*			*	*		*		*	O
E7	Insufficient research funds											*				R
E8	Lower costs of virgin materials/ Higher costs of recycled materials		*	*		*	*	*				*				C, O, RE
E9	More investment requirement (Quick investment expectation of the customer)		*	*		*	*	*	*				*			Cu, O
E10	Dependence of markets on imports/ established market issues		*				*						*			M, S
E11	Unreasonably high cost of careful removal of components and parts			*				*				*				RE
E12	Low cost of disposal				*	*							*			C, DE
E13	Dependence of the construction industry on other industries										*				*	All
E14	Low profit margins and payback periods		*						*				*			C, O

Note1| A1: Adams et al. (2017), A2: Al Hosni et al. (2020), A3: Bilal et al. (2020), A4: Charef & Lu (2021), A5: Charef et al. (2021), A6: Cruz Rios et al. (2021), A7: Giorgi et al. (2022), A8: Guerra & Leite (2021), A10: Hossain et al. (2020), A11: Kanters (2020), A12: Liu et al. (2021), A13: Morel et al. (2021), A14: Tirado et al.(2022), A15: Torgautov et al. (2021)
Note2| St*: Stakeholder, Contractor (C), Owner (O), Manufacturer (M), Supplier (S), Customer (Cu), Researcher (R), Recycling Enterprises (RE), Demolition Enterprises (DE)

Various employee surveys in Torgautov et al. (2021) revealed that companies generally prefer cheaper and less time-consuming options. Such cases imply that CE strategies are not common and preferred, and even if they were, the motivation would be financial profit rather than the circular economy target. It has been argued that the applicability of strategies such as DfD may increase if economic benefits are provided, necessary regulations are presented, and responsibility is shared among stakeholders (Torgautov et al., 2021). Within the construction industry, a clear economic situation supported by metrics, tools and guidance is crucial to enable greater application of circular economy principles and to encourage stakeholders to

adhere to these principles (Adams et al., 2017). However, high material and construction costs may affect the use of CE principles, especially for owners and contractors. According to Torgutov's research results, the inability to take risks affecting profits is also one of the reasons why the economy is seen as the main obstacle. Companies generally lag in adapting to CE by considering the current economic situation and profit rates, instead of taking risks and using more environmentally friendly technologies (Torgautov et al., 2021).

Table 2 presents the behavioral barriers. The resistance of the sector to change, dependence on other sectors, high labor costs, lack of access to materials that can be adapted to CE, and the lack of regulations specific to the CE can be counted among these obstacles (Kanters, 2020). Similarly, Guerra and Leite (2021) emphasized that budget and costs, project planning, deficiencies in implementation and regulations, lack of awareness in the industry, the industry's resistance to change, and the current construction business model are the main obstacles on circularity. In addition, the industry's adaptation to CE brings along some fears. For example, the possibility of traditional building materials not reaching the target (because they are not intended for CE), the need for certain occupational groups, and the compliance problems of employees may trigger these fears (Kanters, 2020).

Table 2. Behavioral barriers.

Code	*Behavioral Barriers*	*A 1*	*A 2*	*A 3*	*A 4*	*A 5*	*A 6*	*A 7*	*A 8*	*A 10*	*A 11*	*A 12*	*A 13*	*A 14*	*A 15*	*St**
B1	Lack of stakeholders' knowledge and awareness of CE strategies and benefits	*		*			*			*	*		*			All
B2	Lack of clarity on what CE entails	*					*				*		*			C, D, O, R
B3	Lack of stakeholder's experience and skills			*	*		*				*		*			All
B4	Lack and irregularity of information exchange between stakeholders			*	*					*	*		*	*		All
B5	Lack of public awareness on life cycle costs and benefits	*		*		*	*		*				*			G, R
B6	Lack of literature and appropriate training-development programs on CE barriers			*	*		*					*		*		R
B7	Lack of knowledge on circular design	*	*		*	*			*	*		*		*		D, R
B8	Competitive nature of the construction sector						*									D, R
B9	Conservative sector; risk aversion / resistance to chance				*	*	*		*				*	*		All
B10	Lack of stakeholder's interest		*			*	*		*						*	All
B11	Lack of awareness of production responsibility											*	*	*		M, S

Note1| A1: Adams et al. (2017), A2: Al Hosni et al. (2020), A3: Bilal et al. (2020), A4: Charef & Lu (2021), A5: Charef et al. (2021), A6: Cruz Rios et al. (2021), A7: Giorgi et al. (2022), A8: Guerra & Leite (2021), A10: Hossain et al. (2020), A11: Kanters (2020), A12: Liu et al. (2021), A13: Morel et al. (2021), A14: Tirado et al. (2022), A15: Torgautov et al. (2021)
Note2| St*: Stakeholder, Contractor (C), Owner (O), Designer (D), Manufacturer (M), Supplier (S), Researcher (R), Government (G)

The fact that construction projects often have high risks and low profit poses an obstacle to testing and adopting innovative technological methods (Guerra & Leite, 2021). Complexity of building design, lack of standardizations, data management, adequate technology, and awareness of future needs pose technical barriers to a variety of stakeholders (Table 3). Unconsciousness about circularity and lack of awareness of resource consumption are

important obstacles to the adoption of the circular economy. It can be difficult for stakeholders to appreciate something they may need in the future, and this is one of the major barriers to understanding why transitioning into CE is needed.

Table 3. Technical barriers.

Code	*Technical Barriers*	*A 1*	*A 2*	*A 3*	*A 4*	*A 5*	*A 6*	*A 7*	*A 8*	*A 10*	*A 11*	*A 12*	*A 13*	*A 14*	*A 15*	*St**
T1	Uncertain product content of CE materials, lack of material components and problems in material classification				*	*	*			*	*	*				C, DE, RE
T2	Lack of standardization and transportability of building components					*	*	*	*		*	*	*			C, RE, TE
T3	Uncertainty and lack of awareness about future spatial needs/demands, end-of-life and recycling of building materials	*	*		*		*			*	*	*	*	*		C, D, O, R, S
T4	Complexity of building design & design phase	*	*		*	*	*	*	*			*		*	*	D
T5	Improper management of site demolition (existing buildings not designed for dismantling and the potential for damage during demolition)					*	*	*	*			*		*		DE
T6	Lack of space to store disassembled materials					*		*			*	*	*			DE
T7	Difficulty in finding easily removable building products on the market							*				*				C
T8	Challenges of take-back from other companies			*		*										C, O
T9	Lack of standard systems for performance indicators and legislation regulating tests on reused products			*		*		*						*		G, R
T10	Lack of data and data management		*		*	*	*			*			*	*	*	G, R
T11	Undesirable use of second-hand materials and industrialization of natural materials						*					*	*	*	*	O
T12	Lack of necessary technology and infrastructure for salvaged components		*		*		*	*				*	*			RE
T13	Fragmented supply chain	*	*							*						S
T14	Lack of tools and information to identify circularity metrics		*			*	*			*				*	*	G, R
T15	Lack of adequate technology			*	*	*		*	*				*		*	G, R
T16	Lack of connection between digital design technologies and environmental sustainability tools				*	*		*					*	*		G, R
T17	Limited visualization capability for circularity						*								*	G, R

Note1| A1: Adams et al. (2017), A2: Al Hosni et al. (2020), A3: Bilal et al. (2020), A4: Charef & Lu (2021), A5: Charef et al. (2021), A6: Cruz Rios et al. (2021), A7: Giorgi et al. (2022), A8: Guerra & Leite (2021), A10: Hossain et al. (2020), A11: Kanters (2020), A12: Liu et al. (2021), A13: Morel et al. (2021), A14: Tirado et al.(2022), A15: Torgautov et al. (2021)
Note2| St*: Stakeholder, Contractor (C), Owner (O), Designer (D), Supplier (S), Researcher (R), Recycling Enterprises (RE), Demolition Enterprises (DE), Transportation Enterprises (TE), Government (G)

In addition, not updating existing standards and practices is seen as an obstacle to the advancement of more sustainable and circular technologies. Table 4 presents political barriers, mainly associated with governments. Lack of specific regulations and legislation is the barrier that is emphasized by most literature. Lack of commitment, fiscal and regulatory incentives is another main political obstacle posed by the governments to the implementation of circular strategies. Where regulations are less stringent and environmentally conscious, the industry can more easily meet the requirements for the implementation of strategies, with less fear of taking risks and feeling more secure (Guerra & Leite, 2021). On the other hand, existing mandatory documents required to obtain the permit for buildings are based on static structures and do not take into account the possibility of structural change during use, which is a barrier to strategies such as reuse (Giorgi et al., 2022).

Table 4. Political barriers.

Code	*Political Barriers*	*A 1*	*A 2*	*A 3*	*A 4*	*A 5*	*A 6*	*A 7*	*A 8*	*A 10*	*A 11*	*A 12*	*A 13*	*A 14*	*A 15*	*St**
P1	Lack of specific regulations, legislations and laws		*	*	*	*	*	*	*	*	*	*	*	*	*	G
P2	Inadequate incentive and support policies for EOL and CE		*		*		*					*	*			G
P3	Ignoring circularity policies						*							*		G
P4	Warranty and quality issues of using reused/recycled products		*				*			*		*		*	*	C, G, O
P5	Lack of commitment, fiscal and regulatory incentives for CE development		*	*	*	*	*	*				*	*			G
P6	Lack of standards for reused and recycled building products				*	*	*	*				*		*		G
P7	Lack of awareness of the meaning of reversible building							*					*			G
P8	Lack of use of building sustainability certification and building codes					*		*								G
P9	Lack of control and punishment for illegal dumping of waste											*	*			G

Note1| A1: Adams et al. (2017), A2: Al Hosni et al. (2020), A3: Bilal et al. (2020), A4: Charef & Lu (2021), A5: Charef et al. (2021), A6: Cruz Rios et al. (2021), A7: Giorgi et al. (2022), A8: Guerra & Leite (2021), A10: Hossain et al. (2020), A11: Kanters (2020), A12: Liu et al. (2021), A13: Morel et al. (2021), A14: Tirado et al.(2022), A15: Torgautov et al. (2021)
Note2| St*: Stakeholder, St*: Stakeholder, Contractor (C), Owner (O), Government (G)

Failure to understand the buildings' environmental impact and to recycle materials are among the mostly cited environmental barriers. Table 5 presents the environmental barriers, which are not as much cited as the other barriers. It is evident that one of the most influential and influenced stakeholders is the recycling enterprises. Moreover, the literature supports the fact that limitations in the utilization of digital technologies, such as material passports and Building Information Models, pose environmental barriers for CE.

Table 5. Environmental barriers.

Code	*Environmental Barriers*	*A 1*	*A 2*	*A 3*	*A 4*	*A 5*	*A 6*	*A 7*	*A 8*	*A 10*	*A 11*	*A 12*	*A 13*	*A 14*	*A 15*	*St**
EN1	Environmental benefits of reuse are not guaranteed						*						*			C, RE
EN2	Downcycling of building components						*									C, RE
EN3	Failure to recycle all materials in an environmentally effective way					*	*								*	C, RE
EN4	Tradeoffs between different sustainability strategies may hinder CE						*									C, O
EN5	Insufficient understanding of the environmental situation of CE		*				*						*			G, R
EN6	No recyclable infrastructure														*	M, RE
EN7	Lack of using BIM and Material passport				*			*					*			C, D, O

Note1| A1: Adams et al. (2017), A2: Al Hosni et al. (2020), A3: Bilal et al. (2020), A4: Charef & Lu (2021), A5: Charef et al. (2021), A6: Cruz Rios et al. (2021), A7: Giorgi et al. (2022), A8: Guerra & Leite (2021), A10: Hossain et al. (2020), A11: Kanters (2020), A12: Liu et al. (2021), A13: Morel et al. (2021), A14: Tirado et al.(2022), A15: Torgautov et al. (2021)
Note2| St*: Stakeholder, St*: Stakeholder, Contractor (C), Owner (O), Designer (D), Manufacturer (M), Researcher (R), Recycling Enterprises (RE), Government (G)

The literature presents several enablers, aimed at many stakeholders, to improve or eliminate these barriers (Table 6). One of the biggest challenges in the CE approach to optimizing the use of materials and energy is not knowing at which stage of a project material or service should be intervened (Hentges et al., 2021). Giorgi et al. (2022) emphasized that researchers could be involved in all construction phases, while designers in the decision-making (planning and design) phase. The most commonly aggreged enabler is setting and using standards to develop CE strategies, targeting researchers and governments. Raising awareness, collaboration and information sharing among all stakeholders are undeniably significant enablers. It is envisaged that it may be necessary to use special policies for companies in the sector (Torgautov et al., 2021). Local governments are also considered to play an important role in planning CE strategies. Local stakeholders can support the development of CE by providing opportunities and solving challenges that may arise in adapting the CE to the construction sector (Tirado et al., 2022). Regarding the integration of CE and the construction sector, Kanters (2020) emphasized the responsibility of stakeholders, and presented separate dependent variables for each stakeholder that should be controlled. Budget, company image, project risks, client flexibility, materials and tools used, construction management, and methodology are given as examples of these variables (Kanters, 2020). It is emphasized that CE integration and applications in the construction industry can result in success with a client who is willing, supportive, and ambitious for change, a contractor who has mastered the circular economy in terms of materials, technology, and skills, and an architect with the necessary skills (Kanters, 2020). In addition, Cruz Rios et al. (2021) indicated which stakeholders can take an active role for each facilitator, and such mappings are utilized in the tables above. Recognizing the disadvantages of the linear economic model in the construction industry and taking countermeasures can ensure the adoption of a CE model.

Table 6. Enablers.

Code	*Enablers*	*A 1*	*A 2*	*A 6*	*A 8*	*A 9*	*A 15*	*A 16*	*St.*
X1	Ensuring the recovery of materials logistically and commercially	*		*		*	*		C, M
X2	Developing markets and enabling technologies	*	*				*		M, R
X3	Raising awareness on circularity	*		*		*	*		G, R
X4	Enactment of a CE-specific legislation	*		*					G
X5	Making necessary practices to raise awareness and knowledge	*		*		*		*	G, O, R
X6	Having some form of manufacturer responsibility for construction products	*	*	*					D, G, M
X7	Optimizing and extending lifetime of buildings	*					*		G, O, R
X8	Setting & using standards to develop strategies	*	*	*		*	*	*	G, R
X9	Development of financial incentives to use secondary materials and for collaboration between companies	*	*	*				*	G
X10	Making sure secondary materials are of the correct quality and reusable	*						*	C
X11	Adequate experience and knowledge of stakeholders on the performance of the lifecycle	*	*					*	C, D, G, O, R
X12	Collaboration within supply and supply chain management activities and information sharing capabilities	*		*		*	*	*	C, M, O, R
X13	Promoting the use of more prefabricated, organic, environmentally friendly and renewable materials			*		*	*		C, G, O, R
X14	New and robust regulations regarding construction standards			*			*		G, O
X15	Reasonable and competitive prices for materials						*		C, M
X16	Apply lean principles to reduce waste		*		*	*	*		C, O
X17	Developing and using new technologies and construction method		*	*			*		C, O, R
X18	Integrating CE into contract requirements for design			*					C, D, O
X19	Creating and enlarging database for CE		*	*	*				O, R
X20	Dissemination of new volunteer management programs				*				G, R
X21	Changing people's perception & perspective on CE	*		*	*		*		G, R
X22	Ensuring buildings receive necessary maintenance						*		C, O
X23	Establishment and implementation of zero waste policies		*	*		*			C, D, G, M, O
X24	Creating national and regional CE action plans		*	*				*	G
X25	Creating tax deductions for CE design strategies		*	*		*			G, O
X26	Design for manufacture, assembly, and CE							*	D
X27	Integration, knowledge sharing, collaborative working between project team and stakeholders		*					*	All

Note1| A1: Adams et al. (2017), A2: Al Hosni et al. (2020), A6: Cruz Rios et al. (2021), A8: Guerra & Leite, (2021), A9: Hentges et al. (2021), A15: Torgautov et al. (2021), A16: Wuni & Shen (2022)
Note2| St*: Stakeholder, Contractor (C), Owner (O), Designer (D), Manufacturer (M), Supplier (S), Researcher (R)

The main purpose of this study is to synthesize and present the literature that will lay the foundation for research that aims to provide an overview of the barriers and enablers of CE, with related stakeholders, in Turkey.

Conclusion

Considering that the construction industry is one of the largest consumers of raw materials and generators of waste, it is necessary to minimize such practices. The application of CE in the construction sector will not only provide many benefits in this sense but will also help develop many new applications and tools for the future. In this paper, a literature review has been conducted to compile previous studies to learn and understand readiness on circularity. The aim of the study was to identify the barriers to the adaptation of the circular economy in the construction sector and to identify the facilitators offered against these barriers. Literature lists many enablers and barriers of CE. To overcome the barriers, and facilitate CE transition, the related stakeholders and responsibilities should be identified as well. Some studies (e.g., Hentges et al., 2021; Wuni & Shen, 2022) mapped enablers to construction stages, and some (Guerra & Leite, 2021) CE strategies to construction stages, and some enabler to stakeholders (e.g., Cruz Rios et al., 2021). While all the findings are dispersed, many of these studies include research specific to a particular region or country, while others include research on specific methods and strategies rather than investigating the general applicability of CE. In this study, the barriers extracted from the literature are compiled and classified into five categories, including economic concerns, environmental factors, lack of regulations on circularity, low awareness of circular economy, and resistance to change in the construction sector. Enablers of CE, and related stakeholders are mapped in a tabular format. Future studies should represent of the interrelations between CE-related concepts, including enablers, barriers, and stakeholders, to support transitioning into CE in the construction industry. Due to differences in culture, geographical location, and existing regulations, the priority and challenges of CE-related strategies, enablers, and barriers would differ in different regions/countries. Future research directions include assessing the applicability of identified barriers and enablers to Turkey and assessing the priority of the relationship of such CE concepts.

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Sustainability Analysis for the Construction of Rural Houses

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Abstract

Sustainability is one of the major concerns for the construction sector as the construction activities damages the environment significantly. The accommodation units were used to construct by stone or adobe in the rural settlement regions. However, because of the increase in the life quality and the increased rural life enthusiasm of the people living in the highly urbanized regions initiated the escalation of the construction activities in the rural region. In this study, sustainability of construction of a typical one story house suitable for rural settlement is analyzed in terms of CO_2 emission and embodied energy of the utilized construction materials. The analysis is conducted by preparing the quantity take-off of construction items. The material, workmanship and construction machine requirements for unit construction are determined for every construction item. The embodied CO_2 amounts of the construction materials are computed by pairing the unit CO_2 emission amounts of the materials. In addition to this, embodied energies of the construction materials are computed by the same method. Energy consumptions of construction machines are estimated by the data provided by the manufacturers. The computations are linked each other and change in the quantity take-off data directly effects the presented CO_2 emission and embodied energy computations. The developed approach might help to conduct environmental analysis of rural buildings.

Keywords: *carbon emission, embodied energy, sustainability.*

Introduction

Past experience revealed that there is a reverse correlation between the economy and the environment. The growing economy and increasing population damage the environment and the nature. The center of the life cycle of the earth is ecosystems. Unsustainable growth leads to degradation of ecosystem and eventually extinction of species.

When the research trends of the last 25 years in the field of construction are examined, it is seen that more than 80% of the related documents published after 2010 has the keyword "sustainable construction", which is a very novel literature. The subject is a global literature with significant contributions for both economically developed and developing societies. The dominant research on the sustainable construction consists of four main frameworks. These are; alternative materials for sustainable construction, sustainable construction management, recycling and waste reduction, and social sustainability in construction management. On the other hand, the weak chain of the aforementioned four titles is “social sustainability” and the

dominant dimension is “alternative materials” (Udomsap & Hallinger, 2020). The word sustainability comes from the Latin “sus tenere”, meaning to protect or to endure (Jaques, 2020). There are many approaches and definitions on this concept in different fields (Pamuk & Kuruoglu, 2016). However, it basically means that a resource can be used in the future without being destroyed.

In 2011 the United Nations Environment Program (UNEP) organized the International Natural Resources Panel. In this Panel it is stated that if serious steps are not taken, the amount of mineral, ore, fossil fuel and biomass used by human beings will reach approximately 140 billion tons by 2050. The aforementioned amount is three times the annual consumed value today (IRP, 2021). There are stress limits of the Earth, which can be defined as the threshold for the emergence of the negative effects of the specified consumption. Some of the stress limit categories are; climate change, biodiversity loss, ocean acidification, the ozone hole and land use. Even tough exceeding the limit of even one category poses a threat to sustainability, many systems have exceeded the limit value, and the rest have approached the limit. This trend became obvious especially after the industrialization.

For example, the biodiversity loss extinction rate limit value has been exceeded more than 10 times. Alongside, electricity generation, automobile use, and the construction industry are the three largest contributors to greenhouse gas emissions that threaten the Earth's climate (IPCC, 2019). Recognition of this impact on society has led the global construction industry to take increasingly prominent steps aimed at adopting more sustainable practices (Kibert, 2007). While cost reduction, operational efficiency, quality and profitability were the key factors in construction management in the past, project owners and managers are increasingly concerned with the environmental and social impacts of construction projects in the present case (Ortiz et al., 2009). The point to be noted here is; environmental problems always have a connection with the construction sector. This is because the construction industry forms the basis of living spaces. The other reason is that while environmental problems are mostly the result of backwardness in developing countries, the source of this problem in developed countries arises from industry and technological advances.

Developing countries need growth in the construction industry to meet their increasing needs. Construction projects on transportation/infrastructure, energy, residential areas, landscape, dams, and harbours are the main necessities to sustain their economic growth. It is clear that these projects would have a share in the economies of the countries. According to 2012 data, the construction sector constitutes 13.4% of the world production with 7.5 trillion dollars, 6.47% of the gross product of the OECD countries and 10% of the gross product of the European countries (Pamuk & Kuruoglu, 2016). According to the Global Construction 2030 report, the volume of construction production is estimated to increase by 85% worldwide to $15.5 trillion by 2030, accounting for 57% of all global growth (Global Construction Report, 2021). When the situation in Turkey is analyzed, the construction sector constitutes approximately 7 percent of the Turkish economy in 2020 (TR Presidency, 2020). These data support that the construction sector is important even in the global crisis environment. In addition, targets for the construction sector have been determined in the national energy efficiency plans. However, the energy efficiency index does not show the desired development for the housing sector (TR Precidency, 2018). As a result, it is clear that the volume, importance and impact of the construction sector on sustainability cannot be denied today and in the future. While sustainability practices meet basic needs, they should prevent the destruction of the nature and the resources. In other words, unless there is environmental welfare, it is not possible to mention sustainability and welfare in social and economic terms.

To conceptualize sustainability in construction, Kibert argued that the construction industry should move towards the use of 'sustainable practices' that conserve limited resources and promote a healthy environment (Kibert, 1994). In the 2000s, "green construction" and "green building" emerged as umbrella terms denoting a shift towards environmentally friendly construction practices (Ali & Al Nsairat, 2009). The initiation of the 'sustainable development goals' by the United Nations has brought attention to social and environmental responsibility and impact by removing the construction industry from being an economic tool. Moreover, the emergence of these umbrella terms has forced developers and builders to adopt a "sustainability mindset" for the design and management of construction projects (Seyfang, 2010). Practice of sustainability has implications for land selection, land use, design practices, material selection and application, project management, and stakeholder engagement (Barlow & Jashapara, 1998). For example, Horvath (2004) investigated the environmental impact of different choices in construction materials used in infrastructure projects.

The construction industry is heavily dependent on non-renewable resources. Green construction idea basically aims to produce less waste and to alleviate the impact of resource usage by using reusable and less energy-consuming construction materials (Hoşkara, 2007). According to the 2007 data, 50% of the energy, 42% of the water, 48% of the agricultural areas and 50% of the other materials are consumed in the construction, utilization and operation processes of the buildings. At the same time, 50% of the greenhouse gases that cause global warming, 40% of the pollution of the drinking water, 24% of the air pollution, 20% of the surface solid wastes and 50% of the carbon dioxide emissions are caused by the practices associated with the buildings (Ovalı, 2009; Edwards, 2007). The construction industry consumes the resources on earth to a great extent which creates stress in many ways such as global warming, acid rain, waste generation, and artificial environmental pressure.

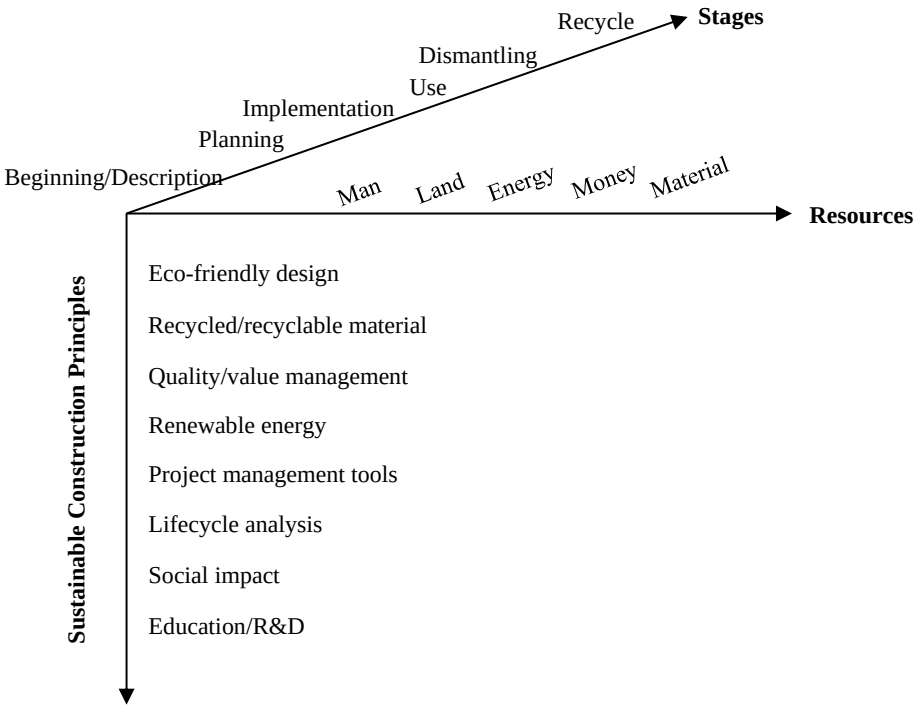


Figure 1: Three-dimensional conceptual model of sustainable construction practices.

Kibert (1994) gathered the sustainable construction principles to be developed under six headings and created a conceptual model. The conceptual model of sustainable construction principles created by Kibert (1994) is presented in Figure 1. The model has been revised based on today's project construction processes, requirements and terms.

Green building evaluation systems and certificate programs have an important role in revealing the environmental effects of buildings in an objective and concrete way. It is mainly divided into two groups as Life Cycle Assessment (LCA) methods and criteria-based certificate programs developed for this purpose. LCA methods are generally used in the design phase of buildings, for purposes such as material and product selection, evaluation of service system options, and their scope is limited (Sev & Canbay, 2009).

Hussin et al. (2013) investigated the necessity, fundamentals and challenges of sustainable construction. To reduce the adverse affects, new project management tools and techniques about sustainability are recommended and application examples are given in the study. Overall energy consumption can be reduced and the utilization of renewable energy can be maximized, wastes can be minimized, water resources can be conserved, water quality can be improved, vulnerability to flooding, polluting emissions, noise, and light pollution can be prevented by adopting sustainable construction. Aforementioned problems can be addressed with the Green building approach, which is more sustainable than existing practices.

Bae and Kim (2008) discussed the concept of sustainability in construction projects and lean construction. The positive and negative aspects of several lean methods on the sustainability principle are evaluated. The negative impacts are based on the fact that environmental and social principles are not directly felt by the project stakeholders. But despite this, lean techniques are beneficial for sustainable construction. Economic benefits are listed as; possible upfront cost reduction, resource savings, operating cost reduction and high performance capability. Workplace safety, user health, community welfare, loyalty among stakeholders and improving external image are the social benefits. Reduced resource consumption, preventing pollution by eliminating waste, and conserving resources are the environmental benefits.

Chen et al. (2010) examined sustainable performance criteria for the selection of construction management in traditional in-situ reinforced concrete works and precast/prefabricated concrete works. At the end of the study 33 sustainable performance criteria are determined. The results reveal a total of seven factors to present the structure that forms the basis of the sustainable performance criteria used to choose a construction method in concrete buildings. These factors are listed as; economic factors (long-term cost-constructability-quality and initial cost), social factors (impact on health and society-architectural impact) and environmental factor (environmental impact). In addition, survey results indicate that social awareness and concerns are increasing.

Yiğit and Şeneren (2018) compared the carbon footprint and cost differences of the construction of a traditional building and a green building, and the amount of emitted carbon dioxide (CO_2), by designing a single-storey building. The comparison revealed that even a small building can be built as a green building with reduced carbon emissions, and even if the initial investment cost is high, this cost will be paid back over time. Bettemir (2012a, 2012b, 2016, 2018) compared the environmental impact of temporary accommodation utilities constructed after a destructive earthquake. Erzurum and Bettemir (2021) estimated the CO_2 emission and embodied energy of temporary accommodation facility.

Method

In this section the computation steps of the embodied energy and the CO_2 emissions are described. The computations of embodied energy and the CO_2 emissions of the building involve the quantity take-off of the construction items. The quantity take-off provides the amounts of the construction works; however this data do not directly give the amounts of materials to be used. In order to obtain the amounts of used materials, job definitions including the workmanships and material requirements of the construction items are required. The mentioned data is obtained by the Ministry of Environment and Urbanization of Turkish Republic. Definitions of construction items are used for the estimation of the required materials and the consumed energy.

Construction activities sometimes require the execution of another construction activity. To illustrate, construction of brick wall involves regularly placement of bricks, as well as preparation and spreading mortar. However, preparation of mortar is another construction activity which involves mixing of cement, fine aggregate, and water. Construction items may require usage of more than one type of construction materials. For example, preparation of the formwork activity requires consumption of plywood or timber for the formwork, utilization of supporting braces for the formwork, consumption of oil, and nails. The total amounts of materials are computed by multiplying the unit requirements mentioned in the activity definition and the quantity take-off amount.

Some of the construction materials can be reused. Timber for the formwork can be given as an example for this situation. Same timber can be used for the formwork of the foundation, columns, beams, and slabs of the building. Therefore the amount of the required timber is less than the total area of the formwork. In addition to this, wooden support for the formwork can be reused for the bracings of the roof system. As a result, reuse can reduce the amount of the required materials. In this study, reuses of wooden elements are taken into account when computing the amount of embodied energy of the utilized materials.

Amounts of utilized materials are multiplied by the unit embodied energy of the considered material and the total embodied energy of the specific material is obtained. The unit embodied energy and CO_2 emissions of the materials are defined in a similar way to the job definitions. The unit embodied energy and CO_2 emissions values per one kg of the material is determined by literature survey and the provide values are matched with the materials of the job definitions of the construction activities. The material units of the job definitions may not be coincident and the units are converted into kg by using the material properties. The procedure is repeated for every construction material and the obtained embodied energy amounts are summed and the total energy content of the accommodation utility is computed. In addition to this effect of utilization of different floor covering materials on the carbon emission and embodied energy is analyzed.

Case Study

In this study, a typical one storey accommodation facility whose floor plan is given in Figure 2, is designed and used as case study. Cost of the building and the effects on the environment are examined. The load bearing system of the examined struction is masonry. In rural areas, masonry structures are more common since the preparation of the reinforced concrete is more

expensive because of the transportation costs and shortage of skilled workers on the reinforcement works.

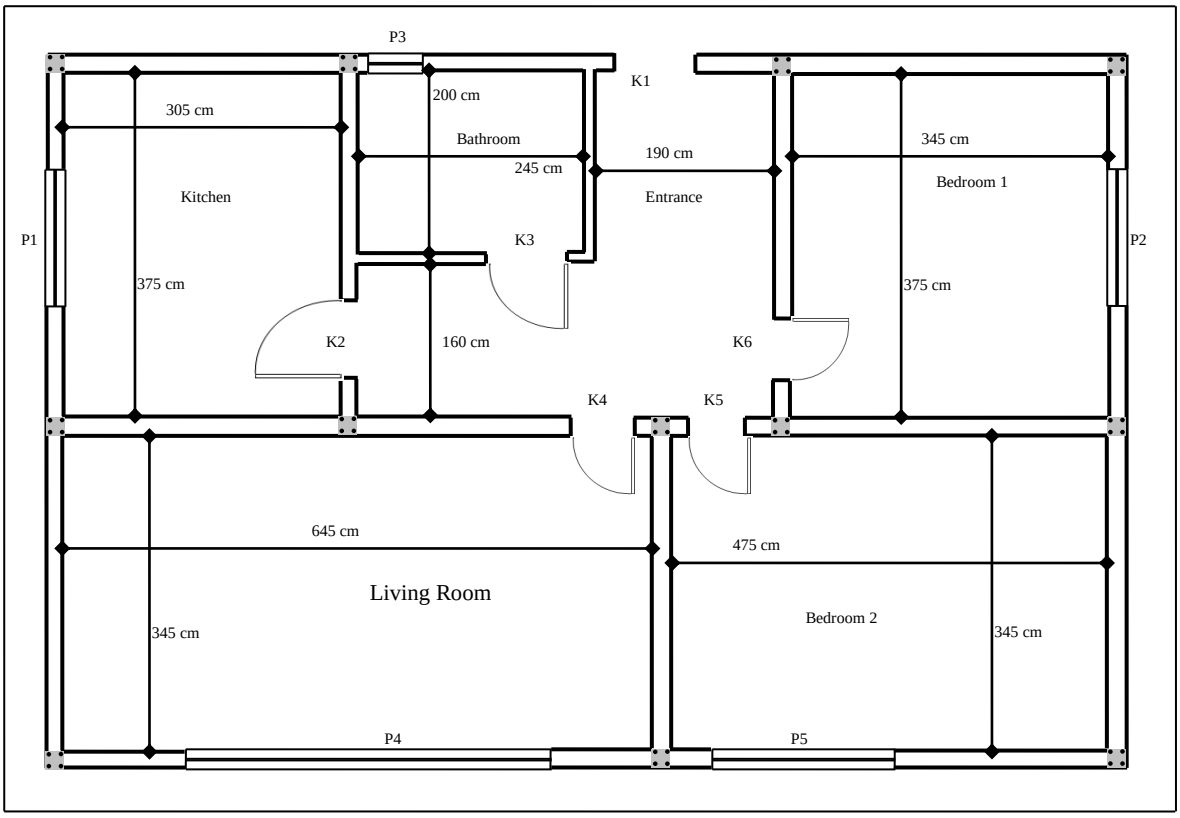


Figure 2: Floor plan of the examined accommodation facility.

Top view of the examined accommodation facility is shown in Figure 2. Foundation, excavation and section drawings are not given because of the space limitations. There are lintels on every door and windows, and the wall thickness of the load bearing walls are 20 cm. The load bearing walls are supported by horizontal and vertical reinforced concrete beams and columns. Walls of the bathroom, floors of the kitchen, entrance and bathroom are covered by ceramic tiles. Floor covering of the living room, bedroom 1 and 2 are laminate parquet. Continuous foundation type is preferred. Foundation elongates under the load bearing walls. The foundation is constructed below the frost depth. The bottom side of the foundation is 2 meters below the ground surface. Width of the foundation is 70 cm and its thickness is 25 cm. At the top of the foundation, 125 cm height stone wall is constructed and a 25 cm reinforced concrete horizontal beam is placed on the stone wall. The top of the reinforced concrete horizontal beam reaches ground surface. The load bearing system of the foundation is covered by water insulation material and this material is protected by thin brick wall.

The walls are plastered by 200 kg dosage cement mortar. Then the plastered surfaces are painted. The tile covered walls are not plastered. Roof eaves are 60 cm by the edge of the walls. Top of the ceiling is covered by heat insulation material. The roof is constructed by plywood boards. Top of the board is covered by bituminous water insulation material. Tiles cover the water insulation. The roof is reinforced by wooden truss system. The wooden truss elements are obtained from the supports of the formwork. Window and door frames are made of wood. The computed quantity take-off of the construction items are presented in Table 1.

Table 1. Quantity take-off of construction items.

Work Item	Quantity	Unit
Excavation	211.463	m^3
Drainage Pipe	41.6	m
Gravel	31.18309746	m^3
Plain Concrete	13.108	m^3
Water Insulation	216.72	m^2
Formwork	217.735	m^2
Reinforcement	3701.39	Kg
Concrete	32.7975	m^3
Stone wall	36	m^3
Load Bearing Brick	137.66	m^2
Partioning Brick Wall	11.42	m^2
Thin Brick Wall	137	m^2
Backfill	77.5	m^3
support for scaffolding	309.3075	m^3
Plastering	416.155	m^2
Ceramic tiles	55.3235	m^2
Concrete tiles	47.96	m^2
Concrete tile baseboard	37.96	m
Painting	400.2376	m^2
Laminate parquet	51.5775	m^2
Ceramic baseboard	22.12	m
Laminate baseboard	47.18	m
Door frame	7.118	m^2
Door Casing	13.454	m^2
Window frame	11.25	m^2
Scaffolding (outside)	119.56	m^2
Window sill	2.85	m^2
Gutter	44.4	m
Downspout	6.30	m
Elbow pipe	6	pieces
Heat insulation (Roof)	117	m^2
Plywood board (roof)	126.01	m^2
Water insulation (roof)	126.01	m^2
Tiles (roof)	126.01	m^2
Ridge Tile	30.45	m
Plumbing	28.40	m
waste water piping	17.35	m

After the coputation of quantity take-off, the next task is to compute the required amounts of construction materials to execute the work items. This is done by identifying the required material to accomplish one unit of each work item. Unit material requirements of the construction items are given in Table 2.

The fourth column of the Table 2 lists the amount of the require materials to construct the complete house. The material amount lists are used to compute the embedded energy which is required to produce the aforementioned material. Total material requirements are computed by multiplying the unit material requirements and the corresponding quantity take-off amount given in Table 1. Table 3 lists the unit embedded energy of the listed construction materials and the unit requirements are multiplied by the material amounts in order to obtain the embodied energy of the consumed material. Unit embodied energy values of the construction materials are obtained by Hammond and Jones (2008).

Table 2. Unit material requirements of the construction items.

Work Item	Unit Material Requirement	Unit	Total Material Requirement (kg)
Drainage Pipe	1.80	kg/m	74.88
Gravel	1800	kg/m3	56129.57542
Plain Concrete	2400	kg/m3	31459.2
Water Insulation Ply1	0.4	kg/m2	86.688
Water Insulation Ply2	2.3	kg/m2	498.456
Formwork Board	4.576	kg/m2	996.35536
Nails	0.3	kg/m2	65.3205
Lubricant	0.1	kg/m2	21.7735
wood timber	1.17315	kg/m2	255.4358153
Reinforcement	1.05	kg/kg	3886.458051
Concrete	2400	kg/m3	78714
Stone wall	2400	kg/m3	86400
Load Bearing Brick Wall	400	kg/m2	55064
Partioning Brick Wall	270	kg/m2	3083.4
Thin Brick Wall	180	kg/m2	24660
Backfill	1800	kg/m3	139500
support for scaffolding (steel pipe)	0.4	kg/m3	123.723
support for scaffolding (steel plate)	0.12	kg/m3	37.1169
Plastering	2000	kg/m2	16646.2
Ceramic	2600	kg/m3	2876.82
Concrete tile	2200	kg/m3	3165.36
Concrete tile baseboard	2200	kg/m3	66.8096
Painting	1500	kg/m3	1801.07
Laminate parquet	1.05	kg/m2	54.16
Ceramic baseboard	1400	kg/m3	24.77
Laminate baseboard	1.05	kg/m2	3.96
Door frame	600	kg/m3	85.42
Door trim	600	kg/m3	161.45
Window frame	1500	kg/m3	843.75
Scaffolding (outside steel pipe)	0.4	kg/m3	47.82
Scaffolding (outside steel plate)	0.12	kg/m3	14.35
Windowsill	2800	kg/m3	159.6
Gutter, downspout, elbow pipe	0.85	kg/m	43.93
Heat insulation (Roof)	120	kg/m3	702
Plywood board (roof)	800	kg/m3	2016.21
Water insulation (roof)	7.68	kg/m2	967.78
Roof Tiles and ridges	45	kg/m2	5944.63

The provided embodied energy values contains the energy required for the transportation of raw materials from the mine or the supplier, energy required for the manufacturing of the construction material and the energy required for the transportation of the material to the construction site. However, the computations involve many assumptions so that the unit embodied energy values are computed for general cases and the values may vary significantly based on the manufacturing techniques and transportation distances. Average values are assigned for the transportation distances and the manufacturing techniques. In this study, the facility is assumed to be built at a rural place which increases the transportation distance between the supplier and the construction site. In addition to this, in Turkey timber and some of the insulation materials are imported. This tremendously increases the transportation distance, thus the embodied energy of the product.

Table 3. Total embedded energy of the construction materials.

Work Item	Total Material Requirement (kg)	Unit Embodied Energy (MJ/kg)	Unit Embodied CO_2 (CO_2/kg)	Total Embodied Energy (MJ)	Total Embodied CO_2 (kg)
plastics/pvc pipe	74.9	67.5	2.5	5054.4	187.2
stone/gravel/chippings	56129.6	0.3	0.0	16838.9	954.2
concrete/general conc.	110173.2	1.0	0.1	104664.5	14322.5
Bitumen	1552.9	47.0	0.5	72987.4	745.4
timber/plywood	3268.0	15.0	0.8	49020.0	2647.1
steel/bar&rod steel	3886.5	36.4	2.7	141467.1	10415.7
stone/general stone	86400.0	1.0	0.1	86400.0	4838.4
clay and bricks/general	82807.4	3.0	0.2	248422.2	18217.6
Soil	139500.0	0.5	0.0	62775.0	3208.5
steel/pipe	171.5	34.4	2.7	5901.2	463.2
steel/plate	51.5	48.4	3.2	2490.9	164.2
plaster/general plaster	16646.2	1.8	0.1	29963.2	1997.5
stone/marble tile	2876.8	3.3	0.2	9579.8	538.0
clay and bricks/tile	9176.8	6.5	0.5	59649.2	4221.3
Paint	1801.1	68.0	3.6	122472.8	6411.8
vinyl flooring	54.2	65.6	2.3	3555.1	124.0
stone/marble tile	24.8	3.3	0.2	82.5	4.6
vinyl flooring	4.0	65.6	2.3	259.9	9.1
timber/general	246.9	8.5	0.5	2098.4	113.6
windows/pvc framed	5.0	2250.0	115.0	11250.0	575.0
stone/marble tile	159.6	3.3	0.2	531.5	29.8
plastics/pvc pipe	43.9	67.5	2.5	2965.3	109.8
insulation/rockwool	702.0	16.8	1.1	11793.6	737.1

The analysis reveals that the total embodied energy of the construction materials is equal to 1,050,223 MJ and the embodied CO_2 is 71,035.7 kg. The exact embodied energy is expected to be more than the computed value, since the facility is assumed to be built at a rural place which would increase the transportation distance of the construction materials.

Discussion of Results

The embedded energy and CO_2 emission computations are automated by forming semantic relations between the construction activities. To illustrate, the support for the scaffolding and the scaffolding activities require the same materials which are steel pipe and steel plate. The mentioned activities are joined so that their material requirements are summed and the embedded energy and CO_2 emission computations are executed simultaneously. This method reduces the computational errors and makes the lists clear and comprehensible.

The rural building is analyzed by preparing the quantity take-off of each construction item which is given in Table 1. Then the job descriptions of the construction items are joined with the quantity take-off data and the material, energy, and equipment requirements for the corresponding construction item is computed as given in Table 2. The material requirements are matched by the embedded energy and CO_2 emission definitions of the corresponding materials as given in Table 3. The material definitions are prepared for unit weight of the material which is kg. The job definitions may not be coincident with the material definitions so that the required material can be defined in length, area or volume. Therefore the material requirements are converted into weight and the pairing became consistent.

Production of the most of the construction material such as cement, steel, aluminum, glass, ceramic, and tiles require important amount of energy. The construction items which utilize

the mentioned materials constitute the most of the embedded energy and the CO_2 emission for the construction. The walls have the %25, cocrete has the %10, reinforcement bars has the 14%, and the paintings has the 12% share of the embodied energy of the construction.

Conclusion

In this study, embodied energy and embodied carbon of a typical one story accommodation facility are computed. Quantity take-off of the construction items is computed according to the technical drawings. The quantity take-off data is matched by the job descriptions of the construction activities. This enabled the estimation of the requited amounts of construction materials, energy and machine usage. The list of the construction materials is prepared and the unit embedded energy values and the CO_2 emissions of the construction materials are derived from the literature. The unit values and the material requirements are matched and multiplied and the total embedded energy and CO_2 emission to construct a typical rural building is computed.

The analyses show that the total embedded energy of a typical rural house is more than one million MJ excluding the additional material transportation. The analysis provided the contribution of each construction material on the embedded energy and the CO_2 emission. The material list gives adequate information for the design of an environmentally friendly house. The designer can detect the worst part of the material selection if an environmentally building certification is aimed. The design can be improved by utilizing lower embodied energy and CO_2 emission materials. This study provides a guideline for the construction of sustainable houses which utilizes construction materials with minimum embodied energy and CO_2 emission.

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Current Concepts Regarding Sustainability Practices and Architectural Education

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Abstract

Renewable energy utilization and energy efficient buildings are very important for the Earth, due to rising population. Many studies have been carried out investigating the subject of sustainability and sustainability in architectural education in Turkey. Architectural Education supports sustainability. The subject of sustainability and environmental systems are included among the knowledge and skills of the Architectural Accreditation Agency (MIAK) that must be acquired by every graduate. Along with the developing technology in the construction sector, many current concepts related to sustainability are encountered. In this study, it is aimed to determine the level of inclusion of current concepts related to sustainability in undergraduate Architectural programs. Within the scope of the study, content analysis method will be used to determine the current concepts in sustainability practices from the publications related to sustainability in the last five years. The current concepts determined from the literature by content analysis will be scanned in the elective course contents of the Architecture Departments of 12 Universities in the sample and the number of repetitions will be reached. Thus, the rate of inclusion of current concepts in sustainability practices in Architecture undergraduate programs will emerge.

Keywords: *architectural education, content analysis, current concepts, sustainability.*

Introduction

There is a much greater requirement for energy today. Studies on renewable energy sources have grown because of the depletion of fossil fuels. Visual and climatic comfort of people should be satisfied with minimum energy. Energy resources have been utilized carelessly for many years. It is known that the energy sources used over time decrease, may run out, and do significant harm to the environment. The necessity for efficient energy use and the hunt for alternate energy sources have resulted correspondingly. Renewable energy utilization is one of the best strategies to improve the energy efficiency of buildings.

Buildings that are environmentally friendly, healthful, and resource-efficient are referred to as “green buildings”. Sustainable building practices is actively aided by the performance

evaluation systems for green buildings. The number of certificated buildings has increased rapidly around the world. LEED, BREEAM, CASBEE, GREEN STAR, DGNB, and SBtool are the primary green building rating systems today. The B.E.S.T. certification system has been established in Turkey as a mean of certifying green buildings by CEDBIK (Environmentally Friendly Green Buildings Association). There are currently 518 certified projects in Turkey, of which 498 are LEED, 70 are BREEAM, and 23 are B.E.S.T. certified as of August 2022 (cedbik.org.tr). The number of certified projects has increased over time in Turkey.

Green building production still faces significant challenges within the context of project management in our country, notwithstanding the rise in the number of green buildings. Lack of education, one of the challenges faced in project management for the construction of sustainable buildings, has a significant role in the acceptance of green buildings (Bicer et al., 2020), and (Ceylan, 2016). If the architects are sufficiently aware of and knowledgeable about sustainability, the environment can be protected during the construction and utilization stage of the buildings. Sustainability principles have been emphasized in architecture education to protect environment.

The publications investigating the relationship between sustainability and architectural education have been analyzed for this study. Keskin et al. (2019) examined the relationship between sustainability and undergraduate diploma projects. Sustainability criteria were determined based on LEED criteria, passive design principles, and information and skills for undergraduate architecture students determined by MIAK (Architecture Accreditation Board). The relationship between sustainability criteria and diploma projects were assessed. Ibrahimgil (2019) identified the role of the sustainability in architectural education and examined the sustainability approach of architecture students in the universities of Turkey. He suggested a curriculum structure for the sustainability approaches. Karadag (2018) assessed the rate and format of ecological approaches in architectural education by examining the course content and the findings of a survey he conducted among architecture students. Ceylan (2016) compared the architectural education in Turkey and abroad. He developed a new model for an undergraduate architecture program. The suggested program included modern ecological and energy-saving practices. Yurtsever et al. (2013) evaluated sustainable building design as part of the architectural education through the experiences of students and instructors. The project course was conducted on the concept of “sustainability” through the Architectural Project Competition hosted in Canakkale. Gulec and Utkutug (2010) considered that traditional architectural design approach in architectural education was not appropriate for putting theoretical knowledge of energy and ecology to practice. As a result, they implemented a test project at Gazi University for a semester to incorporate simulation-supported building performance analysis into architectural education. Several academicians have publications in “Mimarist” Magazine issue titled “Sustainability in Architectural Education,” and many viewpoints on the connection between sustainability and architectural education are offered. Altomonte discussed the qualifications of undergraduate architectural education in this study. He presented the EDUCATE (Environmental Design in University Curricula and Architectural Training in Europe) project (Altomonte, 2011). Esin gave a hint tips on sustainability assessment techniques in the scope of MIAK (Esin, 2011). Oktay (2011) discussed the importance of the environment in architectural education. He proposed a table to measure the competency of Architectural Education Institutions in environmental issues (Oktay, 2011). Ciravoglu analyzed the undergraduate and graduate curriculums of 42 architecture schools in Turkey in the context of the environment. She assessed the environmental issues in curriculums of undergraduate and graduate architectural education.

(Ciravoglu, 2011). Caglar and Aksu presented a 10-point manifesto. They compared the qualifications of the studio indicated in the manifesto and the traditional studio. The studio indicated in the manifesto included sustainability (Caglar & Aksu, 2011)

The literature review revealed that there are a lot of studies about the sustainability in Turkish architectural education. “Sustainability and environmental systems” is the “information and ability” that is expected to obtain by the students of architecture programs according to MIAK. “Sustainability” should be in the content of the curriculum of architecture program according to most recent researches and MIAK’s knowledge and abilities. New concepts related sustainability have been developed with technological development of the construction industry. It should be given the importance to sustainability in architectural education, and architects should know the current sustainability concepts. It has been observed that the majority of the assessments in the current studies are made on required courses. The subjects are treated exhaustively by the elective courses, so current concepts for sustainability practices will be scanned on the elective courses in this study. This study aims to measure the existence of the current concepts for sustainability practices in the undergraduate architectural education curriculum with the rise in certified buildings in Turkey.

Method

After the publications about current sustainability concepts have been scanned on Web of Science, current sustainability concepts will be determined. Current concepts will be scanned on the elective courses of Architecture Department curriculums with content analysis method. The existence of the current concepts for sustainability practices in the undergraduate architecture program curriculum will be determined.

Content analysis is a method of analyzing written, oral, or visual communication messages (Cole, 1988). It allows the researcher to test theoretical issues to enhance understanding of the data. Through content analysis, it is possible to distil words into fewer content related categories. It is assumed that when classified into the same categories, words, phrases and the like share the same meaning (Cavanagh, 1997). It is the systematic examination of text and field notes by identifying and grouping themes and coding, classifying, and developing categories (Jonge et al., 2007). Content analysis is an appropriate method that can be used to scan the texts in the literature to determine the current sustainability concepts. When scanning the relevant literature within the scope of the content analysis method, the frequency of the current concepts for sustainability practices in undergraduate architecture programs will also be revealed.

Determination of the Sample

The sample consists of 12 universities that provide undergraduate degrees in architecture. The sample consists Architecture Programs located in various parts of Turkey. As many of Architecture Programs located in Istanbul, 5 of the programs have been selected from Istanbul. 2 programs from Ankara and one program each from Izmir, Trabzon, Bursa, Gaziantep, Cyprus have been selected. 7 of them are public universities and 5 of them are foundation universities. When the sample has been determined, the accredited Architecture Programs are preferred. The sample consists Istanbul Technical University (ITU), Middle East Technical University (METU), Yildiz Technical University (YTU), Mimar Sinan Fine

Arts University (MSFAU), Karadeniz Technical University (KTU), Uludag University (UU), Dokuz Eylul University (DEU), Istanbul Kultur University (IKU), TOBB University, Hasan Kalyoncu University (HKU), Eastern Mediterranean University (EMU) and Bahcesehir University (BAU). Architecture Programs of ITU and YTU are accredited by National Architectural Accrediting Board (NAAB). Architecture Programs of YTU, MSFAU, IKU, EMU and BAU are accredited by MIAK.

Determination of Current Concepts Regarding Sustainability Practices

The determination of the sample step is followed by the determination the categories step in content analysis method. Current concepts regarding sustainability practices have been determined from the literature. Similar concepts have been collected under a same category.

The publications mentioning sustainability practices have been searched on Web of Science from 2017 to 2022. 40 publications on Web of Science have been scanned to determine the current sustainability concepts. 38 publications are articles. Abstracts and keywords of the publications have been scanned to determine the current concepts (Table 1).

Table 1. Determination of current concepts related to current sustainability practices.

Current Concepts	References & Year
Green Architecture	Ibrahim, 2022; Grover et al., 2020
Green Construction	Hejl et al., 2020
Sustainable Construction	Leringer, 2020; Liu, 2020; Wuni et al., 2019; Georgievska et al., 2018
Green Technology	Xiaolei & Pei, 2020
Green Building	Elshafei et al., 2022; Li et al., 2022; Leringer, 2020; Liu, 2020; Wuni et al., 2019; Chen, 2018; Georgievska et al., 2018; Zhu, 2017.
Net-Zero Energy Building	Ahmadi et al., 2021; Parkin et al., 2019
Zero Energy Building	D'Agostino et al., 2022; Barrutieta et al., 2021; Zhang, et al., 2021; Karlessi, 2017; Heeren et al., 2017
Near Zero Energy Building	Sağlam, 2019
Nearly Zero Energy Building	Rukavina et al., 2022; Mohamed et al., 2021
Low-Carbon Buildings	Xi & Cao, 2022; Parkin et al., 2019; Zhu, 2017
Ecological Building	Nan, 2021
High Performance Building	Günhan, 2019
Smart Building	Karlessi, 2017
Biomimetic Architecture	Vitalis & Chayaamor-Heil, 2022; Harsha & Velpula, 2020
Biomimicry	Harsha & Velpula, 2020
Regenerative Design	Benyus et al., 2022; Zhonghua & Xiaohuan, 2017
Kinetic Facade	Salah & Kayili, 2022; Balkan & Koca, 2021; Hosseini et al., 2019; Hosseini et al., 2019; Almusaed et al., 2021
Smart Facade	Jafari & Alipour, 2021
Double Skin Facade	Bielek et al., 2022; Almusaed et al., 2021; Özbalta & Yıldız, 2019

Double Facade	Keskin et al., 2019
Green Roof	Alim et al., 2022; Hejl et al., 2020; Keskin et al., 2019
Shading Elements	Keskin et al., 2019
Smart Building Materials	Yaman & Arpacıoğlu, 2020
Smart Material	Topal & Arcıoğlu, 2019
Smart City	Han & Kim, 2022; Çetin & Çiftçi, 2019; Ahmed et al., 2019
Eco- City	Deng et al., 2021
Certification Systems	Kaçar et al., 2022; Leringer, 2020; Georgievska et al., 2018

27 concepts have been determined at the end of the literature survey. When similar concepts have been collected under a same category, 12 categories have been determined for current concepts. “Sustainable Architecture”, “Green Building”, “Zero Energy Building”, “Biomimetic Design”, “Kinetic Facade”, “Smart Facade”, “Double Skin Facade”, “Green Roof”, “Shading Elements”, “Smart Building Materials”, “Smart City”, and “Certification Systems” constitute the categories (Table 2).

Table 2. Categories of current concepts.

Current Concepts	Reciprocal Concepts
Sustainable Architecture	Green Architecture, Green Construction, Sustainable Construction
Green Building	Green Technology, Green Building
Zero Energy Building	Net-Zero Energy Building, Zero Energy Building, Near Zero Energy Building, Nearly Zero Energy Building, Low-Carbon Buildings, Ecological Building, High Performance Building, Smart Building
Biomimetic Design	Biomimetic Architecture, Biomimicry, Regenerative Design
Kinetic Facade	Kinetic Facade
Smart Facade	Smart Facade
Double Skin Facade	Double Skin Façade, Double Facade
Green Roof	Green Roof
Shading Elements	Shading Elements
Smart Building Materials	Smart Building Materials, Smart Material
Smart City	Smart City, Eco- City
Certification Systems	Certification Systems

Assessment of Current Concepts Regarding Sustainability Practices in Undergraduate Architecture Programs

Frequency of the data has been considered as counting system in content analysis method. The current sustainability concepts in elective courses of 12 Undergraduate Architecture Programs have been assessed (Table 3). Absolute frequency of the concepts has been calculated from Table 3.

Table 3. An assessment of current sustainability concepts in elective courses of 12 Undergraduate Architecture Programs.

Sample	Courses \ Current Concepts	Sustainable Architecture	Green Building	Zero Energy Building	Kinetic Facade	Biomimetic Design	Double Skin Facade	Smart Building Materials	Green Roof	Certification Systems	Smart City	Smart Facade	Shading Elements
ITU	Building, Climate and Energy Relationship	x	x	x									
	Energy Efficient Housing												
	Solar Architecture												x
	Facade Systems												
	Roof Systems												
	Computer Applications in Evaluation of Climatic Performance of Built Envir.												
	Lighting in Cultural & Art Centers												
	Polymer Building Materials in Architecture												
METU	Environmental Aesthetics												
	Environmental Aesthetics I												
	Lighting in Architecture												
	Appropriate Technology	x	x					x					
	Integration of Building Systems in Architectural Design for Environmental Control		x										
	Fundamentals of Site Planning												
MSFAU	Composite Building Materials	x											
	Construction Biology and Ecology in Buildings	x	x					x					
	Sustainable New Constructions in Built Environment	x											
	Heat, Humidity and Water Problems in Buildings												
	Environmental Awareness In Arch. Design	x							x				
	Sanitary Equipment Design in Building												
	Sustainable Building Technologies	x	x							x			

Sample	Courses	Sustainable Architecture	Green Building	Zero Energy Building	Kinetic Facade	Biomimetic Design	Double Skin Facade	Smart Building Materials	Green Roof	Certification Systems	Smart City	Smart Facade	Shading Elements
YTU	Continuity in Architecture												
	Social Environmental Effects in Design												
	Alternative Energy Use in Architecture	x	x										
	Environment and Ecology	x	x										
	Solar Control												x
	Daylighting												
	Lighting												
	Climatic Building Design												
EMU	Ecological Thought	x											
	Renewable Energy Sources	x	x										
KTU	Building Facade Systems and Materials						x						
	Ecology and Architecture	x	x										
	Lighting of Architectural Buildings												
UU	Heating – Ventilation												
	Ecology and Architecture	x	x										
	Composite Building Materials	x											
	Sustainability and Architecture	x											
	Solar Architecture												
	Material Selection in Architecture	x						x					
DEU	Sustainable Urban Development and Residential Areas												
	Solar Energy and Utilization in Architecture												
	Sustainable Architecture	x	x										
	Ecological Architecture	x	x						x	x	x		
	Zero Carbon Settlements		x	x									
IKU	Ecology and Architecture	x	x	x		x			x				
	Solar Decathlon	x	x							x			
	Solar Control												x
TOBB	Sustainable Architecture	x											
	Building Facade Performance Assessment												
HKU	Air Conditioning and Lighting												
	Energy Efficient Building Design												x
	Sustainable Architecture	x	x					x					
BAU	Sustainable Design	x	x	x			x			x			
	Integrated Building Systems												
	Issues In Sustainability	x											
TOTAL 1310		24	17	3	0	1	2	4	3	4	1	0	4

Results and Conclusion

The contents of the elective courses of 12 Architectural Programs in Turkey have been scanned. “Sustainable Architecture” and “Green Building” have been the most frequently used current concepts in the elective course contents. “Smart Building Materials,” “Certification Systems,” and “Shading Elements” have been repeated four times. Although there are several green building projects in Turkey, the concept of “certification systems” has repeated four times. “Green Roof” and “Zero Energy Building” have been repeated three times. “Double Skin Facade” has been repeated twice. “Biomimetic Design,” and “Smart City” have been repeated once. The elective course contents have never included the concepts of “Kinetic Facade” and “Smart Facade”.

7 current concepts have been featured in the contents of IKU and 6 concepts have been featured in the contents of DEU. 5 current concepts have been featured in the contents of MSFAU and BAU. The courses with the most concepts in their contents are “Ecology and Architecture” (DEU) and Ecological Architecture (IKU). 5 of the 12 current concepts have been included in the contents of these courses.

Current concepts regarding sustainability practices have been determined from the recent five years of publications. As a result of the study, it has been noticed that awareness of the current concepts related to sustainable practices have been occurred in Turkish Undergraduate Architecture Programs. “Sustainable Architecture” and “Green Building” have been the most frequently used current concepts and they are sustainability practices in building scale. Sustainability practices in building element and material scale are important for green buildings, but these concepts are rarely included in the course contents. “Double skin facade”, “smart facade”, kinetic facade”, “green roof”, “shading elements”, etc. should be included in the courses for the increase of the sustainability practices. We hope current concepts regarding sustainability practices will increase in the content of the courses of Undergraduate Architecture Programs in future and architects in Turkey will have sufficient knowledge about current sustainable practices.

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Analyzing the Effects of Occupants' Demographic Characteristics on Indoor Thermal Sensation in Office Buildings

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Abstract

Maintaining comfort requirements of occupants in buildings are a challenging task for facility and building managers since the diversity of occupant profiles might result in different comfort requirements. One of the factors causing this difference is occupants' demographic characteristics such as gender, and age. This study aims at investigating the effects of occupants' demographic characteristics on occupants' thermal satisfaction levels in an office building. Within this context, a case study was conducted in 3 enclosed and 12 open-plan offices during the cooling season. Five demographic characteristics including gender, age, thermal history, education level, income level as well as occupants' thermal satisfaction levels were obtained via a survey campaign. Next, statistical analyses were conducted to understand the effects of demographic characteristics on thermal satisfaction levels. The results show that occupants' gender, age, education level and income levels impact occupants' thermal satisfaction in office buildings.

Keywords: *thermal comfort, thermal satisfaction, occupant demographic characteristic, office buildings.*

Introduction

Thermal comfort can be defined as the conditions that occupants feel themselves physically and mentally comfortable in indoor environments (Mıhlayanlar et al., 2017). Maintaining a satisfactory thermal environment for occupants is as an important part of the built environment that affects not only health and wellbeing but also productivity of occupants (Kocaman et al., 2021). There are widely accepted standards that define reference values for environmental (indoor air temperature, relative humidity, air velocity) and personal (metabolic rate, clothing insulation) variables for thermal comfort. These are namely "ISO 7730 (2005): Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria" used in European countries (ISO 7730, 2005) and "ASHRAE Standard 55 (2017): Thermal Environmental Conditions for Human Occupancy" used in America (ASHRAE Standard 55, 2017).

Building occupants' thermal satisfaction also depend on environmental and personal variables (Maiti, 2014). However, thermal satisfaction of the occupants may not be understood by only considering the variables defined in the standards. In addition, the diversity of the occupant

profiles in the buildings might cause different occupant thermal satisfaction levels (Brown et al., 2010; Frontczak & Wargocki, 2011; Klepeis et al., 2001). One of the factors causing this difference is the demographic characteristics of the occupants, including gender, age, hometown, education level and income level. In the literature, there are studies investigating the effects of demographic characteristics of occupants on thermal satisfaction. Bae et al. (2020) focused on identifying the effects of gender, age, tenure, and weekly working hours spent in office environment on indoor environmental quality satisfaction. In this context, the responses obtained from the surveys of 2275 occupants in 30 office buildings were analyzed. The results showed that male occupants were more satisfied than female occupants. In addition, it was determined that the middle age group satisfaction was less than younger and older groups. Indraganti et al. (2015) investigated the impacts of age, gender and anatomy on thermal comfort in India from January 2012 to February 2013. A thermal comfort questionnaire was applied to 2787 occupants in 28 office buildings and the responses were statistically analyzed. The results showed that gender have a statistically significant difference on thermal satisfaction. In addition, it was concluded that younger occupants preferred higher temperatures than older occupants.

As seen above, studies on the effects of demographic characteristics on thermal satisfaction in the literature generally focus on age and gender. Therefore, the effects of demographic characteristics on thermal satisfaction needs to be investigated extensively. This study aims to investigate the association of demographic characteristics including gender, age, hometown, education level, income level of the occupants with thermal satisfaction levels. In this context, 15 offices located in Izmir were selected as a test bed and thermal satisfaction levels of the occupants were obtained via surveys. The responses were analyzed by statistical methods. Next sections introduce the material, explain the methodology and present the results.

Material

The study was conducted between July and August 2019 in an office building located in Izmir, Türkiye. The office building has open-plan offices as well as enclosed offices and the building has a central air-conditioning system for cooling and heating. In addition, enclosed offices are equipped with split air conditioners that allow occupants to manually change the indoor air temperature. The surveys were conducted in a total of 15 offices including 3 enclosed and 12 open-plan offices. The detailed specifications of the offices are described in Table 1.

Table 1. Specifications of the offices.

		Area (m^2)	Number of Tables	Air Conditioning System	Indoor Air Temperature Control
Enclosed offices	E1	192	20	Central	Unavailable
	E2	130	20		
	E3	130	20		
Open-plan offices	O1	12	1	Split air conditioners	Available
	O2	12	1		
	O3	45	5		
	O4	56	5		

	O5	35	3		
	O6	20	3		
	O7	30	4		
	O8	50	4		
	O9	12	1		
	O10	12	1		
	O11	25	4		
	O12	40	4		

The survey data contains (i) gender, (ii) age, (iii) hometown, (iv) education level, (v) income level and (vi) thermal satisfaction level. Thermal satisfaction was evaluated according to the commonly used 7-point Likert scale (Kandasamy et al., 2020). According to the scale, thermal satisfaction ranges from (-3) very dissatisfied to (+3) very satisfied (Aryal et al., 2020). A total of 83 occupants participated in the study. It should be noted that each occupant participated in the survey only once to avoid response bias. Incomplete surveys were omitted and a total of 80 surveys were included in the analysis.

Methodology

Statistical analyzes were carried out by using the SPSS 20.0 (IBM Corp., 2011) statistical program. Chi-square test was performed to determine the relationship between demographic characteristics and thermal satisfaction. This test is selected since it is applied to find the relationship between the variables in the data where the independent variables are categorical (Fayyaz et al., 2022). In the chi-square test, three p values are used based on the Asymptotic (Pearson chi-square test), Exact (Fisher's exact test) and Monte Carlo methods (Elmalı, 2005; Mehta & Patel, 2007; Ramos et al., 2021). The p value to be used in the further analysis is decided according to the chi-square test results. Chi-square test method calculates the Chi-square for each category as shown in Eq. 1:

$$X^2 = \frac{(OF - EF)^2}{EF} \tag{1}$$

where OF is the number of class observations and EF is the number of expected class observations to estimate whether there is a relationship between the variables.

Results

This section presents the results of chi-square analysis between demographic characteristics of the occupants and their thermal satisfaction. The results of chi-square analysis between gender and thermal satisfaction are given in Table 2.

Table 2. Results of chi-square analysis between gender and thermal satisfaction.

		Value	df	Asymptotic p-value	Ex. p-value
Thermal satisfaction	Pearson Chi-square	12.269	6	0.056	0.046
	Fisher Exact test	11.922	-	-	0.047

Exact p-value was based on the chi-square analysis between gender and thermal satisfaction. As can be seen from the table, there is a statistically significant relationship between gender and thermal satisfaction since the significance level (0.047) is less than 0.05. In other words, the gender of the occupants is effective on thermal satisfaction. The results of chi-square analysis between age and thermal satisfaction are given in Table 3.

Table 3. Results of chi-square analysis between age and thermal satisfaction.

		Value	df	Asymptotic p-value	Exact p-value
Thermal satisfaction	Pearson Chi-square	23.704	12	0.028	0.022
	Fisher Exact test	23.697	-	-	0.014

Exact p-value were based on the chi-square analysis between age and thermal satisfaction. As can be seen from the table, there is a statistically significant relationship between age and thermal satisfaction since the significance level (0.014) is less than 0.05. In other words, the age of the occupants is effective on thermal satisfaction. The results of chi-square analysis between hometown and thermal satisfaction are given in Table 4.

Table 4. Results of chi-square analysis between hometown and thermal satisfaction.

		Value	df	Asymptotic p-value	Exact p-value
Thermal satisfaction	Pearson Chi-square	25.613	36	0.901	-
	Fisher Exact test	33.848	-	-	0.678

Exact p-value were based on the chi-square analysis between hometown and thermal satisfaction. As can be seen from the table, there is not a statistically significant relationship between hometown and thermal satisfaction since the significance level (0.678) is more than 0.05. In other words, the hometown of the occupants is ineffective on thermal satisfaction. The results of chi-square analysis between education level and thermal satisfaction are given in Table 5.

Table 5. Results of chi-square analysis between education level and thermal satisfaction.

		Value	df	Asymptotic p-value	Exact p-value
Thermal satisfaction	Pearson Chi-square	21.756	12	0.040	0.042
	Fisher Exact test	19.503	-	-	0.024

Exact p-value were based on the chi-square analysis between education level and thermal satisfaction. As can be seen from the table, there is a statistically significant relationship between education level and thermal satisfaction since the significance level (0.024) is less than 0.05. In other words, the education level of the occupants is effective on thermal satisfaction. The results of chi-square analysis between education level and thermal satisfaction are given in Table 5.

Table 6. Results of chi-square analysis between income level and thermal satisfaction.

		Value	df	Asymptotic p-value	Exact p-value
Thermal satisfaction	Pearson Chi-square	20.808	12	0.053	-
	Fisher Exact test	19.331			0.037

Exact p-value were based on the chi-square analysis between income level and thermal satisfaction. As can be seen from the table, there is a statistically significant relationship between income level and thermal satisfaction since the significance level (0.037) is less than 0.05. In other words, the income level of the occupants is effective on thermal satisfaction.

Conclusions

This study aimed to investigate the effects of occupants' demographic characteristics including gender, age, hometown, education level, income level on thermal satisfaction levels. In this context, thermal satisfaction levels of the occupants were obtained through questionnaires. The main findings can be summarized as follows:

- There is a statistically significant relationship between gender and thermal satisfaction.
- There is a statistically significant relationship between age and thermal satisfaction.
- There is not a statistically significant relationship between hometown and thermal satisfaction.
- There is a statistically significant relationship between education level and thermal satisfaction.
- There is a statistically significant relationship between income level and thermal satisfaction.

It is well known that occupant complaints can arise when there is a mismatch between indoor environmental conditions and actual occupant needs (Kocaman et al., 2021). The findings of the study are beneficial to building owners and facility managers to understand the occupant complaints from the perspective of occupants' demographic characteristics. However, this study only focused on office buildings. Future studies can incorporate different types of buildings (i.e. residential) to validate the results of this study.

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Simulation-Based Solar Energy Generation Potential Assessment of Houses

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Abstract

The price of electricity generated through fossil fuels has gone very high putting up a significant burden on household earnings. Renewable energy generation can provide the best alternative to reduce such expenditures in a household. This can also help reduce the pollution generated during conventional power generation. The rooftop of houses in most cases has significant solar energy generation potential, which can be the cheapest way to generate alternative power and energize the dwellings. This paper deals with the simulation-based assessment of the solar energy potential of existing houses in district Central of Karachi. The simulation was done using a building information modeling tool integrated with a cloud-based energy assessment tool that can provide Photovoltaic (PV) i.e. solar energy generation potential. The assessment was done based on the useable rooftop area of the houses. Results show that the solar energy generation potential of the modeled houses of district Central Karachi can be almost two times the amount of electricity being currently used by the same dwellings based on yearly electricity consumption data collected from their bills.

Keywords: *energy analysis, residential buildings, solar energy potential, useable area.*

Introduction

In Pakistan, most of the primary energy supply is obtained from burning fossil fuels like oil and natural gas. Renewable energy resources are beginning to dominate the power sector without emitting high carbon footprints and protecting the environment from hazardous gas emissions. According to a press release from the International Renewable Energy Agency in July 2021, the cost of a solar energy producing alternatives is reduced by 7% (Zhongming et.

al., 2021). According to the current statistics from The News International of Pakistan, residual furnace oil-based electricity has a 16.84 percent stake in the energy mix, or 6,274 MW, whereas coal-based power has a 12.80 percent share, or 4,770 MW (Aslam, 2021). Natural gas accounts for 12.15 percent of total electrical generation, or 4,529 megawatts. Nuclear power now accounts for 6.68 percent of total energy generation or 2,490 megawatts. Similarly, wind-generated power accounts for 3.31 percent of the total energy mix, or 1,235 megawatts. And power through solar is at 1.07 percent with 400 MW and through baggase has a share of 0.98 percent that stands at 364 MWs (Aslam, 2021). Due to the need to limit the health and environmental risks associated with electricity generation using fossil fuels, renewable energy sources are now universally viewed as a legitimate substitute for fossil fuels in supplying the rising demand for power throughout the world. RE sources are growing more popular as carbon-based fossil fuels become scarcer, and they are taking center stage in policy choices all around the world.

At the household level, building envelops, specifically house geometry, do provide a significant opportunity to generate localized solar energy using the rooftop area of a house. However, often this potential remains unused due to unawareness regarding such potential and also the initial cost of investments in solarizing a house. For solar energy generation, rooftops, and the usable area of houses play an important role. In Karachi complete rooftops of houses are not available for the installation of PhotoVoltaics panels. To estimate the usable area of the rooftop house visual analysis is required to be done by eliminating the rooftops of the mumty room and overhead water tanks (OHWTs). This paper provides an assessment of the solar energy generation potential of houses in the district centra of Karachi using information modeling, energy simulation, and comparison of results with the electricity bills for one year.

Objective Scope And Methodology

The objective of the study was to assess the solar energy generation potential of houses in Karachi using information modeling and energy simulation. The scope of the study is limited to the 15 existing dwellings of the district Central of Karachi in the range of 80 to 400 sq yds.

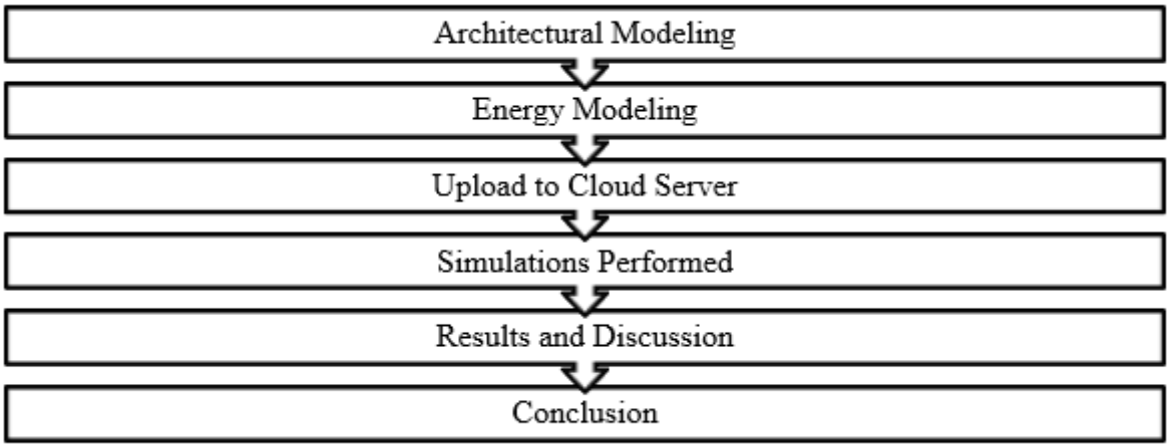


Figure 1: Research methodology.

The step-wise methodology was adopted which is illustrated in Figure 1. The first step was to generate the architectural model of the houses using building information modeling tools using realistic values collected by performing energy walkthrough audits of particular houses. The second step was to develop the energy model by providing real-world energy settings (i.e. lighting density, power density, occupancy schedule, etc.) of a house. In the third step, the developed energy model was uploaded to a cloud server for performing energy simulations as the fourth step. As a result of simulations, the solar potential of each house was found in the form of energy use intensity (KWhr/m^2/yr). This value was converted into solar energy potential in KWhr by multiplying it by the usable area for solar panel installations on the rooftop of each house. Finally, the solar energy potential of each house was compared with actual yearly energy consumption gathered through electricity bills of houses to conclude solar energy potential.

Literature Review

Aslani and Seipel (2022) proposed a methodology in which they performed automatic extraction of building footprints, automatic segmentation of roof faces, and automatic identification of utilizable areas of roof faces for solar infrastructure installation. The study shows a high success rate with 95% correctness and completeness in extracting building utilizable areas. Furthermore, results show that the methodology adopted was effective in identifying the roof occlusions and roof superstructures satisfactorily and Rooftop PhotoVoltaic (RPVs) assessment is effective in an urban region. Thanh et. al. (2021) studied the performance of rooftop solar power generation in which they assess the office building in the northeast region of Vietnam by integrating solar panel systems with and without battery storage. As a result, they found out that both the options are viable as the benefit to cost ratio is greater than one. However, the grid-tied rooftop solar power generation with storage is not quite feasible due to the capital cost invested in the system and the payback getting over a long period. Ayodele et al. (2021) investigated the growing electrical energy demands of a cosmopolitan city in Nigeria using rooftop solar PV systems. Mohajeri et. al. (2016) conducted research to identify the impact of roof types on solar potential generation by integrating solar photovoltaics (PV). They calculated the ratio of useful roof area and building footprint area that is near one. They find out that footprint is a good measure of useful area for PV and ranked the roof types concerning the PV generation efficiency. The highly efficient rooftop is gable whose ratio is greater than 1 (i.e. 1.18) than the flat roof and in the end, the hip roof has the least PV potential. Izquierdo et al. (2011) quantified the amount of energy used for electricity using Photo Voltaic solar systems in buildings. They also use a geo-referenced method to find out the available roof area for solar facilities. They installed solar hot water systems (SHWS) and Solar Photo Voltaic systems on the rooftops and results show that SHWS contributes up to 1662 ktoe/y of primary energy however, PV systems would provide 10 T W h/y of electricity.

Modeling And Simulation

The first step towards the analysis is the architectural modeling of the houses collected from the district Central of Karachi. Each house was first architecturally modeled in Autodesk Revit using the 2D architectural plans and the information gathered from the physical energy walkthrough audit of each particular house. Figure 2 shows the architectural model of a house.

After generating an architectural model real-world energy settings (i.e. lighting density, power density, occupancy schedule, etc.) were provided to the model to develop the energy model of the house. According to Arif and Zaman (2021), when real-world energy settings were provided as input to the energy model the results generated had a 7% variation from the actual values.

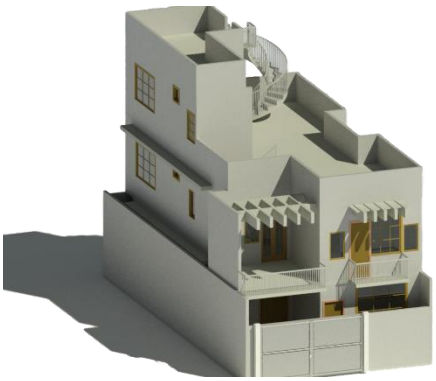


Figure 2: Architectural model of a house.

Figure 3 shows the energy model of a house which was uploaded to the insight 360 clouds for energy simulations.

Figure 2 and 3 shows the architectural and energy models of a single house as an example. However, the rest of the houses were also modeled similarly and simulated after being uploaded to the cloud.

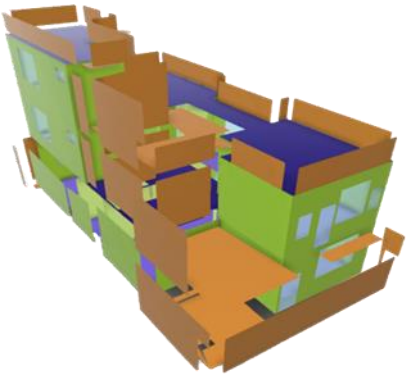


Figure 3: Energy model of a house.

Results And Discussion

After getting simulations were performed, the result of each house was generated in the form of Energy Use Intensity (EUI) which means the energy consumed per meter square in a year by that house (kW.hrs./m2/yr). Results show the solar energy generation potential of each house in the form of EUI which was converted into per year generation potential by taking a product with the useable area of that house. Two types of areas were presented to calculate the per year solar energy generation potential of houses one was the available rooftop area which is the total roof area excluding the openings. The second was the useable area which shows

how much of the available area can be used to generate solar energy. Analytical calculation of the useable area can be comprehensible from Figure 4, the blue shaded area is the available rooftop area, while the area that can be used for solar PV panel installations is shaded with an inclined hatched lines pattern.

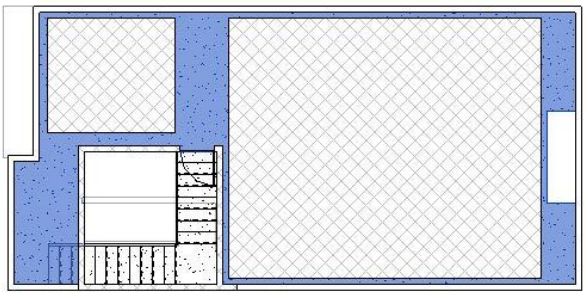


Figure 4: Useable area.

The result of all analyzed houses from district Central of Karachi city is tabulated in the form of Table 1which is as follows

Table 1. Solar energy generation potential of houses.

S.No.	ID	Available Rooftop area (m^2)	Useable area (m^2)	Solar Potential from Simulation		Actual Electricity kW.hrs. *(Jun 20-May 21)*
				kW.hrs./m^2/Yr.	kW.hrs./Yr.	
1	C-01	348	278	103.98	28906.44	15682.0
2	C-02	99	62	184.98	11468.76	5979.9
3	C-03	102	82	125.11	10259.02	2564.3
4	C-04	94.11	71	133.7	9492.7	6846.3
5	C-05	206	123	177.95	21887.85	6482.0
6	C-06	99	44	141.71	6235.24	5510.0
7	C-07	96	67	37.88	2537.96	1627.6
8	C-08	93	63	74.88	4717.44	4631.1
9	C-09	76	44	229.04	10077.76	3709.0
10	C-10	93.16	70.5	297.73	20989.965	4702.0
11	C-11	86	67	231.16	15487.72	6629.0
12	C-12	63.5	37	192.43	7119.91	1720.0
13	C-13	99	76	104.59	7948.84	4026.0
14	C-14	106	92	219.85	20226.2	2563.0
15	C-15	91	69	66.95	4619.55	2660.0

Table 1 shows the solar energy generation potential in kW.hrs./m2/Yr. from simulation and actual annual electricity consumption which was calculated from the electricity bill of that house. Results show that the solar potential is approximately two times the electricity consumption. This shows that if the solar PV panels get installed on the rooftops, then these rooftops not only reduce their energy bills but will be able to supply to the grid which will ultimately be in the benefit the house owner as well government.

Conclusion and Recommendation

The study shows the simulation-based assessment of the solar energy generation potential of the houses of district central of Karachi city. This study also concludes that useable area is approximately equal to 70% -80% of the available area of the house. If the house owners in the district central of Karachi get installed solar PV panels on their rooftop they can reduce their energy bills and transfer the surplus amount to the grids.

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Impact of Partial Replacement of In-situ Reinforced Concrete (ISRC) on Materials and Final Embodied Energy of the Building: A Case Study

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Abstract

This work investigates the effect on Embodied Energy (EE) of concrete when in-situ reinforced concrete (ISRC) is partially substituted with Pulverized Fly Ash (PFA) and Ground Granulated Blast Furnace Slag (GGBS) at the building scale and on material efficiency. The goal of the research project is to demonstrate potential improvements to the EE of a university building by comparing the EE of the cement mix with PFA and GGBS replacement to that of baseline case of traditional concrete by using EDGE application. The current study utilizes supplementary cementing materials (SCM) data to provide insight into EE reduction from a material to building scale. The change in the final EE of the building was observed by using two different types of in-situ reinforced concrete, "ISRC with > 30% PFA" and "ISRC with > 25% GGBS", instead of the concrete used in the original university building construction. It has been determined that the final EE of the existing ISRC in the building is 1200 MJ/m2. It was observed that the final EE of the building decreased from 1200 MJ/m2 to 1015 MJ/m2 when the ISRC with >30% PFA was used instead of the ISRC used in the building. The use of these materials also increased the material efficiency of the building such as the efficiency of ISRC which was 22.43% at the base case. The results show that the use of "ISRC with >30% PFA" and "ISRC with >25% GGBS" content, increased the material efficiency by 34.43% and 34.72%, respectively. The demonstrated reduction in EE values were calculated by using EDGE application were illustrated: Increasing the percentage of recycling materials like GGBS and PFA lowers the total EE of the building.

Keywords: *conventional concrete, embodied carbon energy, ground granulated blast furnace slag, pulverized fly ash, sustainability.*

Introduction

The most recent report of Intergovernmental Panel on Climate Change (IPCC) warns of observed changes in weather extremes such as heat waves, heavy precipitation, droughts, and tropical cyclones (IPCC, 2021). In order to prevent global temperatures from exceeding 1.5°C, global net anthropogenic carbon dioxide (CO2) emissions must decline by about 45% from 2010 levels by 2030 and reach net zero by 2050 (IPCC, 2018). Under the light of these scientific findings, there is an urgency for the decarbonization of the building industry until 2030. When considered over their full life cycle, the building industry influences nearly every

major sector of global GHG emission. The largest contributor to global emissions by end use is the industrial sector, contributing 30% of global emissions (IEA, 2021). Building materials are one of the largest sources of industrial emissions, meaning they are potential drivers to reducing emissions from this sector. A significant portion of the materials are used in buildings and other infrastructure.

Concrete is the material with the most carbon in the world due to the small quantify of EE (carbon) in 'one tonne of concrete' multiplied by the vast volume of concrete utilized (Crawford & Stephan, 2013). The single most significant part of decreasing the effect of EE is to design long-life, resistant, and resilient buildings (EE). Wherever possible, building materials with a lower EE should be used. (Rawlinson & Weight, 2007). Since concrete is the most abundant man-made material in the world, cement production has a major impact on the world's increasing CO2 emissions and is the largest contributor to tangible carbon in the built environment. The concrete is the pourable mix of cement, sand, water, and gravel which hardens into a super-strong building material. The cement which is part of concrete is a fine powder made up of crushed minerals such as limestone and clay. The cement industry is responsible for about 8% of global carbon dioxide emissions. Key strategies to cut carbon emissions in cement production include improving energy efficiency, switching to lower-carbon fuels, promoting material efficiency and advancing process and technology innovations such as Carbon Capture and Storage (CCS) (IEA, 2021).

Embodied carbon (EC) refers to CO2 emissions related to building or infrastructure construction materials and techniques. EC is the carbon footprint that exists prior to the building or infrastructure project's development. It also covers the CO2 generated for waste transportation and recycling, building maintenance, and eventual demolition. Up to now very little attention was paid to embodied impacts in building-related energy research. One of the difficulties is the life cycle of buildings include both energy consumption and GHG emissions. Both multidisciplinary collaboration and research is needed in order to use the top-down statistics and environmental considerations which are typically broken down by economic sectors (Röck et. al., 2020). The most recent IPCC report aimed to overcome this division by including a short discussion of embodied energy in buildings (de Coninck et al., 2018). The results of their study highlight the need to address and further reduce the life-cycle-related GHG emissions of buildings by optimizing embodied emission investments for new construction and promoting 'carbon-effective' investments for the refurbishment of existing buildings. Concrete required binders and binders like cement production need high temperature calcination which is an energy intensive process (Benhalal, 2013).

There are various methods and approaches to reduce the EE level of the concrete. Rebuilding buildings is a manufacturing approach that aims to keep materials in use by extending product life and returning waste as a resource. Reusing buildings instead of building new ones, compared to constructing a new building, renovation and refuse projects generally save between 50 and 75 percent in EC emissions. At first, determining the low carbon concrete mixes is the most important factor. Although the emissions per tonne are not so significant, concrete is often the largest (EC) resource on any project in practice, due to its weight and ubiquity in a structure. In terms of concrete content, this high level of EC is due to cement. A common strategy to reduce CO2 emissions is to replace Portland cement with supplementary cementitious materials (SCM). Options are to work with your structural experts to create lower carbon concrete mixes using fly ash, granulated blast furnace slag, or even low-strength cementitious concrete because it is important that a structure is not a structural problem. When it comes to the reuse of material, there will be a significant reduction in the level of EC.

Recovered materials (such as cracked concrete) typically have a much lower carbon footprint than newly manufactured materials because the carbon needed to produce them has already been spent.

Energy and pollutant emissions, such as carbon dioxide (CO2), may be considered "embodied". So, EE might be defined as the amount of energy needed to process and procurement the material under discussion to the construction site (Australian Government, 2013). To calculate the magnitude of this EE, an accountancy system that averages the energy inputs over a significant portion of the material supply chain or life cycle is required (Hammond & Winnett, 2006). EE has since been recognized as a principal or intrinsic component of the whole energy required to create and operate processes or other equipment. Similarly, EE (and carbon) is increasingly seen as equally essential in the context of structures and building materials (Menzies et al., 2007). The benefits of each construction material in terms of increasing the building's performance over its life cycle should be considered when choosing a material. Identifying the EE of a substance, component, or entire building is a challenging undertaking. Every building is made up of a complex combination of materials, each with its own production history and contribution to the EE of the structure. Because the efficiency of processes, energy sources, and material transit varies among companies, EE for the same type of product might also vary (Strine, 2013). The embodied carbon in building materials comes from two sources: fossil fuel inputs (which are pertinent with EE) and that released, during the limestone-to-cement conversion process (Rawlinson & Weight, 2007). EE must become a major factor to evaluate in building design for a variety of reasons. The first is the building industry. Second, shorter renovation cycles, lower-quality materials, and various energy-intensive maintenance practices can all raise a building's EE. Recycling and reuse, on the other hand, help to minimize landfill waste by repurposing previously used resources to create new items (EIA, 2012). This helps to reduce the consuming of virgin raw resources. Although recycling requires more transportation, energy consumption, and carbon emissions, the overall savings in EE and carbon emissions surpass the costs (Rahman et al., 2018). “Preservation Green Lab” conducted a study on the environmental benefits of building reuse vs new construction, comparing the environmental impacts of new versus reused and rehabilitated structures over a 75-year life cycle. According to this study, the environmental savings of building reuse can range from 4 to 46 percent, depending on building location and type, as well as energy efficiency level. They determined that building reuse always saves carbon when compared to new structures of comparable function, size, and energy-efficiency level. These savings have been demonstrated to be evident even in the majority of newer types of buildings with better levels of energy efficiency (Rahman et al., 2018). The building envelope has a considerable impact on the EE and operational energy use of structures. According to Mithraratne and Vale's research results, the building envelope (floors, walls, roof, and finishes) contributes around 48–50% of the EE of a typical house (Mithraratne & Vale, 2004).

Concrete's cementitious component contributes considerably to embodied CO2 emissions. Concrete is held together by cementitious materials, which act as a glue. Among these components are traditional portland cement (PC) and various cementitious additives such fly ash (FA), ground granulated blast-furnace slag (GGBS), limestone fines, and silica fume. These ingredients are either blended at the cement plant (to make composite cement) or mixed at the concrete plant (the cementitious product is called a combination in this case). Cement manufacturing is the world's single largest source of carbon pollution, accounting for 8% of worldwide emissions. Limestone is a significant raw material for Portland cement, as it emits

carbon dioxide when heated in a cement kiln. Over 55 percent of cement-related emissions come from this process (Beyond, 2017).

Methods

Methodology

The methodology was set to replace Portland cement with supplementary cementitious materials (SCMs) as well as using different cement types for a pilot building. Since the manufacture of Portland cement is energy intensive, to goal is to replace it with SCMs to lower the high EE content. These SCMs are Pulverised Fly Ash (PFA) and Ground Granulated Blast Furnace Slag (GGBS). PFA, also known as fly ash, is a waste product of coal fired at power stations. This research use PFA as one of the cement replacements. Ground granulated blast-furnace slag (GGBS) is obtained by quenching molten iron slag (a by-product of iron and steel manufacture) from the blast furnace in water or steam, producing a glassy, granular product which is then dried and ground into a fine powder.

Using the latest experimental data from replacing OPC with PFA and GGBS, provides an insight into EE savings from material up to a building scale. At the same time, the embodied energy levels of OPC, PFA, and GGBS-containing concrete when used in a building were determined.

The research is conducted by using an online green building certification system-EDGE. EDGE, an innovation of International Finance Corporation (IFC), focused on making new residential and commercial buildings more resource-efficient (EDGE, 2022). Using the EDGE application, initially the effect of different cement types on the embodied energy level of the building was determined. To lower operating costs and environmental impact, EDGE enables the early design stage identification of technological solutions. The researchers also used EDGE system to forecast operational savings and decreased carbon emissions based on the information inputs and choice of green initiatives. The EDGE application is used to determine the correct embodied energy level. It was applied as 25% and 30% by mass as complementary cementitious materials (SCMs). The effects of changes in the amount of cementous materials were also detected.

The pilot building is chosen as the Istanbul Medipol University D2 block which is an existing building. By collecting all the available information about this building (within the scope of energy, water, and material efficiency) from the facilities engineer and entering the data into the EDGE application, embodied energy savings of the building was calculated in the Giga joules (GJ) unit and instant available embodied energy level was calculated in MJ/m2 unit (Mega Joule). OPC was used throughout the building construction. The available data were recorded and the embodied energy level of the pilot building in its current state was calculated in the EDGE application. Using the same model building data, the embodied energy levels that would occur if the pilot building concrete was replaced with PFA values 25% and 30%, and then GGBS values 25% and 30% instead of OPC was calculated. As a result of the study, 5 different results were obtained.
To apply material data to achieve building-scale EE results, PFA and GGBS substituted concrete were integrated into the entire building by using EDGE application, and results are

analyzed. Two key variables were used in the embodied carbon calculations for buildings; cement types and percentage of cement types by mass as can be seen from Table 1.

Table 1. Substitutions used during the study and their percentages.

Number	Cement Type	Mixed Ratio
1	Ordinary Portland Cement	%100
2	Pulverised Fly Ash	%25
3	Pulverised Fly Ash	%30
4	Ground Granulated Blast Furnace Slag (GGBS)	%25
5	Ground Granulated Blast Furnace Slag (GGBS)	%30

If OPC is replaced with other SCMs, it is critical that the concrete does not show any weakness in strength. It must be superior to, or at least the same, strength as OPC. When examined based on the strength issue, various data were obtained when the research was conducted for both PFA as can be seen from Table 2 and Figure 1 and GGBS from Table 3.

Table 2. Concrete mixture proportions (kg/m3).

Series	Mix ID	Binder			Aggregate		Water (kg/m^3)	Superplasticiser (kg/m^3)	w/b	Slump (mm)
		Fly ash (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	Granite (kg/m^3)	Sand (kg/m^3)				
	A-00	0	355	0	1185	740	145.5	5.11	0.41	140
A	A-30	30	308	132	1185	661	141.0	4.77	0.32	170
	A-40	40	264	176	1185	665	136.5	4.75	0.31	185
	B-00	0	517	0	1185	594	150	6.77	0.29	150
B	B-30	30	362	155	1185	570	150	4.80	0.29	175
	B-40	40	311	207	1185	561	150	4.24	0.29	160

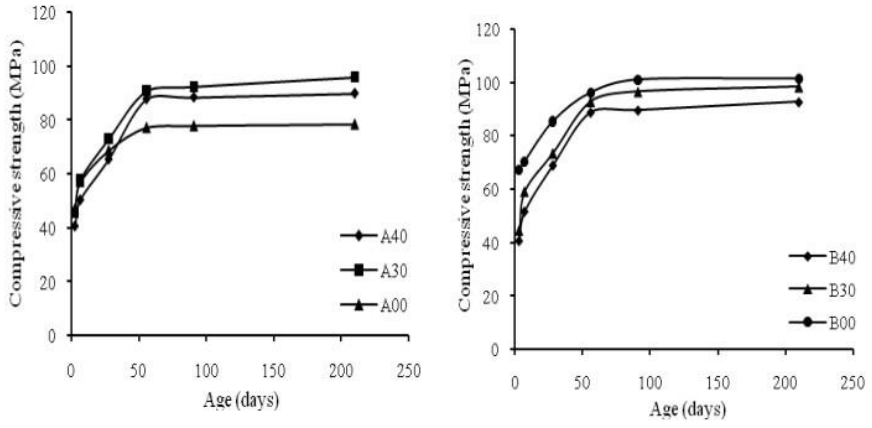


Figure 1: Compressive strength development in Series A (left) and Series B (right).

Table 3. Compressive Strength of concrete for.

Mix Proportions for One m^3 of concrete

Grade	Cement	Fine aggregate	Course aggregate	Water	w/c ratio
Units	kg/m^3	kg/m^3	kg/m^3	kg/m^3	
M20	338.2	641.07	1226	186	0.55
M40	442.85	610.54	1167.54	186	0.42

Table 4. Compressive Strength of concrete for M20.

Compressive Strength of concrete for M20

Sl. No.	% of GGBS	Compressive Strength (N/mm^2)	
		28 days	90 days
1	0	33.3	46.2
2	30	35	50.11
3	40	36.42	52.49
4	50	32.2	48.12

Table 5. Compressive Strength of concrete for M40.

Compressive Strength of concrete for M40

Sl. No.	% of GGBS	Compressive Strength (N/mm^2)	
		28 days	90 days
1	0	49.99	54.22
2	30	51.12	55.02
3	40	53.6	57.46
4	50	50.12	54.27

Materials

Pulverised Fly Ash (PFA)

Pulverised Fly Ash or Fly Ash is the inorganic mineral residue obtained after burning coal/lignite in boilers. Fly ash is a pozzolan containing aluminous (Al2O3) and siliceous (SiO2) material that forms cement in the presence of water. *The chemical reaction between PFA, Calcium Hydroxide, and water, to form additional cementitious products that improve many of the desirable properties of concrete (Formula 1).*

Fly ash chemically reacts with calcium hydroxide, a by-product released by the chemical reaction between cement and water, to form additional cementitious products that improve many of the desirable properties of concrete. Fly ash shows varying degrees of cementitious properties depending on the chemical and physical properties of both the fly ash and the cement.

FLY ASH + Ca (OH)2 + H2O (1)

The use of industrial waste pozzolans (Fly Ash, Ground Granulated Blast-Furnace Slag) which are not directly used due to the by-products formed at the end of industrial processes, but show pozzolanic properties, can be used in the production of cement with additives, or they can be used instead of cement to a certain extent. These artificial pozzolans, which have low EE values due to being by-products, also reduce the EE value of the concrete they are included in.

In line with the research, it has been observed that SCMs do not pose any strength problems. In fact, it has been determined that PFA and GGBS substituted concrete samples have more strength than OPC. When the 25% and 30% SCM substitution rates by mass used in the EDGE application are examined as can be seen from the Tables 2, 3, 4, 5 and Figure 1, they provide the desired strength.

Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS) is the material formed by rapid cooling of the slag, which is formed as a by-product during the extraction of cast iron in the blast furnace, and exhibits pozzolanic properties when ground and turned into fine particles. Iron ore is melted in blast furnaces at 1400-1600 °C for smelting. During this process, while the cast iron with high specific gravity stays at the bottom, slag containing lime, silica, and alumina is formed on it because it is lighter. Thanks to SiO2 and Al2O3 coming from GGBS iron ores, which have an amorphous structure due to their rapid cooling, it exhibits pozzolanic properties when finely ground and combined with Ca(OH)2 in an aqueous medium.

Blast furnace slag is used as coarse aggregate in concrete in an unground state, but it is also used in concrete production by replacing cement. In this way, CO2 emissions can be greatly reduced. The reduction of clinker as much as the slag added in the slag cement production from the mixture and the decrease in the clinker demand will reduce all the negative effects that are harmful to the environment in the process until the clinker production. Chief among these is the CO2 gases released from the rotary kiln, from which clinker is obtained. CO2 emissions occurring during both coal and so on will reduce the consumption of resources.

Results and Discussion

A base case is created for the building in the EDGE application.

The floor ceramics used for the building construction had high EE. A lower EE product is found from the market research and used for the pilot project. The improved case is obtained with the EDGE application. The building's embodied energy drop can be seen from Figure 2 by changing the floor product of the building. The trials with GGBS and PFA started once the improved case is obtained. Different types of cement to reduce the EE of concrete is studied for the pilot building project. The whole building concrete is used for the calculations. The results show that, the use of industrial waste pozzolans (such as volatile, silica fume, blast furnace slag, rice husk ash, and metakaolin) in concrete reduces the EE value of concrete. Because these pozzolans are by-products, they have low EE values and contribute reducing the EE value of the concrete in which they are incorporated. Since 25% ''GGBS'' and 30% ''PFA'' types of these alternative cement added concrete types are available in EDGE application, the use these pozzolanic concrete ingredients in order to reach the results were possible. In the EDGE application, the final EE of the building decreased below 1200 MJ/m2

when these types of cement additives are used instead of the Portland cement. The change in the final EE of the building was observed by using two different types of in-situ reinforced concrete, “ISRC with> 30% PFA” and “ISRC with> 25% GGBS”, instead of the concrete used in the initial building construction. It has been determined that the final EE of the existing ISRC in the building is 1200 MJ/m2. It was observed that the final EE of the building decreased from 1200 MJ/m2 to 1015 MJ/m2 when the ISRC with >30% PFA was used instead of the ISRC used in the building. The use of these materials also increased the material efficiency of the building such as the efficiency of ISRC which was 22.43% at the base case. The results show that the use of “ISRC with >30% PFA” and “ISRC with >25% GGBS” content, increased the material efficiency by 34.43% and 34.72%, respectively. The demonstrated reduction in EE values were calculated by using EDGE application showed that increasing the percentage of recycling materials like GGBS and PFA lower the total EE of the building.

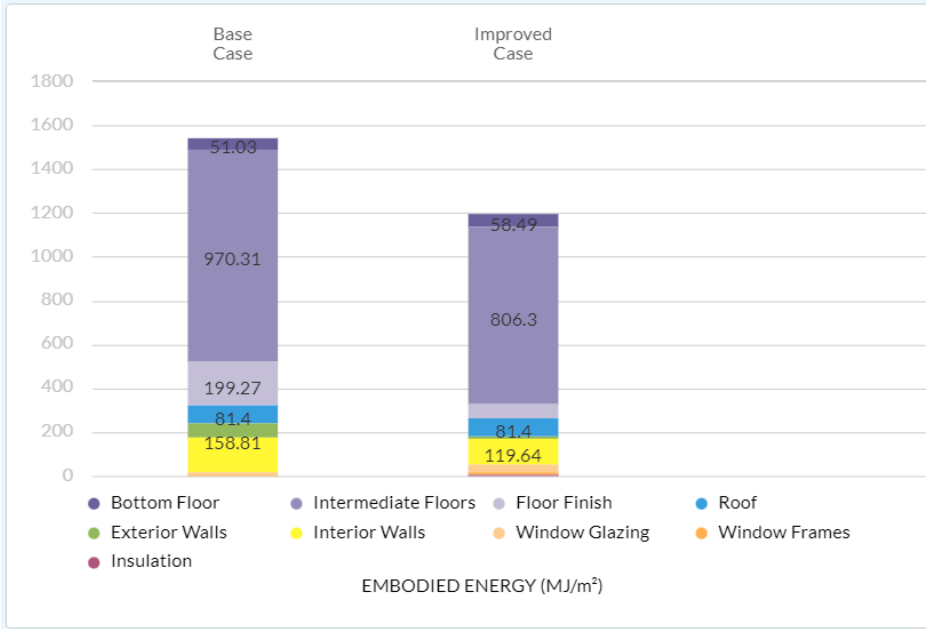


Figure 2: Base case vs improved case result for the pilot building.

Conclusions

In-situ reinforced concrete (ISRC) is partially substituted with Pulverized Fly Ash (PFA) and Ground Granulated Blast Furnace Slag (GGBS) to observe the effect on embodied energy (EE) at the building scale and on material efficiency. The results show that the final EE and EE saving in the existing pilot building was found 1200 MJ/m2 and 40164,22 GJ. Calculated EE savings- 40164.22 GJ in the pilot project showed substantial savings. The results also show that the use of “ISRC with >30% PFA” and “ISRC with >25% GGBS” content, increased the material efficiency by 34.43% and 34.72%, respectively Based on the methodology used, substitutions succeeded in reducing the final EE both on the building scale and on material efficiency. These results show that the use of recycled materials like PFA and GGBS is very important to drastically reduce the EE in a building. Replacement levels for GGBS and PFA in the research varied from 25% to 30% as applicable. Future research can use higher levels since it is common in the industry. Using GGBS and PFA also helps to reduce air and water pollution, leading to more sustainable construction.

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Application of Prisoner's Dilemma Game in Resolving Conflicts During Green Building Construction in Turkey

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Abstract

As technology advances and resource reliance grows, destruction of the environment and the threat of exhaustion of natural resources have increased. To address these issues, a global framework has been developed, most notably the Paris Agreement, which was signed in 2015. Industries have been given social and environmental duties in this path. Construction companies are among those that take over these duties, as they consume a lot of energy across the globe. Therefore, sustainability research in the construction industry has gained prominence such as sustainable construction and green building practices. Even so, as the most powerful influencer on sustainable innovation, the government does not necessitate contractors to build higher grade green construction, and little does, while the overwhelming number of buyers have little desire for sustainable green houses. While this real-life relation between two parties forms a conflict, on paper this represents a suboptimal equilibrium. This paper utilizes game theory, particularly the Prisoner's Dilemma model, to illustrate strategies to emission reduction and greenhouse gas (GHGs) mitigation measures in Turkey's construction industry, as well as to forecast whether incentives might help eliminate those barriers. As a result, it states that in order to encourage better level green building, the government now must offer incentives to both contractors and buyers, which would be relatively inexpensive for the Reserve Bank. Finishing up with lower energy costs and gain of support, prestige, and unity as the market moves to a new equilibrium, better for all involved throughout the construction industry.

Keywords: *construction industry, construction management, game theory, green building, prisoner's dilemma, sustainable building, Turkey.*

Introduction

Greenhouse gas levels are currently at their greatest in 2 million years and continue to grow (World Meteorological Organization, 2021). Climate change has become one of the most critical issues ever tackled in the areas of civil society stability and security, access to natural resources, and the environmental preservation of the ecosphere. Accelerated warming and the expected high rate of climate change consequences will create a new and unpredictable world, necessitating adaptation by both human society and natural ecosystems. Sustainable

infrastructure, as stated in the United Nation's (UN) 9th Sustainable Development Goal (SDG), is one of the most lucrative techniques of fostering innovation for a greener future. Green construction has a significant impact on climate change mitigation. Green buildings have earned popularity in past years as a notion that aims to satisfy both ecological and financial goals by utilizing resource-efficient procedures through a building's existence. To support the green construction approach, numerous nations, including Turkey, have created a wide range of grading standards as well as other regulatory measures (Karademir, 2021). This study not only offers a decision making foundation for the construction industry have optimum strategies within diverse situations, but it also serves as a guideline for the administration to develop a suitable procedure that is favorable to a sector that reduces carbon emissions in order to combat climate change.

Green Building Evaluation Tools

The present movement to promote constructing energy efficient buildings date back to the early 1970s, as oil prices skyrocketed and concern over future fuel resource got tangible. Through the development of solar, wind energy and insulation systems, the advancement of green technology has surged, not just for transportation but also for buildings. However, as oil prices got less towards the 1980s, green initiatives were stalled. Based on the current political and administrative circumstances, green construction in the United States as well as Europe, has grown with occasional government backing. The environmental movement gained traction in Europe and the United States, with green building evaluation methods first appearing in the early 1990s (Cohen, 2017).

Although, the criteria considered while developing the green building evaluation are expressed with different names in different systems, in general, the criteria cover a variety of corresponding subjects. These subjects mainly include but are not limited to the following:

1. The selection of the land where the building is located,
2. Its location on the land,
3. Its relationship with its physical and social environment,
4. Its ability to provide the users with comfort needs such as,
    a. thermal, visual and acoustic ease,
5. The CO_2 emission,
6. The amount of water consumption,
7. The need for operation and maintenance/repair and
8. The materials used in the building.

Certification systems do not go beyond the scope of their own standards and regulations of the countries in which they are developed, and they also provide a general framework for sustainable buildings, as they provide a community of information by referencing these documents (Kobaş, 2011). In general, it is aimed to encourage the buildings to be environmentally friendly and to be built in a way that causes the least damage to the nature. However, since the development level and geographical conditions of the countries are different, each country has its own priorities. For instance, the most important criterion for arid countries is the efficient use of water and the energy efficiency criterion is considered in energy-importing countries. Due to the conservation of natural resources, attention is paid to the effective and efficient use of materials (recycling, reuse of materials) in developed countries (Işıldar, 2018). In each certification system, there are criteria such as energy and water efficiency, interior space, environmental quality improvement, operation and maintenance and

repair optimization, waste and toxic reduction, and each criterion is determined in line with the characteristics of the regions where the need arises. Hence, the scores vary in this context.

Green Building Standards in Turkey

The first developments in green buildings in Turkey started with the establishment of the Turkish Green Building Council (ÇEDBİK) in 2007. Then the establishment was followed by, the "First International Summit of Green Buildings" event held in Istanbul in February 2012, and in this event, beneficial information was shared about environmentally friendly policies, green economy, greening existing buildings, life in green buildings, smart cities, environmentally friendly building materials and their production (Gelişen & Güzelkokar, 2019). Now, ÇEDBİK has certified 518 projects throughout Turkey, in addition to its 425 LEED and 70 BREEAM projects (ÇEDBİK, 2022).

In Turkey, no insulation element has been applied to approximately 77% of the building stock (Ministry of Industry and Technology, 2021). When the existing construction in Turkey is compared to an average building in Sweden, a building in Sweden can be constructed approximately 2.8 times less than a building in Istanbul and 3.6 times less than a building in Ankara, with less fuel consumption. These data are remarkable in terms of understanding how much green building practices are needed in Turkey and the distance to be covered even in terms of insulation and green material.

Ever since the green building certificate systems emerged, it has been observed that the logic of the systems resembled each other. While the countries issuing the systems implemented their own directives, the countries that had no certificate systems had started developing their own systems based on the universal standards. As of 2007, ÇEDBİK pioneered the studies carried out in this context in Turkey. The certification system, called "B.E.S.T." was prepared for the development of the National Green Building Certificate for Turkey, with the guidance of the members of the association and the international certification systems (ÇEDBİK, 2019). Valid only for the housing category, from newly built single-family houses to residences with a total usage area of over 20,000 m^2, the system is applicable for a wide scale. Main criteria considered for the BEST Certification is shown below.

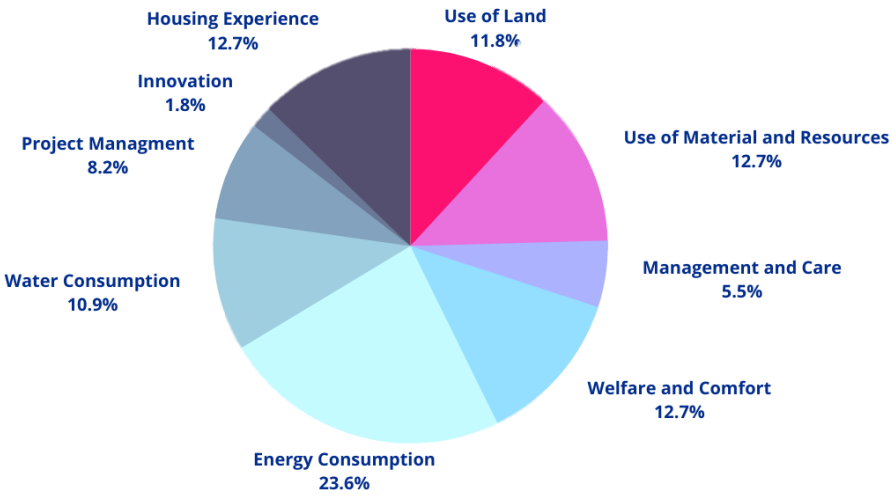


Figure 1: B.E.S.T. certification score distribution.

Case Study

The utilization of mathematical models to anticipate the behavior of sophisticated logical individuals in scenarios of dispute or collaboration is known as game theory (Owen, 2012). It is used in many areas, such as industries, politics, and entertainment. It can be used to manufacture strategies that steer collaborating or warring players in the way that the game planner desires. Game theory may detect and interpret the behaviors of different parties involved in construction project obstacles, as well as define how relations between multiple parties can result to a project's evolution. A few of the issues come from distrust among social, political, and economic parties, that leads inevitably to suboptimal activity patterns. The Prisoner's Dilemma game is built upon the same distrust concept, and this paper examines how to lessen it through the context of green building. The minimization necessary to describe a complicated and layered real-life situation as a game is a major constraint of game theory. Yet, this does not subtract from their predictive potential. Foundationally, game theory is the investigation of strategic interdependence situations, which means that first party's actions impact both its own and the second party's benefit, and conversely. Strategic interdependence is difficult to manage since parties must predict, act, and respond. Especially in this case, willful ignorance does not benefit any parties. The Prisoner's Dilemma is the earliest and therefore most discussed model in game theory, with a clear resolution.

Players

This model comprises 3 major interacting players:

1. Potential Buyer

Buyers of condominiums and houses may select green constructions in order to reduce energy consumption or delay climate change. When a buyer arranges and constructs their own house, they possess the most control. Most house purchasers, nevertheless, purchase units in multi-family compound structures and have no to little direct influence over their design and construction. Furthermore, since the market is a sellers' market, house buyer's impact in Turkey is more restricted. Furthermore, "greenness" is rarely a prominent criterion in apartment selection by generally being trumped by other variables such as pricing, service accessibility and quality, particularly school quality, and closeness to job location (Fundaminsky, 2007). The first payment is crucial. As per Turkey's Central Bank's (TCMB) annual assessment on the housing index, one of the severe property crises on record is faced. According to the TCMB, the median cost of a house in Istanbul is 1.6 million Turkish lira, which is approximately $110,000 in the year 2022, rising from 750,000 Turkish lira the year before (Data Governance And Statistics Headquarters Survey And Indices Directorate, 2022). According to the TCMB, property prices around Turkey rose an average of 96.4 % per year in February 2022, with Istanbul taking the lead at 106.3 %. Also, in the cities Diyarbakır and Şanlurfa, in the country's southeast, which are considered the least developed region of the country, the growth has reached 111%. To summarize, most Turkish purchasers have little authority or motivation in assessing if their house is environmentally friendly.

2. Construction Entrepreneur

Some Turkish businesses have lately begun to create green buildings or adapt existing structures for certification. In Turkey, there are now 779 certified buildings, 7 award-winning constructions, and 2 case studies (GBIG, 2022). Many constructors, however, remain cautious,

fearing that the expenditure of green building, particularly at a more demanding degree, would be more costly in terms of both time and money. While house purchasers may be unable to bear the additional expenditures, this skepticism appears to be more prevalent in the edge, among constructors, where buying power is smaller and profitability is more precarious. Individual financers are sometimes hesitant to take on the overall price of certification and by doing so suffer the "liability of newness", (Stinchcombe, 1965) even though green building is not a new nor uncommon approach in around the globe, supporting more of a "laissez-faire" policy.

3. Government

The government can participate in green building in a variety of ways, including research, management, legislation, and subsidization. As green construction standard in Turkey is currently voluntary at national scale, hence the government does not control its implementation. However, the government is already participating in supporting research and sponsoring initiatives through its ministries and may in the future implement obligatory measures. Governments, particularly those in the European Union, have provided subsidies for green building in order to comply with EU requirements (such as restrictions on nonrenewable energy usage) or to secure availability of subsidies and grants.

Player Strategies and Utilities

The Prisoner's Dilemma in this paper is a model wherein the 3 players face the following strategic quandaries at the same time.

- *Potential Buyer*: buying a greener apartment | buying a conventional apartment
- *Construction Entrepreneur*: building green | building conventionally
- *Government*: prioritizing green building | following a laissez-faire policy

The benefit that the player will acquire is determined by the following decisions:

In the case of the Potential Buyer:

Buying a house at a cheaper initial price.

If not, recovering money over time by cutting energy costs and achieving a greater unit monetary worth in the event of resale. Also, helping the environment recover from the on-going climate change.

In the case of the Construction Entrepreneurs:

Stronger profit potential.

If not, stronger monetary threat.

In the case of the Government:

Conserving energy and satisfying global expectations while demonstrating concern about citizen wellbeing and environmental concerns.

If not, exposed to subsidy expenses, consisting of the budgetary and administrative costs of management and implementation.

Parameters

Table 1. Parameters defined in the game.

Parameter	Definition
T_0	Conventional Unit Price
T_1	Moderate Level Green Unit Price
T_2	Certified Level Green Unit Price
α	Potential Buyer's eagerness for potential savings
pot	Potential savings
β	Potential Buyer's level of awareness and worry regarding climate change
env	Environmental return of the built building
D_0	Conventional Unit's Building Cost
D_1	Moderate Level Green Unit's Building Cost
D_2	Certified Level Green Unit's Building Cost
D_3	New Skill Acquirement Cost
S	Subsidy Cost
A	Governmental Acquisition - global benevolence, electoral support, and energy efficiency

In this model it is assumed that $T_0 < T_1 < T_2$ and $D_0 < D_1 < D_2$.

Accordingly, the benefit of the Potential Buyer is,

$$U_i = -P + \alpha * pot + \beta * env + S$$

$$\frac{\partial U_i}{\partial \alpha} = pot$$

The greater overall long-term reductions generated by greener construction technology, the greater the benefit to the wellbeing of unit purchasers. Likewise, for β:

$$\frac{\partial U_i}{\partial \beta} = env$$

The more value that unit purchasers place on the planet, the greater the impact of high-quality green buildings are to their wellbeing. If both α and β rise over time, enhancing the wellbeing of green building owners, the government will have the option to withdraw subsidies or, alternately, builders will be able to charge higher prices for green buildings, boosting their incentive to create such housing units.

The Game

The present status of the Turkish market may be represented as a concurrent 3-player game utilizing methods of game theory. The benefit of the Construction Entrepreneurs, Potential Buyers, and Government are represented by the first, second, and third expressions in each cell, sequentially. The colored cell in the first matrix represents the existing balance, while the colored cell in the second represents the intended outcome.

In the case that the Government provides no subsidies therefore no green buildings are constructed:

Table 2. The matrix for the case that the government does not provide subsidies.

Potential Buyer / **Construction Entrepreneur**	Conventional Building	Green Building
Conventional Building	$T_0 - D_0, -T_0, 0$	$T_0 - D_0, -T_0, 0$
Moderate Level Green Building	$T_0 - D_1 - D_3,$ $-T_0 + (T_1 - T_0), R$	$T_1 - D_1 - D_3,$ $-T_1 + \beta * env, R$

In the case that the Government provides subsidies therefore green buildings are constructed:

Table 3. The matrix for the case that the government provides subsidies.

Potential Buyer / **Construction Entrepreneur**	Conventional Building	Green Building
Conventional Building	$T_0 - D_0, -T_0, 0$	$T_0 - D_0, -T_0, 0$
Moderate Level Green Building	$T_0 - D_1 - D_3 + S,$ $-T_0 + (T_1 - T_0), R$	$T_1 - D_1 - D_3 + S,$ $-T_1 + \beta * env, R - S$

As demonstrated by the matrices, if a customer wants a green house but none are available, they will be required to compromise for a conventional house. In contrast, if a buyer inclines for a conventional unit however the construction entrepreneurs construct green, they will purchase a green unit, yet pay the cheaper option of a conventional one since they will only be spending P_0. Nevertheless, whenever they sell their house, it shall be worth the same as a green one. As a result, they will have a projected return (Luterbacher, 2021) of P_1-P_0. Moreover, because this buyer initially intended to purchase an average unit, they are unlikely to be concerned about the planet, and hence their β worth is 0. Ultimately, because the green units are on the moderate level, their efficiency gains are minimal, and so the parameter sav has a value of 0 (As labelling a unit as green increases its apparent worth and hence its value, even though it cuts little energy).

The Turkish market is currently in an equilibrium state in which construction entrepreneurs chose to construct conventional buildings or moderate green houses, whilst government avoids issuing subsidies and spending surveillance expenses, and purchasers avoid the extra cost of green buildings. These methods may be in equilibrium in the game, since:

$$T_0 - D_0 > T_0 - D_1 - D_3$$

The Turkish economy's objective is to achieve a new equilibrium wherein constructors and buyers prefer green housing, with the motivation of multiple factors explained through the paper. Nevertheless, such a shift is not likely to occur if the government retains a laissez-faire policy, owing to distrust among participants, similarly to the Prisoner's Dilemma phenomena. The benefit for each player is unquestionably greater when greener policies are used, as shown below.

For Construction Entrepreneurs:

$$T_1 - D_1 - D_3 + S > T_0 - D_0$$

For Potential Buyers:

$$-T_1 + \beta * env > -T_0$$

For Government:

$$R - S > 0$$

In order to reach an equilibrium achieved by countries such as England, Germany or France, this paper suggests that the government should acknowledge the higher gain of green building than conventional building, while two kinds of subsidies are brought in the game for a sway in parties' decision. To summarize, the government's incentive system would provide both builders and buyers - for certified green projects, either through direct subsidies or by granting lower interest to both buyers and builders of green buildings.

The Remodeled Game

After the establishment of the new incentive system, the two new variables are as shown:

Table 4. Newly defined parameters for the Remodeled Game.

Parameter	Definition
S_1	Buyers' Subsidy
B	Government's Electoral Advantage

The current matrix is as shown:

Table 5. The matrix for the case that the government provides subsidy also for the buyers.

Potential Buyer / **Construction Entrepreneur**	Conventional Building	Green Building
Conventional Building	$T_0 - D_0, -T_0, 0$	$T_0 - D_0, -T_0, 0$
Certified Level Green Building	$T_0 - D_2 - D_3 + S,$ $-T_0 + (T_1 - T_0) + \alpha * pot,$ $R - S$	$T_2 - D_2 - D_3 + S,$ $-T_2 + \alpha * env + S_1,$ $R + K - S - S_1$

Since this green building is certified, it conserves energy, therefore sav is included to the buyer's benefit model. If a buyer purchases a certified green apartment for the same price as a standard one, they will not obtain any governmental assistance.

The inequalities below compare each party's predicted benefit in the new equilibrium to the benefit they gained in the previous one.

For Construction Entrepreneurs:

$$T_2 - D_2 - D_3 + S > T_0 - D_0$$

For Potential Buyers:

$$-T_2 + \alpha * pot + \beta * env + S_1 > 0$$

For Government:

$$R + B - S - S_1 > 0$$

The proposed incentive could enable the market to shift to a better-for-all equilibrium for which constructors construct higher-level green buildings, buyers purchase them, and the government gives incentive both for buyers and constructors to promote the practice. Following this amelioration, the methods are in balance, as shown below:

For Construction Entrepreneurs:

$$T_2 - D_2 - D_3 + S > T_0 - D_0$$

For Potential Buyers:

$$-T_2 + \alpha * pot + \beta * env + S_1 > -T_0 + P_2 - P_0 + \alpha * pot$$

For Government:

$$R + B - S - S_1 > R$$

Conclusion

As the aftermath of many technological advancements, increased dependence on energy has brought up environmental destruction and uncontrolled consumption of natural resources. As excessive and wasteful consumption results in soil, air and water pollution problems, this has prompted organizations and states, and the concept of sustainability has gained importance.

With a big responsibility regarding this matter, construction industry has a major role in helping the globe recover from the ongoing pollution and climate change. When enough attention is given into what changes could be done in this sector, green buildings are one of the most promising reforms that fosters innovation.

For success in sustainability, it is necessary to set standards and monitor the process through measurement. Businesses are expected to care about both quality and the environment in their strategic planning and implementation processes. In this direction, criteria should be determined in terms of sustainability management and certification is required. Since the environmental, social and economic dimensions of each country are unique, it is thought that it would be appropriate for each of them to have their own certification system. However, it is generally seen that countries cannot always establish their own systems. Therefore, internationally certified frameworks are used to evaluate construction all over the world as well as a few more recent tools that are in use (such as the B.E.S.T. in Turkey).

Currently, Turkey's green building criteria may be inadequate to contribute significantly to greenhouse gas reduction and energy efficiency. A further development of the regulated green building standard is acknowledged as a necessity, which is likely to motivate those seeking to reduce GHG and save energy to function through some form of the green building regulation (Pamuk, 2016). Throughout this paper, it is believed that certified green construction standards can help achieve this purpose. It is also proposed that government incentives be used to encourage constructors and buyers to choose buildings with far higher levels of green construction standards.

Utilizing game theory, it has been demonstrated that supplying financial subsidies (while ensuring surveillance and implementation of the criteria) for certified green buildings might very well improve urban residents' wellbeing while enhancing government prestige, improving efficiency, and working the environmental issues. Finally, it is proposed that once such green building standards are implemented in a greater amount of construction, construction at that level will become increasingly more common, even if government subsidies are lowered or withdrawn, because the mistrust and uncertainty that leads to the Prisoner's Dilemma will be reduced.

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Predicting Permanent Disability of Construction Workers Using Support Vector Machine

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Abstract

Several environmental uncertainties and dynamic nature of the construction industry render it one of the riskiest industries around the globe. Hence, occupational accidents are omnipresent in the industry, which requires a robust safety risk management plan to reduce the number and severity of construction accidents. This study develops a machine learning model to predict permanent disability status of construction workers. To achieve this objective, a dataset of construction accidents that occurred in Turkey was collected in the first step. Then several data preprocessing methods were adopted to prepare the data for prediction task. For the machine learning application, Support Vector Machine (SVM) was used. The findings show that the SVM yielded the recall values of 0.6988 for classifying permanent disabled workers. The results of the feature importance analysis also show that working days lost, type of injury, and daily wage were the most significant attributes in the model. The findings are expected to help construction professionals develop safety management strategies to minimize accidents that may result in permanent disability.

Keywords: *artificial intelligence, construction safety, machine learning, occupational accidents, support vector classifier.*

Introduction

Safety management is one of the most critical concerns in the construction industry (Koc et al., 2021). Adverse safety outcomes encapsulate accidents, injuries, disabilities, fatalities, along with the social and economic costs (Feng et al., 2015; Forteza et al., 2017). Therefore, strategies to improve safety performance of the industry are necessary to help construction workers increase their work and life conditions.

Occupational accidents resulting in permanent disability are regarded to be among catastrophic events in construction projects. This is a serious problem since more than 11% of all disabilities occur due to occupational accidents (Koc et al., 2021). After occupational accidents, early designation of disability status of construction workers may help construction professionals plan their workflows, construction workers consider permanent disability

application, institutions use it as a benchmark, and safety professionals understand in what conditions permanent disability occurs. Therefore, predicting permanent disability status of construction workers have diversity of advantages. In this vein, machine learning methods can be used effectively to detect the output variables.

This study aims to develop a prediction model to identify permanent disability status of construction workers. To achieve this objective, the dataset consisting of construction accidents experienced in Turkey was captured and several preprocessing steps have been performed. Then, a machine learning application was performed by means of support vector machine (SVM). Feature importance was also explored to increase the interpretability of the research findings. Overall, this study is expected to provide practitioners with valuable insights about the permanent disability conditions of construction workers.

Methodology

This study investigates the permanent disability status of construction workers using machine learning approach. The flowchart of the analysis procedure is presented in Figure 1. First, the dataset related to construction accidents occurred in Turkey was collected from the Republic of Turkey, Social Security Institution (SSI). Then the output variable was selected as permanent disability status of construction workers which include permanent disability (PD) and non-permanent disability (NPD).

In order to predict the output variable eight input attributes were selected through a diligent investigation of the dataset (Table 1). These include education level, working days lost, type of injury, injured body part, material used, type of construction, number of past accidents of workers, and daily wage. Then, missing values, inconsistencies, and duplicates were removed from the dataset, which ensured the size of the dataset as 47,938 (including 1,074 PD and 46,864 NPD). Then the categorical variables (i.e., education level, type of injury, injured body part, material used, type of construction) were subjected to label encoding to convert the categorical attributes into their numerical counterparts (Sarker et al., 2020a). The following step covers the data scaling to minimize effects of the range and magnitude of the attributes on the prediction output. Among several data scaling methods, standard scaler due to its wide applications was used (Sarker et al., 2020b; Swarna Priya et al., 2020; Thippa Reddy et al., 2020).

The dataset was divided into two major categories as training and testing sets. This was achieved by randomly taking the 70% and 30% of the dataset, respectively. This step was followed by the data resampling. Data resampling is necessary because there was an imbalance between minority (PD) and majority (NPD) classes. Hence, without data resampling, the model can predict all the cases as NPD with high but misleading accuracies. In this respect, random under-sampling (RUS) was used as one of the most widely adopted resampling strategies (Allah Bukhsh et al., 2020; Kang & Ryu, 2019) and considering the time efficiency into account (Liang et al., 2020). In the RUS algorithm, instances of the majority class are randomly removed from the dataset until the balance in the class distribution is achieved. It is important to note that data resampling strategies should be implemented only on the training set, since testing set, which is used to measure the model performance, should still be imbalanced similar to real-life applications.

As a major step of the analysis SVM method was used to predict output labels. The main principle of SVM relies on the statistical learning theory along with the structural risk minimization procedure (Cortes & Vapnik, 1995). Several classes of data points are identified in terms of a line, i.e., hyperplane in the SVM method (Koc et al., 2022). An optimal hyperplane is one that achieves the minimum of an error as well as maximum of the margin among all hyperplanes (Mahmoodzadeh et al., 2021). Kernel function used in the SVM method is significantly important for the model performance. Radial basis function (RBF) kernel covers a large function space compared to other kernels and has a flexible structure with generalization ability, while generating all relationships speedily (Yu et al., 2011). Therefore, we adopted RBF SVM to predict permanent disability status of construction workers. It is important to note that all the inertial parameters of SVM were determined by means of a trial-error.

After the developed models are fitted with the training sets, model performance is evaluated by blinded testing set. In this respect, recall and area under the receiver operating characteristic (AUROC) were used to examine the performance of the proposed model. Recall is determined by taking the rate of true positive instances to the sum of true positive and false negative instances (Buckland & Gey, 1994). In other words, it measures how well the label A is predicted as A. On the other hand, AUROC plots two metrics as true positive rate (TPR) and false positive rate (FPR). By taking the TPR at the vertical and FPR at the horizontal axes, area under the curve can be calculated (Dai et al., 2015). Despite the accuracy being another performance evaluation metric (Attal et al., 2015), AUROC is documented to be more robust metric when there is an imbalance between output labels (Choi et al., 2020). In addition, AUROC makes the interpretation and representation of the results easier, hence used in this study. After the performance of the model is evaluated, the random forest feature importance was used to identify the most influential attributes in the model.

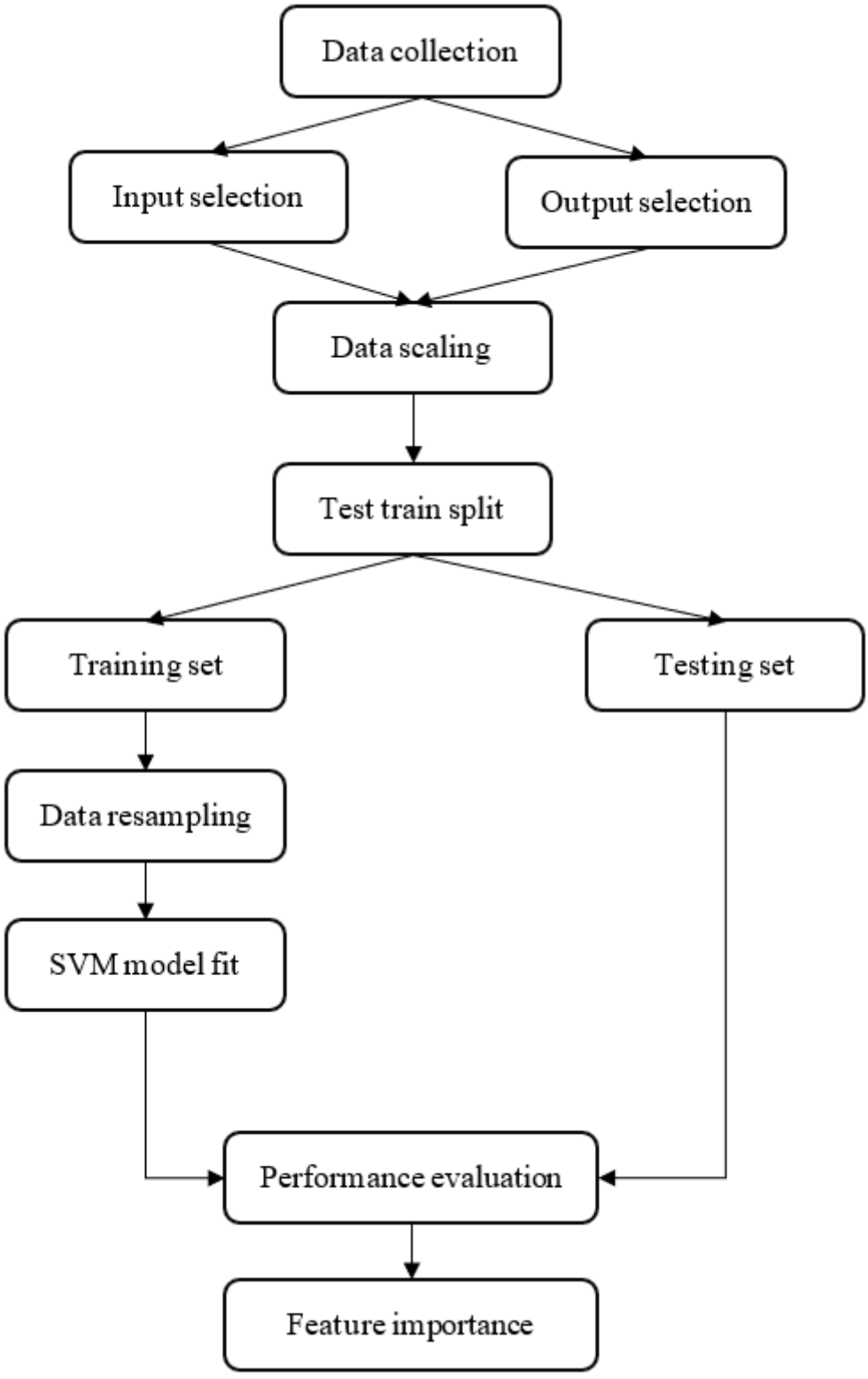


Figure 1: Flowchart of the study.

Table 1. Features used in the prediction model.

Features	Type	Descriptions
Education level	Categorical	This indicates the education level of worker including illiterate, only literate, elementary, secondary, high, graduate, Master, PhD.
Working days lost	Numerical	This indicates the number of days that the worker cannot work due to the accident.
Type of injury	Categorical	This indicates the type of injury of the worker including acute, chemical exposure, temperature exposure, fracture, shock, fluid effects etc.
Injured body part	Categorical	This indicates the part of the body of the worker injured due to occupational accident including, head, hand, leg, shoulder etc.
Material used	Categorical	This indicates the material used during the accident including construction machinery, construction materials, assembly kits, hand tools etc.
Type of construction	Categorical	This indicates the type of the construction that the accident is experienced including residential projects, road projects, water projects, etc.
Number of past accident	Numerical	This indicates the number of past accident of workers.
Daily wage	Numerical	This indicates the daily wage of the worker.
Permanent disability status	Binary	This indicates the output label including permanent disability and non-permanent disability.

Results

This study focuses on the permanent disability status of construction workers. First, the dataset (1,074 PD and 46,864 NPD) captured from the SSI was divided into testing and training sets, with 30% and 70% of the dataset. Hence, the size of the testing set become 332 PD and 14,050 NPD workers. On the other hand, the training set was subjected to RUS algorithm to equalize two output labels, i.e., PD and NPD. This process resulted in 742 PD and NPD instances, accounting the total number of 1,484 instances in the training set. In other words, balanced 1,484 cases were used for model training while imbalanced 14,382 cases were used for testing the model. Table 2 shows the changing size of the dataset regarding PD and NPD classes.

Table 2. Size of the datasets.

Dataset	Disabled (PD)	Non-disabled (NPD)	Total
Raw data	1,074	46,864	47,938
Test data	332	14,050	14,382
Train data	742	742	1,484

Testing performance regarding recall values are shown in Figure 2. The findings show that the SVM model achieved the prediction rate of 0.6988 for predicting PD class while it was 0.8797 for classifying NPD instances as NPD. In addition, Figure 3 shows the ROC curve of

the model performance. The findings show that the model achieved the prediction power of 0.84 of AUC, which indicates a good model performance (Choi et al., 2020).

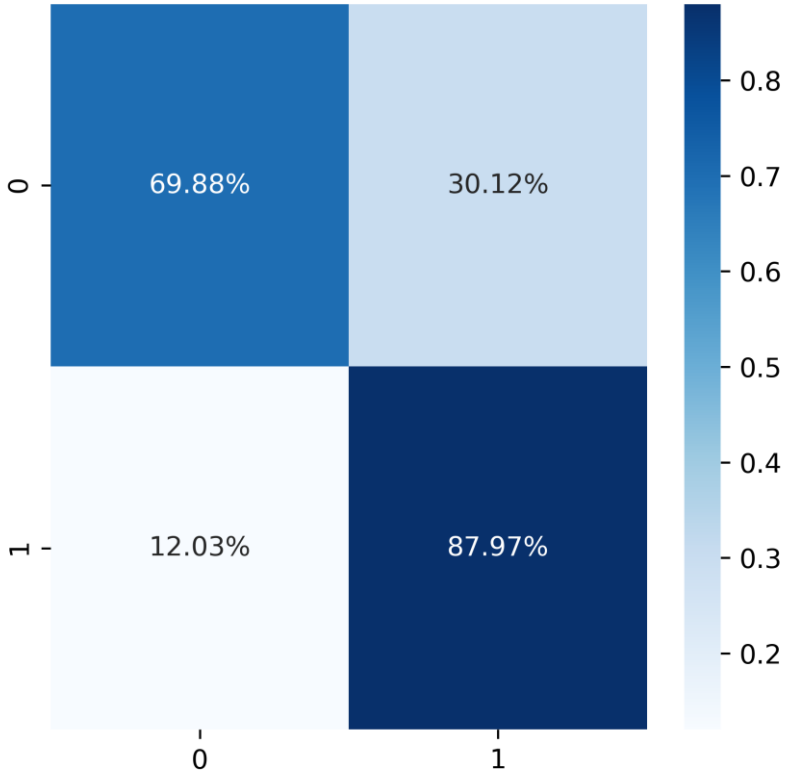


Figure 2: Confusion matrix of the model.

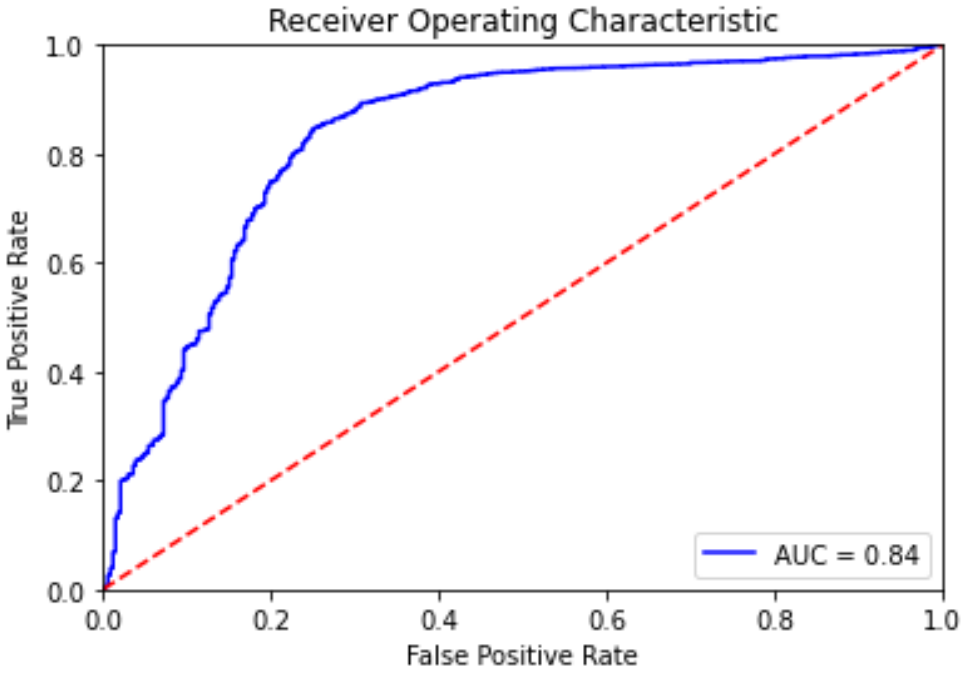


Figure 3: Receiver operating characteristic curve of the model.

This study further explored the impact of features on the predictions. Figure 4 shows the random forest feature importance results. The findings show that working days lost, type of injury, daily wage, and injured body parts were significant attributes. Working days lost can address the severity of injuries, thus can be related to permanent disability, which support its high effect on the prediction. On the other hand, some injury types can be related to specific outcomes on the workers' bodies, which can be associated with the severity and type of disabilities. Similarly, some body parts such as arm can be related to disability status of workers (Koc et al., 2021), while some body parts are affected only by minor injuries. This can also be related to the job of the workers, and daily wage can be influential in this regard since daily wage can provide some means to identify the job of the worker as well. Overall, this study shows that the characteristics that define the injury and severity of workers are highly effective in understanding the permanent disability of construction workers.

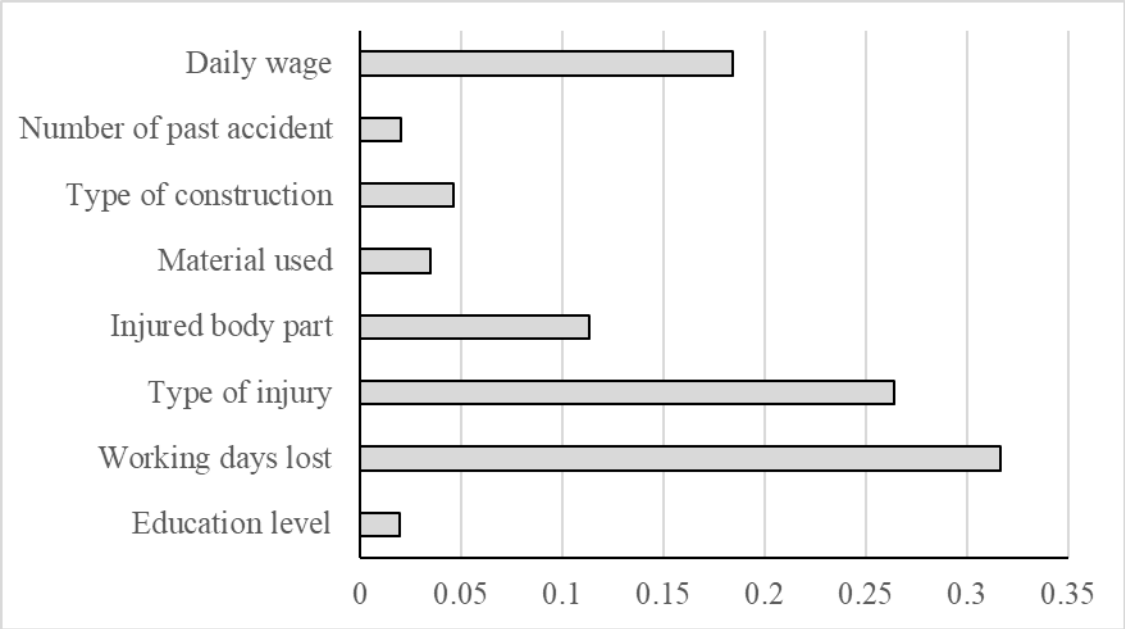


Figure 4: Feature importance.

Conclusion

This research investigates the permanent disability of construction workers in a binary classification problem. In this regard, machine learning-based solution provides significant means to understand and explore in what conditions permanent disability occurs. After several preprocessing elements, this study adopted the SVM method for detecting permanent disability status of construction workers. The findings show satisfactory model performances. In addition, attributes that define the type of injury, the affected body part, the severity of accident, and job of the worker were found to be influential attributes. This study presents some limitations similar to many studies. First, parameter optimization techniques can provide higher accuracies with improved model configuration. Besides, permanent disability status can also be predicted with only pre-accident attributes with a cost of accuracy. Still, it can provide significant insights for professionals to prevent accidents that might result in permanent disabilities. With methodological and practical improvements, we believe that the accidents that lead to permanent disability can be prevented with proactive safety risk management.

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A Literature Review on Health and Safety Studies in Turkey

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Abstract

In Turkey, the construction industry is almost always among industries with poor health safety records. In this respect, a broader evaluation of past studies may reveal the current health and safety performance of the construction industry and provide a useful framework for future efforts. The aim of the study is to conduct a systematic literature review of health and safety studies carried out in Turkey. To this aim, past studies from 2009 to 2021 were evaluated regarding topic, method(s), and findings in order to present a review of these studies. Overall, the results obtained may help to identify the current health and safety performance in the construction industry and to guide researchers for future studies about health and safety issues in Turkey.

Keywords: *construction industry, health and safety, review, Turkey.*

Introduction

The construction industry can be regarded as one of the most dangerous industries in terms of occupational incidents (Carter & Smith, 2001). Occupational accidents in construction cause human tragedy and huge economic losses (Kartam, 1997). Expenses of occupational accidents and illnesses may cause 6% of the total construction turnover (HSE, 1997). Each 1 US Dollar investment in health and safety precautions will save 2.27 US Dollars (Tang et al., 2004). Risk potential of a fatal accident in the construction industry is five times more likely than in a manufacturing-based industry (Davis & Tomasin, 1990). The main causes of construction accidents can be listed as: (i) lack of proper training, (ii) deficient enforcement of safety, (iii) lack of safety equipment, (iv) unsafe methods or sequencing, (v) unsafe site conditions, (vi) not using provided personal safety equipment, (vii) poor attitude toward safety, and (viii) isolated, sudden deviation from prescribed behaviour (Toole, 2002). According to Arslan and Kivrak (2009), lack of safety training was found as one of the important factors that can cause construction accidents in Turkey. Larsson et al. (2008) stated that key point to safety lies within the management (Larsson et al., 2008). Lack of training can be attributed to poor safety and health management by the companies. Therefore, occupational health and safety (OHS) issues of the construction industry have great potential to be investigated in academic studies. The aim of the study is to conduct a systematic literature review of OHS studies carried out in

Turkey. To this aim, past studies from 2009 to 2019 were evaluated regarding topic, method(s), and findings in order to present a review of these studies.

Literature Review

The literature on safety issues is vast due to the continuous interest of researchers. ‘There are numerous studies in the literature on OHS. Based on the language of the paper, the exclusion of duplicates, the inclusion of peer-reviewed journal articles alone, and the inclusion of publications based on the subject in Scopus and Web of Science, thirteen papers were obtained. The selected studies for this research were listed in Table 1. Table 1 categorizes the studies based on aim of the study, the used method in the study, utilized data and obtained results.

Table 1. Past studies from 2009 to 2019.

Reference	Aim	Method	Data	Result
Gürcanlı (2009)	To investigate the characteristics of accidents and to draw the attention of safety professionals.	956 expert reports submitted to criminal and labour courts were investigated.	956 expert reports and 971 fatal and non-fatal injury reports submitted to criminal and labour courts were examined in detail.	The negligence of basic safety rules in accidents caused by non-employee or third parties.
Gürcanlı and Müngen (2013)	This study was carried out to better understand the new laws and regulations among academicians as well as employees.	By examining the expert reports, the result of the incident, the date and time, the main causes of the accident, the type of the construction site, the profession, the responsible parties.	Expert reports on work accidents.	Inappropriate and unsatisfactory conditions, and the parties responsible for occupational injuries and an in-depth analysis of each type of accident.
Ulubeyli et al. (2014)	To view general information about OHS conditions in the Turkish construction industry from the perspective of construction workers.	A survey was conducted with 800 workers employed in 32 construction projects in Turkey.	Survey results were analysed in accordance with statistical methods.	Uninsured workers in the Turkish construction sector industry. Lack of unionization.

Table 1. Past studies from 2009 to 2019 (continued).

Gürcanlı et al. (2015a)	The purpose of this study is to combine construction project planning, risk assessment activities, and construction cost estimation into the cost of security of value and its distribution throughout a project.	Cost analysis was performed, and the results were analysed comparatively	Drawings, technical specifications, and invoices of 25 concrete residential buildings in the province of Istanbul were collected, construction sites were visited and information on OHS practices was collected from field engineers.	As a result of this study, it has been determined that the ratio of security cost to total cost is 1.92%, and according to 2013 prices, 0.85 USD should be spent per man-hour.
Gürcanlı et al. (2015b)	To determine the risk perception of construction equipment operators in Turkey.	Statistical methods such as t-test, ANOVA analysis, Kruskal Wallis one-way analysis of variance and ManneWhitney U test	Survey study with 198 heavy equipment operators in 51 construction projects	Pointed out that the type of construction project has an impact on the risk perception of the operators, and this is reflected in both severity and probability scores.
Ulubeyli et al. (2015)	To reveal cultural differences and understandings of OHS applications in several countries.	Semiotic Analysis	Cartoons from an International Occupational Health and Safety Cartoon Contest	Cartoons can be a good material for better understanding and retention of OHS practices.
Ulutaşdemir et al. (2015)	The aim of this study is to evaluate the effect of OHS practices on healthy lifestyle behaviours of workers.	Survey analysis	A survey was conducted with 400 construction workers.	Getting OHS training and using PPE is a healthy lifestyle affect their behaviour positively.

Table 1. Past studies from 2009 to 2019 (continued).

Arslan et al. (2016)	Identifying the problems of occupational safety experts and producing suggestions for the solution of these problems	A survey was conducted with 110 occupational safety experts.	Survey analysis	(i) Employer intervention, (ii) feeling of not being able to work independently, (iii) insufficient working and consulting time, and (iv) paying experts by the companies they consult
Birgönül et al. (2016)	A literature search was conducted in the construction industry, the causes of the accidents and the results of the lawsuits were analysed.	84 inspection reports were examined, and a method (DsSafe) was developed to determine the causes of construction accidents in Turkey.	Case reports.	DsSafe performed extremely well in 13 of 30 real cases studied and tested. Error rates are estimated to be 100%.
Gündüz and Laitinen (2017)	A 10-stage occupational health and safety management system (OHS MS) has been developed to help SMEs improve their working conditions.	The OHS MS rating system contains 50 items and each item is ranked on a 3-point scale where 0 means poor, 1 means average, 2 means good.	Performance data of 15 firms were utilized.	OHS MS provides a measurable performance monitoring tool to help develop and maintain a positive behavioural change towards better working conditions.
Yılmaz and Kanıt (2018)	The aim is to estimate the security costs of residential construction projects.	Adding a new software module to a computer program	All work items defined in the existing data modules of the computer program of the Turkish Ministry of Environment and Urbanization	To reduce the loss of life and to reduce safety costs resulting from serious injuries, deaths, administrative procedures, legal liabilities and litigation costs.

Table 1. Past studies from 2009 to 2019 (continued).

Baradan et al. (2019)	To investigate the relationship between HDI and mortality rates in the construction industry, as well as the parameters that make up HDI.	Curve fitting and correlation analysis (R2) is used to find the best fit line/curve for a set of data points.	Gross national income, life expectancy, average years of education, expected years of education	The higher level of development has a positive effect on reducing mortality rates in construction.
Yılmaz and Uğur (2019)	Calculating and budgeting prevention costs at the start of repair and maintenance projects	Estimation of the overall mandatory OSH costs, including all expenses incurred during the implementation of the measures.	Comparing the estimated OHS costs at the pre-tender stage with the actual OHS costs	Tender preparation process has been simplified by providing an accurate enough estimation of OHS costs.

These studies reveal different perspective of OHS research conducted in Turkey. Considering their themes, past studies were grouped under six topics; (i) legal litigation analysis, (ii) OHS and welfare level relation, (iii) workers working conditions, (iv) international comparison of OHS concept, (v) cost of OHS, and (vi) OHS performance evaluation.

Legal Litigation Analysis

Gürcanlı (2009), Gürcanlı and Müngen (2013), and Birgönül et al. (2016) analysed expert reports to conclude the reasons of occupational accidents and results of legal litigations of these accidents.

OHS and Welfare Level Relation

Baradan et al. (2019) concentrated on Human Development Index and studied the relation between OHS and gross national income, life expectancy, average years of education, expected years of education of countries.

Working conditions of workers

Ulubeyli et al. (2014) conducted a survey with 800 workers employed that is a massive number, in order to reflect general information about HS conditions in the Turkish construction industry from the perspective of construction workers. Moreover, Ulutaşdemir et al. (2015) evaluated the effect of OHS practices on healthy lifestyle behaviours of workers and they surveyed 400 construction workers. Gürcanlı et al. (2015b) aimed to determine the risk perception of construction equipment operators in Turkey and 198 heavy equipment operators were surveyed in the study. Arslan et al. (2016) interviewed 110 OHS experts in order to reveal current problems of them.

International Comparison of OHS Concept

Ulubeyli et al. (2015) presented a unique approach to OHS of construction industry. In their study, several cartoons on OHS applications were analysed utilizing Semiotic Analysis Method to reveal cultural differences or similarities of countries on this topic. There are also studies which concerns OHS costs for Turkish construction firms.

Cost of OHS

Gürcanlı et al. (2015a) focused on the cost of security, Yılmaz and Uğur (2018) researched security costs of residential construction projects, and Yılmaz and Uğur (2019) calculated prevention costs for maintenance projects from the perspective of OHS.

OHS Performance Evaluation

Gündüz and Laitinen (2017) developed a computer program to improve small and medium enterprises' performance concerning OHS applications.

Discussion and Conclusion

The construction industry has high safety hazards for workers at sites due to the complex and confined working environment. Construction workers face a lot of struggles and difficulties in the workplace due to the improper balance between work and their safety. Regarding to official numbers of occupational incidents, construction industry is one of the most dangerous industries in Turkey. From this point of view, researches on OHS have a significant role to sustain a safer and better conditions for construction workers.

Legal litigation results and expert reports reveal that most of the occupational incidents arises due to improper working environment, negligence of basic safety rules, and lack of safety awareness. Moreover, type of construction project has an impact on the risk perception of workers and operators in the construction site. Therefore, an effective OHS training system and using PPE may positively affect workers' behaviour. From the perspective of construction workers, their most significant problems are lack of insurance and unionization. These problems should be considered and solved in order to maintain job security. Regarding to costwise approach, OHS applications have not a devastating effect on project budget. Moreover, cost of precautions relatively lower than cost of occupational accidents recovery.

Considering the past studies in Turkey (Table 1), it can be asserted that lack of OHS culture and negligence of basic OHS rules cause most of the occupational incidents in Turkish construction industry. In addition, low unionization of workers and existence of uninsured workers result with poor OHS records for construction companies and workers. Therefore, there is a need of studies which concentrate on creating an OHS culture in Turkish construction industry. Regarding the cost of OHS practices, most of the construction companies, especially small and medium companies, should have better understanding of the importance to reduce safety costs resulting from serious injuries, deaths, administrative procedures, legal liabilities and litigation costs and expenses. In that case, more studies should be conducted in collaboration with construction companies to reveal the importance of cost of OHS precautions.

The limitation of the study is that the selection of articles for review is considered as only peer-reviewed articles, and publication from 2009 to 2019. Other sources of relevant articles such as book parts, chapters, conference proceedings, and Ph. D. theses were not considered. For future studies, a bibliometric analysis of OHS studies of Turkey can be carried out in order to reveal a better perspective for Turkish construction industry.

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Awareness of Occupational Health and Safety in Architectural Office Workers: Kayseri Example

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Abstract

Academic and practical studies on occupational health and safety in the field of construction are carried out with seriousness. However, the occupational health and safety issue for the works in architectural offices where the design phase of the sector takes place is ignored. While the job classification is very dangerous in construction sites, it is evaluated in the less dangerous class in offices. This causes the ergonomics problems faced by architectural office workers to be ignored. However, the ergonomics problems brought by long desk jobs put employee health at risk. In this study, it was tried to measure the awareness of occupational health and safety of architectural office workers. It is expected that the study carried out on the scale of Kayseri will contribute to the studies to be carried out throughout the country.

Keywords: *architectural offices, ergonomics, occupational health and safety.*

Introduction

The importance of the concept of Occupational Health and Safety (OHS) increases with the injury, death or damage of many employees as a result of occupational accidents each year, due to occupational diseases. The purpose of OHS activities; to identify dangerous situations that threaten the life of the employee, to protect them from these dangers, to minimize the damage of risky situations, in other words to create a healthy and safe working environment. OHS studies also include all activities and measures to ensure labor productivity. The importance of occupational health and safety has increased rapidly in business lines that contain risk factors. With OHS, it is possible to identify risky situations that threaten the health of employees, to protect employees against these situations and to reduce the impact of the damage to be encountered.

Fulfilling the requirements of ergonomics in office working conditions is of great importance in ensuring OHS. Employees working in the same position for a long time in intense work tempo in architectural offices have various risks in terms of OHS and ergonomics. Dangerous situations can be prevented with various arrangements to be made in order to work in conditions suitable for ergonomics. In this context, this study was needed to measure the awareness of OHS in architectural offices in Kayseri. The fact that Kayseri has important potentials in the field of architecture and that no relevant studies have been carried out in the province have been a factor in the selection of Kayseri. In the study, the number of samples was decided with

statistical analyses and a field study was carried out in 56 offices with the aim of reaching more participants. Responses were received from 141 office workers.

Although there are extensive studies on OHS related to office workers in Turkey, the absence of any study on architectural offices has led to the formation of this study. Within the scope of the research, it is aimed to draw attention to the importance, applicability, necessity and awareness of OHS in the works in architectural offices. The problems related to the subject were identified and the findings for the architectural office workers were included, and it was aimed to raise awareness for everyone and to increase the importance given to OHS. The main objective was to increase the level of knowledge about OHS by ensuring that the results revealed in the architectural offices in Kayseri, which were selected as the field in the study, were disseminated. Within the scope of the study, the universe of the application consists of the employees of the architectural offices registered with the Kayseri Chamber of Architects. While deciding on the sample selection, room registration information of the Chamber of Architects was obtained, and the number of offices and surveyed offices was decided by using the Statistical Page Program for Social Science (SPSS) 22.0 Program and the Power Analysis method. It is aimed that this study will be a guide for other architectural office workers in Turkey, and that the study conducted in Kayseri will set an example for the country in general and to increase awareness and correct practices on the subject.

Occupational Health and Safety in Architectural Offices

Occupational health and safety is the set of measures necessary to prevent employees from experiencing accidents and occupational diseases, and to provide a physically and mentally peaceful working environment (Çelik, 2016). OHS activities include the activities carried out to protect workers and other individuals in the workplace from adverse conditions. OHS is defined as a branch of science that works to eliminate risks before dangerous situations occur (Turan, 2016). With the development of technology in the world and in Turkey, along with industrialization, important problems have emerged regarding the health and safety of employees. Due to changing working conditions, diversified business lines bring many dangerous and risky situations. Adverse conditions reduce productivity by causing an increase in work accidents and occupational diseases. OHS practices are of great importance as they include activities aimed at eliminating or minimizing such adverse conditions. Negative conditions in the working environment harm the right of employees to live and work in a healthy environment. Due to such reasons, it is necessary to give the necessary importance to the issue of OHS and to take the necessary precautions (Çelik, 2016).

Since the OHS activities did not develop at the same pace with the realization of the industrial revolution, the losses in business life were seen as a natural part of the production process. Most of the time, the employee himself was held responsible for the accidents, not the employer. Heavy and risky working conditions, which continued until the 19th century, were turned into a scientific issue by industrial countries such as England and Italy. Until this period, treatment methods for employee health have been adopted. Until the 1900s, preventive practices on OHS were not included. In the 1980s, scientists' research on topics such as workload, psychological risks, work stress, psycho-sociology and work organization was realized as a result of targeting preventive activities. With the scientific studies in the following periods, the necessary importance was given to OHS and its transformation into today's state was ensured.

Architectural offices are busy working areas where design activities are carried out in a coordinated manner, usually at the computer. Since it is known that most of the life is spent in offices, taking into account the occupational health and safety conditions in the offices provides important contributions to both the employer and the employees (Demirci & Armağan, 2002). In terms of occupational health and safety, as in other offices, criteria such as lighting, ventilation, noise, temperature, humidity, color, decoration, cleanliness, ergonomics are among the issues to be considered in architectural offices. As in every office environment, the quality and performance of the architectural offices increase by increasing the productivity with the employees working in conditions suitable for OHS. In this context, the appropriate physical environmental conditions are important in terms of providing OHS.

It is important for the office workers who work in front of the computer for a long time in architectural offices to pay attention to ergonomics in ensuring OHS. Ergonomics; it is a part of OHS studies aimed at reducing and eliminating the risks foreseen to prevent occupational diseases and work accidents. Being aware of the relationship between ergonomics and OHS and working accordingly is another important issue. In this context, it is necessary to be aware of the importance of ergonomics in OHS. Taking short breaks in busy work schedules and doing exercises during breaks are essential for ensuring employee health and OHS structure in offices. In this study, it is aimed to observe the awareness of OHS in architectural offices in Kayseri.

Method

As a result of the literature studies, some calculations are included in order to determine how much office field work should be done in the study. While deciding on the sample selection, room registration information of the Chamber of Architects was obtained, and the number of offices and surveyed offices was decided by using the Statistical Page Program for Social Science (SPSS) 22.0 Program and the Power Analysis method. Then, the conditions to be examined in the field study were determined. Questionnaire questions were created to measure the knowledge level of employers and employees about OHS and awareness of OHS in architectural offices in Kayseri. The questionnaire was applied to architects, civil engineers and technicians working in architectural offices. In the study, data entry and analysis with SPSS, sample selection with statistical analysis, and analysis with Chi Square test were deemed appropriate. While deciding on the sample size created to define the study universe; concepts such as population size, confidence interval, margin of error have become important. In this context, the formula used in selecting the sample is as follows:

$$\boldsymbol{n = \frac{Z^2 . \sigma^2 . N}{e^2 . (N - 1) + Z^2 . \sigma^2}} \quad (1)$$

N = the size of the total universe.
σ = represents the standard deviation of the population. If this data is unknown, 0.5 is assumed.
e= 5% (taken as 0.5)
Z = 95%, which is necessary for the study to be considered reliable, is the minimum value (95%–Z-Score = 1.96).

If $p \leq 0.05$, it is concluded that there is a significant difference in the results of employers and employees. If $p > 0.05$, it is concluded that there is no significant difference in the findings of employers and employees.

$$\mathbf{38} = \frac{(\mathbf{1,96})^{\mathbf{2}} \,.\, (\mathbf{0,5})^{\mathbf{2}} . \mathbf{139}}{(\mathbf{0,5})^{\mathbf{2}} . (\mathbf{139} - \mathbf{1}) + (\mathbf{1,96})^{\mathbf{2}} \,.\, (\mathbf{0,5})^{\mathbf{2}}} \quad (2)$$

According to the formula, it was determined that fieldwork should be done in 139 offices, with a confidence interval of 95%, with a standard deviation of 0.5 and approximately 38 offices. A field study was organized for 56 bureaus, aiming to increase the authenticity of the results by reaching more samples. While choosing the office; project approval rates were checked from the chamber of architects in Kayseri. As a result of the survey, responses were received from 141 office workers.

Examining OHS Awareness in Kayseri Architecture Offices

It was aimed to determine the knowledge level of office workers by creating a multiple-choice question in the survey study created within the scope of the study. In this question, the definition of the concept of OHS was asked. In the question in which the definition of the concept of OHS was asked in line with the answers received from 141 employees in architectural offices; it was determined that 92.9% (131 people) of the participants could fully define the definition of OHS, while 7.1% (10 people) had an idea about the definition of OHS, but defined the concept incompletely. 88.7% (55 people) of the employers who answered the questionnaire gave the most correct answer knowing the definition of OHS exactly, and 11.3% (7 people) interpreted the definition incompletely due to their incomplete approach to the subject despite knowing the definition of OHS (Figure 1). 96.2% (76 people) of the employees who participated in the survey were seen as having a good grasp of the definition of OHS, and 3.8% (3 people) as those who knew the definition of OHS but misinterpreted them (Figure 2). According to the results, it has been seen that the employees' knowledge of the definition of OHS is higher than that of the employers. The majority of the participants are fully familiar with the definition of OHS.

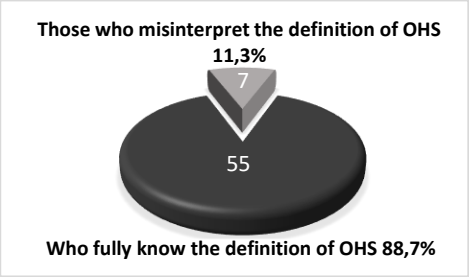


Figure 1: OHS approaches of employers.

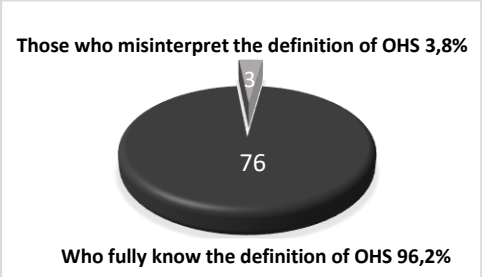


Figure 2: OHS approaches of workers.

In the case of receiving OHS training, 61.7% (87 people) of the participants stated that they received OHS training, of which 27% (38 people) were employers and 34.7% (49 people) were employees. It was observed that 25.6% (36 people) did not receive OHS training, of which 11.4% (16 people) were employers and 14.2% (20 people) were employees. 12.8% (18 people) of the participants expressed their indecision on this issue. 5.7% (8 people) of the undecided participants were observed as employers and 7.1% (10 people) as employees. Considering the level of OHS training of the participants working in architectural offices, it was seen that 61.7% of them stated that they received training (Table 1). It has been observed that employees receive OHS training at a higher rate than employers. However, this rate was not considered sufficient for the employees of architectural offices.

It is important for health to take short breaks between works in ensuring OHS. Resting the tired office worker at regular intervals creates a healthier working environment in terms of both ergonomics and OHS. In this context, in the question asked about the situation of taking short breaks in office work; 90.8% of the participants (128 people) stated that they work by taking breaks. 38.3% (54 people) of those who gave this answer were identified as employers and 52.4% (74 people) as employees. Of the participants, 2.1% (3 people) were employers, 1.4% (2 people) were employees, and 3.5% (5 people) stated that they worked at the computer for a long time without taking short breaks. 3.5% (5 people) of the participants were employers, 2.1% (3 people) were employees, and 5.7% (8 people) expressed their indecision on this issue (Table 1). When the rates of working by taking a break were examined, it was observed that the majority of the participants took breaks from their studies. This shows that employers and employees are aware of the importance of working by taking breaks in providing OHS.

It is also important to do exercises during breaks from office work. Therefore, in another question, the participants were asked whether they did exercises during the breaks. Of the participants, 16.3% (23 people) were employers and 20.6% (29 people) were employees, 36.9% (52 people) stated that they worked by doing exercises. Of the participants, 20.5% (29 people) were employers, 24.8% (35 people) were employees, and 45.4% (64 people) stated that they continued their work all day long without exercising. 17.7% of the participants (25 people) stated that they were undecided on this issue. 7.1% (10 people) of those who gave this answer were observed as employers and 10.6% (15 people) as employees. When the rates of exercise during the breaks were evaluated, it was observed that only 36.9% of the participants exercised (Table 1). It has been observed that this rate is higher in employees. However, the rate of exercise of architectural office workers who continue their activities in an intense work tempo was found to be low.

When asked about the awareness of the importance of ergonomics in providing OHS; 29.8% (42 people) of the participants were employers, 36.2% (51 people) were employees, and 66% (93 people) stated that they were aware of the relationship between OHS and ergonomics and that they worked under appropriate conditions. 0.7% (1 person) of the participants were employers and 1.4% (2 people) were employees, and 2.1% (3 people) stated that they were not aware of the link between OHS and ergonomics. Of the respondents, 13.5% (19 people) were employers and 18.4% (26 people) were employees, 31.9% (45 people) stated that they were undecided about the awareness of the relationship between OHS and ergonomics. The rate of participants who have awareness of OHS and ergonomics was determined as 66% (Table 1). It was observed that this rate was higher in employees (36.2%). Although the definitions of OHS and ergonomics are known, it is not enough to have 66% awareness of the relationship between the two concepts. It is thought that it is important to organize training for office workers in order to eliminate this deficiency.

Table 1. Analysis results for OHS awareness in Kayseri architecture offices.

		Absolutely I agree	**I agree**	**I'm undecided**	**I do not agree**	**I strongly disagree**	**p**
Obtaining OHS training	employer % (n)/ worker % (n)	12,1%(17)/ 19,1%(27)	14,9%(21)/ 15,6%(22)	5,7%(8)/ 7,1%(10)	5%(7)/ 7,1%(10)	6,4%(9)/ 7,1%(10)	**0,900**
	Total	**31,2% (44)**	**30,5%(43)**	**12,8% (18)**	**12,1%(17)**	**13,5% (19)**	
	employer % (n)/ worker % (n)	17%(24)/ 26,2%(37)	21,3%(30)/ 26,2%(37)	3,5%(5)/ 2,1%(3)	2,1%(3)/ 0,7%(1)	0%(0)/ 0,7%(1)	**0,405**

Taking short breaks in office work	**Total**	**43,3% (61)**	**47,5% (67)**	**5,7% (8)**	**2,8% (4)**	**0,7% (1)**	
Exercise during short breaks at the office	employer % (n)/ worker % (n)	7,1% (10)/ 12,8% (18)	9,2% (13)/ 7,8% (11)	7,1% (10)/ 10,6% (15)	17% (24)/ 16,3% (23)	3,5% (5)/ 8,5% (12)	**0,358**
	Total	**19,9% (28)**	**17% (24)**	**17,7% (25)**	**33,3% (47)**	**12,1% (17)**	
Awareness of the importance of ergonomics in OHS	employer % (n)/ worker % (n)	14,2% (20)/ 14,9% (21)	15,6% (22)/ 21,3% (30)	13,5% (19)/ 18,4% (26)	0% (0)/ 0% (0)	0,7% (1)/ 1,4% (2)	**0,888**
	Total	**29,1% (41)**	**36,9% (52)**	**31,9% (45)**	**0% (0)**	**2,1% (3)**	

($P \leq 0.05$ indicates that there is a significant difference between employers and employees.)

As a result of the questions asked to measure the OHS awareness of architectural office employees; it has been seen that the participants have knowledge about OHS but are not fully aware of the relationship between them and other disciplines. It has been observed that the employees of architectural offices that know OHS do not fully fulfill the requirements of working in conditions suitable for OHS, and this is due to the lack of knowledge on the subject.

Results

With the developing technology conditions, important transformations have taken place in working life as in every field. This situation has both positive and negative effects. In terms of OHS, experiencing negativities is one of the main problems. Occupational diseases and occupational accidents have also diversified with the emergence of different business lines that have increased with the industrial revolution. This situation necessitated taking measures for OHS. The purpose of OHS is to protect the health of employees and ensure that they work at high efficiency. Working in conditions suitable for OHS is of great importance in office work areas. The results of the fieldwork carried out in the architectural offices in Kayseri are discussed in this section.

Discussion

There have been significant changes in office work with the new working styles brought by the changing living standards with the developing time conditions in the world and in Turkey. Especially with the widespread use of computers, most of the studies started to be carried out at the desk in front of the screen. As a result of this situation, various dangers to ergonomics arise. Working in conditions suitable for OHS and ergonomics for office workers, who are in the working environment for a long time, minimizes dangerous situations and ensures a healthy work environment. For this reason, the concepts of OHS and ergonomics maintain their importance with the intense office activities today. These concepts also show their effect in studies conducted in the world and in Turkey. In the studies conducted, it was seen that the risks related to ergonomics in terms of OHS were evaluated. In the studies, it has been observed that the common purpose is to improve the working conditions such as increasing the performance and productivity and providing OHS.

Results

Employees working in the same position for a long time in intense work tempo in architectural offices have various risks in terms of OHS and ergonomics. Dangerous situations can be

prevented with various arrangements to be made in order to work in conditions suitable for ergonomics. In this context, this study was needed to measure the awareness of OHS in architectural offices in Kayseri. The fact that Kayseri has important potentials in the field of architecture and that no studies related to the subject have been made in the province have been a factor in the selection of Kayseri. In the study, the number of samples was decided with statistical analyzes and a field study was carried out in 56 offices with the aim of reaching more participants. Responses were received from 141 office workers.

Using a five-point Likert scale, a questionnaire study was created that aimed to rank the opinions of the participants and to provide easy answers. The survey data were analyzed with the Chi Square test in the SPSS (22) program. It was examined whether the status of being an employer and an employee made a significant difference in the results. Since $p>0.05$, it was concluded that there was no significant difference between employers and employees in all of the data. When the findings of employers and employees in architectural offices in Kayseri are examined, it has been determined that employers have more information about OHS than employees. In general, this rate was found to be close to employers among employees. Therefore, it was observed that there was no significant difference in the results.

The responsibility of providing OHS in architectural offices belongs to the employer. Working in a healthy environment, ensuring high performance and efficiency is an important issue in architectural offices as in every business activity. For this reason, employers have a great responsibility to ensure that employees work in conditions suitable for OHS and produce quality products. Since office activities are in the less dangerous class, the seriousness of the employees about OHS may decrease. For this reason, the issue is not given due attention. In order to prevent this situation, employers should inform their employees, organize trainings, monitor working conditions under appropriate conditions and ensure the continuation of the necessary regulations. Employees should be encouraged to work in accordance with OHS. It has been observed that there are deficiencies in the level of education since some employers do not hold themselves responsible for receiving OHS and ergonomics training. This is a misconception. The education level of all employees, both employers and employees, must be sufficient and in a suitable condition to work. It is recommended that employers be more aware of this issue and eliminate their deficiencies. It will be important that the level of knowledge is sufficient in order to ensure that the employees work in conditions suitable for OHS and ergonomics. It is recommended that employers organize seminars and trainings for their employees at regular intervals. It has been observed that exercises are not done during short breaks in offices and they work in the same position for a long time. Although this issue is seen as unimportant by office workers, it causes serious health problems if not taken care of. For employers, this situation causes loss of performance and workforce in their employees. For this reason, it is necessary to raise awareness of employees especially about doing exercises by employers.

Academic researches on the working environment in architectural offices are considered important due to the limited number of studies in the field. Considering the architectural office workers in architectural offices throughout Turkey, the importance of guiding studies on the subject increases. It is foreseen that this study, which is thought to have an important contribution to the literature, will form the basis for other studies to be carried out. It is thought that the missing aspects of the work station examined within the scope of the research will be eliminated with other studies to be done and it will have an important place in the literature.

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Construction Safety Hazard Recommendation using Graph Representation Learning

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Abstract

Construction safety possesses a considerable challenge to the construction industry. Factual risk assessment (RA) is vital for the effective identification of construction hazards and controlling the associated risks. In this regard, a wide range of machine learning (ML) methods are used over the construction safety records, for achieving a better representative RA. This study first depicts the accident records in form of graph-structured datasets and then utilizes graph representation learning (GRL) *methods for obtaining the node embeddings and optimizing a neighborhood-preserving. To this end, a technique is used to learn the hazard by embedding an unbiased random walk in the neighborhood space of construction accidents. As a result, the developed system is beneficial for the construction site managers to receive recommendations of possible site safety hazards based on the existing hazard scenario.*

Keywords: *construction risk assessment, graph representation learning (GRL), hazard recommendation, machine learning, semi-supervised learning.*

Introduction

Site occupational safety poses a considerable challenge to the construction Industry. Before any intervention for improving the site safety status, the risk assessment (RA) procedure is conducted, comprising the identification, analysis, and evaluation of safety risks. The first stage of risk identification is to identify any item with the capacity of causing negative health outcomes. In this respect, hazard identification involves gathering job-specific information and site inspection. Considering the complexity of the construction site, identification of all the hazard items is difficult and time-consuming. Despite its essential role in RA procedure, there exists no international regulation for hazard identification (Chartres et al., 2019). Collecting the hazard items using experience, research and brainstorming is prone to human error and negligence and thus reduces the confidence level of RA procedure and affects the risk-informed decision-making outcome. Unless a hazard item is identified, an appropriate RA procedure cannot be conducted. This in turn hinders effective implementation of the risk countermeasures and reduces the site safety status.

To increase confidence in hazard identification utilization of the past accident records and experience gathered from the previous projects is vital. Utilization of the past construction accidents enhances the breadth of the hazard item lists. The collected accident records contain rich information about the accident, associated causations, and embedded hazard items. One way to effectively utilize the past event dataset is to train the Machine Learning (ML) algorithms for the specific task. In the existing body of knowledge, the ML methods are well developed over the past decades in a wide range of construction safety applications (Cheng et al., 2020; Comberti et al., 2018; Koc et al., 2021; Yang & Kim, 2020; Yang et al., 2022). For example, ML approaches are used for predicting construction falls (Mistikoglu et al. 2015; Piao et al. 2021; Yang et al. 2016), traffic (Almamlook et al. 2019; Chong et al., 2005; Lee et al. 2020; Sohn & Lee 2003; Wang et al. 2019) and workplace (Matías et al. 2008) accidents. Likewise different Natural language Processing (NLP) are used to retrieve textural safety information (Cheng et al., 2020; Tixier et al. 2016). However, amongst different ML and NLP methods, there have found no literature for developing a hazard remuneration system to assist the RA procedure.

Recommendation engines are providing useful information to end-users and hence improve the quality of their decision-making process. These recommendation engines offered practical solutions to information retrieval platforms LinkedIn, YouTube, Facebook, Netflix, and Amazon and thus lately have attracted the attention of researchers (Awan et al., 2021). Considering the usefulness of the recommendation engines for information retrieval from the dataset, this study develops a novel recommendation engine based on graph representation learning (GRL) (Hamilton, 2020) to facilitate hazard identification as well as to improve the comprehensiveness of the hazard list. As one of the most promising and fast-growing sub-areas of ML, GRL has shown great potential in deriving knowledge embedded in different kinds of graphs. Specifically, many GRL techniques, such as random walk and graph neural networks, have been developed to learn the particular type of relations modeled by graphs, and have been demonstrated to be quite effective (Wu, 2021; Wu et al. 2021).

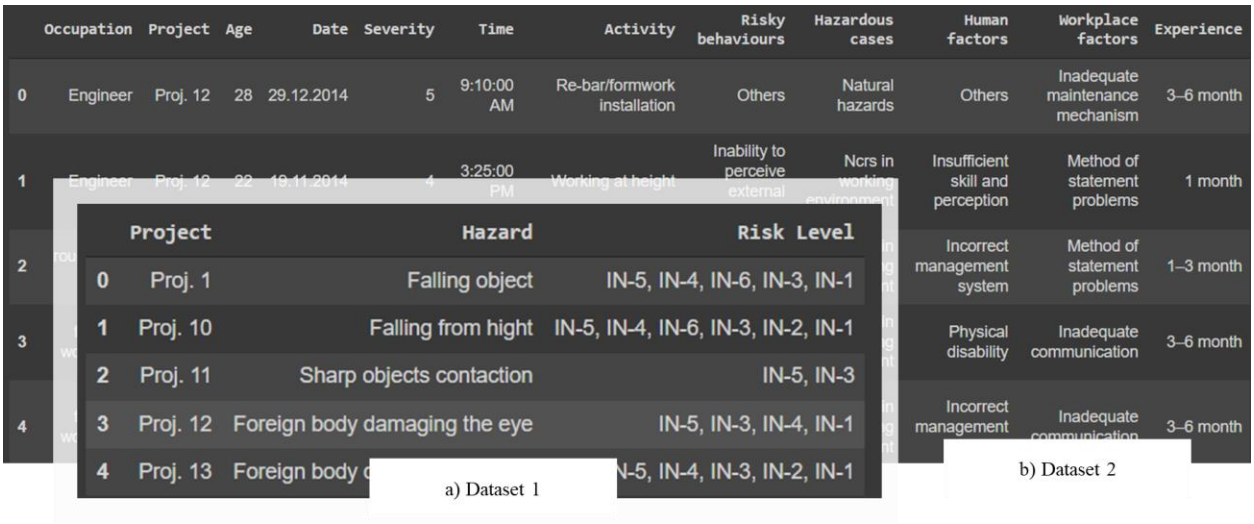
In addition, GRL understands the embedded nodal and link information of the construction accident features. These mandate learning the representative features themselves, with all the associated diverse connection patterns, perceived within the established network (Grover & Leskovec, 2016). Identifying influential features in maximizing the odds of preserving the nodes within a neighborhood, allows for mapping them in low-dimensional space with the project information in each node (Grover & Leskovec, 2016). Here, the node2vec algorithm can continuously learn the embedded mapping between the nodes and feature representation in a network of construction projects linked with their associated safety indicators. For effective exploration within diverse patterns of all neighborhoods, a biased random walk procedure is implemented by the node2vec algorithm. This secures flexible neighborhood exploration and facilitates learning a richer feature representation, whereby generalizing the notion of network neighborhood (Grover & Leskovec, 2016). Therefore, the GRL-based recommender advances the hazard recommendations for three reasons; firstly, GRL illustrates the relationship between the characteristics of different accident data collection across various projects while considering the project similarities in terms of the shared hazard items; secondly, a relation-aware representation (RAR) datasets is structured while assigning each hazard item to both project and its accident features and also to the different construction occupations; thirdly, a hazard recommender engine is developed which is capable of suggesting the relevant hazard items considering the accident

features shared amongst different projects and construction occupations. Compared with the literature this study is innovative in sense of its first time developing a safety/hazard recommender engine while combining the NLP algorithm with the optimization method.

Construction Safety Network

The construction safety network is developed, as the input data of the proposed hazard recommender engine, within the five steps as follows.

Step 1. Create a graph-structured dataset, placing project information at nodes, while connecting the projects based on the shared hazard items, referred to as edges. For this, two datasets are generated where dataset 1 shows graph-structured dependency information (Figure 1a) while dataset 2 details the safety features associated with each project node (Figure 1b).



	Occupation	Project	Age	Date	Severity	Time	Activity	Risky behaviours	Hazardous cases	Human factors	Workplace factors	Experience
0	Engineer	Proj. 12	28	29.12.2014	5	9:10:00 AM	Re-bar/formwork installation	Others	Natural hazards	Others	Inadequate maintenance mechanism	3–6 month
1	Engineer	Proj. 12	22	19.11.2014	4	3:25:00 PM	Working at height	Inability to perceive external	Ncrs in working	Insufficient skill and perception	Method of statement problems	1 month
2										Incorrect management system	Method of statement problems	1–3 month
3										Physical disability	Inadequate communication	3–6 month
4										Incorrect management	Inadequate communication	3–6 month

a) Dataset 1

	Project	Hazard	Risk Level
0	Proj. 1	Falling object	IN-5, IN-4, IN-6, IN-3, IN-1
1	Proj. 10	Falling from hight	IN-5, IN-4, IN-6, IN-3, IN-2, IN-1
2	Proj. 11	Sharp objects contaction	IN-5, IN-3
3	Proj. 12	Foreign body damaging the eye	IN-5, IN-3, IN-4, IN-1
4	Proj. 13	Foreign body c	N-5, IN-4, IN-3, IN-2, IN-1

b) Dataset 2

Figure 1: a) Dependency information and, b) accident features in the safety network.

Step 2. Weights are added to the hazard connectivity information based on the age of construction workers. For this the positive mutual information method is used between project node X and project node Y. Thus, the hazard connectivity will be defined as stated in Eq. (1).

$$log(XY) - log(X) - log(Y) + log(D) \quad (1)$$

Where, XY shows the number of workers' ages shared, while X and Y are the hazard-based worker's ages at node X, and node Y. The outcome of Eq. (1) quantifies the discrepancy between the probability of node X adjacent to node Y, under the assumption of having independent joint and individual hazard connectivity edges. Additionally, D show the total number of workers' age-based hazards. Besides, the proposed system accommodates the flexibility of excluding irrelevant hazard features. Also, to demonstrate this, the hazard connectivity information related to workers older than 60 years old is removed from the created network. The generated safety network

comprised 73 project nodes, and 2394 hazard edges, while the weight between the edges shows the age of the construction workers (Figure 2). In Figure 2b, the node ranking shows the importance of the node degrees (Figure 2c) based on their number of hazard connections. Also, the number of hazard-based connections within the dataset collected across different projects is shown by the node density.

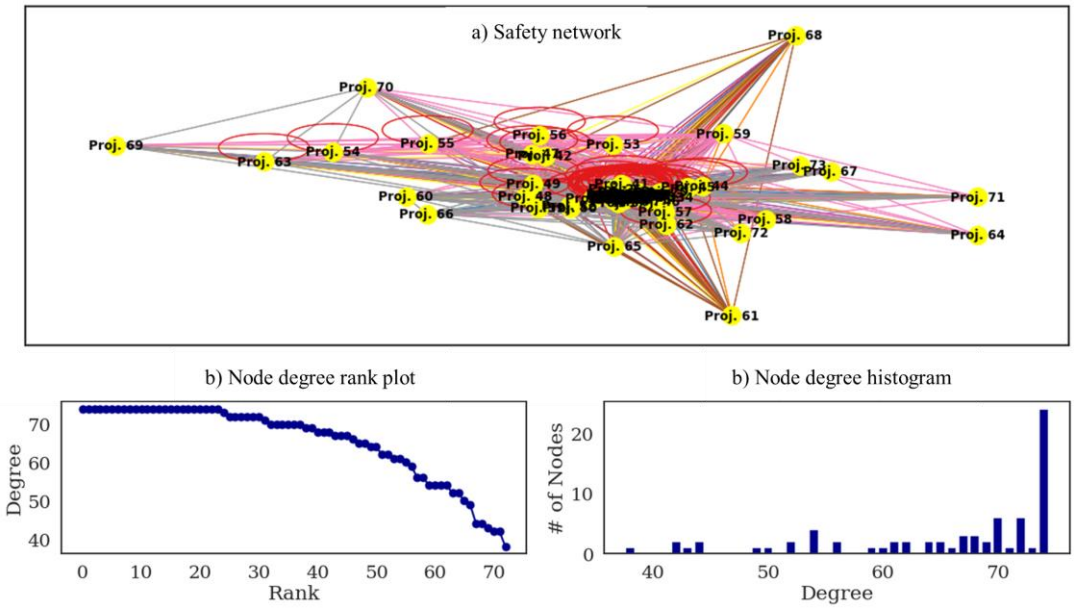


Figure 2: Safety network.

In the node degree in Figure 2c, more than 30 projects are sharing 70-75 hazard items. This further emphasizes the importance of using past accident records for achieving an all-inclusive hazard item list. To illustrate the application of node degree in information retravel from construction accident records, the highest degree node was identified from the created hazard network (Figure 3).

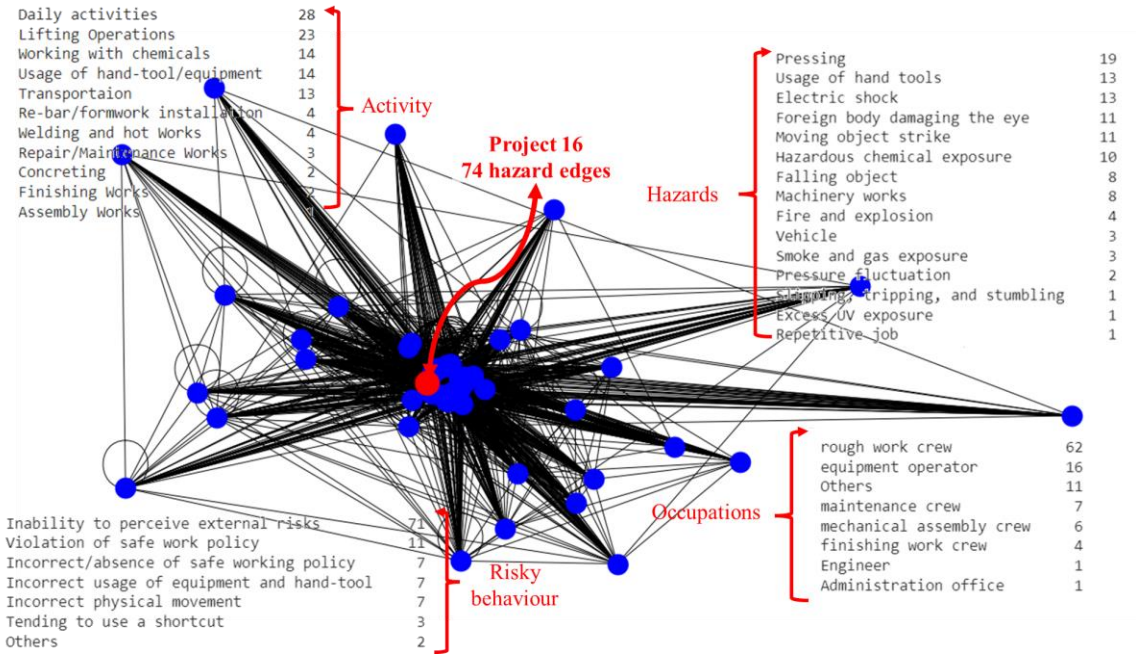


Figure 3: Retroviral of the project safety information with the highest hazard connectivity.

Besides, the centrality (closeness) of the network is measured, showing the reciprocal summation of the shortest connections amongst the nodes. In this respect, the project node with higher centrality is closer related to other projects in terms of the shared hazard items (Figure 4a). Besides, betweenness shows the degree that which project nodes are standing between each other, and thus represents their higher influence on the overall safety network (Figure 4b).

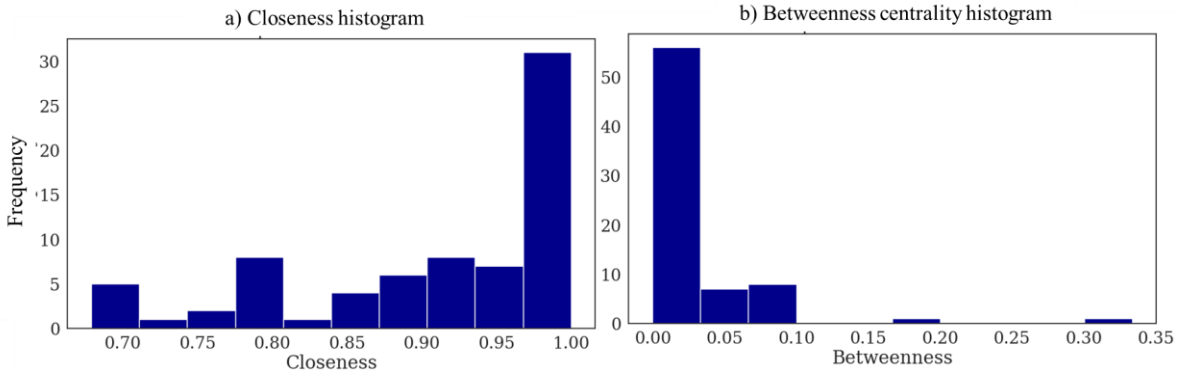


Figure 4: a) Closeness and b) centrality betweenness within construction safety network.

Based on Figure 4, the most critical information can be retrieved through careful investigation of the accident dataset in central projects.

Step 3. A vocabulary of projects concerning different construction occupations is created while mapping the project IDs into the associated integers.

Step 4. The generated GRL is utilized to learn embedded hazard information at the safety network. For this Node2vec (Awan et al., 2021) is used for learning the low-dimensional embeddings from the project nodes and optimizing the received safety information from neighborhood project nodes. Here, a biased random walk is initiated from a certain node, while the next neighborhood is randomly selected based on probabilistically the age weights within the hazard edges. The number of steps taken in each of the random walks is based on the generated sequence of the related project nodes. The adopted random walk is advantageous compared to either visiting just local project nodes (breadth-first sampling) or visiting the distance nodes (depth-first sampling) (Awan et al., 2021). Here, setting high or low likelihood values encourages moderate exploration or local walk, respectively. Besides, the in-out parameter is set as one, showing the inward or outward search allowance. Setting a higher in-out parameter biases the random walk towards the neighborhood nodes, while its lower parameter biases the for visiting distant nodes. In this study, the likelihood of immediate revisiting of a node during a random walk is set as 10 while taking the in-out parameter as one. Besides, five walks, each taking 10 steps arranged.

Step 5. Create positive and negative examples through these walks from one project node to another, while the age of the worker (weight) shows the frequency of hazard items between the nodes within a sequence of a random walk. This resulted in 4260 nodes, labels, and weight matrixes.

Modeling the Hazard Recommendation Engine

Recommending the related hazard items over the construction accident network necessitates feature engineering before the recommendation task. The adopted methods are summarized within four steps as follows. It is also to be noted that the developed safety network, as well as the hazard recommendation engines, are scripted within a Python environment using the Google Colab web-based integrated environment while using a GPU hardware accelerator.

Step 1. Training the skip-gram model.

Training a continuous skip-gram model for prediction of the before and after words. To learn the word embedding, this study adopted a natural language processing (NLP) method named as Word2Vec: a family of ML models which perform both ML and optimization that learns embedding from a large dataset. Subsequently, the dot products amongst node embeddings are sent to the sigmoid activation function, while using a binary Crossentropy loss. Hence, the architecture of the described skip-gram model is presented in Figure 5.

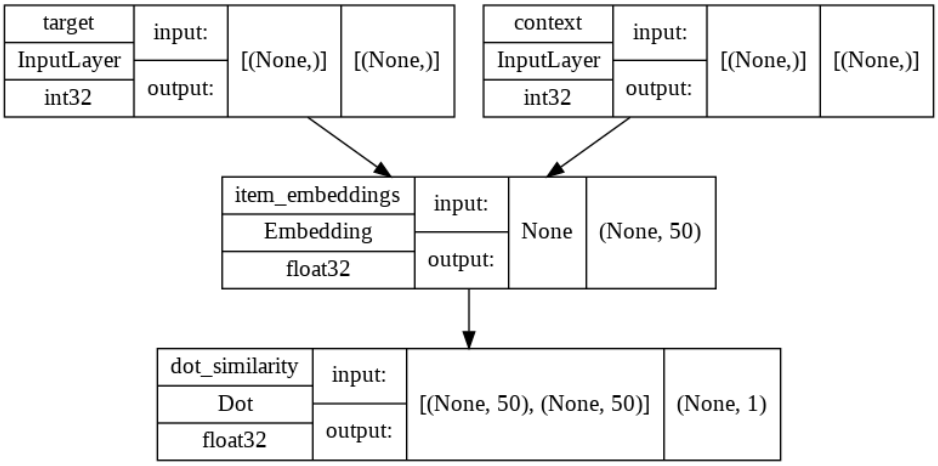


Figure 5: The architecture of the skip-gram model.

According to Figure 5, the learning rate, embedding dimension, number of epochs, and epoch size for training the skip-gram models are set as 0.1, 50, 250, and 1024, respectively.

Step 2. Embedding the hazard information.

To find the embeddings from the entered hazard item, its cosine similarity with other hazard items is calculated, and accordingly, the top five similar hazard items are presented.

Step 3. Evaluating the skip-gram model.

The training loss of the skip-gram model is illustrated in Figure 6 while using the 13.8s CPU time.

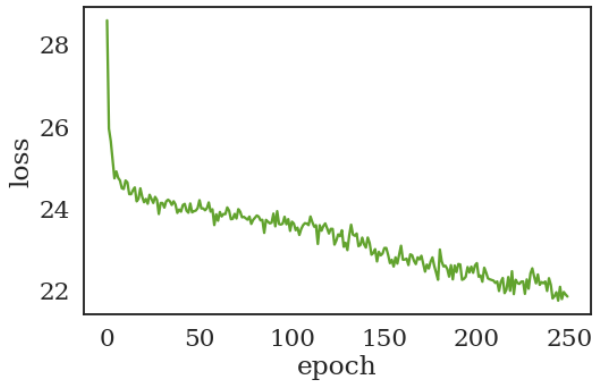


Figure 6: Training loss of skip-gram model.

Step 4. Recommending similar hazard items.

The hazard word vectors visualization was evaluated to better interpret the implementation of the proposed hazard recommendation engine. Accordingly, the analyzed embedding is illustrated in

three-dimensional space of the 1st, 2nd, and 3rd principal components, with 16.9%, 4.1%, and 2.8% variance within the whole hazard space (Figure 7).

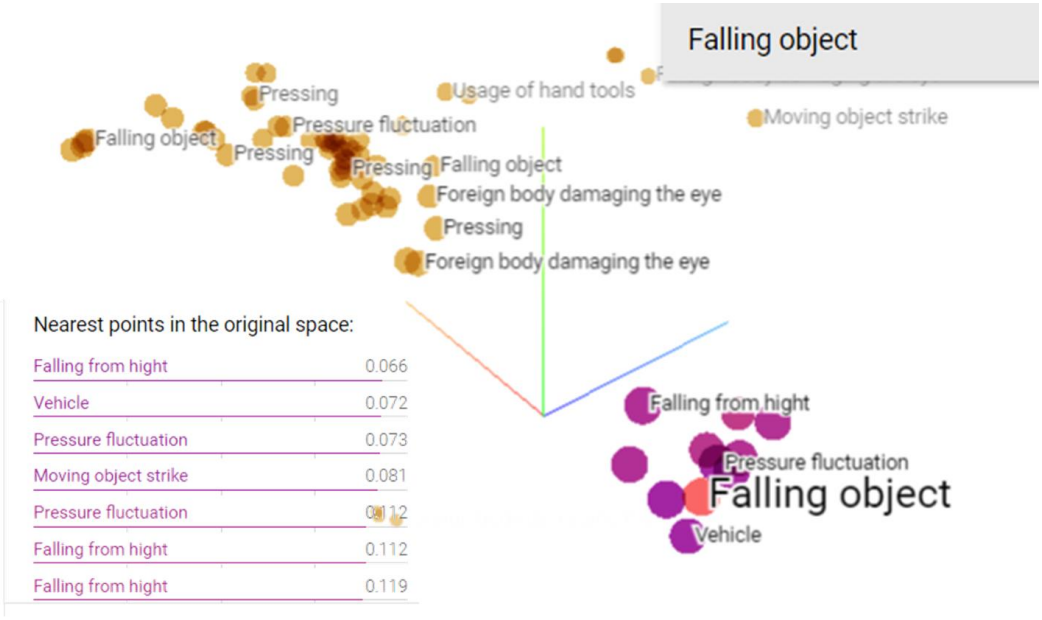


Figure 7: Illustration of the falling embeddings.

As it is shown in Figure 7, the hazard recommendation engine recommends similar hazard items using the cosine distance amongst the project safety nodes. In this study, there exist multiple records of a hazard item, that each defines a single neighborhood.

To illustrate the application of the developed hazard recommendation engine, different hazard items are processed while the system recommendation in terms of similar hazards is presented in Figure 8.

```
Falling from height
-------------------
- Falling from height
- Falling from height
- Pressure fluctuation
- Pressing
- Falling object

Slipping, tripping, and stumbling
---------------------------------
- Slipping, tripping, and stumbling
- Falling object
- Usage of hand tools
- Slipping, tripping, and stumbling
- Foreign body damaging the eye

Foreign body damaging the eye
-----------------------------
- Foreign body damaging the eye
- Pressing
- Falling object
- Slipping, tripping, and stumbling
- Foreign body damaging the eye

Sharp objects contaction
------------------------
- Sharp objects contaction
- Pressing
- Pressure fluctuation
- Foreign body damaging the eye
- Pressing
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Figure 8: Sample hazard recommendation using the proposed recommender engine.

To recommend the most related hazard item, the developed model searches through the hazard information within the embedding space and selects the nearest cosine nodal information as the first recommendation. Accordingly, the further distant nodes are to be listed as the next hazard items.

Overall, the developed recommender system enhances the hazard identification procedure and thus facilitates the risk-informed decision-making for accident prevention in construction sites. Besides, the system can be further improved by integrating the identical hazard recommendation to select the best recommendation items. In practice, the model can be integrated with Microsft Excel to suggest a similar hazard item to what is entered by the user. Since the system is trained over the past accident records, its accuracy increases with the accumulation of the accident dataset.

Conclusion

To effectively utilize the accident records for hazard identification, this study develops a construction accident safety network for the use of a hazard recommendation system. The developed recommendation engine utilizes the node2vec algorithm as a semi-supervised ML technique that learns the represented hazard information at nodes of the created construction safety network. The system also adopts a biased random walk for exploration of different project neighborhoods within the created safety network, whereby offers a richer learning experience to the developed system in terms of flexibility in feature learning before obtaining the mapped information from the low-dimensional space. The model enhances the comprehensiveness of the hazard list during the RA procedure by recommending similar hazard items based on past accident records. This recommendation engine facilitates hazard identification tasks and thus improves the comprehensiveness of the construction RA. The created safety network provided rich information about the construction hazards shared amongst the accidents across different construction sites.

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A Framework for Management of Welfare Facilities in Construction Projects

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Construction projects involve many manual or physical activities, and the construction sites have a challenging working environment. These harsh working conditions negatively affect workers physically and mentally. Welfare facilities such as living accommodations, sanitary facilities, washing facilities, drinking water, changing rooms, rest facilities, and canteens all help reduce fatigue and improve worker health. Deficiencies in the management of welfare facilities cause employees to be unable to meet their vital needs, weakening their commitment to health and safety practices, loss of motivation and productivity, and legal sanctions. On the other hand, the provision of welfare facilities in construction projects is a legal requirement in many countries as part of health and safety regulations and more stringent requirements may vary according to contract terms. Additionally, employee well-being is also a matter of sustainability. Therefore, it is important to ensure welfare of employees in construction projects. This study discusses the management of welfare facilities in construction projects from the perspective of construction management. In addition, it presents a framework on how to determine the criteria to be considered for the design and operation of welfare facilities and how the requirements should be addressed at different stages of construction projects.

Keywords: *construction management, occupational health and safety, sustainability, welfare facilities.*

Introduction

According to Cambridge Dictionary (2022), welfare means physical and mental health and happiness, especially for a person. People have a set of needs to be healthy and happy. Maslow's (1943) theory can provide a perspective for a fundamental approach to this issue. According to Maslow's hierarchy of needs, physiological needs (breathing, food, food, water, sexuality, sleep, healthy metabolism, excretion) and safety needs (body, work, resources, morals, family, health, and property security) come first. Considering that most people spend a third of a day at work, it will be better understood why these basic needs must be met. In addition, in some construction projects, migrant workers spend all their working days at the construction site. For this reason, it is necessary to meet the basic vital needs of workers, even for temporary periods.

The construction industry is one of the riskiest industries in terms of accident frequency and accident results. Improving the health and safety conditions of workers in construction is one of the most important issues (Gurcanli et al., 2015). The working environment in the construction industry is challenging because the operations require intensive labor and are

easily affected by climatic conditions. Also, construction projects involve a lot of manual or physical activity. These harsh working conditions negatively affect employees physically and mentally.

Ensuring well-being of employees in the construction industry is generally considered a part of occupational health and safety practices. Studies show that a problem experienced by the construction industry in occupational health and safety also ensures welfare of workers. In addition, meeting welfare needs of workers reduces workforce absenteeism and increases employee productivity. In other words, ensuring well-being of employees is not only a matter of occupational health and safety but is also directly related to productivity (Gyamfi, 2021; Aravamudhan et al., 2019; Chandrasekaran & Ganeshprabhu, 2020).

Employee well-being is directly related to sustainability. In the early years when the concept was first introduced, it focused mostly on environmental and economic issues. However, in recent years, the International Labour Organization (ILO) (2015) has also included social sustainability in its contributions to the sustainable development goals published by the United Nations (UN) (2015). In summary, social sustainability has subheadings that include ethical, legal, and moral needs of employees (See Figure 1).

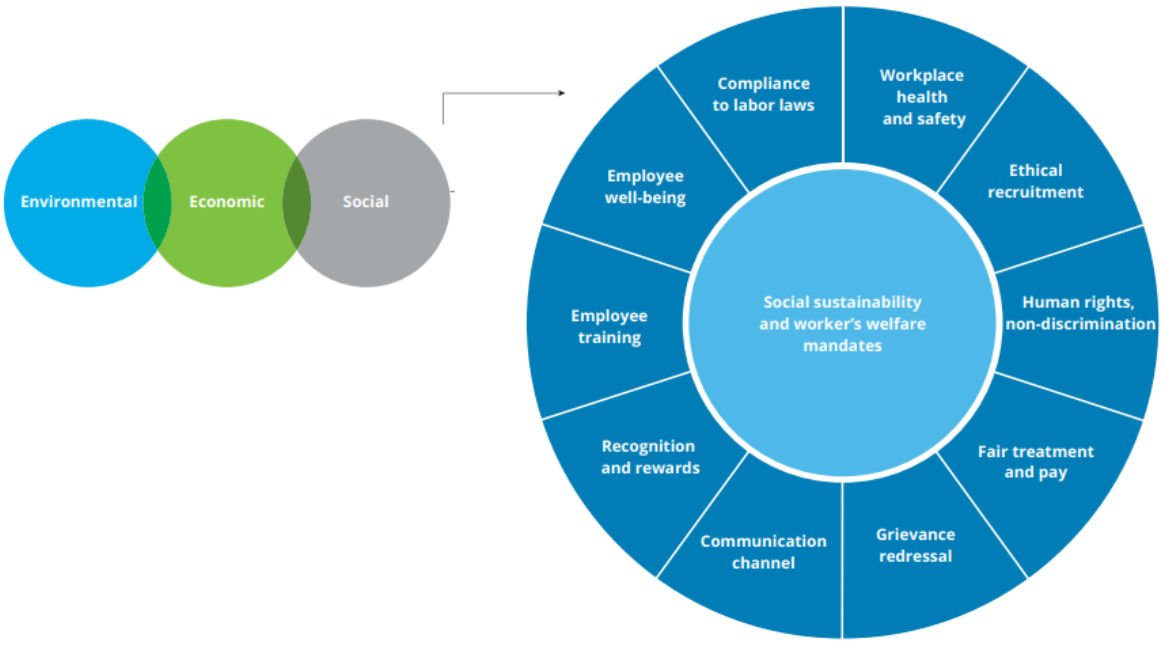


Figure 1: Three pillars of sustainability and relation with welfare (Deloitte, 2019).

Although there are legal regulations in many countries of the world to ensure welfare of employees, there are certain criteria for the management of environmental and social risks in the financing processes of investment projects (International Finance Corporation (IFC), 2012; European Bank of Reconstruction and Development (EBRD), 2019). In this context, providing welfare opportunities to employees has turned into a financial and ethical responsibility of organizations besides their legal responsibilities. As seen in Figure 1, worker welfare mandates include numerous topics, such as occupational health and safety, worker welfare, training, grievances, etc. To increase welfare of the workers, these issues should be linked and a holistic approach should be developed.

If the subject is discussed from the perspective of the construction industry, first, it is necessary to describe the industrial specifications. The main features that distinguish the construction industry from other industries are construction site organization, product, project stakeholders, business, and process. A construction site is established for each new product (building), and it is dismantled after the building is completed. The type of construction and the conditions of the production(construction) site differ for each project. The topographical structure of the construction site, ground type, transportation conditions, climatic conditions, workers, materials, and equipment possibilities vary according to project types. Social facilities are needed in all construction projects. These are site offices for technical staff, warehouses, welfare facilities, etc. All the construction site facilities have a temporary character. At the end of the work, they are completely dismantled. In other words, to construct a building, temporary facilities need to be built to meet the administrative and social needs of employees. Some studies have stated that construction contractors hesitate to make the necessary investments due to this characteristic feature of the facilities (Hatem et al., 2019). To manage a successful construction project, it is important to design these facilities considering various parameters (legal/contractual) during the preparation phase of construction projects so that worker welfare is conflict-free throughout the project (Nuhu et al., 2015).

The aim of this study is to present a practical approach to determining the basic requirements for welfare facilities management in construction projects and handling them in project management. The basic requirements are stated by reviewing the literature and international standards/guidelines. A flowchart has been developed to address these requirements during the preparation phase of the projects.

Construction Welfare Facilities and Basic Requirements

The ILO has broadly defined what constitutes welfare facilities for workers. According to the ILO, there are eight categories of social assistance facilities, which are sanitary facilities, washing facilities, catering, eating facilities, changing, storage and drying facilities, recreation/accommodation rooms and childcare facilities (ILO, 1961, 1992, 1999). In addition, first aid and fire precautions are also included in these facilities. Although the ILO defines welfare facilities in a general context, they need to be adapted according to industrial specifications. Directive 92/57/EEC published by the European Union on construction works has defined general rules in this regard (EU, 1992).

Ensuring the well-being of workers on construction projects is regulated in many countries. In most countries, ensuring the well-being of workers is covered in occupational health and safety law and construction work regulations. Policies and implementation guides have been published by international financial institutions to meet the accommodation and other basic needs of workers, apart from the national legislation regulations in the countries (IFC, 2012; EBRD; 2019; IFC & EBRD, 2009). In addition, some companies and autonomous institutions have published various specifications to avoid worker welfare issues by creating a detailed compliance framework regarding worker welfare requirements. These specifications describe various norms as part of the tender/contracts for the construction project (Expo Dubai 2020; QF, 2013)

There are similar expressions about welfare facilities in the ILO and EU regulations and national legislation accepted by the countries. The common emphasis in the regulations is that

an employer is responsible for ensuring the well-being of workers. In this context, the employer should ensure the welfare of the workers by allocating sufficient resources and making adequate planning. In addition, these regulations contain general descriptions of the minimum conditions required to ensure the welfare of the workers. However, general definitions do not include specific measures of minimum welfare requirements (e.g., accommodation rooms must have $4m^2$ of space per worker, etc.). Expressions such as "adequate or appropriate" describe that the employer must manage the welfare facilities in a way to meet the requirements in the legislation.

In IFC and EBRD's performance standards, there are defined dimensions (size, count, etc.) in some titles (accommodation and sanitary facilities). Similarly, some construction organizations have definitions of minimum requirements (CIDB, 2018). In summary, there are not any internationally standardized norms to describe the minimum requirements for welfare facilities in construction projects in detail. Nevertheless, the specified legislation regulations and guides provide sufficient information on the subject. The highlights of international guidelines and things to be considered in welfare facilities are summarized in the following sections.

Accommodations

It is difficult to provide home comfort for employees in a temporary facility. For this reason, if possible, it should be considered to provide the workforce by making use of local opportunities and to ensure that workers do not stay in a temporary accommodation facility. This can eliminate many accommodation-related risks in terms of the risk control hierarchy. However, workers may need to stay on camp for many reasons, such as insufficient local labor supply or the location of the construction site far from residential areas. In these cases, building type or conventional containers for the accommodation of workers should be preferred depending on the specificity of the project. Where accommodations are provided for single workers or those who are separated from their families, additional housing standards should be considered (IFC & EBRD, 2009):

- a separate bed for each worker
- gender-specific accommodation
- adequate sanitary conveniences
- common dining rooms, canteens, rest and
- recreation rooms and health facilities, where not otherwise available in the community.

Accommodation facilities should be located at a reasonable distance from the construction site to be protected from wind, dust, floods, fires and other disasters. These facilities must have sufficient structural strength and adequate dimensions. In these areas, adequate measures should be taken against the risk of fire (fire detection devices and alarm, fire-fighting equipment, etc.). It is also the employers' responsibility to take adequate measures for the workers' transportation from the accommodation area to the construction site.

The area where workers live should have adequate thermal comfort. For this, the dimensions of rooms and some other requirements, such as air conditioning, must be at acceptable levels. The recommended dimensions in the guidance published by IFC and EBRD (2019) are as follows: "Density standards are expressed as minimum volume or minimum floor area per resident, ranging from 10 to 12.5 cubic meters (volume) or 4 to 5.5m² (surface). Other

restrictions that can affect the design of temporary facilities should include a minimum ceiling height of 2.10 meters. In minimized collective rooms, only a reasonable number of workers are allowed to share the same room to give workers some privacy, ranging from two to eight as a standard. When using a double deck, there should be sufficient free space (0.7 to 1.10 meters) between the bottom and top bunks of the bed". "Ensuring good standards in living facilities helps to avoid safety hazards and to protect workers from diseases and illness resulting from humidity, the spread of the fungus, proliferation of insects or rodents, as well as to maintain a good level of morale".

Sanitary and Toilet Facilities

Sanitary and toilet facilities include water closets, portable chemical toilets and urinals (HSE, 2010). There should always be an adequate number of sanitary and toilet facilities in the construction. Adequate facilities mean making sure there are enough toilets, so people do not have to queue for long periods to go to the toilet. In addition, adequate hygienic conditions should be ensured in these facilities. Toilet arrangements are necessary in construction projects to prevent any contamination caused by biological risks and to prevent the spread of infectious diseases.

The COVID-19 pandemic has revealed the importance of occupational hygiene. The cleaning frequency should be determined according to the number of utilizations. Daily cleaning may not be sufficient; thus, there should be a cleaning plan for these facilities.

The recommended practices for sanitary and toilet facilities in the guidance published by IFC and EBRD (2009) are as follows: "Standards range from one unit per 15 persons to one unit per six persons. For urinals, the usual standards are one unit per 15 persons. Toilet facilities are conveniently located and easily accessible, with standards ranging from 30 to 60 meters from rooms/dormitories. Toilet rooms shall be located to be accessible without any individual passing through any sleeping room. In addition, all toilet rooms should be well lit, have good ventilation or external windows, have sufficient hand washbasins, and be conveniently located. Toilets and other sanitary facilities should be ("must be" in cold climates) in the same building as rooms and dormitories. An adequate number of handwash facilities are provided to workers, with standards ranging from one unit per 15 persons to one unit per six workers. Handwash facilities should consist of a tap and a basin, soap, and hygienic means of drying hands. An adequate number of shower/bathroom facilities are provided to workers, with standards ranging from one unit per 15 persons to one unit per six persons". The BS6465 code (2006) recommends a ratio of one toilet per seven persons where portable toilets are emptied once a week.

Washing and Laundry Facilities

Activities in the construction industry often take place in a dusty and dirty work environment. Activities include the handling and use of chemicals and other hazardous materials. For this reason, an adequate number of washing facilities should always be available in construction areas as a hygiene measure. Washing facilities include basins or sinks that allow people to

wash their hands, face, and forearms (HSE, 2007). In addition to running water (hot and cold), sufficient soap and other personal cleaning materials should be provided. Washing or shower facilities are provided for particular dirty work or work exposing workers to a hazardous substance such as concrete pouring (HSE, 2007). These facilities must be kept in good working condition, cleaned frequently, and always ensure that there is sufficient ventilation and lighting (HSE, 2010). The recommended practices for washing facilities are as follows: "An adequate number of handwash facilities are provided to workers. Standards range from one unit per 15 persons to one unit per six workers. Handwash facilities should consist of a tap and a basin, soap and hygienic means of drying hands" (IFC & EBRD, 2009). Employers should provide the necessary facilities for the workers to wash their dirty clothes. When work clothes are used in contact with a dangerous substance (for example, the application of pesticide), special laundry facilities (washing machines) should be provided (IFC & EBRD, 2009).

In case of special chemical risks such as asbestos in demolition and renovation activities, the number, location, and adequacy of these facilities should be specially evaluated.

Drinking Water

Construction workers take part in strenuous activities. They can face many risks from dehydration on a routine day. To prevent this, workers should always be encouraged to consume enough water, and accordingly sufficient clean water should be easily accessible at the construction site. A healthy source of drinking water should preferably be readily available from the mains. If this is not possible, potable water tanks and bottles can be considered. In all cases, containers that contain drinking water must be protected from contamination. The source of drinking water should be marked to distinguish between potable and non-potable water, such as hazardous liquids and non-potable water (HSE, 2007).

Canteen/Dining Halls/Cooking Facilities

These facilities must be kept in clean and sanitary conditions. The canteen, kitchen, cooking floors, ceilings and walls should be made of easily cleanable materials. The canteen and dining hall should be adequately furnished. Tables, benches, individual glasses and plates, and other necessary materials should be available in sufficient numbers and suitable conditions in these areas. These areas should be designed in sufficient size so that workers do not wait in line at mealtime sanitation.

Hygiene while cooking for workers and food safety is important. Places for food preparation should be designed to permit good food hygiene practices, including protection against contamination between and during food preparation (IFC & EBRD, 2009).

Adequate precautions should be taken against fire in kitchens. For this, sufficient fire/gas detection sensors and the right type of fire extinguisher should be available. Wall surfaces adjacent to cooking areas in kitchens should be made of fire-resistant material.

Changing Rooms and Lockers

Changing rooms and lockers are essential for workers to store their belongings and change their daily clothes with the necessary protective clothing. Work clothes should be kept away from personal clothes. Because work clothes can be contaminated with dangerous substances, clothes can become dirty due to the working environment.

Changing rooms should have such a design that workers can dress comfortably and there should be a separate locker for each worker. Standards vary from providing an individual cupboard for each worker to providing 475-liter large lockers and one meter of shelf unit (IFC & EBRD, 2009). The cabinet lock must be personal. The safety of personal belonging in locker rooms should be ensured by facility security personnel.

Rest Facilities

Activities carried out in construction projects are labor intensive. In a routine working day, it is inevitable for workers to take breaks at certain times. Breaks are important to reduce the mental and physical fatigue of workers. For this reason, suitable and adequate resting facilities should be provided so that workers can easily access during break times. Rest areas can also be in working areas only if they are clean enough (for eating). However, these areas should not be used to store equipment or supplies. Rest areas should be designed in a way that is less affected by seasonal conditions (wind, rain, etc.).

The size of the remaining facilities is proportional to the workforce in the project. If there is an accommodation facility in the project, special areas should be created for the workers in these areas apart from the working areas. Adequate seating groups and tables should be provided in rest facilities, as well as equipment and materials to enable workers to consume hot drinks and meals.

Medical Facilities

Providing adequate first aid training can save lives and prevent minor injuries from becoming major injuries. The availability or level of medical facilities provided in workers' accommodations is likely to depend on the number of workers living on the site, the medical facilities already existing in the neighboring communities and the availability of transport (IFC & EBRD, 2009).

Other Social Facilities and Requirements

To improve workers' well-being, it is important to provide workers with basic recreational and social facilities. The building contractor should consider providing basic public social areas (e.g. prayer rooms, libraries, multipurpose halls, TV rooms, etc.) and additional leisure/sports facilities. Communication systems, such as an Internet connection, should be provided conveniently or free of charge.

Management of Construction Welfare Facilities

Every construction project needs different sizes and types of welfare facilities to ensure the well-being of workers. The size and variety of the facilities may vary depending on the legislation in the country of the construction, company policy, client/investor expectations/contract conditions, project type and workforce. Therefore, before starting any project, the welfare requirements in the project should be analyzed in detail. If these requirements are not understood and the necessary planning is not done, in most cases, it is not possible to expand and diversify these facilities during the construction phase. In addition, analyzing the construction welfare facilities can also help define the cost analysis and the resources to be allocated during the project.

Welfare facilities planning in construction projects should be considered during the planning and preparation phases of each construction project before construction work begins. HSE (2010) proposes to consider the following when planning outreach to constructions:

- "the nature of the work to be performed and the associated health risks (physical, chemical and biological risk factors)
- duration of work and number of different locations
- the number of people who will use them
- are relocated during the construction phase."

Multiple parameters affect the size and location of welfare facility types. The association made by the ILO (n.d) regarding the types of welfare facilities in constructions and the factors affecting them has been updated by the author in Figure 2.

Considering the parameters and relations specified in Figure 2, the type, size, and location of welfare facilities should be determined. The site layout should be prepared after evaluating the location of welfare facilities and their relationship according to the emergency planning and site access roads (Elbeltagi et al., 2004). Another work to be done during the preparation phase of the project is to plan the management of these facilities. It is recommended to prepare a written Construction Welfare Facilities Management Plan (CWFMP) for this. This plan should be linked to other plans and procedures as a component of the project's health and safety management system. The CWFMP should contain, as a minimum, the followings:

- A policy that meets workers' welfare needs
- Identification of facilities (types, sizes, location, and minimum requirements)
- Identification of key personnel and their responsibilities for the maintenance and management of the facilities (site manager, accommodation manager, security guard, HSE team, etc.)
- Methods for risk reduction in facilities (including relocation of facilities)
- Routine checks and drills
- Regular maintenance activities
- Relationships with the communities and grievances
- Facility security

Facility/Factors	Factors affecting sizing of facility							Factors affecting locating of facility						
	Statutory requirement	Company policy	Past experience	Size of workforce	No. of workers	Site location/Type	Phase of project	Statutory requirement	Company policy	Past experience	Size of workforce	No. of workers	Site location/Type	Phase of project

Accommodation		•	•	•		•		•	•	•	•	•		•
Sanitary and toilet	•	•	•	•				•	•	•	•	•	•	•
Washing and laundry	•	•	•	•				•	•	•	•	•	•	•
Canteen/Dining hall	•	•	•	•			•	•	•	•	•	•	•	•
Changing rooms and lockers	•	•	•	•			•	•	•	•	•	•	•	•
Rest facilities	•	•	•	•				•	•	•	•	•		•
Medical facilities	•	•	•	•		•		•	•	•	•	•	•	•

Figure 2: Affecting factors and welfare facility type (adapted from ILO, n.d).

The CWFMP should be completed during the preparation phase of the project; if needed, it can be revised later. Mobilization planning should be carried out using the CWFMP. According to the CWFMP, installed/assembled facilities should be inspected and regularly maintained throughout the construction period.

Employees should be informed about the rules for the use of facilities. In addition, emergency drills need to be conducted. The condition of the facilities should always be reviewed as part of the emergency planning in the project, especially fire.

If it is necessary to relocate welfare facilities at various stages of the project, this should be done by observing the minimum criteria previously described in the CWFMP. The optimum positioning of welfare facilities is important, particularly in projects with insufficient construction areas. For this, modular systems can be rented or purchased. In light of the factors affecting the type of facility and the above information, the association made by the ILO (n.d) for the design and management of welfare facilities in construction projects has been developed and updated by the author as shown in Appendix 1.

It should be reminded that the temporary facilities mentioned in this study are related to the basic vital needs to ensure welfare of the workers. Workers' holistic needs for health and well-being require more than just building and operating these facilities. It should also be reminded that ensuring well-being in the workplace also covers issues such as recognition and rewards, communication channels, grievances, fair treatment and pay, human rights, and nondiscrimination.

Conclusion

Ensuring the well-being of employees has become a practical necessity in terms of sustainability in addition to being a legal obligation. If welfare of the workers is not ensured sufficiently in constructions, there is a risk of worsening their health, an increased loss of working days, loss of motivation in the workers regarding occupational health and safety

practices and loss in productivity. For this reason, although welfare management is considered a component of the occupational health and safety activities conducted in the project, this should be considered as a title of project risk management. For construction projects to be more efficient, healthy and safe, project managers can acquire deeper knowledge of the needs of health, safety, and wellbeing. They can also consider international best practice recommendations in the design of facilities and ensure that workers are fully provided with welfare facilities during construction.

This study has defined the steps to be followed for the management of welfare facilities from the preparation phase of the project to the end of the construction phase. It is recommended to implement a plan called CWFMP for the management of welfare facilities in construction projects. The criteria specified in this study are limited to the norms specified in the references. As mentioned earlier, welfare requirements in construction projects may differ according to the type of projects, the legislation of the countries in which they are carried out, and other requirements of commercial contracts. These variables can change the depth of information that may be required for the CWFMP and other related documents.

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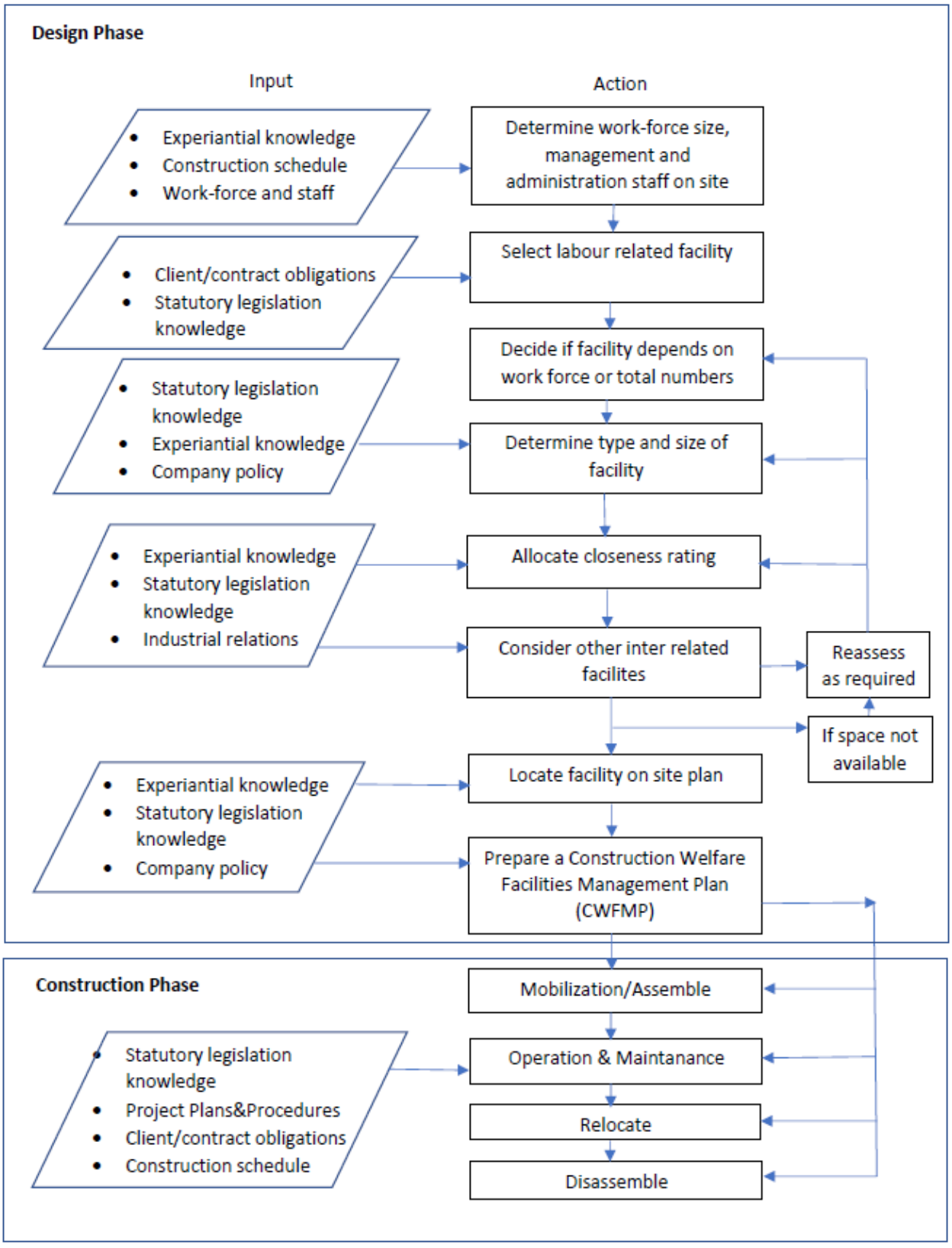
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Appendix 1. Design and management scheme of construction welfare facilities (adapted from ILO, n.d).



A Review Study for Real-time Monitoring in Construction Health and Safety

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Abstract

The construction industry has one of the highest accident ratios according to international occupational safety statistics. Construction safety monitoring is mostly done by manual supervision in present applications. It is challenging for safety inspectors to continuously monitor and manually determine all events that have potential health and safety risks. To deal with this matter, real-time monitoring of construction sites is necessary to detect and remove possible dangers on time. Therefore, both the hazardous status of environments and the risky behavior of workers must be monitored in real-time to protect workers from injuries and fatal accidents. Monitoring systems can include a variety of components and methods, can be applied to different kinds of environments and activities, and satisfy the needs of the safety inspection. This study aims to review the previous works and present the current research status on this subject. Literature research and interpretation in construction monitoring are presented in this review. The results show the advantages of monitoring in real-time, system components, effects of monitoring on safety, and limitations of the system. In a conclusion, real-time monitoring system elements can be chosen according to site conditions, and they are more powerful in safety the contrast to manual inspection.

Keywords: *construction site safety, real-time monitoring, sensors.*

Introduction

Sensor and monitoring technologies have been in a rapid development process in recent years. The production of more sensitive, fast data transfer, affordable and suppliable products is increasing. With these products, control and monitoring of large areas can be realized. In order to meet the increasing population and needs, the size of the structures to be built is also increasing. As a result, construction sites also cover large areas, and monitoring of these sites becomes essential for occupational safety and worker health. Monitoring of construction sites is essential for internal and external stakeholders as well as employees. The right time and regular flow of information are crucial for the success of the project (Naticchia et al., 2013; Teizer et al., 2007). Many fatal accidents are common on construction sites. Visual control and monitoring become more and more difficult in construction sites where many employees work together (Xiong et al., 2022).

The construction industry strictly depends on monitoring the construction area as well as taking precautions against occupational accidents. And taking precautions depends on

monitoring the construction field. Various tools are developed such as RFID, UAV, and Computer Vision. And besides, the outcomes of these tools are investigated in various research studies (e.g., Rao et al., 2022). This study focuses on safety issues and solving them by using emerging technological devices and methods. Besides this, a scientometric study is applied to see the trends and current developments of sensor applications on safety issues in construction management.

Studies about IoT and Sensors on Construction Monitoring

The Internet of things (IoT) represents a group of interconnected sensors and devices that work simultaneously to process specific tasks. In industry, IoT can be applied for tracking of safety management in warehousing systems (Zhao et al., 2021). And in the construction sector, IoT is used for detecting the unsafe behavior of construction workers. There are several initial studies about monitoring the construction field to provide occupational safety (Chi et al., 2008; Lee et al., 2009). Khan et al. (2022) designed a safety hook monitoring system using smart safety hooks at high working places. A similar study is conducted on falling from scaffolds by using computer vision techniques (Khan et al., 2022). By using these technologies, a significant decrease in falling from heights appears. Kim et al. (2019) developed a Zigbee-based IoT alarming system that is triggered when a worker reached a hazardous zone. Early warning systems can be built by using IoT technologies. Kanan et al. (2018) develop an IoT-based system to warn workers of the risk of occupational accidents. Zhou and Ding (2017) developed a safety barrier warning system for underground workers. Zhang et al. (2019) used an IoT-based system to detect nonuse of hard hats in the construction area.

By using IoT technologies, a worker can be spotted by using low-energy Bluetooth sensors in the construction zone (Lim et al., 2016). As a result of the spotting ability of IoT techniques, BIM technologies can practically cooperate along with IoT technology. Especially for facility management, IoT can be easily applied for monitoring the facility and labeling BIM data. Su and Kensek (2021) detect anomalies (e.g., inconsistencies with ASHRAE 55 comfort standards) and display anomalies in 3D BIM models. Cheung et al. (2018) developed an early warning system for hazardous gases which employs both BIM and a wireless sensor network. Zhang et al. (2021) used an AI-based IoT technology to monitor tunnel construction and estimate construction-based settlements using the random forest algorithm. Tang et al. (2019) provide a literature review for BIM and IoT-related publications. Besides, IoT and 5G technologies are used for recycling construction wastes (Sartipi, 2020).

Studies about Wearable Devices

Wearable devices include several kinds of technologies that enable tracking workers' situations such as locations, working speed, and health situations. In recent years, various studies are conducted on the benefits of wearable devices. By using these devices, projects can be monitored in more detail and more frequently. Monitoring could be done before adopting these devices. Such as, Teizer and Vela (2009) used video cameras to track construction personnel. By using wearable technologies, personnel's physical condition can be tracked alongside their locations (Al Jassmi et al., 2021). The basic challenge is to transform the acquired data from the devices into a more structured form to be more useful to project managers (Rebolj et al., 2008).

Studies about Construction Monitoring

Scientometric studies are conducted for obtaining new trends in the literature. There are various software packages developed for generating network graphs that show connections between authors, keywords, or other various fields. In this study, VOS viewer is used for analyzing the literature field. A detailed literature review was performed to obtain a complete overview of real-time monitoring studies in terms of construction health and safety. The focus of this review is giving scientometric background on the related articles that were published between 2006 and 2022. For the purpose of finding relevant papers, the following academic databases were used: ASCE, Emerald Insight, ICONDA CIB Library, ITcon, MDPI, Science Direct, and Taylor&Francis. 85 studies were obtained to be more pertinent as a consequence of the search. Journal articles and conference proceedings are the two types of acquired studies. Totally, seven conference proceedings and 78 journal articles were obtained. The scientometric analysis is conducted for these documents.

Figure 1 shows the percentages of databases in a pie chart. The ScienceDirect database holds the largest number of studies with 52 papers, 61% of all publications. ASCE database includes 16 papers and 19% of the total publications. . These 16 studies include 10 journal articles and 6 conference proceedings. The rest of twenty percent of publications were found from these databases: 6% (5 articles) from the ITcon database, 5% (4 articles) from the MDPI database, 5% (4 articles) from the Taylor&Francis database, 3% (3 articles) from Emerald Insight database, and 1% (1 conference proceeding) from ICONDA CIB Library database.

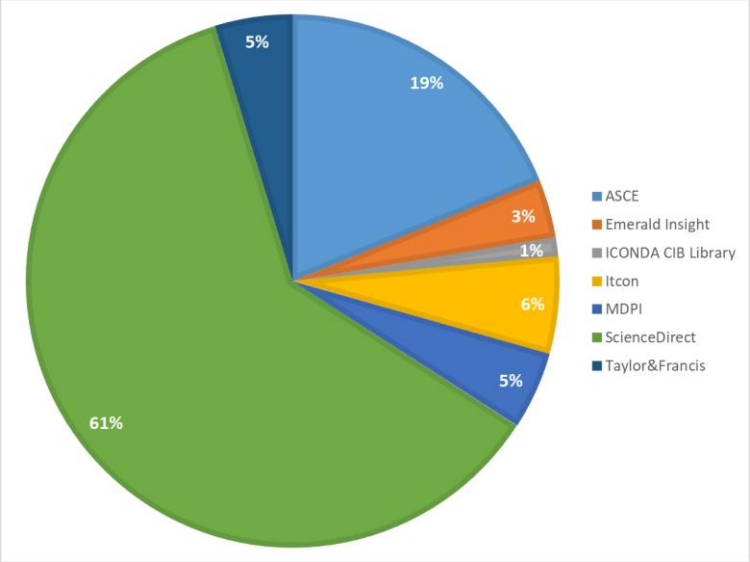


Figure 1: Distribution of databases used to find relevant studies.

Figure 2 illustrates the quantity of journal papers in different journals. A total of 78 journal articles are published in 23 distinct resources. The Automation in Construction journal has the most articles, 32 total, accounting for 41% of all publications. 7 articles (9%) published in Safety Science, 6 articles (8%) published in Journal of Construction Engineering and Management, and 5 articles (6%) published in Advanced Engineering Informatics. There are three articles (4%) for each of the following journals: Journal of Civil Engineering and Management, Journal of Computing in Civil Engineering, Journal of Information Technology

in Construction, and Sensors. Electronic Journal of Information Technology in Construction has 2 articles, accounting for 3%. 14 other journals, each with one publication, account for the remaining 14%.

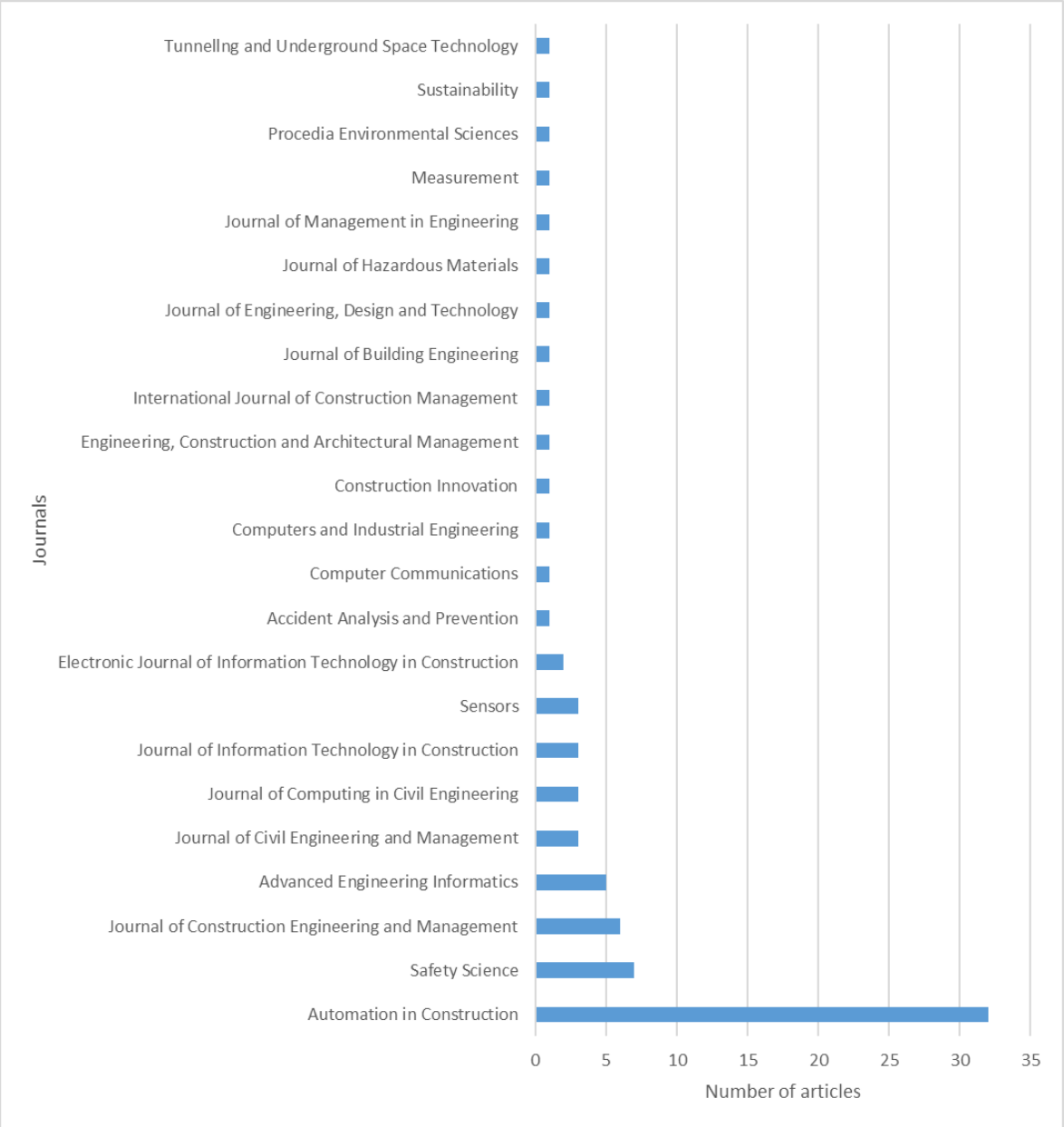


Figure 2: Number of articles published in various journals.

The geographical distribution of research on the topic of real-time monitoring in construction health and safety is visualized in Figure 3. Whole publications are submitted from 17 different countries. In the case of multiple authors, the country of the corresponding author was taken into account while generating the geographical distribution of the articles. The majority of studies are from the United States. There are 30 studies (35%) from the United States, 24 studies (28%) from China, 6 studies (7%) from South Korea, 5 studies (6%) from Germany, 3 studies (4%) from Australia, 3 studies (4%) from Italy, 3 studies (4%) from the United Kingdom, 2 (2%) studies from Israel and 9 (10%) from other countries. Additionally, just one

publication was discovered on the following 9 countries: Brazil, Japan, Pakistan, Poland, Singapore, Spain, Taiwan, Turkey, and United Arab Emirates.

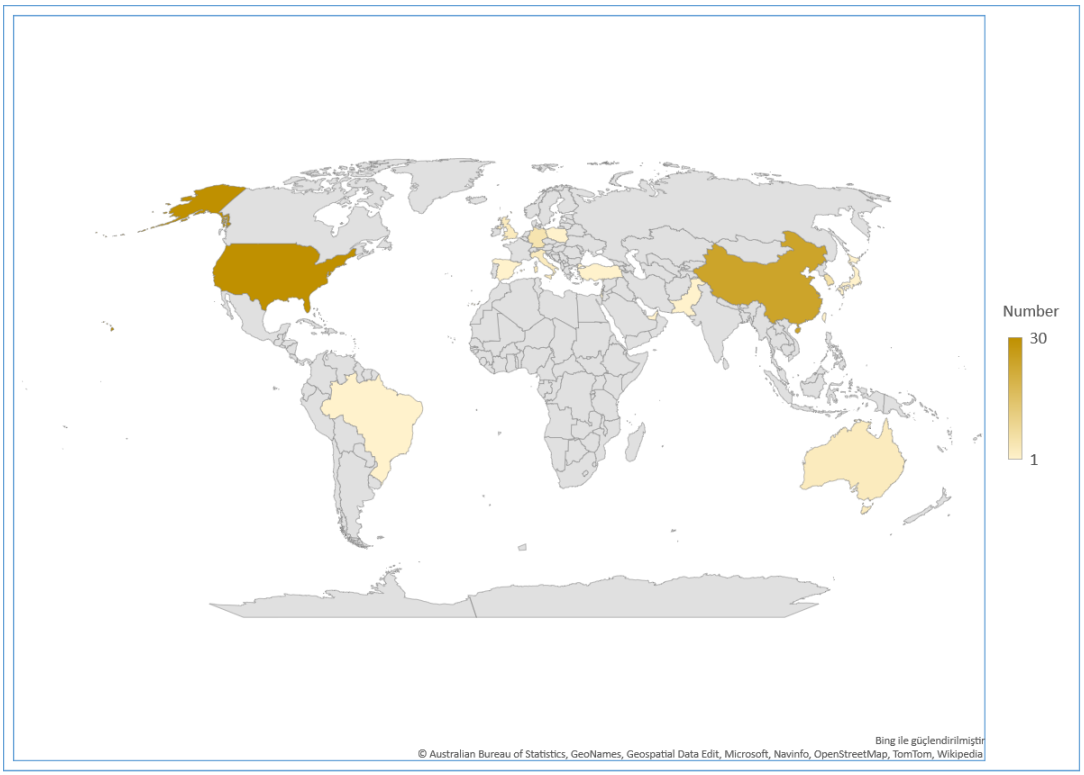


Figure 3: Geographical distribution of articles about real-time monitoring in construction site safety.

Figure 4 shows the chronological distribution of publications on real-time construction safety monitoring between the years 2006 and 2022. The trendline, a line that closely passes the data points, is plotted on this graph. The plot shows that the number of studies about construction safety monitoring has been increasing over the years, and that means the trend in the area is increasing.

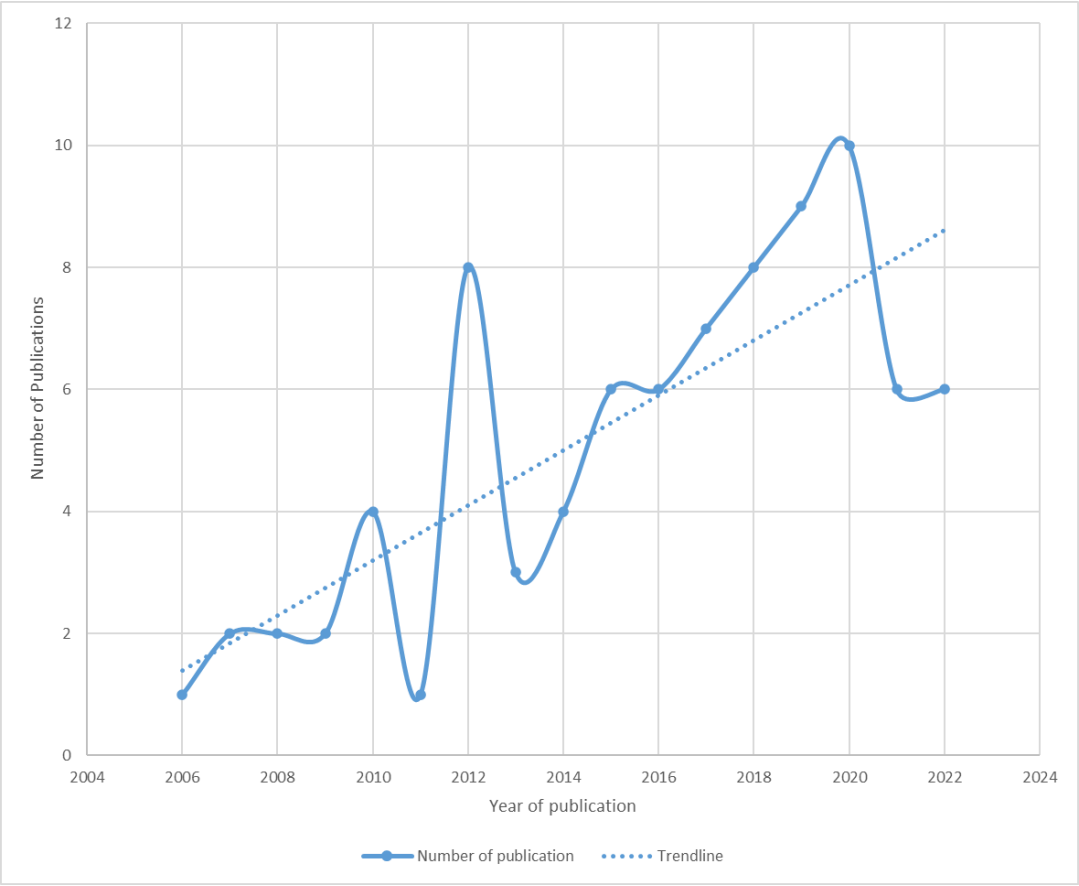
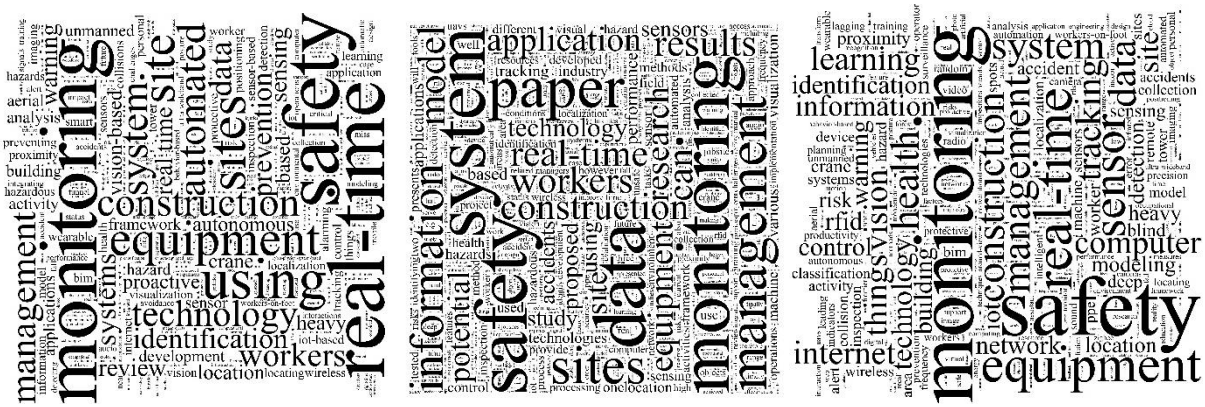


Figure 4: Number of studies about real-time construction safety monitoring per year.

Figure 5 shows the frequency of words used in studies analyzed using the word clouds. Word clouds for the keywords, abstracts, and titles were all generated separately.



(a) Title (b) Abstract (c) Keywords

Figure 5: Distribution of terms depending on how frequently they appear in the title, abstract, and keywords of the papers under analysis.

Another type of textual analysis that was carried out with the use of the VosViewer software tool was similarity analysis. The relations between terms are demonstrated by similarity analysis. The Vosviewer software tool supports a variety of data sources for creating maps, including bibliographic database files from Web of Science, Scopus, Dimensions, Lens, and

PubMed, reference manager files from RIS, EndNote, and RefWorks, and data through API from Crossref, OpenAlex, Europe PMC, Semantic Scholar, OCC, COCI, and Wikidata. Firstly, the publications in Mendeley, a kind of reference manager, were exported as a RIS file and then imported into Vosviewer to perform similarity analysis. After the analysis and counting methods were chosen, the maps were generated.

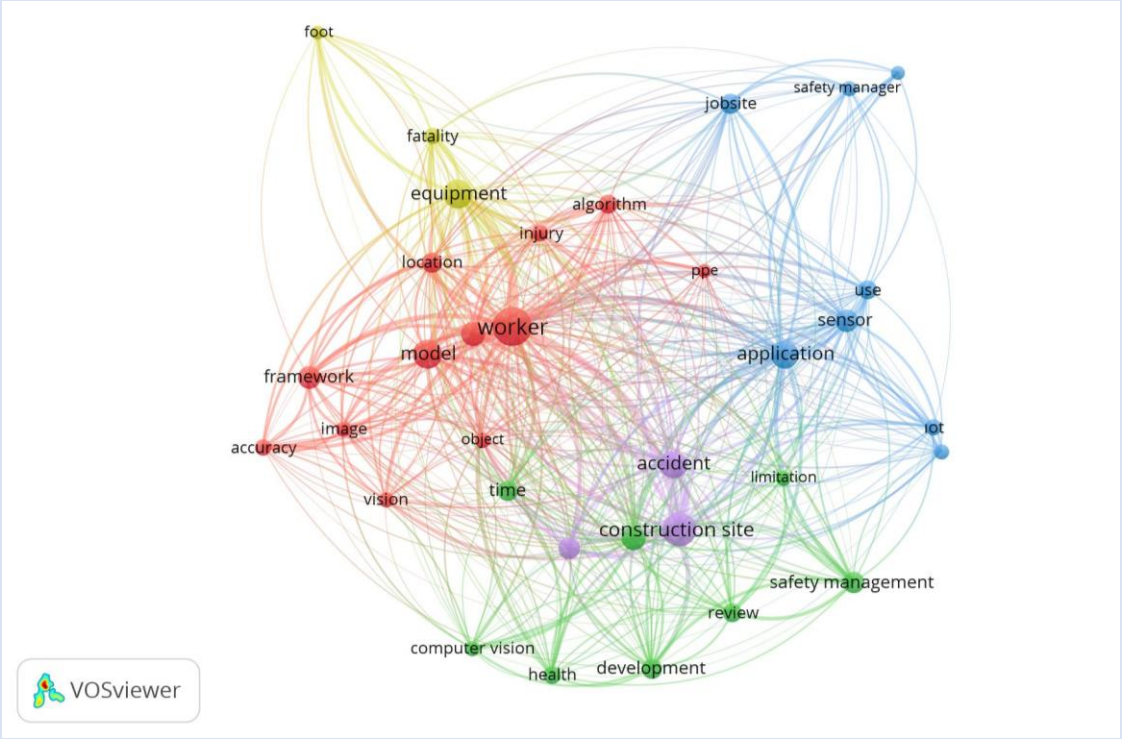


Figure 6: Term similarity analysis within the corpus of texts.

The similarity analysis using a graph is demonstrated in Figure 6. According to the proportion of co-occurrence, the graph in Figure 6 displays the connection between the terms in the abstracts. Larger words appeared more frequently in the abstracts than smaller ones, and more lines imply higher co-occurrence. Figure 7 shows the co-authorship network map which also indicates the year of studies that the author contributes by the color of circles. And each line represents the co-authorship between authors.

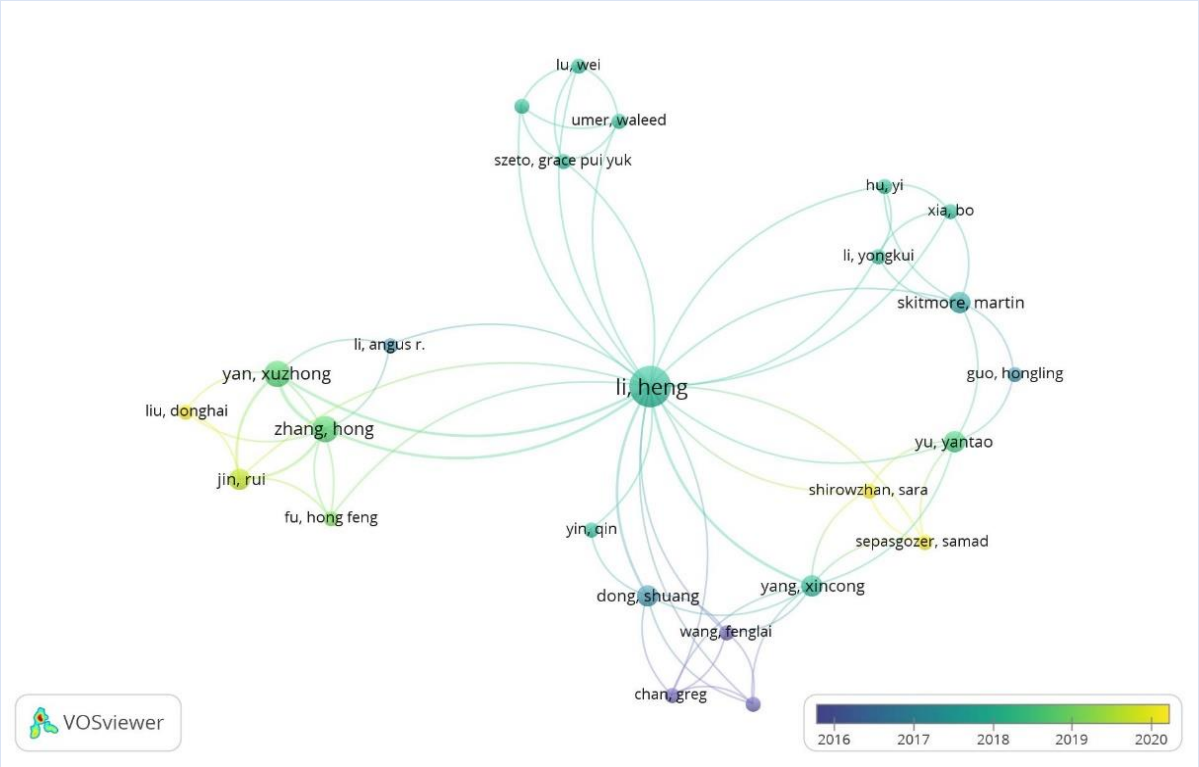


Figure 7: Co-authorship network visualization of analyzed studies.

Conclusion

Various kinds of research are conducted to increase measure levels of occupational safety. In recent years, various novel technologies such as IoT, BIM, and RFID accompanied occupational safety research studies. The difficulty of monitoring construction sites with complex structures is emphasized, and automation is recommended to overcome this difficulty. However, high investment costs and adaptation processes can be considered obstacles to the widespread use of real-time sensing and monitoring technologies in construction projects. In the construction management discipline, IoT and different types of sensors are starting to be used more frequently for safety issues. There is a need of conducting scientometric analysis for the related works. This study shows the increased interest in dealing with safety-related problems by using these kinds of devices.

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Assessment of Occupational Health and Safety Problems in the Construction Sector in the World and in Turkey

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Abstract

The construction sector is one of the leading sectors of the Turkish economy, as in all other countries. Due to the large number of employees, difficult working conditions and a dynamic structure of the construction sector; occupational accidents, injuries and acquired diseases have reached serious numbers over time. They have caused damage to human life, the sector and the economy. According to the data of the Social Security Institution in Turkey, 281.191 people have had work accidents for the last five years and 2,432 people died in the work accidents. Occupational health and safety aims to provide necessary controls and to minimize accidents with the measures to be taken in line with these factors. In this study, the literature about the occupational health and safety in the construction sector will be scanned, and the problems of occupational health and safety on the basis of countries will be evaluated with content analysis method. Content analysis method is an appropriate method that can be used in scanning the texts in the literature in order to express and classify the problems with certain words. The problems and the weights of the problems for occupational health and safety in the construction sector will be determined on the basis of countries with content analysis method. The problems identified in the world will be evaluated and compared with those in Turkey.

Keywords: *construction sector, content analysis, occupational safety.*

Introduction

The construction sector is a dynamic sector that communicates and interacts with almost every sector in the country and includes many sub-sectors. The construction industry in Turkey is the locomotive industry. The construction sector has undertaken important functions such as providing resources to the economy, creating employment, activating other sectors, influencing the natural and social environment, adding value and creating competition. For this reason, positive and negative developments in the country's economy directly affect the construction sector. Positive and negative developments arising from the sector directly affect the country's economy.

The construction industry has become a sector that has many risks and dangers due to the large number of employees, difficult working conditions and active structure. Due to the structure of the sector; accidents, injuries and acquired diseases have reached serious numbers

and have caused material and moral damage to human life, the sector and the country's economy.

According to the definition of the World Health Organization (WHO), “Occupational accident; It is an unplanned event that often leads to personal injury, damage to machinery, tools and equipment, and production stoppage for a while”. (WHO). According to the definition of the International Labor Organization (ILO); “An unexpected and unplanned event that causes specific harm or injury” (ILO).

When the distribution statistics of the within the scope of article 4-1/a of the Social Security Institution (SGK) Law No. 5510, who had a Work Accident, had a fatal work accident or got an Occupational Disease, according to Economic Activity; it has been determined that the construction industry in Turkey inflicts thousands of material and moral losses every year between the years 2016-2021.In the last five years, a total of 281.191 people in the construction sector have had work accidents and have become incapable of work for a certain number of days. However, a total of 2,432 people lost their lives due to work accidents. In addition to production technology, production tools, environmental conditions, many sociological, psychological and physiological factors play a role in the occurrence of occupational accidents. However, all the factors that cause occupational accidents can be reduced to two main factors. These are the unsafe situations in the workplace and the unsafe behaviors of the employees (MMO, 2012). The measures taken to prevent these unsafe situations and unsafe behaviors of employees, and which are legally obligatory to be taken are called "Occupational Health and Safety Precautions".

Within the scope of this study, national and international literature in the field of occupational health and safety in the construction sector has been reviewed. Theses covering the terms "Construction", "Occupational health" and "Occupational safety" have been scanned from YÖK Thesis Center.

The fact that there have been many publications in the field of occupational health and safety in every sector up to now, especially in sectors where occupational accidents and occupational diseases have been frequently encountered, shows the importance of the subject.
In this study, as a result of the literature review, National and International publications in the field of occupational health and safety in the construction sector were evaluated by content analysis method and the publications were classified according to the determined categories. It is aimed to determine the category weights and to compare these weights in Turkey and in the world.

Method

The flow chart of the method of the study is shown in Figure 1. Studies in the field of occupational health and safety in the construction sector have been compiled. The related sources were scanned by content analysis method and their repetition frequency was determined by classifying them according to the determined categories.

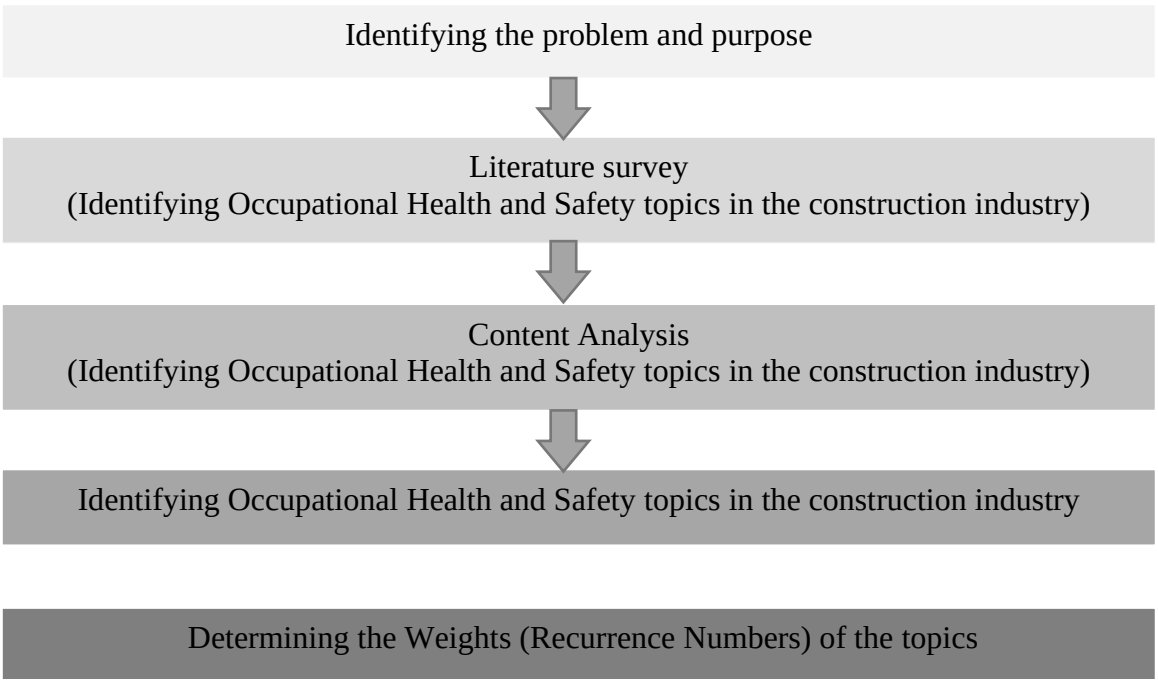


Figure 1: Method flow chart.

Literature Research

When the studies in the literature have been examined, many studies have been found in the fields of Health, Industry, Education-Training, Law, Business Administration, Architecture and Engineering, including the terms "Construction sector", "Occupational health and safety", "Worker". Theses published in the fields of Architecture and Engineering have been examined and a total of 76 theses have been reached in this field. According to the literature review made on Web of Science, a total of 126 resources were reached, including 83 articles, 32 Papers, 6 Review articles, 5 Article-Book sections. The publications reached in the literature will be scanned with the content analysis method in the next stage of the study. Categories will be determined as a result of the content analysis.

Content Analysis

Content analysis is a method of analyzing written, oral or visual communication messages. (Cole, 1988) It allows the researcher to test theoretical issues to enhance understanding of the data. Through content analysis, it is possible to distil words into fewer content related categories. It is assumed that when classified into the same categories, words, phrases and the like share the same meaning (Cavanagh, 1997) It is the systematic examination of text and field notes by identifying and grouping themes and coding, classifying and developing categories (Jonge et al., 2007) In qualitative content analysis, the results are presented in the form of categories and/or themes. (Graneheim et al., 2017).

Determination of the Sample

A total of 126 publications, including articles, papers and book chapters containing the terms "Construction sector", "Occupational health" and "Occupational safety", published in the Web of Science between 2010-2022 were scanned.

Determination of the Categories

Within the scope of the study, the topics in the International Occupational Safety and Employee Health Congress and the International Occupational Health and Safety Congress have been scanned (Table 1). At the end of the assessment of national and international publications with the topics of both congresses (Table 1), "Occupational and Worker Safety", "Occupational Health and Accidents", "Design", "Occupational Safety Management System", "Accident Risks", "Occupational Health and Safety Culture", "Occupational Health and Safety", "Safety practices", "Legislation", "Occupational safety training", "Audit" and "Cost" have been determined as categories.

Table 1. Topics of international occupational health and safety congresses.

INTERNATIONAL OCCUPATIONAL SAFETY AND EMPLOYEE HEALTH CONGRESS (http://www.isguvenligivecalisansagligikongresi.org/)	**INTERNATIONAL OCCUPATIONAL HEALTH AND SAFETY CONGRESS** (http://www.iohsc2017.org/)
Emergency Management	Behavioral Sciences and OHS
Employee Safety	Chemical Industry and OHS
Employee Health	Emergency Management and OHS
Nutrition in Employees	Incentive Mechanisms in OHS
Motivation and Performance in Employees	Ergonomics and OHS
Security Engineering Applications	Good Practices in OHS
OHS Security	Inspection and Audit Practices
OHS Emergency Communication	Occupational Hygiene
Risk Analysis in OHS	Maintenance, Repair and Periodic Controls of Work Equipment
Risk Management in OHS	Metal Sector and OHS
OHS Training	Accidents at work
OHS Cost Analysis	Occupational Health and Occupational Diseases
OHS Legislation	Occupational Health and Safety Services

OHS Database	OHS and Law
OHS Statistics	OHS in Public Institutions and Organizations
OHS Management Systems	OHS Culture
Industrial Products in OHS	OHS Regional Cooperations and Networks
Accident Analysis	OHS organization in the workplace
Controls and Documents to be Issued (Documentation)	OHS in the Agriculture Sector
OHS in mines	OHS in the Construction Sector
Health Informatics	OHS in the Mining Industry
Social Security System	OHS in the Use of Chemicals
Hazardous Substances and Waste Management	OHS Management Systems
Technology Management and Use	Personal Protective Equipment
Fire Response Techniques	OHS in Planning and Project Design
Structural Health and Safety	Process Safety and Management Systems
OHS in Construction Works	Risk management
Occupational Hygiene	Scientific and Technological Developments
Labor Law Employee Rights	Sectoral OHS Practices
Work health	Education and OHS
Business and Quality Management	Working at Height
Equipment Maintenance and Repair in Businesses	
Health Management in the Workplace	

Data Analysis

Identified categories have been assessed on the basis of the 126 publications. Abstracts of the 126 publications have been reviewed and the categories identified have been analyzed based on the words in the abstracts. The countries of publications have been assessed, too. (Table 2). "Occupational and Worker Safety", "Occupational Health and Accidents", "Design", "Occupational Safety Management System", "Risk Analysis", "Occupational Health and Safety Culture", "Occupational Health and Safety Practices", "Legislation and Legislation

appropriate work", "Occupational safety training", "Inspection", "Cost" categories have been assessed in terms of countries. Identified categories have been assessed for Turkey, too.

Table 2. Category classification in terms of countries (https://access.clarivate.com/).

COUNTRY	**CATEGORY**	**PUBLICATION (AUTHORS AND YEARS)**
USA	Work and Worker safety	Hinze et al. (2013), Gatti & Schneider (2014), Park et al. (2015), Bhoir & Esmaeili (2015), Choi et al. (2017), Yang et al. (2017), Hindman et al. (2017), Lee et al. (2017), Kang (2018), Hasanzadeh et al. (2018), Cho et al. (2018), Nnaji & Karahan (2020), Hasanzadeh & de la garza. (2020), Nath et al. (2020), Lee et al. (2020), Zhang et al. (2015)
	Accident risks	Nguyen et al. (2016), Jin et al. (2019), Bhandari et al. (2020)
	Design	Young & Corbet. (2014), Tymvios & Gambatese (2016), Zhao et al. (2016), Tello & Grau. (2018)
	Occupational health and accidents	Kang et al. (2017), Hernandez & Dos Santos (2020)
	Occupational safety Management system	Hallowell & Gambatese (2010), Hallowell (2011), WanbergiHarper & Hallowell (2013), Azhar (2017)
	Occupational health and safety practices	Melzner et al. (2013), Scanlon et al. (2015)
	Work safety education	Marin & Roelofs (2017), Ferrada et al. (2019), Namian et al. (2016)
CHINA	Work and Worker safety	Yu et al. (2019), Yu et al. (2021)
	occupational health and safety culture	Fang & Wu (2015), Chan et al. (2016), Gao et al. (2017), Li et al. (2018)
	Audit	Liao & CW (2015)
	Accident risks	Bai et al. (2020), Zhang & Mohandes (2020), Lu et al. (2021)
	Occupational health and accidents	Wong et al. (2016), Leung et al. (2016), Chan et al. (2018), Wong et al. (2019)
	Occupational safety Management system	Yiu et al. (2019), Chan&Tatlım (2016), Zhao (2014)
	Occupational health and safety practices	Zhao et al. (2018), Antwi et al. (2019)
MALAYSIA	Work and Worker safety	Yap et al. (2020)
	Occupational health and safety culture	Zid et al. (2018), Mohammad & Hadikusumo (2020)

	Accident risks	Al-anbari et al. (2015), Rupansinghe & Panuwatwanich (2020), Abas et al (2021)
	Design	Ibrahım et al. (2020), Ibrahım & Belayutham (2020), Ariffin et al. (2020)
	Occupational health and accidents	Ayob et al. (2018), Zaini et al.(2020)
	Occupational safety Management system	Salim et al. (2016), Adnan et al. (2019), Mohd et al.(2020)
GENERAL	Work and Worker safety	Dejus (2013), Gündüz et al. (2017), Li et al. (2019), Khoshnava & Rostami (2020), Fargnoli & Lombardi (2020)
	Occupational health and safety culture	Manu et al. (2020)
	Occupational health and accidents	Li et al. (2015), Alexander et al. (2017)
	Design	Manu et al. (2019)
SPAIN	Work and Worker safety	Rubio & Garcia (2013), Forteza et al. (2020)
	Accident risks	De los Pinos & Garcia (2017)
	Design	Arevalo (2013), Lopez & Rubio. (2015), Casanovas et al. (2016)
	Occupational health and accidents	Hola & Szostak (2017), Gerassis et al. (2017)
	Occupational safety Management system	Fernandez & Montes (2012)
	Accident risks	Cortes & Prieto (2020)
AUSTRALIA	Work and Worker safety	Sunindijo (2015), Newaz et al. (2020)
	Occupational health and safety culture	Oswald et al. (2018)
	Design	Pirzadeh & Lingard (2017)
	Occupational safety Management system	Sunindijo & Zou (2013)
	Cost	Lingard et al. (2019)
LITHUANIA	Design	Dejus (2010), Simanaviciene et al. (2014)
	Occupational health and accidents	Liaudanskiene & Ustinovichius (2010)
	Occupational health and safety practices	Liaudanskiene & Ustinovichius (2010)
PORTUGAL	Accident risks	Rodrigues et al. (2021)
	Design	Rodrigues et al. (2018)
	Occupational health and accidents	Couto & Ihale (2020)
TURKEY	Occupational health and safety culture	Erdal et al. (2018)
	Accident risks	Gül & Ak (2018)

	Occupational health and accidents	Ayhan & Tokdemir (2020)
SOUTH AFRICA	Occupational health and accidents	Agumba & Musonda (2020)
	Occupational safety Management system	Okonkwo & Wium (2020)
	Legislation	Windapo et al. (2020)
INDONESIA	Occupational health and safety practices	Gusti et al. (2019)
	Work safety education	Endroyo et al. (2015)
INDIA	Occupational health and safety culture	Deepak & Mahesh (2019), Sharma & Mishra (2021)
IRANIAN	Occupational safety Management system	Mohammadfam et al. (2016)
	Occupational health and safety practices	Ghahramani (2016)
IRAQ	Work and Worker safety	Karakhan et al. (2018)
SINGAPORE	Work and Worker safety	Poh & Ubeynarayana. (2018)
ENGLAND	Occupational health and safety culture	Manu et al. (2017)
NORWAY	Audit	Suleiman et al. (2021)
GERMANY	Accident risks	Teizer & Cheng (2015)
SLOVAKIA	Accident risks	Mesaros et al. (2019)
BANGLADESH	Occupational health and accidents	Ahmed (2019)
UZBEKISTAN	Occupational health and accidents	Sultanov et al. (2019)
SYRIA	Occupational health and accidents	Abduljabbar & Saad (2020)
TAIWAN	Occupational safety Management system	Liao & Çan (2017)
GHANA	Occupational safety Management system	Asah et al. (2020)
NIGERIA	Legislation	Adeyemo & Smallwood (2017)
PAKISTAN	Legislation	Qayoom & Hadikusumo (2020)
SOUTH KOREA	Occupational health and safety practices	Choe & Leite (2017)

Determination of the Counting System

"Occupational and Worker Safety", "Occupational Health and Accidents", "Design", "Occupational Safety Management System", "Accident Risks", "Occupational Health and Safety Culture", "Occupational Health and Safety Practices", "Legislation", "Occupational safety training", "Audit", "Cost" categories have been analyzed on the contents and abstracts of the publications, and the frequency of categories have been determined. Frequency of the data has been considered as counting system for the assessment of data

Evaluation of the Findings

In the research conducted on Web of Science between 2010-2022, publications of 27 countries in the field of occupational health and safety have been found. USA 34 in this regard; China 19; Malaysia 14; Spain 10; Australia 6, Lithuania 4; Turkey 3; Portugal 3; South Africa 3; Indonesia 2; Iran 2; India 2; South Korea 1; Pakistan 1; Nigeria 1; Taiwan 1; Ghana 1; Iraq 1; Syria 1; England 1; Norway 1; Germany 1; Slovakia 1; Bangladesh 1; Uzbekistan 1; Singapore has 1 publication. Nine of the studies are general studies, not country-based. It is seen that the countries with the highest number of studies are the USA, China and Malaysia, respectively. Turkey is in 8th place.

The frequency of categories in the world and in Turkey is shown in Figure 2. In 126 publications in the literature; 30 in the “Occupational and Worker Safety” category, 19 in the “Occupational health and accidents” category, 16 in the “Design” category, 15 in the “Occupational safety management system” category, 15 in the “Risk analysis” category, 12 in the “Occupational health and safety culture” category, There were 8 publications in the "Occupational health and safety practices" category, 3 publications in the "Legislation" category, 3 publications in the "Occupational safety training" category, 2 publications in the "Audit" category, and 1 publication in the "Cost" category (Figure 2).

In 76 graduate theses published in Turkey; 3 in the "Occupational health and accidents" category, 2 in the "Design" category, 9 in the "Occupational safety management system" category, 16 in the "Accident Risks" category, and 16 in the "Occupational health and safety culture" category. 7, 15 studies were found in the "Occupational health and safety practices" category, 2 in the "Legislation" category, 11 in the "Occupational safety training" category, 2 in the "Audit" category, and 9 in the "Cost" category. There hasn’t been a graduate thesis on "Occupational and Worker Safety" category.

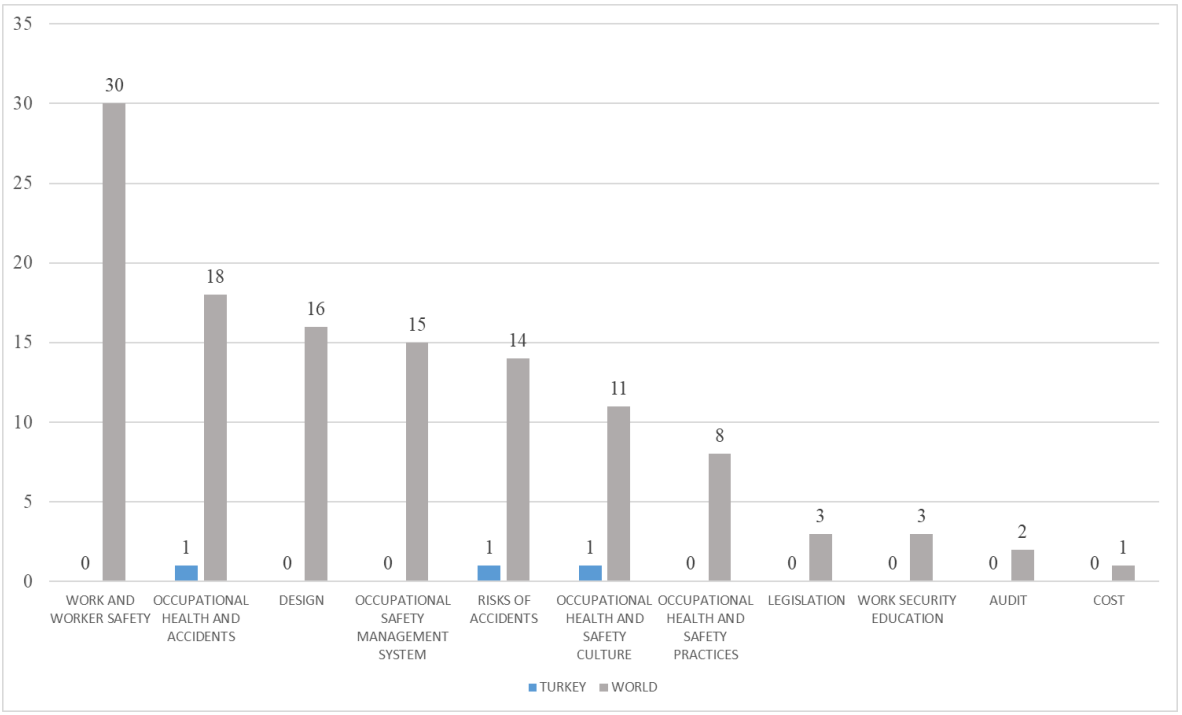


Figure 2: Frequency of categories in the world and in Turkey.

Most of the studies done in the world belong to America, China, Malaysia and Spain. Most of the American publications are on "Occupational and Worker Safety". China has made most of its publications on "Occupational health and accidents", "Occupational health and safety" and "Accident risks" (Figure 3).

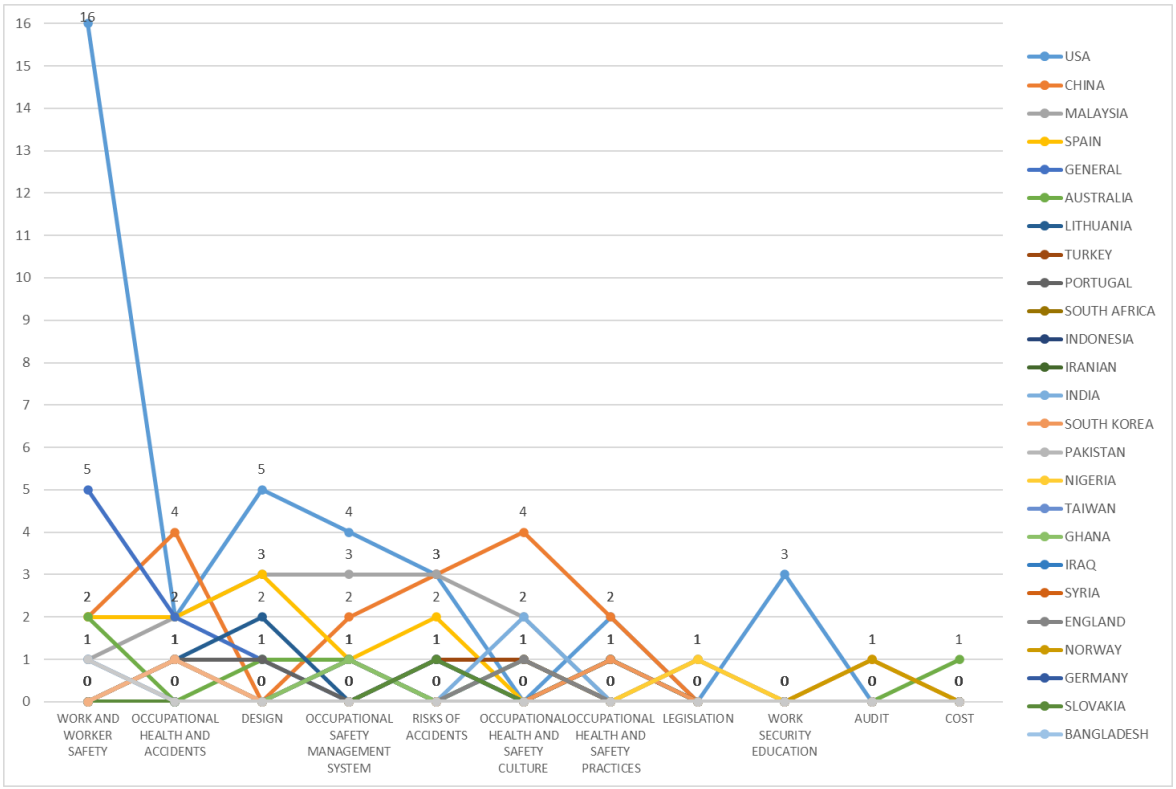


Figure 3: Distribution of studies conducted in the world by categories.

Results and Conclusion

As a result of the content analysis, there are many studies on the "Work and Worker Safety" category in the world, but there is no study in Turkey. However, while there are many studies on "Occupational health and accidents" and "Design" categories in the world, there are very few studies in Turkey. The frequency of the studies carried out in the world and in Turkey in the categories of "occupational safety management system", "accident risks" and "occupational health and safety culture" is almost the same. The studies conducted in Turkey in the categories of "Occupational health and safety practices", "Occupational safety training" and "Cost" are much more numerous than the studies conducted in the world. Very few studies have been conducted in Turkey and in the world on "Legislation" and "Control" categories.

The limited number of studies in the fields of "Occupational and Worker Safety", "Occupational Health and Accidents" and "Design" in Turkey may be a topic suggestion for future studies. The fact that these subjects have been studied in few numbers in Turkey is a major disadvantage for the prevention of occupational accidents.

Occupational Safety Specialist, employer, and worker; need information resources to train themselves and others in the field of Occupational Health and Safety. In this context, the lack of knowledge resources in the current situation is one of the inadequacies in preventing accidents.

As a result of the study, compared to countries such as the USA, China and Malaysia, it is seen that the number of studies conducted in Turkey is quite low in all categories. The small number of studies conducted is a negative situation that coincides with high accident rates. According to SGK statistics between 2016-2021 in Turkey; In the fields of Building Construction, Non-building constructions, Special construction activities, Architecture and Engineering activities, technical inspection and analysis, 281.191 people had work accidents and 2,432 people had fatal work accidents. (SGK,2021). These occupational accidents were mostly caused by falling from a height, falling from roof cavities, being electrocuted. (SGK,2021) For this reason, studies in the fields of Occupational Health and Safety Culture, Design and Risk Analysis in our country will play a major role in preventing occupational accidents and increasing public awareness. It is anticipated that this study will be a guide for future studies in the field of Occupational Health and Safety.

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Rethinking Occupational Health and Safety Standards: As a Key to the OHS 4.0 in the Construction Industry

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Abstract

Construction industry (CI) experiences adverse effects of accidents and near misses. Occupational health and safety standards (OHSS) can play guiding role in enhancing Occupational Health and Safety (OHS) performance in CI. Standards need to be and are kept updated in line with the changing needs, technologies and requirements with respect to the OHS in the CI. This research aims to rethink and examine OHSS from the integration of the industry 4.0 technologies (I4T) into the OHS in the CI. With this aim, 10 international OHSS have been examined. Furthermore, an online questionnaire survey has been applied to the sample consisting of professionals who have experience and/or publications in the relavant field in the CI and academics who have academic publications in this research related field. This study reveals potential of the examined 10 standards to adopt the I4T to the OHS in the CI and provides recommendations. This study may be beneficial to academics and professionals in the relevant field as well as to the workers and professionals in the CI.

Keywords: *construction industry 4.0, industry 4.0 technologies, occupational health and safety standards 4.0.*

Introduction

Adverse consequences of accidents in the construction industry (CI) can be reduced through occupational health and safety standards (OHSS) in CI. CI is an inherently dangerous industry (Taylor, 2015). While construction continues to be a leading industry with respect to annual injuries and deaths, various institutions and organizations work dedicatedly to ensure that injuries and deaths are minimized (Chokor et al., 2016). According to the OSH law, employers are responsible for providing safe workplace which does not contain OHS hazards (Breitbarth, 2021). OSHA's mission is to determine working conditions and standards, and to provide training, social assistance, etc. for the implementation of standards, and to ensure that employees work in a safe and healthy environment (OSHA website, n.d.). Before the OHS law came into force, the number of deaths due to work-related accidents was very high and it was not possible to know the actual number (360trainingwebsite, 2022). The numbers obtained did not even take into account non-fatal injuries, illnesses, and workplace risks (e.g.,

from prolonged exposure to the cancer-causing chemicals) (360trainingwebsite, 2022). Responsibility conscious companies can be willing to take part in environment, OHS applications enable workers to work in a safe environment and to establish appropriate mechanisms for cases such as injury and illness cases (compliance quest website, 2022). Regulatory interventions such as standards and regulations are among the most effective factors in prevention of occupational safety related problems in the CI (Choe et al., 2016). Complying with OHSS can provide many benefits to the employers (e.g., reducing the costs of insurance) (Paoletta, 2019). Even if implemention of OSHA standards (OSHAS) may seem to be costly in the short term, employers who comply with the standards can save from various factors (e.g., workers' compensation and other insurance costs, enabling workers to create a safer workplace and making workers feel productive) in the long term (Graphic products website, 2022). For example, U.S. worker employment has been doubled since OSHA's founding in 1970, whereas workplace death, illness, and injury rates have been dropped by approximately two thirds (Graphic products website, 2022). OHS measures to be taken by experts/specialists in accordance with the changing conditions with Industry 4.0 should be in line with new standards and the legislation need to be updated so that they cover related issues (Tepe, 2021). As industry 4.0 technologies (I4T) are gaining importance depending on the development in technologies, it is necessary to ensure the adaptation of that OHSS in CI are adapted to these changes covering use of I4T in OHS in CI. This study focuses on rethinking and examining OHSS from the perspective of the integration of I4T into OHS in the CI.

Relationship Among OSHAS, CI and Industry 4.0

OSHA (Occupational Safety and Health Administration) was established in the early 1970s as a result of the OSH Act (360trainingwebsite, 2022). Even if the OSH Law was not the first workplace safety law in the country, it was the most comprehensive one (360trainingwebsite, 2022). As part of the US Department of Labor, it is the government agency that sets rules about workplace safety (Woodson, 2012). OSHAS are rules that define the methods which employers should use to protect their employees from hazards (Shrm website, 2022). OSHAS are a set of guidelines and requirements implemented by the OSHA to minimize OHS risks/hazards in US based workplaces (safetyculture website, 2022). These standards encourage employees to be active in establishment of these policies (Safetysign website, 2022). OSHAS are developed to support workplace OHS for all employees (safeopedia website, 2018). OSHA's primary rule is that employers are responsible for maintaining a safe workplace (safeopedia website, 2018). Even if depending on the industry, there may be many OSHA safety regulations for which employers are responsible in their workplaces, these regulations have common points as they were created to protect workers (Safetysign website, 2022).

There are four main groups of OSHAS (i.e., General Industry, Construction, Marine and Agriculture General Industry, Construction, Maritime, and Agriculture) (OSHA, 2019). Some OSHAS are detailed with specifications that vary from industry to industry (360trainingwebsite, 2022). Some standards are industry specific whereas others apply to all industries (Creative safety supply website, 2022). CI standards set specific requirements for all CI employers (Keller, 2010). CI employers are legally required to comply with these standards and all relevant 29 CFR Part 1910 General Industry standards (Keller, 2010). All businesses, regardless of their size and industry, must adhere to OSHAS (Breitbarth, 2021). There are following five main and basic clauses that all employers must comply with:

providing a safe and hazard-free workplace; posting OSHA's healthy and safe workplace advertisements and posters where employees can see them; keeping records for work-related injuries and illnesses, and written emergency action; creating a plan, giving regular training to employees about all risks in the workplace (Breitbarth, 2021). Employees have the right to file their complaint to OSHA and request inspection of their workplace (Paoletta, 2019). Before OSHA can issue a standard, it must go through an extensive and lengthy process involving significant public engagement (compliance quest website, 2022). OSHA can enforce its regulations by conducting scheduled inspections after a serious injury or death in the workplace (Creative safety supply website, 2022). Violated regulations can result in penalties ranging from fines to six months imprisonment (Creative safety supply website, 2022). Many rules, regulations and standards have been developed over the years to minimize the risks faced by employees (Graphic products website, 2022).

Industry 4.0 refers to the intelligent use of data and digital technologies to improve business processes and production systems in the manufacturing industry (i4amf website, 2022). Real-time communication, human–machine cooperation, etc. are becoming increasingly important in industry (Badri et al., 2018). As I4T's effects on daily life increase, new paradigm changes can occur and OHS management can be affected (Badri et al., 2018). Furthermore, it is important to raise awareness of the integration of OHS into I4T, and it is necessary for a smooth transition that field experts and industrialists collaborate (Badri et al., 2018). I4T is a new production paradigm which has a strong impact on work and employees (Zorzenon, 2022). Effects of I4T on OHS are uncertain (Zorzenon, 2022). I4T refers to new developments in automation and data exchange in production technologies (e.g., big data, additive manufacturing, cloud computing, artificial intelligence) (Iavicoli et al., 2022). I4T may lead to new OHS risks and necesitate appropriate risk assessment (Iavicoli et al., 2022). I4T have the potential to help create a sustainable environment as they can provide perspectives regarding future innovation and business growth (Javaid et al., 2022). In the age of Industry 4.0, production is linked with information and communication systems (Javaid et al., 2022). This I4T revolution has been designed to enhance efficiency, flexibility and quality of industrial production, and it can affect the way work is organized and performed as well as employees' OHS (Leso et al., 2018). Standards are an integral part of the transition to industry 4.0 (I4amf website, 2022). There is a growing awareness of the need for standards to strengthen Industry 4.0 (i4amf website, 2022).

OSHAS Related Studies

Literature on OSHAS and the relationship of these studies to I4T can be executively summarized as follows: Based on data obtained from the Bureau of Labor Statistics, Choe et al. (2016) provided evidences for the effectiveness of the revised OSHA 29 CFR 1926 standard in preventing general occupational injuries in structural iron and steel industry in the US CI. With the aim of providing information that can help prevent future recurrences and help policymakers identify inadequate safety standards, Al-Bayati et al. (2021) has conducted a study on evaluation of OSHA's death and disaster investigation summaries. Koshy et al. (2021) conducted a study on future worksite biohazards and infectious diseases. Grant and Hinze (2014) conducted an analysis of the OSHA death and catastrophic event database to better understand the risks associated with truss installation. Malaby (2016) aimed to examine the history of OSHA's laboratory standard. Chokor et al. (2016) focused on analyzing OSHA report data using Unsupervised Machine Learning. Woodson (2012) focused on providing information and general requirements so that employers do not fail OSHA audits and

encounter expensive consequences. Taylor (2015) focused on the benefits of OSHA's 10 hours safety training and developed recommendations for keeping records of accidents and injuries. Biller (2016) worked on the current version of OSHA's Eye and Face protection standard. Keller (2010) focused on the OSHA Subpart regulations for electric safety. Tepe (2021) discussed in detail the views on how the OHS in CI can be affected by Industry 4.0, and on new risks that may cause various occupational diseases and accidents.

OSHA's Standards

A brief description of the 10 OSHAS examined within the scope of this study can be provided as follows:

- *Fall Protection, construction (29 CFR 1926.501):* It describes employers' action to be taken regarding the risks of falls that workers may face. It contains information on issues such as unprotected edges, railings, wall openings, and structural integrity that may cause fall risks.
- *Hazard Communication Standard, general industry (29 CFR 1910.1200):* It indicates that the potential hazards of all chemicals produced or imported must be examined and classified by employers. It explains the information and details (e.g., labels and forms) that should be made by the employer about the hazards to which the employees may be exposed.
- *Respiratory Protection, general industry (29 CFR 1910.134):* It is a standard in which the precautions that employers should take under the situations that may cause various occupational diseases (e.g., harmful dusts, mists, fumes) are provided.
- *Scaffolding, general requirements, construction (29 CFR 1926.451):* It is a standard that deals with the precautions that employers should take against the risks related to the subject starting from the fact that the scaffolds should be designed and constructed by experts professionally to ensure safety of workers on the scaffolds.
- *Ladders, construction (29 CFR 1926.1053):* It contains details of actions (e.g., related with load amount, clearance information) to be taken to address the risks related with fixed ladders or portable ladders.
- *Control of Hazardous Energy (lockout/tagout), general industry (29 CFR 1910.147):* It covers the details for controlling the energy that may endanger workers, and controlling the related machinery.
- *Powered Industrial Trucks, general industry (29 CFR 1910.178):* This standard contains details on the safe use (e.g., fire protection, maintenance and design) of special industrial trucks in workplaces.
- *Fall Protection–Training Requirements (29 CFR 1926.503):* It includes details about the employers' obligation to inform all employees about the risk of falling, and to provide various trainings.
- *Eye and Face Protection (29 CFR 1926.102):* It includes the details of employers' obligation to provide eye and face protection against various substances that may harm employees.
- *Machinery and Machine Guarding, general requirements (29 CFR 1910.212):* It contains several details on employers' obligation to protect operators and other workers working with machinery from various hazards such as rotating parts and sparks.

Research Method

Within the scope of the literature review, relevant previous studies, importance of OHS standards and Industry 4.0 in CI, OSHA's top 10 most frequently cited standards (OSHA web site, 2021) were examined. Following the literature review, a questionnaire survey was applied to a sample consisting of professionals who have experience and/or publications in the relavant field in the CI and academics who have academic publications in this research related field. This survey was prepared to evaluate the potential of the relevant standards to be integrated with I4T. The survey was created through the veti system of Istanbul Technical University and contained questions on respondents' profile and background, and assessment of the standards based on the 5 point Likert scale. The 5 point Likert scale assessment of the standards (where 1 indicates "the lowest potential for integration" whereas 5 indicates "the highest potential for integration") aimed at evaluation of the potential of the 10 OHS standards to be integrated with I4T. Questionnaire survey was applied online to the sample. Respondents were informed that participation to the survey was totally voluntary. None of the questions was obligatory. In total, 58 participants answered the questionnaire. Data obtained through the questionnaire survey have been analysed, mean values, standard deviation and rankings have been provided.

Results

The survey data were analyzed via the SPSS program. Reliability analyzes were performed for each standard separately and for all standards. The Cronbach's Alpha value for the answers given to all questions is 0.870 which indicates reliability. In the following step, the number of participants who answered the questions about the relevant standards, the mean values of each standard, and the standard deviations were calculated and listed. These findings are given in the Table 1.

According to the respondents, the standard with the highest potential (mean=4,4310) to be integrated with/cover I4T is the FPT, whereas the standard with the lowest potential (mean=4.00) is the EFP. 57 participants answered the question asked about the potential of CHE to be integrated with I4T, and it was seen that this standard, with an average value of 4,2105, was in the 2nd rank. 57 participants answered the question about the potential of MMG and RP to be integrated with I4T, and the average value of the answers was 4.1930, and it was seen that they were both equal and in the 3rd rank. 58 participants answered the question about the potential of HC to be integrated with I4T, and it was seen that this standard, with an average value of 4.1724, was in the 4th rank. 58 participants answered the question about the potential of FP and PIT to be integrated with I4T, and it was seen that the average values of the answers given were 4,1552 for both standards, and they were in the 5th rank. 58 participants answered the question about the potential of L and S to be integrated with I4T, and it was seen that the average values of the answers given were 4,1034 for both standards, and they were in the 6th rank. As even the lowest average value is 4.00, based on respondents' assessment in the 5-point Likert scale, indicates that all standards have been indicated by the respondents as capable of being integrated with I4T.

Table 1. Descriptive statistics.

OSHA's Top 10 Most Frequently Cited Standards	Mean	Std. deviation	N	Rank
Fall Protection Training, construction (29 CFR	4.4310	.75189	58	1

1926.503) FPT				
Control of Hazardous Energy (lockout/tagout), general industry (29 CFR 1910.147) CHE	4.2105	.86058	57	2
Machinery and Machine Guarding, general industry (29 CFR 1910.212) MMG	4.1930	.93424	57	3
Respiratory Protection, general industry (29 CFR 1910.134) RP	4.1930	.93424	57	3
Hazard Communication, general industry (29 CFR 1910.1200) HC	4.1724	.88135	58	4
Fall Protection, construction (29 CFR 1926.501) FP	4.1552	.98767	58	5
Powered Industrial Trucks, general industry (29 CFR 1910.178) PIT	4.1552	.98767	58	5
Ladders, construction (29 CFR 1926.1053) L	4.1034	.98568	58	6
Scaffolding, construction (29 CFR 1926.451) S	4.1034	.98568	58	6
Eye and Face Protection, construction (29 CFR 1926.102) EFP	4.0000	1.11803	57	7

*Items in the right columns refer to the OSHAS names

Discussion

When the literature on studies on OSHAS is evaluated, it is seen that publications generally focus on a single standard or the content of the standards (e.g., Choe et al. 2016; Malaby, 2016). Chokor et al. (2016), however, investigated OSHAS and I4T and stated that the analysis of accident reports, which are stated to be mandatory in OSHAS, can be done through machine learning. Chokor et al. (2016) evaluated one OSHAS and I4T together in this respect. Many studies (e.g., Choe et al., 2016; Biller, 2016) examined in the literature specifically examined one or more of the OSHA standards, but did not evaluate them holistically in terms of integration with I4T. There is lack of studies discussing each I4T in detail and how the I4T can be integrated more specifically and effectively into each of the standards. It was stated that even if it was indicated in the literature that changing conditions due to industry 4.0 can cause new and various accidents and occupational diseases (e.g., Tepe, 2021) and the standards should be handled comprehensively (e.g., Tepe, 2021), there is lack of studies specifically focusing on OSHAS from this aspect.

According to the survey participants' evaluation of the potential of 10 OSHAS to be integrated with/to cover I4T, the highest average value receiving standard obtained 4.43 whereas the lowest average value receiving standard received 4.00. This reveals that even the lowest average value receiving standard received relatively high value regarding its integration potential.

The CI has developed solutions related to OSHAS to get rid of the adverse effects of accidents and near misses. OSHAS is developing day by day both procedurally and sectorally, as it can be seen as a result of this literature review. Complying with the developments in I4T and changing needs, there is need to consider the OSHAS for minimizing and eliminating OHS problems together with I4T in CI. Figure 1 highlights that OSHAS, I4T, and CI need to be considered and rethought in an integrated and holistic way.

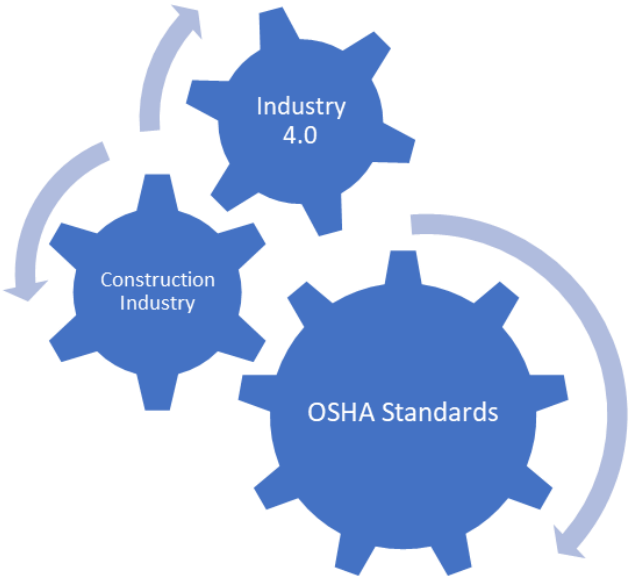


Figure 1: Relationship among OSHAS, I4T and CI.

OSHAS integrated with I4T in CI can have the potential to contribute to sustainability in the CI. For example, OSHAS integrated with I4T can contribute to the reduction in/elimination of worker death and injury and relevant compensations; and to the reduction in accidents and near misses. Considering CI's significance in development in nearly all countries, highlights the significance of the potential support of I4T integrated and covering OSHAS' effectiveness in CI and sustainable development. Even if compliance with OSHAS integrated with I4T in CI may seem to be perceived as costly due to many potential reasons (e.g., initial investment and training costs), it can have potential to provide an economic advantage in the long run enabling the companies to catche up with the era and to adapt themselves to the current situation in CI. Lean management in the CI can have potential to be supported through the integration of I4T and OHSS as accidents and near misses can be expected to be further eliminated/minimized (Erusta & Sertyesilisik, 2019).

Conclusion

As CI is being significantly affected by the consequences of accidents, it is necessary to carry out studies to minimize or completely eliminate the effects and causes of these accidents and near misses. Effectiveness in the OHS management and performance can be supported by OSHAS in CI as OSHAS imposes certain responsibilities on employers and requires them to provide a safe working environment for all CI stakeholders. OSHAS' potential for being a solution to the OHS problems has been indicated in the literature (e.g., Choe et al., 2016; Paoletta, 2019; 360trainingwebsite, 2022; Compliance quest website, 2022). Changing needs of OHS in compliance with development in technologies and requirements require the need for keeping OSHAS up-to-date. The holistic handling of ever-developing I4T with OHS and their adaptation to OSHAS can positively affect the solution of OHS problems in CI. As OHS standards can play an effective role in enhancing OHS performance in CI, integration of I4T into the OSHAS may be important.

OSHAS integrated with I4T in CI can support sustainability in CI especially to this integration's potential contribution to reduction in accidents, deadths, illness, injuries and relevant costs and compensations as well as to the image of CI and companies regarding their OHS performance and record. Furthermore, effective integration of OSHAS with I4T in CI can further support sustainable development.

Within the scope of this study, following the literature review, an online questionnaire survey was applied to get an understanding on the potential of the relevant OSHAS to be integrated with/to cover I4T. According to the respondents, FPT is in the 1st rank as the standard, which is considered to have potential to be integrated with I4T in CI whereas the EFP standard ranked in the last rank having mean value of 4.00 in a 5-point Likert scale assessment indicating EFP being considered by the respondents as capable of integrating I4T in CI. According to the participants, all relevant standards have high potential to be integrated with/to cover the I4T in CI. Future researches can focus on more studies on each OSHAS' integration with I4T in CI and how each updated OSHAS can contribute to sustainability in CI.

This study emphasised importance of and need for rethinking and updating the OSHAS through the integration of I4T into OHS in the CI. This study can be beneficial for academics and professionals working in the relevant field, as well as for workers and professionals working in CI.

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Detection of Helmet Usage of Construction Workers with Image Segmentation

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Abstract

To protect the health and safety of employees, the law in force in Turkey is the Act No. 6331 on Occupational Health and Safety. Within the scope of this law, the measures to be taken by the workplace begin with collective protection measures. However, due to the diversity of work items and the difficulty of applicability on construction sites, employees often have to work individually in different regions and dispersed settlement. For this reason, the necessity of protecting employees with the use of personal protective equipment arises. Legally, in order to protect the employees from possible disasters in hazardous construction areas, helmet which is the one of the personal protective equipment have to be used by the employees. Similarly, according to this law, the employer is obliged to observe whether the helmets given to the employees are worn or not. Also, the employer is obliged to warn the employees who do not wear the helmet, too. But, the wide and dispersed construction sites make it difficult to observe employees. Today, thanks to the developing technology, these obligations can be easily observed with automation systems. In this direction, in this study, detection of helmet usage of construction workers was carried out by using the segmentation method based on deep learning. The study was diversified with different analyses and the outputs were evaluated comparatively.

Keywords: *deep learning, helmet detection, image segmentation.*

Introduction

The concept of Occupational Health and Safety (OHS) is deal with making the working environment safe by considering the interests of both the employer and the employees, and thus protecting and maintaining the health of the workers. In Turkey, Occupational Health and Safety is carried out within the scope of the Act No 6331 on Occupational Health and Safety Law. It is extra important that this law is applied meticulously in dangerous business lines such as the construction sector, where construction works are carried out. Within the scope of this law, collective protection measures are primarily used to protect employees from dangers. However, collective protection measures in the construction industry are often insufficient, as employees often work independently and dispersedly on construction sites. At this point, personal protective equipment is used, which aims to protect workers individually in order to protect and maintain worker health. Personal protective equipment is the collection of items used or worn by the worker to protect the worker from hazards. In this study, the helmet which is one of the PPEs, is only emphasized. It should also be noted that within the scope of

this law, the use of PPEs must be supervised by employers and OHS specialists. Considering this control requirement, in this study, the helmet usage status of the workers was examined by using image segmentation method based on deep learning in order to provide an automatic solution. Deep learning, a subtype of machine learning, emerged with the development of artificial neural networks over time. In data processing, it follows the functioning of the human brain (Önün, 2019). It has features such as natural language processing, speech recognition, image recognition and processing, video and audio processing. Thus, recently, it has been preferred for problem solving in different fields such as medical medicine applications, translation linguistics, security and defense industry, robotics industry, computer vision and economy etc. (Doğan & Türkoğlu, 2019; Khallaf & Khallaf, 2021). Object detection, image classification and image segmentation are the three main application forms of deep learning. When the studies on helmet detection with deep learning are examined, it is seen that all the studies can be reached in the literature are carried out with the object detection method. These studies are briefly summarized. While detecting the workers with helmets using the deep learning method, Xie et al. (2018) also examined whether the helmets were properly worn. Fang et al. (2018), presents a method for estimating helmeted workers, focusing only on workers who do not wear helmets. Sağın (2019) and Mneymneh et al. (2019) created algorithms that first identify the workers and then determine whether the determined workers are in helmets. Bo et al. (2019), Wang et al. (2020) and Huang et al. (2021) conducted studies focusing on the heads of workers while examining the use of helmets. In addition to these studies, there are studies that detect protective vests while detecting helmets in workers (Wang et al., 2020; Nath et al., 2020; Torres, 2021). Saudi et al. (2020) detected protective boots in addition to hard hats and protective vests for workers. Önal and Dandıl (2021) suggested a comprehensive study in which the use of various PPE components such as vests, masks, goggles, and gloves was supervised, not just hard hats. There are also studies in the literature enriched with algorithms that are sensitive to helmet colors (Wu et al., 2019; Casuat et al., 2020) and more sensitive to detect small objects (Xu et al., 2019; Zhang et al., 2021; Tan et al., 2021) in order to perform helmet detection more accurately. In this study, image segmentation method based on deep learning was used in order to automatically detect the use of helmets at the construction site. The reason for choosing image segmentation as the automatic method is that when previous studies were examined, the studies were carried out only with the object detection and it was desired to offer a new automatic solution to the helmet detection by using the image segmentation method. For this purpose, U-Net algorithm was used for the image segmentation method. In addition, various analyses were executed according to different analysis combinations in order to evaluate how the model training could be more performant. The most determinative factor among the analyses is that the helmet detection is carried out with reference to either the whole body integrity of the workers or only their heads.

Methodology

In this study, helmet usage was determined by making use of the image segmentation method based on deep learning. The methodology of the study, which consists of data collection, image masking, data augmentation, model training and model testing, is given in Figure 1.

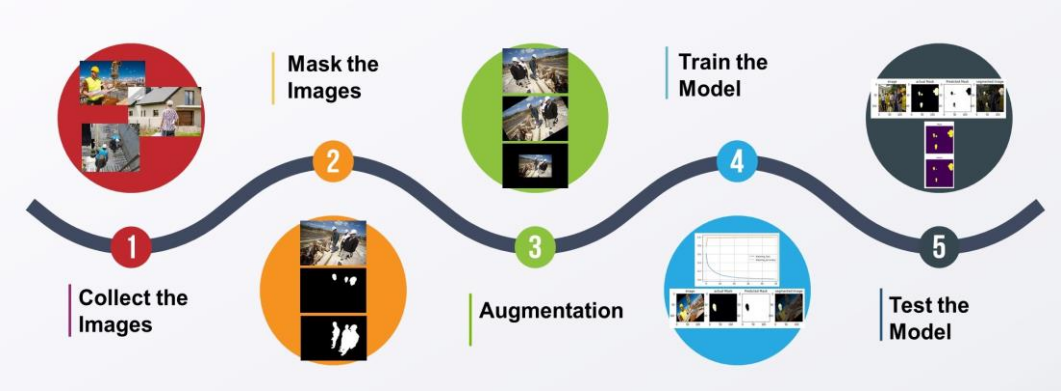


Figure 1: The methodology of the study.

Data Sources

A total of 164 images were brought together to create a dataset to be used in the training of the model. In 124 of these images, only helmeted workers were present, while in 40 of them there were workers with and without helmets together. In order to achieve high success in model training, it is requested that the dataset consists of images with different characteristics as much as possible. Accordingly, the dataset images were diversified according to features such as different angles, distances, and light etc. The 164 images that make up the dataset are images taken personally by the author at the construction sites or accessed from the internet.

Mask the Images



Figure 2: Examples of original images and masked images of helmeted workers with reference to their entire body integrity and only their heads.

The training dataset was created from the original images and masked images. Masked images were obtained by identifying and painting the helmet areas in the original images. In this direction, the areas of the workers with helmets, which were selected with reference to the whole body integrity of the workers and only their heads, respectively, were painted white and the other areas were painted black. Figure 2 illustrates the original images with masked images by reference regions.

Augmentation

The masking process is a time-consuming and laborious process. Within the scope of the study, masking of the images took place in 22 hours and 16 hours, respectively, with reference to the whole body integrity of the workers and only their heads. For this reason, instead of increasing the number of inputs in order to increase the number of images in the dataset, the data augmentation method was applied to the existing inputs. Data augmentation was performed by applying brightness, 30^0 rotation, mirror reflection, -30^0 rotation and zooming operations to each of the original images and masked images that make up the data set. In Table 1, the processes performed for data augmentation over an image are shown with reference on the entire body integrity of the workers and only their heads.

Table 1. An example of the augmented form of the images.

Original	Brightness	Rotation (30^0)	Vertical Flip	Rotation (-30^0)	Zoom Out
					

Accuracy Assessment

The measurement metrics used to evaluate the performance of the model in the study are accuracy, loss and intersection over union (IoU). The metric that expresses the ratio of the cases correctly determined by the algorithm to all cases is called accuracy. It can take values between 0 and 1. In models with high predictive ability, this value is expected to be as high as possible. The metric that gives the difference between the true value and the value predicted by the model is called loss. It can take values between 0 and 1. In models with high predictive ability, this value is expected to be as low as possible. The ratio of the intersections of to combination of the class space determined by the algorithm and the class space that is actually true represents the IoU metric. In models with high predictive ability, the IoU value should be as close to 1 as possible (Semercioğlu, 2022).

Results and Discussion

Model Training

Google Colab Notebook with virtual GPU, a free cloud service, was used for the training of the model. Colab was powered by Intel Xeon Processor with two cores @ 2.20 GHz and 13GB RAM. The dataset was trained under 6 different analyses detailed in Table 2. Analyses were diversified according to the reference region, inclusion/exclusion of helmetless workers, and data augmentation. In the study, the epoch was determined as 50 and the particle size was determined as 16. While Analysis 1, 2, 3 and 4 were trained in 1 minute, Analysis 5 and 6 were trained in 3.5 minutes.

Table 2. Detailing of different analysis combinations.

	Reference of the Images	Group of the Images	Number of Images
Analysis 1	Entire body integrity	All images	164
Analysis 2	Entire body integrity	Only helmeted workers	124
Analysis 3	Only head	All images	164
Analysis 4	Only head	Only helmeted workers	124
Analysis 5	Entire body integrity	All images (with data augmentation)	984
Analysis 6	Only head	All images (with data augmentation)	984

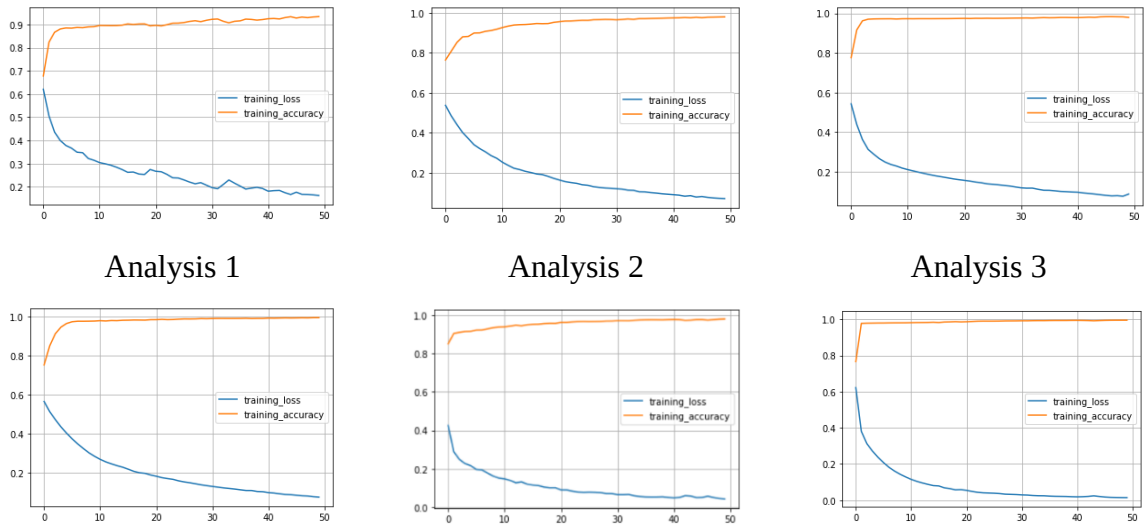


Figure 3: Loss and accuracy graphs of analyses.

Figure 3 shows the accuracy-loss graphs achieved by each analyses as a result of model training. In these graphs, the curve representing the training accuracy is the orange curve, while the curve representing the training loss rate is the blue curve. Table 3 presents the loss-accuracy values reached by each analyses as a result of model training. As a result of model training, when the accuracy-loss values acquired by the analyses were interpreted, it was seen that the model predictive ability was high. Analyses that give the most efficient results in

terms of accuracy-loss values are Analysis 5 and 6, in which the number of inputs is increased by data augmentation. When these two analyses were evaluated in themselves, Analysis 6, which only referenced the heads of the workers, was found to be more successful than Analysis 5, which referenced the entire body integrity of the workers. When the loss-accuracy values of all analyses are compared, example images of the training data of Analysis 6, which were seen to reach the most successful results, are given in Figure 4 by comparing their masked and predicted images. Images are selected from images with different IoU values. The average IoU values of the training datasets for each of the analyses were calculated as 0.45, 0.40, 0.23, 0.34, 0.72 and 0.60, respectively. When the IoU values reached by the analyses were examined, it was seen that the values varied. In models with high predictive ability, the IoU value is expected to be close to 1. Most of the analyses were below 0.5, indicating that the predictive ability of the model remained weak in general.

Table 3. Loss and accuracy values of analyses.

	Analysis 1	Analysis 2	Analysis 3	Analysis 4	Analysis 5	Analysis 6
Loss	0.1628	0.0718	0.0862	0.0773	0.0422	0.0137
Accuracy	0.9338	0.9803	0.9797	0.9938	0.9810	0.9950

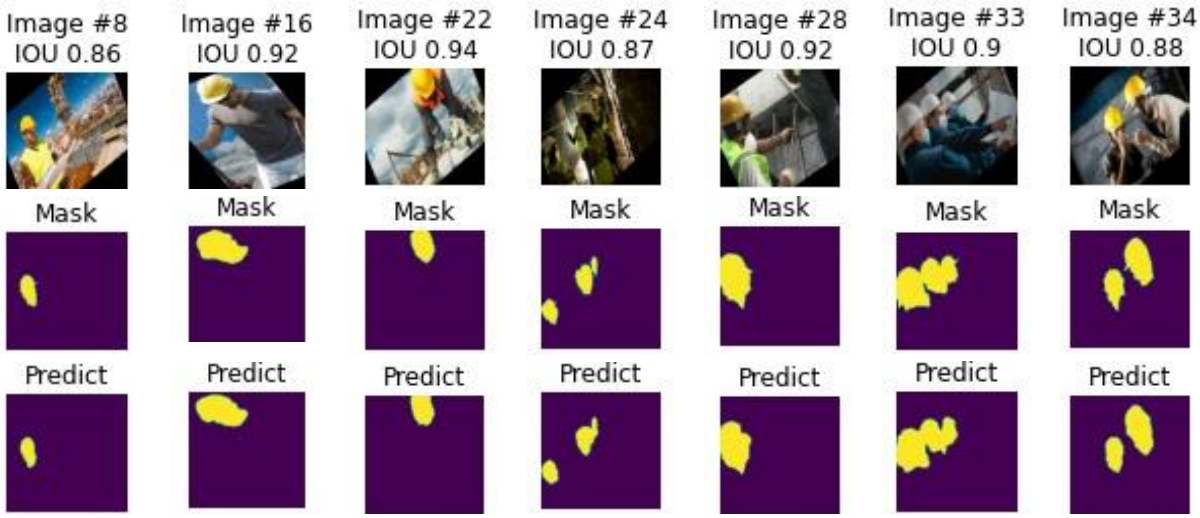
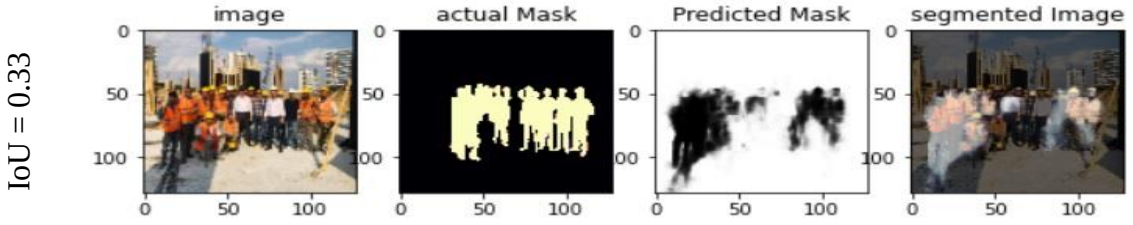


Figure 4: Masked and predicted image examples of analysis 6.

Model Testing

In order to evaluate the performance of the trained model, the model was tested for each analyses with a test dataset consists of 7 images. For achieve the performance evaluation in an objective manner, test dataset was created from images not seen before by the model.



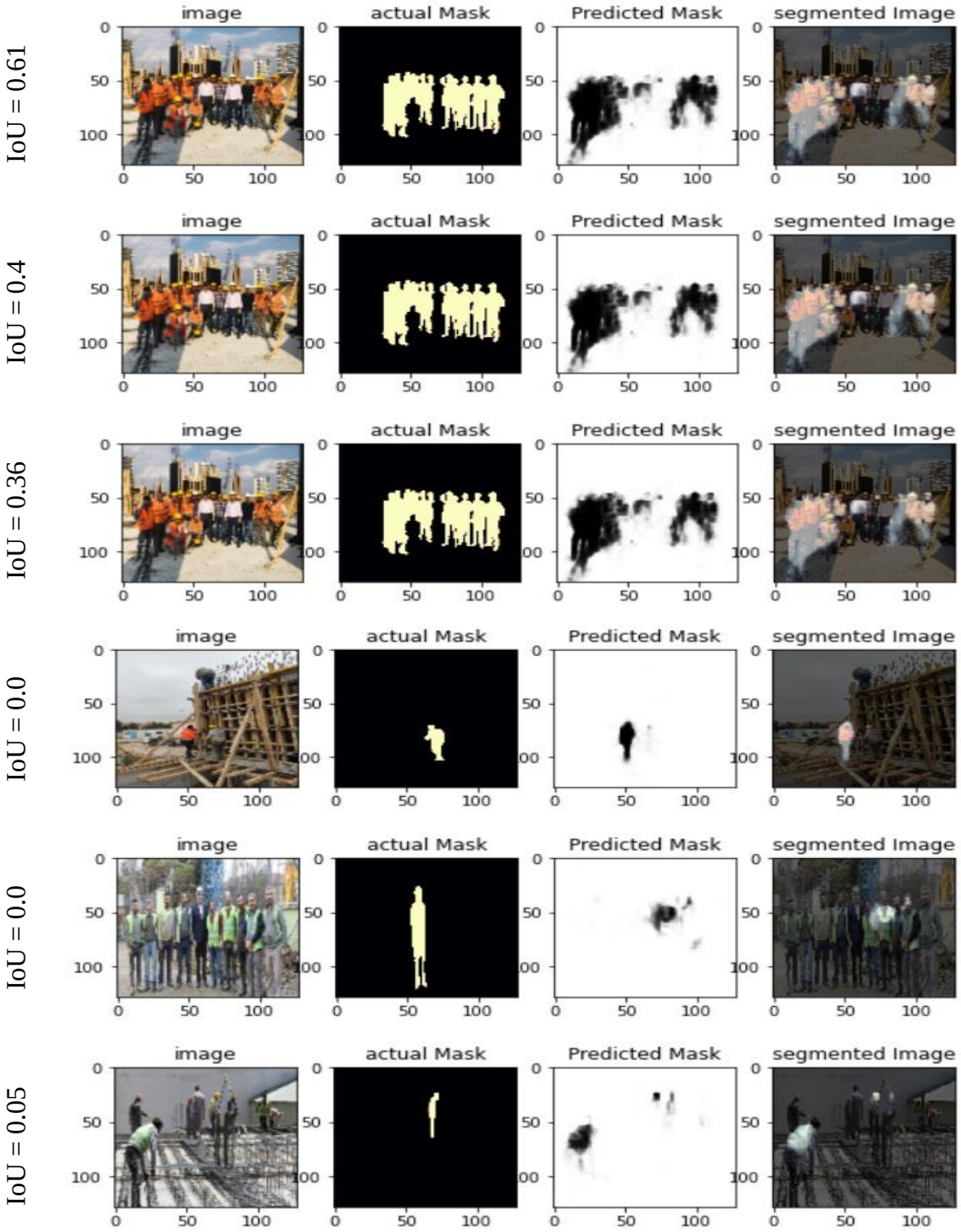


Figure 5: Results of test images for analysis 5.

Test evaluations are based on the average validate IoU measurement metric. The test average validation IoU values of analyses 1-6 were 0.21, 0.08, 0.13, 0.03, 0.25, and 0.23, respectively. When the predictive ability of the model was interpreted according to the test average validate IoU values reached by all analyzes as a result of the model test, it was observed that the results were far below the desired ones. It was thought that the insufficient number of data in the test dataset caused this situation. Analyses that give the most efficient results in terms of training and test average validate IoU values are Analysis 5 and 6, in which the number of

inputs is increased by data augmentation. When these two analyses were evaluated in themselves, Analysis 5, which referenced the entire body integrity of the workers, was found to be more successful than Analysis 6, which only referenced the heads of the workers. Figure 5 shows the results of the test images for Analysis 5.

Conclusions

In this study, the detection of the helmet usage situations of the workers working in the construction sites was carried out within the scope of the segmentation method based on deep learning. For this purpose, U-Net architecture was used. The study was diversified by presenting different analysis options.

As a result of 6 different analyses performed, it was observed that the analyses showed high performance in terms of loss and accuracy values, but remained underperformed in terms of training and test average validation IoU values. According to the loss and accuracy values, Analysis 3, 4 and 6, which reference only to the heads of the workers, were interpreted to be more performant than the others. Among these three analyses, the analysis that achieved the highest model performance was determined as Analysis 6 with data augmentation. Considering all evaluation metrics, it was determined that Analysis 5 and 6 were the most successful analyses. These analyses, in which data augmentation was performed, came to the fore with the increase in both the number and variety of input data. The missing and validation values of the two analyses strongly support the model performance. While the training average validation IoU values were high, the reason for the low test average validation IoU values was interpreted as the test group data being composed of a small number of images. Also, when compared to reference regions, no significant difference was observed between Analysis 6, which referenced only the heads of workers, and Analysis 5, which referenced entire body integrity of workers.

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Motivation Factors after a Work Accident in Construction Industry

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Abstract

Because each construction project has a unique process, various problems may arise during the implementation. Work accidents come first among these problems. Work accidents in the construction industry can result in death, serious injury, or long-term incapacity. Other problems such as stopping the construction after a work accident, punishing the employer or the responsible persons, and loss of motivation in the employees after a work accident may occur. Therefore, it is extremely important to re-motivate the employees when they return to work after a work accident. For this study, survey statements were created. As a result of this study, the factors that are important when returning to work after an accident that may occur in the construction sector have been revealed.

Keywords: *construction project, motivation, work accidents.*

Introduction

In this period of increasing industrialization, one of the important problems regardless of the sector is work accidents. The construction sector is one of the sectors with the highest number of work accidents. Accidents in the construction industry can result in death or serious injury. Although we tried to take precautions, we have not been able to reduce the work accidents to the numbers we want yet. The main reason for these measures is the completion of the construction activities without harming any employees. In addition to this main reason, it becomes extremely important to minimize the damage to construction companies.

Various problems will occur after a work accident that may occur. Employees are directly or indirectly affected by work accidents. In a fatal or severe work accident, other employees are also indirectly affected. These indirectly affected employees may think that they may be affected in a similar work accident that may occur. Or the employee who has been exposed to a work accident may be his own relative or acquaintance. Therefore, an emotional impact will occur. As a result, there will be a loss of motivation. Therefore, it will be important for employees to continue to work without losing their motivation when returning to work. Continuing to work with low motivation of employees after a work accident may result in a

repeat work accident due to insufficient concentration, and delays in construction activities may occur because they work with low productivity. For this, it will be necessary to mention the motivation after a work accident in the occupational health and safety (OHS) culture or climate. The aim of this study is to reveal the factors affecting motivation after a work accident and the scale expressions related to these factors.

Occupational Health and Safety Culture

There are various studies on Occupational Health and Safety (OHS) culture (Yeong & Shah Rollah, 2016; Jin et al., 2019; van Nunen et al., 2018; Kalteh et al., 2021; Kim et al., 2019; Newaz et al., 2019a). In these studies, they mentioned the importance of an effective OHS culture from different perspectives so that there are fewer work accidents. Comprehensive studies have been carried out from communication to human factors, from management approach to incentives. For example, a study identified 13 main factors affecting OHS performance in construction projects. These are motivation, rules and regulation, competence, OHS investment and costs, financial aspects and efficiency, resources and equipment, work pressure, working condition, culture and climate, attitude and behavior, lessons learned from accidents, management systems, organization, and OHS programs (Mohammadi et al., 2018). In a study by Ghasemi et al. (2015), it was found that incentives proved to improve employee safety performance in the short term.

In an effective OHS system, new studies are constantly emerging. Within the framework of OHS culture, attention is drawn to different aspects. It is also important to restore motivation after a work accident in an effective OHS culture. There were not many studies on this subject in the studies. This is the reason for this study. Because after a work accident, the productivity and well-being of workers drop significantly (Ling et al., 2019). It is expected that the motivation of the employees in enterprises with a good OHS culture will return to normal quickly and effectively after a work accident. This is also extremely important for businesses in terms of productivity. If the welfare, peace, and confidence of the employees are in place, their productivity will also be good. Because there is a positive relationship between the well-being of employees and their productivity (Ling et al., 2019). In this context, factors related to post-work accident motivation are tried to be brought together.

Methodology

Since there is no ready-made survey about motivation after a work accident, the survey was created by using the literature. For this, studies using various keywords (such as construction sector, motivation after a work accident, productivity) were examined. From these studies, 28 motivational factors and 28 survey statements related to these factors were obtained. The survey is administered to construction workers. The survey statements are asked to be answered according to a 5-point Likert scale (1=affects very negatively; 5=affects very positively). Since the application of the survey has not been completed yet, this study is limited to how the motivation factors after a work accident survey is developed. When the survey is finished, different statistical analyzes will be made, especially regarding the reliability of the survey.

Results

Motivation factors after a work accident were obtained with the help of literature. Motivation factors after a work accident are shown in Table 1 below. The scale expressions based on these factors are also shown in Table 1. Motivation survey after a work accident consists of 28 statements. Different analyses will be made in future studies by revealing a motivational survey after a work accident. The implementation of the survey continues. When the desired sample size is reached, various analyses are made and it is aimed to be published in different places. Since enough samples were not reached, this study was limited to how to reveal motivational factors and scale expressions.

Tablo 1. Motivation factors and survey statements after a work accident.

Literature Source	Factors	Survey Statements
Andersen et al., 2018; Fargnoli et al., 2019; Marín et al., 2019; Mohammadi et al., 2018; Chen et al., 2018; Aburumman et al., 2019; Brondino et al., 2012	Attitudes of colleagues about OHS	The attitude/reaction of my colleagues about occupational safety after a work accident is important.
Andersen et al., 2018; Chen et al., 2018; Brondino et al., 2012	Co-workers taking care of each other	It is important for my colleagues to take care of each other emotionally after a work accident.
Kim et al., 2019; Al-Bayati et al., 2019; Duryan et al., 2020; Aburumman et al., 2019; Ma et al., 2020	The employer's emphasis on OHS	It is important for the employer to pay more attention to occupational safety after a work accident.
Kim et al., 2019; Probst et al., 2019; Luo, 2020	Employer accountability	After a work accident, it is important that the employer is accountable/transparent to the workers regarding occupational safety.
Kim et al., 2019; Al-Bayati et al., 2019; Newaz et al., 2019b; Yiu et al., 2018; Chen et al., 2018; Probst et al., 2019; Aburumman et al., 2019; He et al., 2020; Luo, 2020	Employer's OHS commitment	It is important that the employer undertakes to take the necessary measures to prevent an accident after a work accident.
Fargnoli et al., 2019; Ling et al., 2019	Performing activities under time pressure	It is important that the work progresses more slowly/controlled after a work accident.
Newaz et al., 2019b; Yiu et al., 2019; Duryan et al., 2020; Chen et al., 2018; Brondino et al., 2012	Fulfilling the obligations of the workers	It is important for workers to take the necessary precautions to prevent an accident after a work accident.
Yiu et al., 2019; Duryan et al., 2020; Chen et al., 2018; He et al., 2020; Brondino et al., 2012	OHS behavior of workers	It is important for workers to act more carefully after a work accident so that no more accidents will occur.
Kim et al., 2019; Mohammadi et al., 2018; Ghasemi et al., 2015; Ling et al., 2019	Incentive programs	Paid leave or financial incentives are important after a work accident.
Jiang et al., 2020; Sharma &	Effective OHS	The positive realization of the process

Mishra, 2020; Kalteh et al., 2021; Wen Lim et al., 2018; Gharibi et al., 2016	application after accident	after a work accident depends on the effectiveness of occupational safety practices in the workplace.
Jiang et al., 2020; Sharma & Mishra, 2020; Kalteh et al., 2021; Wen Lim et al., 2018	Effective OHS practice	An effective occupational safety performance depends on the effectiveness of occupational safety practices in the workplace.
Probst et al., 2019; Luo, 2020	Employer sees safety as a value	The employer's emphasis on occupational safety shows that he values our employees.
Probst et al., 2019; Musonda et al., 2018; Shuen & Wahab, 2016	Employer communication	It is important for the employer to contact us after a work accident.
Probst et al., 2019; Li et al., 2020; Shuen & Wahab, 2016	Employee communication	It is important for employees to communicate with each other after a work accident.
Probst et al., 2019; Luo, 2020; Vinodkumar & Bhasi, 2010	OHS Training	It is important to repeat the training on occupational safety after a work accident.
Aburumman et al., 2019; Musonda et al., 2018; Ma et al., 2020	Employer's leadership	It is important for the employer to lead after a work accident.
Musonda et al., 2018; Ma et al., 2020	Employer's adherence to procedures	It is important for the employer to comply with the occupational safety rules after a work accident.
Musonda et al., 2018; Ma et al., 2020	Employer's guidance	It is important for the employer to guide the employees after a work accident.
Ma et al., 2020	OHS management behavior of the employer	It is important that the employer adheres to occupational safety practices after a work accident.
Li et al., 2020	Employee confidence	It is important for employees to trust each other after a work accident.
Li et al., 2020	Trust between employers and workers	It is important that employees and employers trust each other after a work accident.
Li et al., 2020; Ling et al., 2019	Solidarity of employees	The solidarity of the employees after a work accident is important.
Luo, 2020	OHS audit	It is important to increase the inspections related to occupational safety after a work accident.
Gharibi et al., 2016	Work accident experience	Previous work accident experience has an importance in my attitude after a work accident.
Han et al., 2019; Gharibi et al., 2016; Ling et al., 2019	Working attitude with a sense of job security	After a work accident, my working style does not change in terms of occupational safety.
Ling et al., 2019	Security concern	After a work accident, my concerns about occupational safety may change.
Gharibi et al., 2016; Ling et	Rapidly	It is important to quickly improve the

al., 2019	improving site safety	missing measures related to occupational safety after a work accident.
Ling et al., 2019	Psychological support	It is important for employees to receive psychological support after a work accident.

Conclusions

This study aims to reveal the scale expressions of factors affecting motivation after a work accident. When the desired sample size of the survey is reached, different analyses will be made. The productivity of the employees needs to work without losing their motivation after a work accident. The main goal after a work accident is to try to keep employees away from work accidents by re-creating their motivation. In addition, it is an important problem in productivity. Because construction projects are expensive projects and are made within a certain plan. Any delay caused by the performance of the employees will cause direct or indirect costs. This will increase the construction cost. Therefore, motivating after a work accident is important not only for workers but also for employers. Factors and scale expressions obtained with the help of the literature are expected to be a source for future studies.

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Work Conditions and Psychological Stressors among the Construction Workforce in South Africa

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Abstract

This study investigates organizational stressors among the construction workforce in South Africa. The study focuses on the working conditions and interpersonal relationships among the workforce. Work conditions, workplace relationships, and pressures from groups can result in adverse health conditions among the workforce. A combination of these factors results in occupational stress affecting employees 'work-life balance and worker's well-being. This quantitative study forms part of ongoing empirical research. A snap survey was conducted and the questionnaires were distributed among 40 conveniently sampled contractors in the Kwa-Zulu Natal province. The study achieved an 80% response rate and the internal reliability was 0.725 and deemed acceptable. Convenience sampling was favored due to the respondent's proxy to the researcher and also, to speed up the data collection process due to COVID-19 challenges. The self-completion data were analyzed using descriptive statistics methods on IBM SPSS v25. The, findings of the study revealed that working at night and during weekends as a result of work overload; job insecurity, and unfair reward were the most prevalent issues among the workforce. However, homogeneity among the groups of respondents was not achieved and the findings of the study may not be generalized due to the small sample size.

Keywords: *construction industry, construction workforce, occupational stress, work conditions, work relationships.*

Introduction

Construction fatalities emanate from a number of known and unknown factors. Predominantly, causes of fatalities and accidents in construction have been classified as faulty equipment accidents; falls from heights; slips, trips and falls on the same level; repetitive stress injuries; inhalation, absorption or ingestion accidents; trench accidents; elevator shaft accidents; electrocution; motor vehicle accidents; struck by accidents; caught in between; and gas leaks, fires and explosive (OSHA, 2021; FEMA, 2021) with no mention of occupational stressors as mental health problems under the classifications. Although the construction industry is regarded as one of the most stressful occupations, more attention has been placed on preventing physical injuries with little focus on mental health issues such as stress, depression, anxiety, suicide, and substance abuse (Leung et al., 2005; Ng et al., 2005; Liang et al., 2021). It is therefore, essential to monitor and to address the issues of mental health among the construction workforce in order

to better understand their effects and to subsequently prevent occupational injuries and increase productivity (Boschman et al. 2013).

Psychological stress can be defined as the physical processes created by conditions exerting psychological demands on an individual (Selye, 1976). These demands exerted on the body are called stressors (McGrath, 1982). Occupational stress is defined as the individuals 'perception of the discrepancy between the environmental demands (stressors) and individuals 'abilities to satisfy these demands (Topper, 2007; Vermunt & Steensma, 2005; Varca, 1999; Randall & Ross, 1994; Beehr, 1995). Occupational stress is a dangerous illness for industrialized economies and hinders development, threatens production as it affects the physical and mental health of the workers (ILO, 2014). In addition, WHO (2019) contents that recently, occupational stress has become a major public health concern with negative effects on human health. Moreover, psychosocial risks and occupational stress are increasingly among the most challenging issues in occupational health and safety (EU-OSHA, 2021). The EU-OSHA reported that about half of the general European workforce regarded stress as the main contributing factor for about half of all lost workdays. Similarly, ILO (2014) indicated that stress is the second most prevalent work-related health problem and it is believed that the number of workers suffering from occupational stress-related illnesses is likely to increase.

A considerable amount of literature has been published on the causes of occupational stress among the construction workforce and the issues have remained somewhat similar throughout the studies (Goldenhar, 2003; Molen, 2000; Boschaman et al., 2013; Bowen et al., 2013, 2014, 2018; CIOB, 2006; Leung et al., 2016; Ng et al, 2005; Hamid et al, 2014; Lingard et al., 2009, Love, 2010; Sheratte, 2018; Jepson, 2017; Langdon & Sawang, 2018; Bryson & Duncan, 2018; Tijani et al., 2020). Researchers have shown that the adverse working conditions in construction can contribute to stress. The workforce in construction experiences long hours working under pressure with tight deadlines, high levels of conflicts, low job control, lack of managerial support, job insecurity, and lack of work-life balance (Bowen et al., 2013, 2018; Langdon & Sawang, 2018; Panahi et al., 2017; Love et al., 2010; Cattell et al., 2016, Sherratt, 2018).

Furthermore, most workers in construction commute long distances to work and some travel far away from their homes to work which could result in loneliness and be a significant factor contributing to stress, depression and anxiety (Christodoulou, 2021). Construction projects take place over a short period of time leading to job insecurity which in itself is another major stressor (ibid). Over and above dangerous working conditions and strict deadlines, workers must adhere to safe working procedures which can be extremely difficult when working under pressure. As a result, workers worry about their wellbeing and become increasingly anxious where they believe exposure to work hazards may result in diseases or injury and this often causes distress (negative stress) (ibid).

This study seeks to investigate the impacts of working conditions and psychological stress among the South African workforce and how these impacts affect the worker's mental wellbeing in relation to occupational stress. It has been reported that most studies on occupational stress in the construction industry have been conducted in developed countries especially in the UK, USA, Australia and New Zealand with little focus on African countries (Bowen et al., 2013). Developing countries are characterized by extreme socio-economic issues, such as inequality and crime (Bowen et al., 2013). It has also been reported that in South Africa specifically, the nature of mental health issues requires a uniquely South African solution (SACAP, 2019). Furthermore, there exists both a population and a knowledge gap within the

South African context on the causal effects of occupational stress among the general workforce and not only on construction professionals as with other previous studies.

Methods

An extensive literature review on the topic was done and questionnaires were formulated from the literature to conduct a snap survey. Structured questionnaires were distributed to contractors in the Kwa-Zulu Natal province to explore the constructs underlying the research topic. The sample was selected using convenience sampling, and the respondents were sampled based on proximity and familiarity. This form of sampling maximized the response rate as the study was conducted over a short period. Some respondents were referrals recommended by other participants – a variant of snowballing sampling technique. Self-administered questionnaires with a series of close-ended questions were emailed. A total of 40 questionnaires were emailed and the study achieved a response rate of 80%. The study employs a quantitative research approach and data were analyzed using IBS SPSS v25. The exploratory study forms part of ongoing empirical research.

Results

This section presents the analysis of the data collected and discusses the findings. Data were analyzed using IBM Statistical Package for Social Sciences (SPSS) version 25. Descriptive statistics was adopted for the data analysis and further interpreted using inferential statistics. Tables were used to present data and key findings.

Profile of the Respondents

The participants in the study were the general construction workforce working for contractors. The respondents were artisans, construction professionals and construction laborers. Table 1 outlines the demographics/profile of the respondents.

Table 1. Profile of the respondents.

Age and number of years of experience			
	Median	Minimum	Maximum
Age of Employee	33	25	52
Years of Experience	10	2	32
Gender of Respondents			
	Frequency		Percent
Male	20		62.5
Female	12		37.5

Total	32	100.0
Highest formal qualification		
	Frequency	Percent
Secondary or high school	4	12.5
Technical or Vocational College	4	12.5
University Degree	24	75.0
Total	32	100.0
Position in Organization		
	Frequency	Percent
Construction Manager	4	12.5
Health and Safety Officer/Manager	2	6.3
Quantity Surveying	9	28.1
Civil Engineering	6	18.8
Foreman/Supervisor	2	6.3
Artisan	3	9.4
Construction Workers/Labourer	4	12.5
Other (Specify)	2	6.3
Total	32	100.0

The results in Table 1 indicated that the median age of the respondents was 33 years ranging from 25 years minimum to 52 years' maximum. The median years of experience were 10 years ranging from a minimum of 2 years to a maximum of 32 years. The majority of the respondents were male at 62.5%. Most respondents had obtained a University Degree (75%) followed by both technical/vocational schools (12.5) and secondary/high school qualifications (12.5%). Furthermore, most respondents were Quantity Surveyors (28.1%); followed by Civil Engineers (18.8%); both Construction Workers Construction Managers (12.5%); Artisans (9.4%) and Health and Safety Officers/Managers and others (6.3%). Therefore, most respondents were construction professionals (65.7%) followed by Construction Labors (18.8%) and Artisans (15.7).

It is apparent from the findings in Table 1 that majority of the respondents were well within the acceptable working ages although not a true representation of the entire workforce which usually ranges from 18 to 65 in the South African construction industry. The same may be implied for work experience. Further, majority of the respondents were construction professionals. This may be attributed to the fact the study was conducted during the pandemic and mostly data collection was by means of emailed questionnaires and google forms.

Therefore, the results of the current preliminary study should be interpreted with caution because usually, the construction industry has more artisans and laborers than construction professionals.

Data Interpretation

Table 2 presents the data range interpretation based on the 5-point Likert scales used in the study. The group interval coefficient value for the 5-point Likert scale was calculated as (5) /3 = 1.67. The range interpretations for the 5-point Likert scale were used in Table 4-5. For further ease of interpretation, the mean values for the 5-point Likert scale were interpreted as; high, medium and low.

Table 2. Data interpretation ranges.

Range	**5-Point Likert Scale**	
	Agreement Scale	Ease of interpretation
5.00 - 3.34	Strongly Agree	High (H)
	Agree	
3.33 – 1.68	Neutral/Unsure	Medium (M)
≤1.67	Disagree	Low (L)
	Strongly Disagree	

Reliability

Cronbach's Alpha reliability test was conducted in IBM SPSS v25 to determine the reliability and internal consistency of the scales that had been used to analyze compliance and impact of legislative changes on construction workers' wellbeing. The reliability test was done for each construct, as indicated in Table 3. The Cronbach's Alpha coefficients between $0.70 \leq \alpha \geq 0.80$ are 'acceptable' while between $0.80 \leq \alpha \geq 0.90$ are considered 'good' and coefficients $0.9 \leq \alpha$ are 'excellent' (Tavakol & Dennick, 2011). Therefore, the internal consistency of the various scales was deemed acceptable for further interpretation.

Table 3. Cronbach's Alpha reliability test.

Cronbach's Alpha	Reliability
.725	Good

Reliability was acceptable across all the scales used, and further analysis of the results was conducted.

Organisational Stressors among the Workforce

Table 4 indicates the average number of working hours in their organizations.

Table 4. Average working hours per week.

No. of Hours	Frequency	Percent
Between 0-40 hours	8	25.0
Between 41-49 hours	18	56.3
Between 50-59 hours	6	18.8
Total	32	100.0

The findings from Table 4 revealed that 56.3% of the respondents work anywhere between 41-49 hours a week while only 25% work 0-40 hours per week and the rest work for 50-59 hours. According to the Basic Conditions of Employment Act in South Africa, workers are permitted to work for 45 hours per week under normal circumstances. The majority of the respondents had indicated working hours between 41-49 hours. Therefore, based on the findings, the exact number of hours worked is unclear and this calls for further investigation. However, worth notice is that 18.8% of the respondents worked for more than 50 hours per week. This suggests working overtime which is in line with several literature findings (Tijani et al., 2020).

Working Conditions and Psychological Stressors among the Workforce

In Table 5 the respondents were presented with 17 statements based on literature about the most prevalent working conditions that lead to psychological stress. Although several working conditions lead to distress, only 17 statements were selected because they were the most prevalent in most studies (Christodoulou, 2021; Tijani et al., 2020; Chan et al., 2021). Therefore, the respondents were requested to indicate their level of agreement on working conditions leading to psychological stressors based on a 5-point Likert scale where 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree and 5=Strongly Agree.

Table 5. Working conditions.

Statements	Mean	SD	Int.	Rank
I sometimes work at night	3.94	.948	H	1
There is too much workload	3.91	.928	H	2
I sometimes work on weekends	3.84	1.019	H	3
I worry about my job security	3.84	1.221	H	4
I am not happy with my salary/wage	3.81	1.176	H	5

I get support from my boss when I have problems with my work	3.53	.879	H	6
I am not told about change at work	3.47	1.270	H	7
I always get my work done on time	3.47	1.016	H	8
I travel/commute long distance to work	3.44	1.268	H	9
My work is dangerous	3.34	1.285	H	10
I do not get enough training	3.28	1.023	M	11
I have limited decision making at work	3.13	1.129	M	12
My personal values and those of my company are very different	3.03	1.150	M	13
I want to leave my company	2.94	1.045	M	14
I am not satisfied with my company	2.84	1.194	M	15
I do not understand my duties and responsibilities at work	2.13	1.008	M	16
I am bored because there is not enough work	1.91	1.118	M	17

The findings in Table 5 revealed high levels of agreement for unpredictable working hours such as working at night (mean=3.94) and working on weekends (mean=3.84). Workers also indicated that there was too much workload (mean=3.91). Therefore, it may be inferred that workers work on weekends and at night due to workload demands. Workers also reported a high level of concern for their job security (mean=3.84) and their salaries (mean=3.81). Respondents further revealed that their bosses were supporting when they needed help (mean=3.53) although they had also highly agreed that they were not told about changes in the workplace (mean=3.47). Further, most respondents had indicated getting their job done on time (mean=3.47). The respondents also had a high level of agreement regarding long travel time (mean=3.44) to work and the danger of their jobs (mean=3.34). There was however a medium level of response in relation to decision latitude, role demands, career stress and underworking. Workers responded moderately to insufficiency of training (mean=3.28); limited decision making (3.13); role demands (mean=3.03); leaving their current companies (mean=2.94); satisfaction with organization (mean=2.84); role ambiguity (mean=2.13) and boredom at work (mean=1.91).

Discussion

The findings of this study are consistent with the finding from a systematic review conducted by Tijani et al. (2020) (from 1997 to 2020) and Chan et al. (2021) (from 1992 to 2020) about the causes of occupational stress in construction. Work demands such as working at night, working on weekends and work overload which is attributed to tight deadlines were the most prevalent causes of occupational stress among the respondents. It may be inferred from these findings that this leads to home-work conflict which is in line with the findings from Tijani et

al. (2020) where home-work conflicts ranked highest among the causes of occupational stress in construction. Not being able to separate personal life from work and working on site is stressful due to poor working conditions and could also disrupt an individuals' circadian rhythms leading to sleeping and eating disorders and subsequently psychological stress (ILO, 2020).

Furthermore, job insecurity and poor remuneration which have been linked to financial stress ranked high and this is also in line with the systematic review findings. Most construction workers in South Africa are bread winners. Financial stress which has been linked to suicide among the workers (Martin et al., 2016) occurs when these individuals are unable to meet their financial obligations. This has also been cited by Hobfall (1989) in relation to the Conservation of Resources (COR) theory which assumes that stress occurs in any of three situations identified as when people experiences loss of resources, when resources are threatened and when individuals invest their resources without subsequent gain. Therefore, the premise of COR theory maintains that individuals are in constant pursuit to acquire, preserve, nurture, and safeguard the things they value (Hobfoll et al., 2018; Hobfoll, 1996).

Poor working conditions lead to workers' worry about their wellbeing and become increasingly anxious where they believe exposure to work hazards may result in diseases or injury and this often results in depression, anxiety, boredom, frustration, and other negative emotions. Stress and unhealthy working conditions are known to manifest as psychosomatic symptoms such as headaches, low energy, insomnia, back pain or chest pain. Furthermore, increased job demands can lead to unintentional blindness as too much focus on complex tasks often leads to low levels of concentration. It is evident that as mental and physical fatigue mount during prolonged work activities such as working at night, on weekends or work overload workers are most likely to conduct unsafe behaviors.

However, contrary to previous studies on the lack of support by management, this study revealed that they did receive support from their superiors although not fully. Nevertheless, this inconsistency may be attributed to the low sample collected in the study as the respondents further indicated that there was poor communication especially relating to changes in the workplace.

Other issues emerging from the findings of the study revealed dangerous working conditions and traveling long distances to work. These findings are also in line with the finding from previous studies (Tijani et al., 2020; Chan et al., 2021). There was, however, a moderate response level relation to career stressors, role demands and boredom at work. Therefore, the findings of this study while preliminary, are suggestive that unrealistic timeframes (working at night and during weekends) as a result of work overload, job insecurity and unfair reward are the most prevalent issues among the workforce.

Conclusion

This study has investigated the prevalence of work stress emanating from work conditions among workers in the South African construction industry. The research confirms previous findings and contributes to an understanding of how the workforce is affected by occupational stress in a developing country. However, a number of limitations need to be acknowledged. This is a preliminary study that forms part of ongoing empirical research. Therefore, a snap survey was conducted over a short period of time in order to help reveal the common causes of

occupational stress in the South African context among the general workgroups such as artisans, construction workers and construction professionals. Homogeneity among the groups of respondents was not achieved and therefore, it was not easy to distinctly look at how each construct affects each working group as CPPs may not be exposed to similar job conditions as artisans and laborers. Also, the sample size of the study was low due to time constraints. As a result, it is imperative to conduct a study with a large sample size in order to make generalized conclusions.

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What Do Smart Contracts Solve in the AEC Industry? A Qualitative Study

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Abstract

Construction projects include highly complex and risky processes, documents, and approval stages due to the complex structure of the Architecture, Engineering, and Construction (AEC) industry. These processes are traditionally carried out with contract standards such as FIDIC and KIK, and these standards contain various dilemmas within themselves. As an alternative to these, the development of Web 3.0 and the blockchain-based smart contracts included in the AEC industry contain suitable solutions for the aforementioned dilemmas. Therefore, this study aims to determine how blockchain-based smart contracts provide solutions to the problems of traditional contract standards with a systematic literature review. Within this aim, scientific articles which were published between 2018-2022 years were reviewed, and a total of 46 articles closely related to the subject were analyzed. This qualitative synthesis of the research was used to identify the advantages of smart contract implementation in the AEC industry over traditional contract standards. The findings of the study list the contributions, difficulties, and threats to validity and implications of blockchain-based smart contracts, which have features for solving the problems caused by standard contracts, to the process.

Keywords: *AEC industry, blockchain-based smart contracts, construction, meta-synthesis, qualitative study.*

Introduction

One definition of the construction industry treats it as “complex product systems” (Winch, 1998). This complex structure tries to keep up with technological developments with its subsets. The latest developments experienced by the Architecture, Engineering, and Construction (AEC) industry are changing due to both the change in technology and the disruptions imposed by the coronavirus pandemic. For this reason, smart contracts included in the AEC industry can benefit many integrations, especially the supply chain (Hamledari & Fischer, 2021a). With the inclusion of the latest developments in information technologies in the AEC industry, project management and contracts in the industry are also affected and digitally renewed (Pradeep et. al., 2021). Blockchain technology, which is revolutionary for many industries, is a pioneering technology for digital transformation while defining business

processes from the ground up for many industries (Pattini et al., 2021). Large-scale construction projects and process management are very complex, so there is an increasing desire for the industry to adopt emerging technologies and integrate (Hargaden et al., 2019).

Smart contracts are a self-executing program used for the execution of automated transactions, usually determined by parties, when working with a blockchain-based system (Chatterjee et al., 2018; Governatori et al., 2018). This technology is considered by many experts as one of the most effective solutions in the AEC industry (Construction Economy Newspaper, 2018). On the other hand, construction projects contain some uncertainties according to their types. Technologies in construction projects also have their own uncertainties. These uncertainties cause conflicts between stakeholders (Çevikbaş & Köksal, 2018). At the same time, there are various abuses in the system. With this integration, changing project data in construction projects automatically creates inconsistencies that can be detected. In this way, common frauds in the AEC industry can be detected and prevented (Le et. al., 2014). As a solution to voluminous, complex, and incomprehensible construction contracts; smart contracts are an effective and alternative option (Gurgun & Koc, 2021). Blockchain is an internet version that can be traced and authenticated as it is recorded in a distributed database and has features such as transparency and reliability (Lima, 2018). Some pilot applications are carried out with blockchain technology all over the world. Blockchain technology can be used in matters such as custody of judicial files, financing of state structures, money tracking, marital status, voting system, business licenses, criminal records (Ølnes et al., 2017). The integration of blockchain technology and smart contracts has attracted the attention of the AEC industry around the world due to its potential to increase the transparency, traceability, and immutability of construction data (Lu et. al., 2021a). With these developments, blockchain-based smart contracts become a remarkable alternative to traditional contracts that single-handedly govern their terms and obligations (Koç & Gürgün, 2020). While this technology is relatively new, it commonly carries solutions to many business problems. Many institutions, organizations and even governments incorporate this technology into their business processes (Yang et. al., 2020).

Within these backgrounds, this study identifies the contributions of smart contracts to the AEC industry by using meta-synthesis method. It is anticipated that the findings obtained from the study will form a basis for further studies by presenting a summary that brings together the literature deficiencies, main topics mentioned in the literature, problem determinations and development options related to blockchain technology-based smart contracts that will work in integration with the AEC industry. Through meta-synthesis analysis, potential barriers to incorporation into the AEC industry, such as the inability to understand or adopt blockchain-based smart contracts, have been identified. These determinations are important for the determination and selection of the topics that should be focused on in future studies. It is also important to be able to understand the nature of smart contracts in the construction industry as they are incorporated into the project management process.

Research Methodology

The meta-synthesis method is used to determine what the subjects proved by the results of scientific studies want to express or whether there are contradictory results in the scientific literature. In other words, it is a relatively new research synthesis that combines quantitative and qualitative meta-analysis. By using these syntheses, the validity or deficiencies of

previous studies are determined (Sandelowski, 2006; Cooper, 2009). In this way, an integrated result of the information belonging to previous studies is obtained (Sandelowski, 2006). While a systematic literature review is based on empirical evidence and answers research questions by collecting and summarizing all empirical evidence, meta-synthesis uses a qualitative research design and attempts to integrate results from several different but interrelated qualitative studies. A systematic literature review provides us with qualitative data whereas handling the obtained data with meta-synthesis also provides us with quantitative data. Meta-synthesis produces synthesis findings in which quantitative data are combined with qualitative data. Therefore, this study adopts meta-synthesis method since the aim of the study is reviewing, analyzing, and examining the literature and thus establishing the relationship between existing studies to obtain a framework for the possibilities that the application of smart contracts in the AEC sector can provide. As the output of meta-synthesis analysis, a result table (Table 1) was obtained in which the deficiencies, gaps in the literature or the issues that need to be developed for the future work were expressed. The meta-synthesis method contains two main steps which are 1) determining the research questions and 2) inclusion/exclusion criteria necessary for performing the meta-synthesis.

Identification of the research questions. At this stage, research questions that need to be addressed were determined. Questions addressed in this study can be summarized as below:

- How are smart contracts used in the AEC industry?
- What are the benefits of using smart contracts in the AEC industry?
- What are the difficulties and threats to validity of smart contract usage in the AEC industry?

Inclusion/exclusion criteria. To find answers to these research questions, publications related to the subject were examined. Due to the topicality of the subject, it is important to follow the latest developments. For this reason, the studies carried out in the last 5 years covering the years between 2018 and 2022 will be examined. The publications within the scope of the study are selected among the publications in the American Society of Civil Engineers (ASCE), ScienceDirect and IEEE Xplore Digital Library database. To conduct the meta-synthesis analysis, keywords such as smart contracts, block-chain, and Architecture, Engineering, and Construction (AEC) industry were chosen. In this case, there is a special case that can create complexity in the data as a problem. The word "Architecture" is used as a means of expressing the logic of many other subjects, as well as expressing the field of architecture within the construction industry. For example, "domain architecture". Therefore, even if they are not included in the exclusion criteria, studies that are not related to the subject although they provide the keywords are excluded. As a result, 501 article was found suitable for review. In addition, although "supply chain" is a concept used in the AEC industry in general, only those that cover the "construction supply chain" sub-title of the publications on this subject are discussed. Although block-chain technology and smart contracts are often used interchangeably, first, the effects of smart contracts on the AEC industry were examined in terms of the subject of the study. After all the eliminations were completed, a literature review was made on the contributions of block-chain-based smart contracts to the AEC industry over the remaining 46 articles. Figure 1 shows the literature search strategy, and the selected studies and summary findings of selected articles are shown in Table 1.

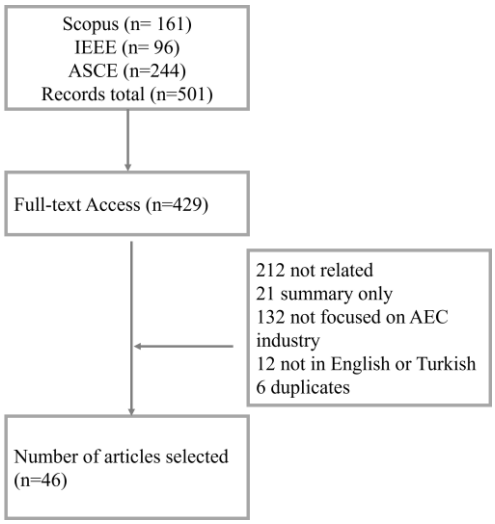


Figure 1: Literature search strategy.

Table 1. Summary findings of selected articles.

#	Title of Publication		
	Author/s - Year of Publication	**Benefits**	**Difficulties and Threats to Validity and Implications**
1	**A Semantic Differential Transaction Approach to Minimizing Information Redundancy for BIM and blockchain Integration**		
	Xue et al., 2020	Intermediary payments are eliminated, and a transparent payment system has established.	This system, which can work in small-scale projects, will create limitations in large-scale construction projects. The instability of the value of cryptocurrencies against each other.
2	**Understanding Stakeholders Needs for Using Blockchain Based Smart Contracts in Construction Industry of Thailand: Extended TAM Framework**		
	Chaveesuk et al., 2020	It has been stated that smart contracts can provide a better allocation of risks in the contract, thanks to their self-executing feature.	The difficulties in implementing smart contracts are serious. Contracts are irrevocable and unchangeable and are prone to human error.
3	**Intelligent Contract Adoption in The Construction Industry: Concept Development**		
	McNamara et al., 2021	In the construction sector, the smart contracts would help eliminate the slow, expensive, and brittle transactions, associated with integrity and transparency issues due to potential records manipulation of the traditional contracts.	Adoption and transition of smart contract intent in the construction industry requires a paradigm shift in perception, formulation, decoupling, and contract management philosophies and guidelines.
4	**Do You Need A Blockchain In Construction? Use Case Categories and Decision Framework for DLT Design Options**		
	Hunhevicz et al., 2020	The increased reliability and traceability of validated information flows on the blockchain makes it possible to use tools to backtrack the construction process at any time.	(-)
5	**Construction Payment Automation Using Blockchain-Enabled Smart Contracts and Robotic Reality Capture Technologies**		
	Hamledari et al., 2021a	Smart contracts provide benefits for the automatic, transparent, and secure process of interim payments made in projects. With smart contracts storage and management costs are reduced.	(-)
6	**Digital Building Twins and Blockchain for Performance-Based (Smart) Contracts**		
	Hunhevicz et al., 2022	Record integrity and data integrity are ensured in construction documents.	Although it facilitates document management for AEC projects, it creates certain security vulnerabilities while taking advantage of blockchain security due to smart contract logic.
7	**BIM Integrated Smart Contract for Construction Project Progress Payment Administration**		
	Sonmez et al., 2022	Fair and accessible storage is provided.	Prototypes need to be tested in realistic environments.
8	**Blockchain in the AEC industry: Current Status, Key Topics, and Future Research Agenda**		
	Xu et al., 2020	It records construction progress in distributed ledgers, facilitating inspections and payments.	A poorly designed smart contract will cause irreversible financial losses. Payments and applications via smart contracts are still in the early stages of development and are far from mass acceptance for now.
9	**Blockchain and Smart Contracts: A Solution for Payment Issues in Construction Supply Chains**		
	Nanayakkara et al., 2021	Integration of blockchain and supply chain provides traceability and real-time information	(-)

		access.	
10	**Digitalization in Construction: Blockchain Applicability in The Industry**		
	Pattini et al., 2021	By using real cases to eliminate information asymmetries and to investigate the legal consequences of contracts, solutions to improve trust and conflict between stakeholders can be produced.	(-)
11	**Public and Private Blockchain in Construction Business Process and Information Integration**		
	Yang et al., 2020	Blockchain-based payment automation has benefits for dispute resolution and construction law informatics.	(-)
12	**Integration of Blockchains and Smart Contracts into Construction Information Flows: Proof-Of-Concept**		
	Ciotta et al., 2021	The article provides insight into the feasibility of potential adoption smart contracts with BIM.	It is thought that this integration will take time.
13	**Blockchain-Based Framework for Improving Supply Chain Traceability and Information Sharing in Precast Construction**		
	Wang et al., 2020	Construction projects potentially generate revenue using the distributed ledger.	Distributed database research in the AEC sector remains at the theoretical level.
14	**Blockchain-Based BIM Digital Project Management Mechanism Research**		
	Ni et al., 2021	Payment system becomes easy and transparent with the use of digital building twins to handle digital payments.	(-)
15	**Blockchain in Construction Management: Applications, Advantages, and Limitations**		
	Mahmudnia et al., 2022	Confidentiality in the industrial environment is protected through smart contracts.	(-)
16	**Construction Quality Information Management with Blockchains**		
	Sheng et al., 2020	Supply chain is protected against malicious data.	(-)
17	**The Role of Blockchain in Improving the Processes and Workflows in Construction Projects**		
	Hargaden et al., 2019	Because smart contracts are decentralized, unnecessary bureaucracies are reduced and communication problems are resolved, while conflicts arising from incorrect documentation and payment issues are avoided.	The challenges of smart contracts are lack of professional training, lack of regulatory clarity, and lack of trust.
18	**Exploring Smart Construction Objects as Blockchain Oracles in Construction Supply Chain Management**		
	Lu et al., 2021a	Functional for supply chain management.	Adoption of new technologies is complex in the construction industry, where expected value is immediately met and short-term views on innovation investments are adopted.
19	**Smart Contracts and Supply Chain Management Using Blockchain**		
	Singh et al., 2022	Blockchain technologies have the potential to make the construction industry more efficient, inexpensive, or completely automated.	The technological state of the industry, skills, resistance to change, readiness for adoption, power, malicious attacks, coding of smart contracts, interoperability, legal, connectivity, and bandwidth are the challenges of blockchain technologies in the construction industry.
20	**Towards Adoption of Smart Contract in Construction Industry in Malaysia**		
	Bolhassan, et al. 2022	The processes in which technological developments are included will provide better service to their customers and in this way, they will gain a competitive advantage.	(-)
21	**The Application of Blockchain-Based Crypto Assets for Integrating the Physical and Financial Supply Chains in The Construction & Engineering Industry**		
	Hamledari et al., 2021b	The fusion of BIM and Blockchain technology creates a process that ensures balance of interests, non-destructive transmission of building information, accountability traceability and customer satisfaction.	(-)
22	**Measuring the Impact of Blockchain and Smart Contracts on Construction Supply Chain Visibility Hesam**		
	Hamledari et al., 2021c	Provides benefits in terms of information management and cash flow management.	Blockchain, as a distributed ledger technology, could disrupt the traditional hierarchy way in which information is shared and processes are developed in the construction industry.
23	**Blockchain-Aided Information Exchange Records for Design Liability Control and Improved Security**		
	Pradeep et al., 2021	A transparent and reliable environment is ensured when quality files are stored with a blockchain-based smart contract.	Issues such as initial development cost need to be resolved.
24	**Securing Interim Payments in Construction Projects Through a Blockchain- Based Framework**		
	Das et al., 2020	Applications of blockchain technology, a reliable, distributed data storage mechanism combined with smart contracts, focus on solutions for complex inter-organizational processes for payment related issues.	(-)
25	**A Smart Contract System for Security of Payment of Construction Contracts**		

	Ahmadisheykhsarmast, & Sonmez, 2020	Construction processes speed up conflicts between stakeholders are reduced payments made easy.	Since the system does not allow price updates, some survey participants hesitated to switch to unit price projects.
26	**Role of Blockchain-Enabled Smart Contracts in Automating Construction Progress Payments**		
	Hamledari et al., 2021d	Construction project management platform based on blockchain, and smart contract technologies can enable peer-to-peer collaboration between construction parties, which improves information flow to reduce cost and time expenditures while increasing quality in construction.	(-)
27	**Building Applications for Smart and Safe Construction with the DECENTER Fog Computing and Brokerage Platform**		
	Kochovski et al., 2021	It is stated that the two projects carried out with smart contracts can increase the integration of crypto assets in cash and product flow.	Risks exist in regulatory environments, security, and price volatility. With the involvement of crypto assets there are risks associated with regulations, security and volatility of cryptocurrencies in projects.
28	**The Role of Blockchain Technologies in Construction Engineering Project Management**		
	Hargaden et al., 2019	With smart contracts, management costs are reduced, service costs are saved, and the efficiency of business processes is increased.	(-)
29	**A blockchain-based Integrated Document Management Framework for Construction Applications**		
	Das et al., 2022	Building trust among stakeholders.	Technological barriers brought by information redundancy.
30	**Designing a Collaborative Construction-Project Platform on Blockchain Technology for Transparency, Traceability, and Information Symmetry**		
	Udokwu et al., 2021	It has the potential to improve the transparency and traceability of materials supply chains.	(-)
31	**A Systematic Analysis of the Application of Blockchain in the Field of Construction Engineering**		
	Fu et al., 2021	New technologies such as blockchain-based technologies are beneficial for the development of the industry.	(-)
32	**A Blockchain Information Management Framework for Construction Safety**		
	Morteza et al., 2021	With blockchain integration, construction workers and the public are protected by providing reliable and complete information at the right time to organizations in projects.	(-)
33	**BIM Fork: Are Smart Contracts in Construction More Likely to Prosper with or without BIM?**		
	Mason et al., 2019	Thanks to digitalization, transaction costs and times are reduced. Stakeholders do not have to deal with internal affairs, thus ensuring risk allocation.	(-)
34	**Blockchain Technology for Governmental Supervision of Construction Work: Learning from Digital Currency Electronic Payment Systems**		
	Lu et al., 2021b	It is recommended for government supervision of construction works because of blockchain technology's traceability, immutability, and transparency advantages.	Even if there is one-way anonymity in the proposed system, authorized institutions can monitor the transactions. For this reason, there would be privacy concerns if it was used for international business transactions.
35	**Blockchain-Enabled IoT-BIM Platform for Supply Chain Management in Modular Construction**		
	Li et al., 2022	Using blockchain for supply chain can save storage costs in BIM and avoid a single point of failure for IoT networks with privacy and security protection mechanisms.	It is unclear how data can be used in an adaptive way as existing smart contracts are almost deterministic.
36	**Construction E-Inspection 2.0 in the COVID-19 Pandemic Era: A Blockchain-Based Technical Solution**		
	Lu et al., 2022	A blockchain-based solution proposal has been presented in the e-audit system proposed for the measurement of construction quality under pandemic conditions.	(-)
37	**Insights into Blockchain Implementation in Construction: Models for Supply Chain Management**		
	Tezel et al., 2021	Blockchain implementations in payment arrangements has been shown to be simpler than traditional methods in terms of workflow in tender management.	Legal reforms are needed to confirm the rights to data held in smart contracts and the immutability of data stored in the blockchain. Besides, a loss of employment in the industry due to automation processes facilitated by blockchain is a general concern.
38	**On-Site Construction Quality Inspection Using Blockchain and Smart Contracts**		
	Wu et al., 2021	The risk of document and data loss and data manipulation will be solved thanks to the immutable and transparent recordability feature of the blockchain.	Integration of blockchain with IoT can work together in a viable and efficient way is a major challenge.
39	**Rationale for the Integration of BIM and Blockchain for the Construction Supply Chain Data Delivery: A Systematic Literature Review and Validation through Focus Group**		
	Hijazi et al., 2021	The lack of resolution of disputes between stakeholders involved in BIM is resolved with a	(-)

		blockchain-based system.	
40	**State-of-the-Art Review of Blockchain-Enabled Construction Supply Chain**		
	Yoon & Pishdad-Bozorgi, 2022	A supply chain management system combined with blockchain technology is proposed to improve sustainability in the supply chain, encourage cooperation and facilitate information sharing.	(-)
41	**Using Blockchain to Improve Information Sharing Accuracy in the Onsite Assembly of Modular Construction**		
	Wu et al., 2022a	Owing to its decentralized consensus mechanism, blockchain has the potential to improve information-sharing accuracy on construction sites.	(-)
42	**Blockchain Technology in the Construction Industry: Current Status, Challenges, and Future Directions**		
	Wu et al., 2022b	Blockchain has a potential from the whole lifecycle of building projects, in the design stage, construction stage and the operation stage.	Immutability challenge of smart contracts, lack of examinations on blockchain-based cooperation and workflows, lack of supporting policies on blockchain adoption, reluctance to change current systems; considered as the problems of the blockchain.
43	**A Turn to Smart Contracts and Future Applications towards Construction Innovation: A Hybrid-Metric Review**		
	Owusu et al., 2020	The feasibility of smart contracts was demonstrated during the planning, purchasing, execution and management of the processes related to the construction project.	(-)
44	**Blockchain: A Theoretical Framework for Better Application of Carbon Credit Acquisition to the Building Sector**		
	Woo et al., 2020	With the blockchain, the sustainability of the construction industry in terms of the carbon market will be ensured.	(-)
45	**Facilitating Smart Contract in Project Scheduling under Uncertainty—A Choquet Integral Approach**		
	He et al., 2022	Smart contracts will help project managers speed up the manpower and scheduling management required in their use of resources.	(-)
46	**Leveraging Blockchain Technology in AEC Industry during Design Development Phase**		
	Singh & Ashuri, 2019	With the incorporation of smart contracts into the AEC industry, a framework will be created to monitor and record design commands and events in a secure, transparent, and collaborative platform.	This technology is in early development as the construction industry is resistant to adapting to new technologies. These technologies are difficult to verify as there are no similar techniques for comparison.

Studies are generally on the integration, potentials, and opportunities of new technology. Although the negative aspects of the use of blockchain are not expressed in all studies, various problems are mentioned as a limitation in most of them. Some studies have focused on the application of the use of blockchain in civil engineering. For example, Fu et al. (2021) used only the construction engineering context in their study. Hijazi et al. (2021) solves a specific problem involving BIM integration; Owusu et al. (2020) on the other hand, conducted a literature review on smart contracts studies until 2018. Although a similar study was conducted with Mahmudnia et al. (2022), this study deals with the benefits and challenges of integration rather than a detailed content analysis. Moreover, more recent studies were examined as a supplement to the reviewed literature. Detailed explanations related to identified 46 reviewed articles is included in the "Implementation of Smart Contracts in the AEC Industry" section.

Implementation of Smart Contracts in the AEC Industry

Blockchain, one of the latest developments in technology, has recently produced an alternative way for the AEC industry to potentially achieve reliable collaboration, especially in construction processes (Risius & Spohrer, 2017). Blockchain and other distributed ledgers hold great potential for the AEC industry to integrate governance and contracting methods that increase trust and collaboration (Hunhevicz & Hall, 2020).

Distrust in construction contracts has become a natural situation. For this reason, it can be said that the blockchain has potential with its cryptographic and verifiable transactions stored in a decentralized ledger, with a system that can ensure trust among construction stakeholders (Xue & Lu, 2020). With the inclusion of the blockchain in the system, the payment security in the construction sector is ensured, while the burden of other payments such as administrative costs, attorney costs, and intermediary bank payments is alleviated (Ahmadisheykhsarmast & Sonmez, 2020). Resource management platform developed by Kochovski and Stankovsk (2020), offers a blockchain-based system to oversee broad categories of construction such as occupational safety, site management, and resource and waste management. In Das et al.'s (2022) study, the use of blockchain-based smart contracts was proposed due to the security concerns that lie in the collection and management of these documents since the documents and their management of AEC projects require record integrity and data integrity. Hamledari and Fischer (2021b) proposed a blockchain-integrated smart contract system in their work that senses construction progress, captures it with machine intelligence and BIM, and analyzes and documents it. With the prototype proposed by Pradeep et al. (2021) individual design inputs are added to the project design in the construction industry, images are recorded, and long-term records of key exchange transactions can be taken. In this case, the design responsibility and control of all stakeholders will be changed. In addition, the evidence in this system is stored independently of a third party. This way, the information's existence, integrity, and authenticity can be verified. Therefore, this integration supports existing information exchange systems. Sheng et al. (2020) presented a system that can be used for the management of quality information in construction with the support of blockchain to enable quality management in the AEC industry. The work by Hunhevicz et al. (2022) proposed a blockchain-based smart contract link that calculates the costs of the devices to be used in the construction project, thus allowing performance evaluation and routing digital payments. In the study of Hamledari and Fischer (2021a), it was stated that two projects carried out with smart contracts can increase the integration of crypto assets in cash and product flow. Yang et al. (2020) presented the process, benefits, and challenges of adopting private and public blockchain technologies by examining two cases to find out the effects of smart contracts in the construction industry. Ciott et al.'s (2021) work aim to reduce human error in the process and increase the reliability and transparency of structural system decision-making processes on construction sites by providing common data environments to support document management of blockchains and smart contracts. By integrating smart contracts into the construction sector, payment security in the construction sector is ensured, while the burden of other payments such as administrative costs, attorney costs, and intermediary bank payments is relieved (Risius & Spohrer, 2017; Ciott et. al., 2021). A survey of construction experts in Sonmez et al.'s (2022) study showed that blockchain has the potential to speed up all construction processes, streamline progress payments, reduce disputes, and improve traditional payment procedures.

Benefits of Smart Contract Applications

It was suggested that blockchain technology can contribute to building trust among construction stakeholders (Xue & Lu, 2020). It is mentioned that the effect-based trust in traditional contracts will be replaced by systems-based trust. As the cooperation between stakeholders increases, so does the trust of users. In this way, stakeholders are gained on the quality of the construction done (Pradeep et al. 2021; Yang et al., 2020). With the idea of a smart contract to be used in the interim payment stages of construction projects, security measures such as the privacy of data and users are taken, while storage and management costs

are reduced (Das et. al., 2020). With the use of smart contracts, performance-based contracts are reliably digitized, performance-based uses are scaled in the embedded environment, and new business models are possible by stimulating project lifecycle-related markets (Hunhevicz et al., 2022). Tezel et al.'s study revealed that using the implementation of blockchain in payment arrangements in construction is simpler than traditional methods in terms of workflow in tender management (Tezel et al., 2021). Lu et al. (2022) proposed a system that provides remote control for conditions such as pandemics. In this case, a blockchain-based solution proposal is presented in the proposed e-audit system for the measurement of construction quality. Thus, this control will be made more secure with rigorous technological analysis. With Hamledari and Fischer's (2021b) proposal to integrate smart contracts with construction progress, construction progress data is stored in distributed ledgers, making payment management easier. Thanks to digitalization, transaction costs and times are reduced. Stakeholders do not have to deal with internal affairs, thus ensuring risk allocation (Mason et al., 2019).

Through the smart contract, data sharing is encouraged. Approval processes are facilitated, operating costs are reduced, collaborative efficiency is increased, a reliable infrastructure is obtained for the digitalization of the construction industry, and labor and cost savings are achieved (Ni et al., 2021). The use of smart contracts in contracts allows for reliable and unalterable archiving of every document in the process, such as drawings, models, datasheets (Pattini et al., 2021). Transparency and traceability of the supply chain are improved in the business process where the blockchain is included. Records cannot be changed and can be viewed retrospectively. In this way, transparency is ensured, and quality fraud issues are alleviated (Yang et. al., 2020). Because smart contracts are decentralized, unnecessary bureaucracies are reduced and communication problems are resolved, while conflicts arising from incorrect documentation and payment issues are avoided (Mahmudnia et al., 2022). Smart contracts ensure that payments are made automatically, eliminating the need for third parties, and saving time and money in case of any dispute involving third parties (Pattini et al., 2021).

In Woo et al.'s (2020) study, with the blockchain, the sustainability of the construction industry in terms of the carbon market will be ensured. Yoon and Pishdad-Bozorgi (2022) points out that the use of blockchain in the supply chain will be beneficial for sustainability.

Difficulties and Threats of Smart Contract Applications to Validity and Implications

The integration of BIM and blockchain and see it as a great potential for achieving more efficient applications, it may face many technological hurdles due to information redundancy (Xue & Lu, 2020). On the other hand, currency fluctuations are the biggest obstacle to the proposed system. Financial risks cannot be fully protected since the relationship of cryptocurrencies with each other will not always progress with a positive correlation. In addition, the current market value of cryptocurrencies creates limitations for large-scale construction projects (Ahmadisheykhsarmast & Sonmez, 2020; Hamledari & Fischer, 2021a).

The current market value of cryptocurrencies creates limitations for large-scale construction projects. Financial risks cannot be fully protected due to currency fluctuations (Ahmadiseykhsarmast & Sonmez, 2020). Due to the continuous development of the use of blockchain in areas such as finance, pilot applications are very few, which limits studies and applications (Wang et. al., 2020). Since distributed database research in the AEC sector

remains theoretical, there are very few applied cases today (Hunhevicz & Hall, 2020). Moreover, payments and applications via smart contracts are still in the early stages of development and are far from mass acceptance now (Hamledari & Fischer, 2021b). Progress payment system proposed by Sönmez et al. since the system does not allow price updates, some survey participants hesitated to switch to unit price projects (Sonmez et al., 2022).

Although the document management system consisting of blockchain-based smart contracts proposed by Das et al. facilitates document management for AEC projects, it may suffer from certain security vulnerabilities while benefiting from blockchain security due to smart contract logic (Das et al., 2022). Moreover, by using real cases to eliminate information asymmetries and to investigate the legal consequences of contracts, solutions to improve trust and conflict between stakeholders can be produced (Hamledari & Fischer, 2021c). Legal reforms are required to confirm the rights of data held in smart contracts and the immutability of data stored in the blockchain (Tezel et al., 2021). According to Pradeep et al.'s (2021) research, smart contracts have theoretical advantages in improving the relationship between stakeholders, but it is recommended for future work to test prototypes in realistic environments. It is doubtful whether the agreement will be reached between the parties in the proposed framework on smart contracts and quality management in construction, and issues such as initial development cost need to be resolved (Sheng et. al., 2020). There is a lack of experience using smart contracts and it is unclear whether this will be beneficial for some stakeholders (Mohammed et al., 2021).

The technological state of the industry, skills, resistance to change, readiness for adoption, power, malicious attacks, coding of smart contracts, interoperability, legal, connectivity, and bandwidth are the challenges of blockchain technologies in the construction industry (Mohammed et al., 2021). The blockchain-based model proposed by Lu et al., authorized institutions can monitor transactions even if there is one-way anonymity in the system, and this will raise privacy concerns for international commercial transactions (Lu et al., 2021b).

A change of mindset and specific training are required so that blockchain-based smart contracts can be used in the AEC industry and integration can be accelerated (Pattini et al., 2021). Although useful, a comprehensive paradigm shift is required in terms of contract management philosophies and guidelines in the transition to smart contracts in the construction industry (Chaveesuk et al., 2020). Despite gaining benefits in theory, the construction industry, which is accustomed to traditional practices, cannot easily trust and adapt to innovations (Pattini et al., 2021). The construction industry has many stakeholders who use the traditional system and are stubborn in using it, so coordination between units is difficult (Nanayakkara et al., 2021). AEC industry lags in the adoption of process-based technologies (Hargaden et al., 2019; Mohammed et al., 2021). In addition, a loss of employment in the sector due to automation processes facilitated by blockchain is a general concern (Tezel et al., 2021)

Discussion and Conclusion

Smart contracts are seen as one of the newest technological developments in the AEC industry. The main purpose is to carry out the construction works, which are quite complicated compared to all other sectors and carried out with many procedures among multiple stakeholders, in a more reliable, transparent, fair, and auditable manner. While

production companies are trying to incorporate smart contracts into their systems as soon as possible, this integration needs to be investigated more through real-life applications. With this meta-integrating qualitative study, the relationship of the project management process of the construction industry with blockchain-based smart contracts and the emerging integration threats are revealed, contributing to knowledge. When the literature review is made, the fact that the current studies focus on the last years shows that the research in this field have increased as we approach the present day, that is, this research topic has gained popularity.

Study findings agree that smart contracts have many benefits for the AEC industry, including resolution of disputes, ensuring record integrity, equality between stakeholders, removing unnecessary bureaucracy, reliability, removal of agents, ensuring cooperation, reducing costs, auditability, providing convenience and transparency. Although all studies have positive thoughts about the integration of smart contracts into the industry, they state that this integration process will be difficult, especially due to the conservative and non-changeable nature of the construction industry. In addition to these difficulties, the risks that the blockchain in the structure of smart contracts will face during the implementation phase are also mentioned due to various features such as irreversibility, immutability, and deficiencies in legal regulations. All but one of the studies discussed focused on the benefits of the mentioned integration, while negative opinions were also mentioned in 23 studies. Studies have focused on the difficulties and threats to validity and implications that may arise with the integration of smart contracts into the AEC industry. When the benefits of smart contract application highlighted in the articles were examined it can be stated that the most intense studies focus on the benefits of "transparency". This is followed by the technology facilitating processes and auditability, which are two features obtained with the inclusion of blockchain technology. There are statements that this integration provides to reduce the costs in the project management processes and beyond that, it improves the relations between the stakeholders. In addition, reliability, the elimination of intermediary institutions and organizations, followed by the end of unnecessary bureaucracy processes are among the benefits. With this integration, while ensuring equality and balance between the stakeholders, the reliability of the records is proven by retrospectively auditing the transactions. Finally, there are benefits of smart contracts for dispute resolution. When the data obtained about the difficulties and threats of smart contract applications were scanned; it was seen that majority of the articles focused on the working of cryptocurrencies depending on the blockchain and the problems arising from the blockchain technology itself. As examples of these difficulties and threats, problems such as not being able to take back the contract clauses, the rules that need to be restructured according to the scale of the project, security vulnerabilities, and the lack of necessary legal regulations can be listed. It has been stated that more real-life examples are needed for the integration mentioned in the 7 articles. In addition, the concern was expressed that the necessary training should be obtained for the adoption and acceptance of blockchain technology by the stakeholders. In 3 articles, the size of the initial development cost of integrating this technology is also considered a problem.

According to the literature, although the integration of blockchain-based smart contracts into the AEC industry has some risks and uncertainties, it is claimed that the mentioned combination is quite facilitating in terms of costs, disputes, payment periods, project completion time, and project management in the industry. However, the literature is insufficient in the solution of the identified risks and negativities. The primary reason for this is that smart contract applications are not widespread and yet have very few experts. In this regard, the findings of this study will be useful for the AEC industries to understand, adopt and list the opportunities and threats they may encounter during the implementation phase of

blockchain-based smart contracts. For this reason, our recommendation for future studies is to expand the studies to be carried out on the benefits of smart contracts to the construction industry, as well as on the improvement of the acquired risks and negativities. Finally, this study reemphasizes the necessity of producing new scientific studies through real-life application examples of the mentioned integration.

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Change Management in Construction: A Systematic Review

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Abstract

Change management is a strategic act that supports organizations in achieving their goals in the global marketplace. Construction firms as project-based entities need to manage change in different settings for survival and competitiveness. Managing change efficiently has become a central concern for construction firms in terms of sustaining and improving their position in a fluctuating environment by rapidly adapting and responding to external changes in a flexible manner. Over the years, a considerable amount of study has been conducted relating change management which revealed various causes of change, the implications of change, the factors relating to resistance to change, the change management models, and the relevant systems in the construction industry from different perspectives. While a significant number of research papers relied on case-based approaches, only a few presented a systematic review of the existing body of knowledge. The main objective of this paper is to conduct a systematic review of the existing scholarly work to clarify gaps and highlight possible paths as inputs for in-depth empirical research. Paper presents the classification of methods and outcomes from the change management studies in construction.

Keywords: *Change, change management, construction firms, systematic review.*

Introduction

Increasing global competition, growing scarcity of resources as well as technological developments put great pressure on all organizations to adapt and survive by responding to constant change (Al-Sedairy, 2001). In a global marketplace characterized by ever-increasing competitiveness and customer expectations, change management has emerged as a strategic function that supports organizations in staying ahead of the competition (Erdogan et al., 2005). The unique and dynamic nature of the construction industry necessitates change management in all phases of the construction projects (Mohammed & Karri, 2020), since scope changes are inevitable over their lifecycles (Padala et al., 2020). Accordingly, a systematic change management system during the construction process is essential to minimize the impact of changes on project targets (Bitamba & An, 2020).

Over the years, a considerable amount of research studies have been conducted relating change management which revealed various causes of change (Wu et al., 2005; Sun & Meng, 2009; Andersen et al., 2011; Oyewobi et al., 2016; Yap et al., 2017; Bitamba & An, 2020; Padala et al., 2020), the factors relating to resistance to change (Davis & Songer, 2003; Davis & Songer, 2009; Lines et al., 2015), the change management models (Price & Chahal, 2006; Ibbs & Chen,

2015; Saoud et al., 2017; Jaaron et al., 2022), the best practices (Zou & Lee, 2009), in addition to various change management systems from different perspectives such as technology adaptation (Maali et al., 2020; Jaaron et al., 2022), and sustainable systems adaptation (Lim et al., 2016). While a significant number of research papers relied on case-based approaches, only a few presented a systematic review of the existing body of knowledge. These studies are mainly based on reviews of change management practices at the project and organizational levels (Erdogan et al., 2005) and the causes and effects of change in construction projects (Sun & Meng, 2009; Padala et al., 2020). Such studies can be seen as a roadmap to review, evaluate and manage changes in projects (Sun & Meng, 2009). However, available literature mostly focused on specific aspects of change management in the construction industry, which indicates the need for a systematic investigation to review the current change management practices and trends in the construction industry.

As a part of an ongoing research study, authors aim to conduct a systematic review of the existing scholarly work on change management. Paper presents the classification of the methods of and outcomes from the change management studies in construction, based on the analysis of publications which shows patterns of changes within a discipline, thus enabling the assessment of the impact of contributions, detecting existing topics related to the research scope, and setting research gaps for future search.

Change Management in Construction Industry

Any extensions, deletions, or alterations to project objective and scope are regarded as change that result in increase or decrease of schedule or cost of a project (Ibbs et al., 2001). For construction firms to achieve a desirable status in the future, there is a need for a structured approach to change. According to Managing Change in Organizations: A Practice Guide (Project Management Institute, 2013), change management refers to *"a comprehensive, cyclic, and structured approach for transitioning individuals, groups, and organizations from a current state to a future state with intended business benefits."* Change management contributes organizations to incorporate stakeholders, structures, processes, business strategy as well as culture (Project Management Institute, 2013). To sustain organizational growth according to business needs, construction organizations should adapt to change in the market (Ozorhon & Demirkesen, 2014). According to Project Management Institute (PMI) (2021), changes may arise from a consequence of project risks or environmental factors, the need for a deeper understanding of project needs, or client requirements. Shipton et al. (2014) argued that changes in construction occur due to the needs of clients, while the availability of construction material or unpredictable ground conditions also lead to various changes. According to Padala et al. (2020), the maximum number of changes occur in the execution stage of the projects which result in time and cost overruns. Bitamba and An (2020) classified causes of changes in construction under various categories: design-related, contractor-related, owner-related, organizational and management-related, project-related, changes related to environment and site conditions, changes related to materials and equipment, changes related to economy and governmental regulations.

Change management in construction requires the consideration of not only the causes of change but also the critical change effects that have critical impact on project outputs in a positive or negative way. Ibbs et al. (2001) argued that change actions cover two significant typologies including beneficial and detrimental ones, while the former should be encouraged, the latter should be avoided, authors argued. Beneficial changes are the output of value management

operations, which help to reduce the degree of difficulty, schedule as well as the cost of the project. Detrimental changes, in contrast, have negative influence on project so they should be minimized carefully (Ibbs et al., 2001). Bitamba and An (2020) argued that detrimental changes can cause uncertainties as well as interfaces which lead to production of non-viable movements. Hwang and Low (2012) pointed out the criticality of the timely description and understanding of project changes' impacts to minimize their adverse effects. Some primary adverse effects of changes were identified by Hwang and Low (2012) as the increase in project cost, recruitment of new professionals, increase in overhead expenses, quality degradation, decrease in labor productivity, delay in procurement process, rework and demolition, safety conditions, and delay in completion schedule.

Construction management literature has focused on both the causes and effects of change (Sun & Meng, 2009; Padala et al., 2020). Sun and Meng (2009) proposed three levels of classification for the construction projects. Level 1 consists of three dimensions including external, organizational and project internal causes. External causes cover environmental, political, social, economic and technological factors. Organizational causes consist of process, people and technology related factors. Lastly, project internal causes are identified as generated by client, design consultant, contractor/subcontractor, and other (such as poor communication, instability of project team and unsuitable organizational structure). Taxonomy for the effects consists of three different levels. Level 1 includes time, cost, and relationship and people effects. Time effects consist of time extension, loss of productivity, and increased risk. Cost effects cover direct and indirect cost increases. Also, relationship, working conditions, staff, as well as quality related factors include the dimensions of relationships and people effects. In a similar vein, Padala et al. (2020) identified 85 causes and 45 effects of change from the literature, and they investigated 3951 changes from 19 projects to define causes and effects in construction projects. Padala et al. (2020)'s taxonomy covers three levels. Level 1 consists of client-related, design, interfere, construction, external, and performance dimensions related to *causes of change.* The identified Level 1 for the *effects of the change* covers time, cost, and others (including site conditions, quality, delays in procurement, and relationships among the project team).

Change management typically arises in construction at two levels including the *project* and *organization* (Erdogan et al., 2005). Project level covers mostly design changes and those prior to the execution stage. Changes in technology, culture, stakeholders, management (Erdogan et al., 2005), politics and economy (Padala et al., 2020) are the examples of organizational level changes. Table 1 summarizes different types of changes in construction at both levels. It is critical to introduce change to the organization since any misunderstanding, fear for the future, the lack of awareness, and the speed of change implementation can be seen as a threat to stakeholders, thereby causing resistance. The latter is seen as a main challenge to organizational change actions which requires the consideration of project scope, size and duration of change event, organizational expectations of change implementation speed, the establishment of formal change agents, and the level of change agent involvement with implementation activities (Lines et al., 2015).

Table 1. The classification of different types of changes (Taken from Erdogan et al., 2005).

According to	**Project Changes (PCs)**	
Type of Impact (Construction Industry Institute (CII), 1994)	*Beneficial Changes*	*Detrimental Changes*
	Reduce cost, schedule or degree of difficulty.	Reduce owner value, have negative impact on the project.
Need for Change (CII, 1994)	*Required Changes*	*Elective Changes*
	Implemented to meet the objectives or regulatory/ legal/ safety/ engineering requirements/standards.	Enhance the project, but are not required to meet the original objectives.
Initiation Nature/Responsiveness of change (Burnes, 1996)	*Emergent/ Reactive Changes*	*Anticipated/ Proactive Changes*
	Unplanned, unexpected. The response is after the occurrence.	Expected before it occurs, therefore necessary actions are taken.
According to	**Organizational Changes (OCs)**	
The difference in the organization due to change (Tichy, 1982)	*Strategic Changes*	*Non-strategic Changes*
	Nonroutine, nonincremental and discontinuous, alter the overall orientation of the organization.	Do not affect the overall orientation of the company, do not result in a drastic difference.
Speed of the transformation in the organization (Cao et al 2000; Cummings and Worley, 1997)	*Incremental/ Gradual/ Fine Tuning*	*Radical/ Quantum Changes*
	Routinely necessary for any organization to adapt to its environment.	Necessitates a thoroughgoing reexamination of all facets of an organization
Initiation Nature (Burnes, 1996)	*Emergent Changes*	*Planned Changes*
	Driven from bottom up and is an open-ended and continuous process of adaptation to changing conditions.	Result of an action research& an analysis of the social and organizational problems in question.
Initiation Nature (Burnes, 1996)	*Emergent Changes*	*Anticipated Changes*
	Same as above.	Not planned by the organization but it's happening is expected.

According to the PMI's PMBOK 7th Edition, the ability to implement new strategic initiatives and change has rapidly become a key differentiator (Project Management Institute, 2021). Effective and efficient management of change supports the achievement of desired project goals, improve the construction firm reputation, and reduce the cost, and schedule of the project. Change management in construction firms requires strong leadership skills, an effective change management plan that establishes the change control board (Project Management Institute, 2017), the involvement of proper project stakeholders (Lines et al., 2015), adapting the speed of change, and benefits and impacts of change communicated to all levels of the organization (Project Management Institute, 2021).

Change Management Models

Numerous change management models have been proposed in the literature which considers the technical (e.g., procedures) and non-technical (e.g., culture and habits) aspects of change. Table 2 shows the commonly cited change management models, in depth explanation of which is beyond the scope of this paper due to space limitations.

Table 2. The classification of change management models (Adapted from Project Management Institute, 2021).

Change Management Models	*Steps*	*Consideration*	*References*
Lewin's Three Step Model	Unfreeze Moving Refreezing	One of the most influential approaches in the change management discipline that indicate the stages of organizational change.	(Lewin, 1947)
William Bridge's Transition Model	Endings Neutral zone New beginnings	Provides an understanding of what occurs to individuals psychologically when an organizational change takes place.	(Bridges, 1991)
Virginia Satir Change Model	Late status quo The foreign element Chaos The transforming idea Practice and integration New status quo	Mainly based on how people experience and cope with change.	(Satir et al., 1991)
Principles of Effective Change Management	Promote a balanced change culture Recognize change (when it occurs) Evaluate change Implement change Continuously improve from lessons learned	Assist project managers to manage change more effectively.	(CII,1994)
The 8-Step Process for Leading Change	Create urgency Form a powerful coalition Create a vision for change Communicate the vision Remove obstacles. Create short-term wins Build on the change. Anchor the changes in corporate culture	Outlines how to systematically and effectively implement change in an organization.	(Kotter, 1996)
ADKAR Model	Awareness Desire Knowledge Ability Reinforcement	Provides a tool for change that is effective on an individual level.	(Hiatt, 2006)
Managing Change in Organizations: A Practice Guide	Formulate change Plan change Implement change Manage transition Sustain change	It is a complementary document to Project Management Institute's (PMI) foundational standard and provides guidance on implementing change management.	(PMI, 2013)

Various change management models or frameworks have also been proposed for construction firms. Ibbis et al. (2001) proposed an efficient system for managing change in projects which covers respectively: promoting a balanced change culture, recognizing change, evaluating change, implementing change, as well as improving from lessons learned. Hao et al. (2008) developed a model for change processes containing identify, evaluate and propose, approve, implement and review phases for construction. Sun et al. (2004) described a toolkit for change management for construction projects, supporting the project team related to the prediction and reaction of change with knowledge and procedural perspectives. Gibson et al. (2012) developed

an organizational change model that includes the forces for change, performance outcomes, diagnosis of the problem, selection of appropriate intervention, limiting conditions, implementation of the method, and evaluation of the method. Al-Sedairy (2001) offered a change management model specific to Saudi construction industry that consists of four stages of action plans each catering to the seriousness or depth of the perceived organizational problem. Jaaron et al. (2021) proposed a model that identified two main phases and ADKAR steps for various project team members to execute an accomplished change management process regarding the BIM adaptation by using the ADKAR model.

Method

A systematic and structured literature review was conducted by focusing on selected scholarly works on change management. Data were obtained from the Web of Science (WoS) database (Web of Science, 2022) and Scopus database (Scopus, 2022), since these databases cover inclusive, interdisciplinary (Scopus, 2022) as well as the high-impact publications (Web of Science, 2022). Considering the scope of the study, the search keywords were identified as "change management," "construction industry," and also, "construction sector." The search was conducted with various combinations of these keywords. The selection criteria were limited in that each publication should address either change issues or change management, or both. The searches were done in the topic field (covering title-abstract-author keywords- keywords plus®) in WoS and in the title-abs-key field (covering title-abstract- keywords) in Scopus. The research was limited to a 22-year time span from 2000 to 2022. The language type was limited to English for the selected documents.

As a result, 110 publications from the WoS database and 201 publications from the Scopus database were identified, totalling 311 documents which includes journal articles, conference proceeding papers, book chapters, book reviews, reviews, and early access. Some of the documents selected for this study included at least one of the keywords defined for this study in their titles, abstracts, or keywords. Publications were arranged in alphabetical order and those with the same title were removed and identified as 189 documents. The title, abstracts, and keywords of 189 documents were investigated to reach relevant studies thus after the investigation 177 documents were included. Lastly, the full texts of 177 documents were assessed in terms of their relevance to change management and construction industry and 75 publications were included to this study. Figure 1 shows the selection processes of total publications identified through WoS and Scopus.

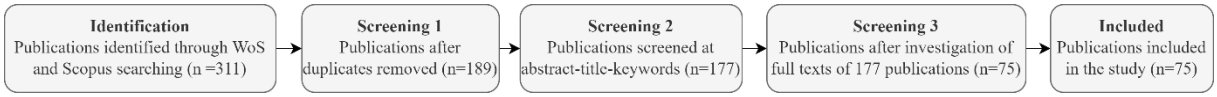


Figure 1: The selection processes of publications for analysis (Search date 22.03.2022).

The second step of the study was a bibliometric analysis by using the VOSviewer software tool (version 1.6.18.) (VOSviewer, 2022) to visualize and create maps by using the network data. The network data consists of 75 scholarly works identified from WoS and Scopus database searches. These 75 publications were added to the reference manager program Zotero, and reference manager files were converted to the RIS format for VOSviewer analysis.

VOSviewer was used to analyze keyword co-occurrence and create network model based on keywords of the identified publications. All duplicating keywords in the network data were

eliminated from the visualization maps using by VOSviewer thesaurus file. The keywords included in VOSviewer were limited to 3 times of repetition.

Findings

Having clarified the need for a systematic investigation of the current change management issues in construction, following parts present the current status, point out the future gaps, and highlight possible paths as inputs for in-depth empirical research, according to the systematic literature review. This section represents the descriptive analysis of selected 75 publications and VOSviewer analysis.

Firstly, the 75 relevant publications were analysed according to the distribution over 22 years period (Figure 2). The maximum number of scholarly works was published in 2009, followed by 2020 and 2017, respectively. Except for the years 2000, 2004, and 2010, at least one study was conducted each year relating change management. Notably, distribution of publications over the years indicates a revival in the field.

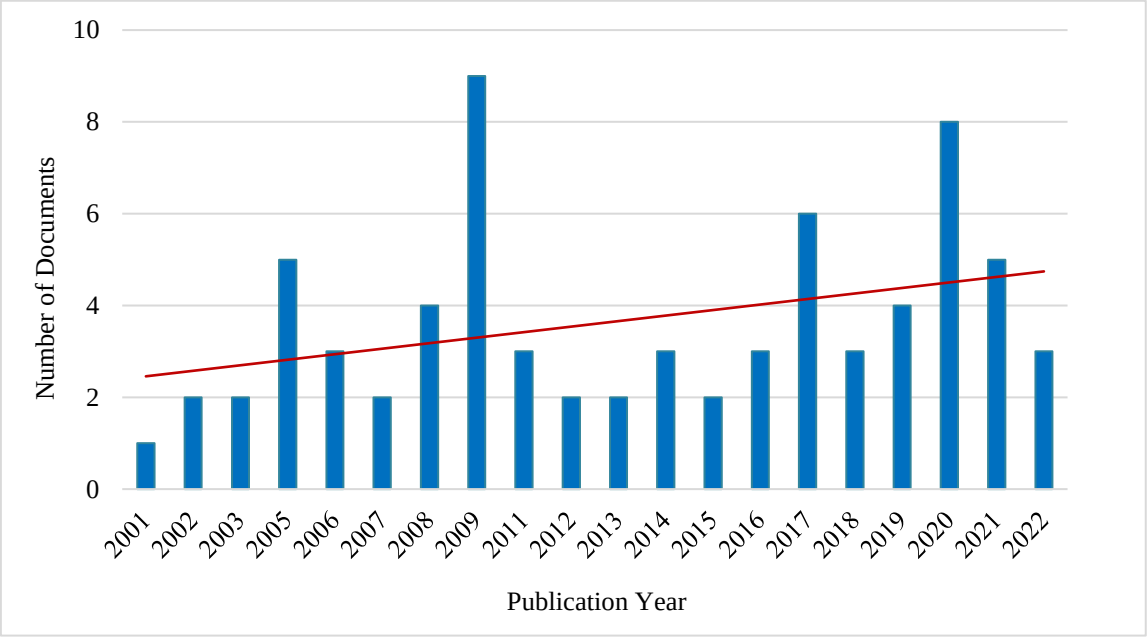


Figure 2: Distribution of publications between 2001 and 2022.

Next, the distribution of publications was analyzed geographically (Figure 3). The USA has the most scholarly works with 15 followed by the UK with 14, demonstrating that change management studies in the construction industry during the period of interest concentrated in these two countries. Figure 3 also shows that research interest in change management has been growing in the Australia and China.

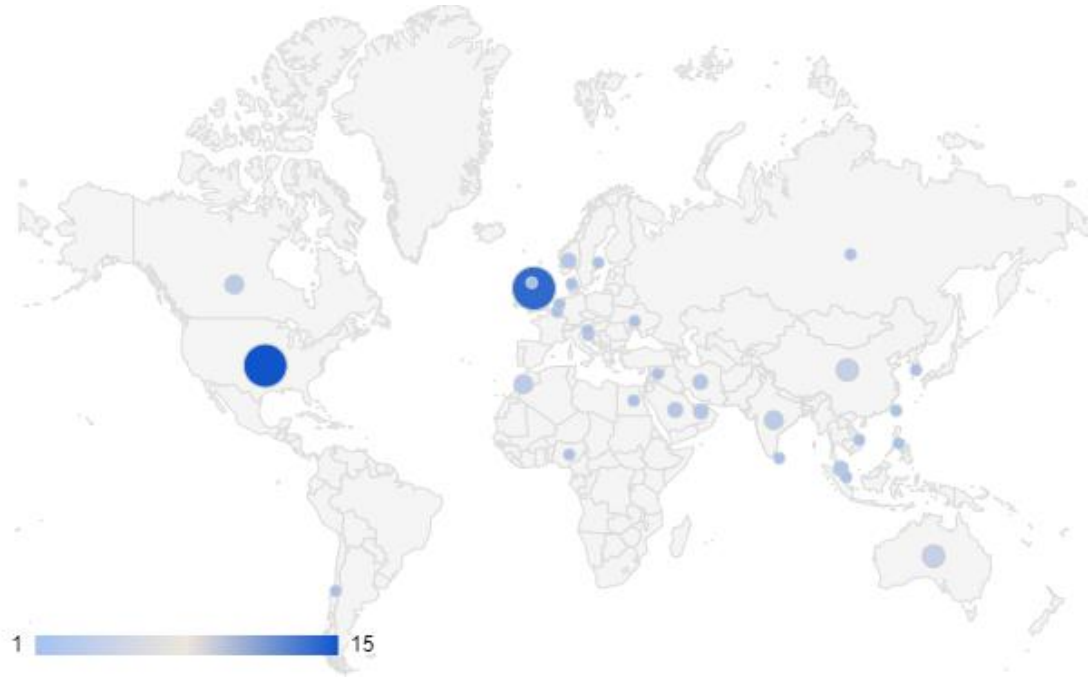


Figure 3: Distribution of publications according to countries (2000-2022).

Selected studies were analysed by considering the main objectives of the studies to summarize the prominent change management themes (Figure 4). In a 22-year period, technological changes like Building Information Modeling (BIM) or sustainability and their adoption into construction organizations and projects were the predominant themes in the construction management field. The management of such technological changes can have positive or negative impacts on project success. In terms of negative influence, resistance to technological change is one of the prominent considerations among technological change, as construction firms face high resistance to change due to lack of communication (Jafari et al., 2020; Maali et al., 2020), lack of understanding of new technology solutions (Maali et al., 2020), lack of establishment of a realistic timeframe for change adoption (Maali et al., 2020), lack of knowledge management and learning (Senaratne & Sexton, 2009), lack of effective change agents and lack of setting clear milestones for change implementation (Maali et al., 2020). Accordingly, the number of publications and citations relating technological change, innovation, BIM and adoption has been growing steadily.

Developing and proposing “change management systems or models or frameworks” were the other prominent themes in the construction management field. To achieve project and company goals and gain a competitive advantage in the industry, proposing roadmaps for effective and efficient change management was a central theme for many scholars. The investigation and classification of “causes or impacts of change management” in construction firms was another area of concentration, since the proper understanding of causes and impacts assist project participants in managing changes proactively (Padala et al., 2020).

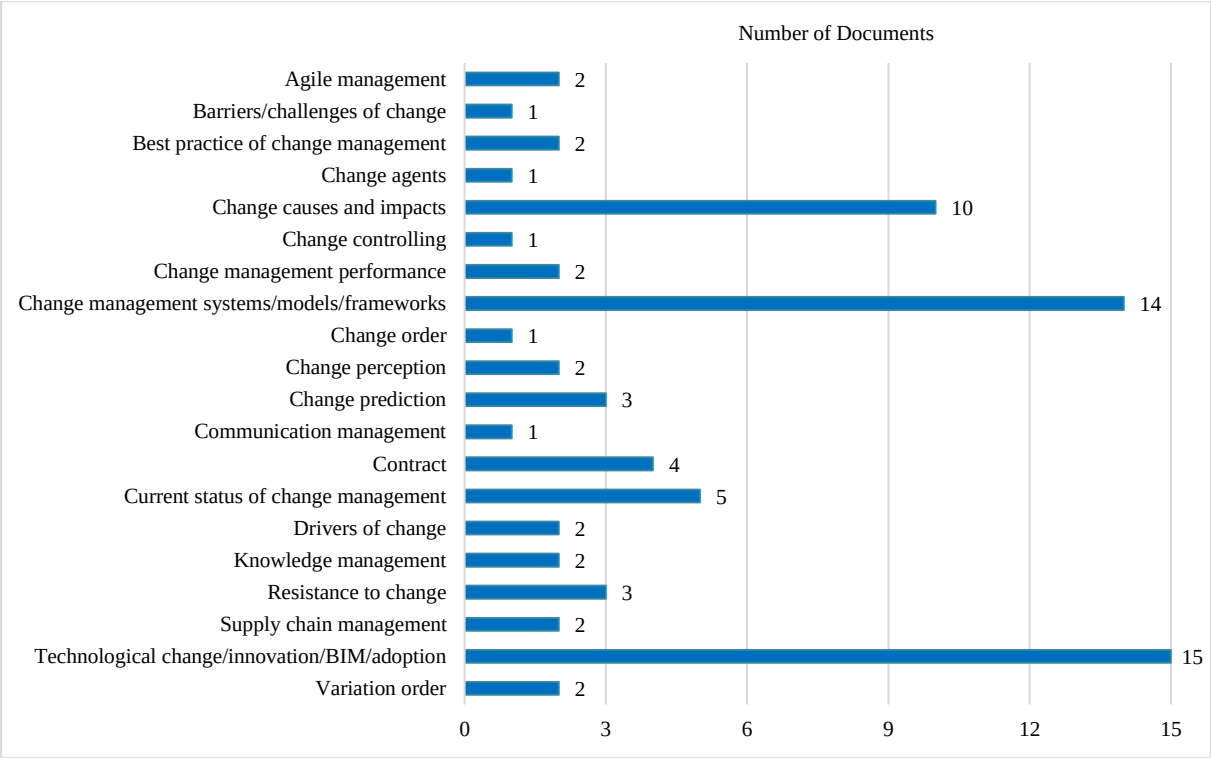


Figure 4: Change management themes in construction management research (2000-2022).

Lastly, to clarify relationships and tendencies based on "change management" and "construction industry" keywords over the period of interest, a network model was created by using VOSviewer. According to VOSviewer analysis, 275 of 1380 keywords meet the threshold. The network maps include various colorful groups known as clusters (McAllister et al., 2021) and each colour represents different clusters. Notably, the clusters in the network map consists of node, labels and links. The nodes are connected with each other by links. The co-occurrence of keywords and the strongness of links impact the size of the nodes and labels (McAllister et al., 2021). Keyword co-occurrence analysis shows that "project management," "change models," "construction management," "management," "knowledge management," "construction," "BIM," "cost management" and "innovation," have larger labels and circles. The aforementioned keywords demonstrate the most preferred research themes under the "change management in the construction industry." Notably, the closer the keywords are to each other, the stronger the relationship between them (Van Eck & Waltman, 2022). The keywords *innovation*, *adoption*, *organizational change*, *communication*, and *information technologies* are located to each other, indicating their strong relatedness. The co-occurrence of knowledge management as a keyword in the publications is high in the VOSviewer, which indicates that knowledge management and organizational learning are seen as essential elements of managing change. However, according to visualization, there is no critical link between "organizational learning" and "change management in the construction industry," this is seen as a possible path for future research.

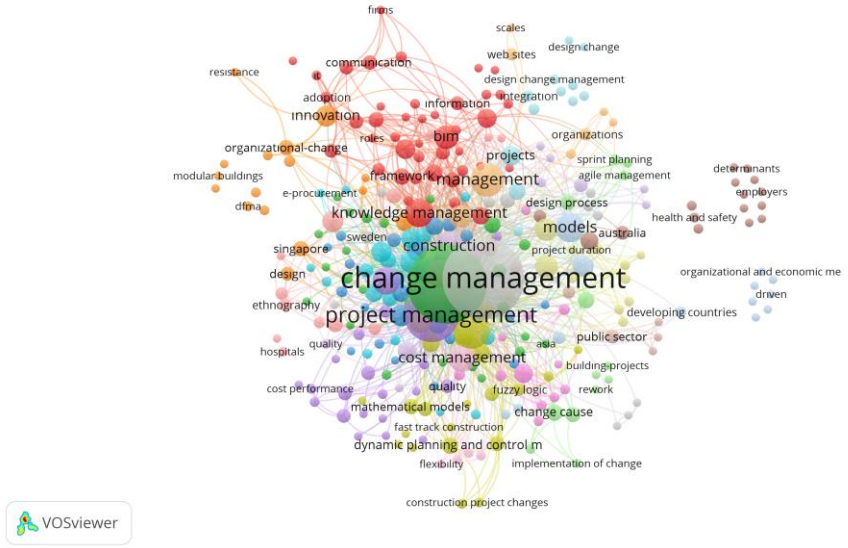


Figure 5: Network visualization of publications keywords.

According to the years, a color scale was created by VOSviewer from the oldest to the newest. The blue color shows the themes considered in previous years, while the yellow color shows the themes that have been considered in recent years. Overlay visualization shows that "agile management," "construction project changes," "information technologies," "adoption of new technologies," "implementation of change" and "BIM" are seen as recent research trends related to change management in the construction industry.

Furthermore, the findings of the systematic review and VOSviewer analysis show that studies with agile management perspectives are limited but agility is a critical consideration in change management since it assists the change in terms of rapid and flexible change reactions. Recent studies in the literature focusing on agile management show that the research gap on the topic has been recognized, although the number of relevant studies is yet limited, and further research effort is needed to address the issues of change and agile management approaches.

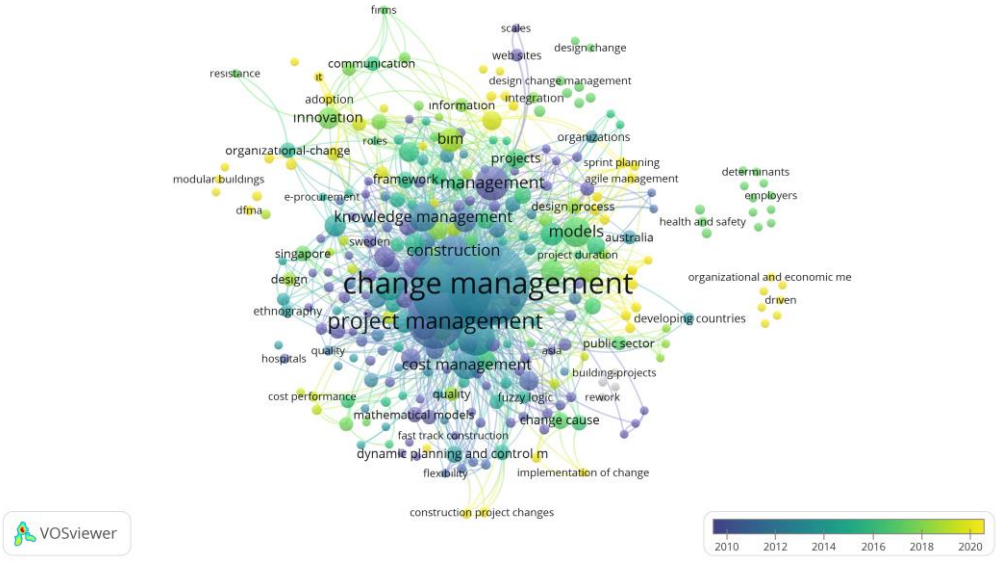


Figure 6: Overlay visualization of publication keywords according to year wise.

Conclusion

Managing change is a strategic competence for construction firms, not only because each project is subject to various changes over its life cycle, but also translating lessons learnt from different projects into company level actions require change management skills to respond to environmental turbulence. Findings of the systematic literature review reveal that the most productive countries identified as USA and UK which have change management studies in construction industry. Outputs of the systematic literature review also indicate that while *technological change/ innovation/ BIM/ adoption, change management systems/ models/ frameworks* and *change causes and impacts* were the predominant focus of interest over the period of interest, there are yet significant research gaps in the construction management literature regarding the implementation of proposed change management systems/models/frameworks and the investigation of the methodological approaches for a better understanding of change management practices in construction. Keyword co-occurrence map signifies that change management in the construction industry is highly related the *management issues (project, construction, knowledge, and cost), change models*, *BIM*, and *innovation.* Overlay visualization indicates that *agile management, construction project changes, information technologies, adoption of new technologies, implementation of change,* and *BIM* have a critical influence and attention over the last years. Overview of the VOSviewer analysis and the systematic literature review show, for example, that further research efforts are needed to explore the potential of agile management approaches to develop rapid and flexible responses to change, as well as the linkage between knowledge management, organizational learning and change. In particular, approaching change management from a learning perspective might be quite fruitful considering that each change is a learning experience for any organization.

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Evaluating Readability Risks in Construction Contracts Using Fuzzy TOPSIS Method

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Abstract

Construction contracts play a significant role in the success of a project. Multiple interpretation of contract clauses in construction contracts may cause adverse outcomes between contracting parties. Therefore, an analysis of risks influencing readability of construction contracts is essential. In this study, fuzzy technique for order of preference by the similarity to ideal solution (TOPSIS) is proposed to assess the readability risks judged by construction professionals who have experience in the construction sector. The findings indicated that unnecessary complexity in noun phrases and improper use of referents, lack of visual representations, and unnecessary length in the clauses, sentences, and words were the most significant risks; while inclusion of matters which are more effectively covered in the technical specification, paraphrasing existing law, and lack of flowcharts between clauses were the least significant risks. The findings are expected to help construction professionals improve readability of construction contracts, aiding to reduce conflicts.

Keywords: *construction project, contract, dispute, fuzzy TOPSIS, readability risk.*

Introduction

Construction contracts, which are written and signed documents that the contracting parties have agreed upon, are important in the successful achievement of project objectives and preventing adverse outcomes such as serious disagreements, conflicts and claims in the project (Chan et al., 2021; Lee et al., 2020). Due to ambiguous and conflicting statements in construction contracts, multiple interpretation of contract clauses may cause negative consequences between contracting parties (Abdul-Malak & Hamie, 2019). Therefore, it is necessary to identify the contractual risks (Lee et al., 2020) and ensure that the readability of the clauses in the contract is clarity, accurate and in precise detail (Rameezdeen & Rodrigo, 2014; Sertyesilisik, 2010).

This research aims at assessing readability risks in terms of project cost, time and quality impacts in the construction projects. Therefore, the readability risks identified by Koc and Gurgun (2021) for more effective contract management were further examined with the fuzzy

TOPSIS method based on construction professionals' opinions. The combination of fuzzy set theory with the simple and easy to understand TOPSIS method (Jang et al., 2017) is expected to provide more accurate solutions to minimize risks influencing the readability of construction contracts.

Methodology

Risk factors affecting the readability of construction contracts were investigated through a comprehensive literature review by Koc and Gurgun (2021) and 18 readability risks were identified as shown in Table 1. 18 predetermined readability risks were assessed using the fuzzy TOPSIS method. Due to the fact that it is related to the performance of the projects, the project time, cost and schedule were determined as criteria to assess the readability risks in this study.

Table 1. Readability risks.

Risk	Definitions
Risk 1	Unnecessary length in the clauses, sentences, and words
Risk 2	Unnecessary complexity in noun phrases and improper use of referents
Risk 3	Excessive use of passive voices
Risk 4	Repetition of words and provisions
Risk 5	Use of negative style of language
Risk 6	Controversial uses of legal terms
Risk 7	Abstractness and ambiguity in word or sentence causing more than one meaning
Risk 8	Use of specialized vocabulary, legal terms, and legal jargon
Risk 9	Using engineering terminology not common to all disciplines
Risk 10	Reader unfriendly layout and the structure of the whole contract document
Risk 11	Lack of visual representations
Risk 12	Paraphrasing existing law
Risk 13	Inclusion of matters which are more effectively covered in the technical specification
Risk 14	Cross-referencing between clauses
Risk 15	Lack of flowcharts between clauses
Risk 16	Placing similar provisions or clauses arbitrarily
Risk 17	Poor grammar use
Risk 18	Unnecessary use of abbreviations

After that focusing on time, cost and quality criteria, the effects of these risks were asked to 20 industry professionals. 65% of the participants had more than 20 years of experience in the industry. Participants were requested to evaluate the effects of readability risks on each other using the linguistic variables used in the fuzzy TOPSIS method given in Table 2.

Table 2. Linguistic scales and fuzzy numbers used in the method.

Linguistic variables	Fuzzy number	Linguistic variables	Fuzzy number
Criteria weights		Alternatives	
Very low	(0, 0, 0.1)	Very poor	(0, 0, 1)
Low	(0, 0.1, 0.3)	Poor	(0, 1, 3)
Medium low	(0.1, 0.3, 0.5)	Medium poor	(1, 3, 5)
Medium	(0.3, 0.5, 0.7)	Fair	(3, 5, 7)
Medium high	(0.5, 0.7, 0.9)	Medium good	(5, 7, 9)
High	(0.7, 0.9, 1.0)	Good	(7, 9, 10)
Very high	(0.9, 1.0, 1.0)	Very good	(9, 10, 10)

The collected data were analyzed using the fuzzy TOPSIS method, which is convenient for solving the group decision making problem in a fuzzy environment (Chen, 2000). The steps of the fuzzy TOPSIS method are as follows (Chen, 2000; Wang & Chang, 2007):

1. Step: A decision matrix as a result of the assessment of the decision makers is developed.
2. Step: A fuzzy normalized decision matrix is constructed.
3. Step: The weighted normalized decision matrix is calculated by multiplying the normalized fuzzy decision matrix with the weight of each criterion.
4. Step: The fuzzy positive ideal distance (A^*) and the fuzzy negative ideal distance (A^-) of each alternative are calculated.
5. Step: The ranking order for each alternatives is defined by a closeness coefficient (CC). The closeness coefficient is computed by taking the distance of the alternatives from A^- divided by the sum of distance of alternatives from A^- and A^*.

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (1)$$

Here, d_i^+ is the distance between the fuzzy positive ideal point and alternative *i*, and d_i^- is the distance between the fuzzy negative ideal point and alternative *i*. A high value of the CC_i index of an alternative indicates a high degree of risk for this study.

Results

This study assessed the risks affecting the readability of construction contracts by focusing on time, cost, and quality effects. Initially, the fuzzy TOPSIS method was applied by considering only the cost, time and quality criteria and the ranking results of the risks are shown in Table 3. Risk 2 was found to be the most significant factor in terms of cost and time criteria, while Risk 11 was the most significant factor in terms of quality criteria. In addition, when only the quality criterion was applied, Risk 2 was one of the significant factors, similar to the ranking results of the factors for other criteria (Table 3).

The readability risks that may be encountered in construction contracts have been evaluated by focusing on the cost, time and quality effects of the project. The overall findings for all criteria are presented in Table 4.

Table 3. The results of fuzzy TOPSIS method based on criteria.

Risk	Criteria 1: Cost				Criteria 2: Time				Criteria 3: Quality			
	d_i^+	d_i^-	CC_i	R	d_i^+	d_i^-	CC_i	R	d_i^+	d_i^-	CC_i	R
Risk 1	0.531	0.534	0.501	5	0.488	0.577	0.542	2	0.602	0.490	0.449	5
Risk 2	0.372	0.733	0.663	1	0.394	0.697	0.639	1	0.528	0.573	0.520	2
Risk 3	0.677	0.386	0.363	11	0.589	0.477	0.447	5	0.702	0.376	0.349	11
Risk 4	0.662	0.405	0.380	9	0.633	0.430	0.405	11	0.646	0.434	0.402	7
Risk 5	0.656	0.408	0.383	8	0.617	0.443	0.418	9	0.659	0.428	0.394	8
Risk 6	0.528	0.538	0.505	4	0.567	0.492	0.465	4	0.629	0.458	0.421	6
Risk 7	0.521	0.565	0.520	3	0.545	0.530	0.493	3	0.592	0.503	0.459	3
Risk 8	0.554	0.518	0.483	6	0.600	0.457	0.432	8	0.707	0.368	0.342	12
Risk 9	0.695	0.364	0.344	13	0.673	0.381	0.361	15	0.714	0.347	0.327	15
Risk 10	0.688	0.359	0.343	14	0.645	0.405	0.386	12	0.740	0.327	0.307	16
Risk 11	0.501	0.568	0.531	2	0.588	0.462	0.440	6	0.518	0.579	0.528	1
Risk 12	0.683	0.378	0.356	12	0.708	0.347	0.329	18	0.758	0.303	0.285	18
Risk 13	0.718	0.341	0.322	18	0.682	0.372	0.353	16	0.756	0.310	0.291	17
Risk 14	0.699	0.362	0.341	15	0.662	0.396	0.374	14	0.717	0.358	0.333	14
Risk 15	0.706	0.355	0.334	16	0.689	0.364	0.345	17	0.715	0.359	0.334	13
Risk 16	0.719	0.344	0.324	17	0.659	0.396	0.375	13	0.689	0.385	0.358	10
Risk 17	0.587	0.473	0.447	7	0.594	0.466	0.440	7	0.592	0.496	0.456	4
Risk 18	0.672	0.395	0.370	10	0.625	0.442	0.414	10	0.672	0.412	0.380	9

Note: R denotes Rank.

Table 4. The results of fuzzy TOPSIS method.

Risk	d_i^+	d_i^-	CC_i	Rank
Risk 1	1.621	1.601	0.497	3
Risk 2	1.294	2.002	0.608	1
Risk 3	1.968	1.238	0.386	11
Risk 4	1.941	1.269	0.395	9
Risk 5	1.931	1.279	0.398	8
Risk 6	1.724	1.489	0.464	5
Risk 7	1.659	1.598	0.491	4
Risk 8	1.861	1.344	0.419	7
Risk 9	2.082	1.092	0.344	15
Risk 10	2.073	1.092	0.345	14
Risk 11	1.607	1.610	0.500	2
Risk 12	2.150	1.028	0.324	17
Risk 13	2.155	1.023	0.322	18
Risk 14	2.078	1.116	0.350	13
Risk 15	2.110	1.078	0.338	16
Risk 16	2.066	1.125	0.352	12
Risk 17	1.772	1.436	0.448	6
Risk 18	1.969	1.249	0.388	10

The results show that “unnecessary complexity in noun phrases and improper use of referents (Risk 2)”, “lack of visual representations (Risk 11)”, and “unnecessary length in the clauses, sentences, and words (Risk 1)” were found to be the top three most impactful readability risks with closeness coefficients of 0.608, 0.500, and 0.497, respectively. While, “inclusion of matters which are more effectively covered in the technical specification (Risk 13)”, “paraphrasing existing law (Risk 12)”, and “lack of flowcharts between clauses (Risk 15)” were the least significant readability risks with closeness coefficients of 0.322, 0.324, and 0.338, respectively.

Conclusion

This study aims to determine the risk factors affecting the readability of construction contracts. To achieve the study objective, fuzzy TOPSIS method was used to assess predetermined readability risks through literature review. 18 readability risk factors and 3 criteria as cost, time and quality were determined. Then, the top three readability risks were found as follows: (1) unnecessary complexity in noun phrases and improper use of referents, (2) lack of visual representations, (3) unnecessary length in the clauses, sentences, and words. Analyzing key risks influencing quality of construction contract could improve risk management practices in projects. Further, the results of this study will be beneficial to construction project professionals to minimize the inconsistency of contract clauses and to reduce disputes and conflicts.

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Smart Contracts and Construction Industry: A Systematic Literature Review

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Abstract

In the globalizing world with the development of technology, industries try to survive in a wide and increasing competition. Industries adopting technological developments continue developing by utilizing technologies' opportunities and producing solutions to their problems. Blockchain, one of these new technologies, has considerably influenced the whole world. It is thought that smart contracts technology, which is the product of blockchain technology, may provide new perspectives to the sectors and offer new opportunities. While the construction industry currently benefits from technologies such as Building Information Modelling (BIM), drones, and 3D printing, it has not paid much attention to the digitization of construction contracts. However, it is thought that this situation may begin to change with smart contracts. This study aims to review the topics of the studies which focus on smart contracts and construction industry and determine potential research areas related to smart contracts and construction industry. This research consists of two-stage systematic literature: bibliometric search and scientometric analysis respectively. Findings of the bibliometric search within the scope were reviewed to present a holistic map of smart contracts and construction industry interaction by using the VOSviewer tool.

Keywords: *bibliometric search, blockchain, construction, construction management, scientometric analysis, smart contracts, VOSviewer.*

Introduction

Although there are many definitions of smart contracts, first mentioned by Nick Szabo in 1994, there is no universally accepted definition (Szabo, 1994; Mason, 2017; Mik, 2017; Cardeira, 2015; Meitinger, 2017). Szabo, a cryptographer, with the idea of placing smart contracts on physical objects, which he defined as smart properties, defined smart contracts as "the computerized transaction protocols that execute the terms of a contract" (Szabo, 1994; Cardeira, 2015).

In the literature, smart contracts are defined as digital programs based on the blockchain consensus system, self-executing, tamper-proof due to their agentless and decentralized nature, and self-executing when contract conditions are met (Christidis & Devetsikiotis, 2016). Smart contracts are digital protocols that would facilitate, verify, or enforce the negotiation or performance of a contract, or that prevent the need for a contractual clause (Fox, 2016).

It is important to know the definition, and understanding of a blockchain to understand how smart contracts work since smart contracts are based on the blockchain consensus mechanism and they are one of the important uses of blockchain technology (Christidis & Devetsikiotis, 2016; Efanov & Roschin, 2018). The "Bitcoin: A Peer-to-Peer Electronic Cash System" article published by Satoshi Nakamoto in 2008 introduced blockchain technology. In this article, it was mentioned that blockchain provides interoperability and interchangeability to its users as a solution to centralization despite classical database technologies (Nakamoto, 2008). Blockchain can be defined as a distributed and decentralized data recording system or a chain of blocks, in which blocks containing encrypted transactions are cryptographically chained to each other (Meitinger, 2017; Vandermerwe & Rada, 1988). The fact that blockchain technology operates without being connected to a center means that there is no third party between the users who request the service and the users who provide the service. The blockchain is a distributed data recording system, it means keeping blocks with the same transaction history as all nodes in the blockchain network. It would not be correct to call the blockchain a database because, in addition to adding data, data updating and deletion can be done in classical database technologies, while the data saved in the blockchain can never be changed or deleted again (Ataşen, 2019; Bodó et al., 2018; Rodrigues et al., 2018). It is thought that smart contracts and blockchain technologies may make significant contributions to various sectors such as the health sector, banking sector, and construction sector due to the characteristics of these technologies (Ekblaw et al., 2016). This study focused on the relationship between smart contracts and construction industry in literature. The main topics and research areas in the academic studies conducted were reviewed through bibliometric search and scientometric analysis.

Methodology

This study consisted of two-stage systematic literature: bibliometric search and scientometric analysis respectively.

Stage 1: Bibliometric Search

1. The "Smart Contract" and "Construction" keywords were searched together in the abstracts, titles, and (or) keywords of publications indexed in Scopus.
2. Selection of all documents.
3. Analyzing the search result.
4. Export the bibliographical data as a CSV file.

The first step of the systematic literature review was the bibliometric search. This bibliometric search, carried out on 17 June 2022, was conducted in the Scopus database. This database consists of a high amount of publications, including scientific journals, books, and conference proceedings. The access strategy used in Scopus was "smart contract" and "construction". Any time limit was not applied to reach all the data in the literature. Likewise, to reach all the data, the Scopus study searched all document types including articles, conference papers, conference reviews, and book chapters. The study only focused on documents written in the English language. A total of 296 documents were obtained. The results were selected to be exported in CVS file format for bibliometric analysis.

Stage 2: Scientometric Analysis

5. Implementing co-occurrence keyword analysis using bibliographic data in VOSviewer.

6. Creating the Thesaurus file to correct typos in the keywords list obtained from VOSviewer.
7. Second implement co-occurrence keyword analysis using bibliographic data with the created Thesaurus file in VOSviewer.

The second step of the review was scientometric analysis, and the studies resulting from the bibliometric search were analyzed using VOSviewer (version 1.6.18) software. The co-occurrence keyword link analysis was performed in the VOSviewer program. This analysis was studied two times to obtain compact data since the keywords can be written in different styles by authors. In addition, the keywords contained typos, so all the keywords were reviewed, and the document was created to help correct errors in the analysis.

Results

From 2015, the publication of the first document, to June 2022, almost 300 documents (the exact number of documents 296) had been published in Scopus. The analysis of the studies was collected in 3 main titles: documents by year, country, and type.

Bibliometric Graphs from Scopus

A bibliometric search provides sufficient information on the necessary records (Bankar & Lihitkar, 2019). It has been used to trace relationships amongst abstract, article, and title citations.

Documents by Year

As mentioned above, blockchain technology started to develop in 2008, and the concept of smart contracts was included in the second generation of blockchain in 2015. In parallel with the development of blockchain, the basis of publications in the field of smart contracts dates back to 2015. According to Figure 1, the number of publications in the smart contracts field has shown an increasing trend since 2017. The published documents reach the highest level in 2021 with 114 publications. Considering the available data at the time of this research, the current number of published documents in 2022 is almost 50, and it can be expected that the total number of publications may increase at the end of the year.

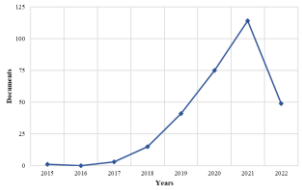


Figure 1: Documents distribution by year (2022).

Documents by Country

Figure 2 shows the top 10 countries listed in the international arena. According to Figure 2, China is at the top of the list with 102 studies, among 54 countries where researchers have

published studies on the theme of the smart contract. With 30 studies, the United States is in the 2nd place and the United Kingdom with 28 studies is in the 3rd place in the list, respectively. Hong Kong ranked fourth and published 19 studies, after which countries such as Italy, Australia, Germany, India, Russia, and Greece complete the list. Greece is located in the last place on this list with 10 publications. Turkey, with a small number 6 of studies, is not located in the top 10 countries list.

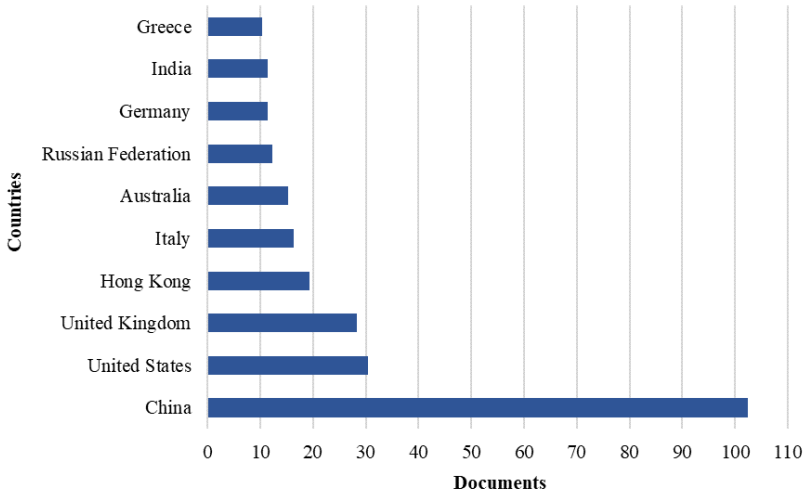


Figure 2: Documents distribution by country or territory (2022).

Documents by Type

According to Figure 3, among the 296 documents on the subject of Smart Contracts in the Construction Industry, conference papers are the most common with approximately 50 percent (146 documents). Then, the subject of smart contracts and the construction industry are discussed in the articles with approximately 35 percent (103 documents). In the third place, the relationship between smart contracts and the construction industry is examined in conference review documents with 8 (24 documents).

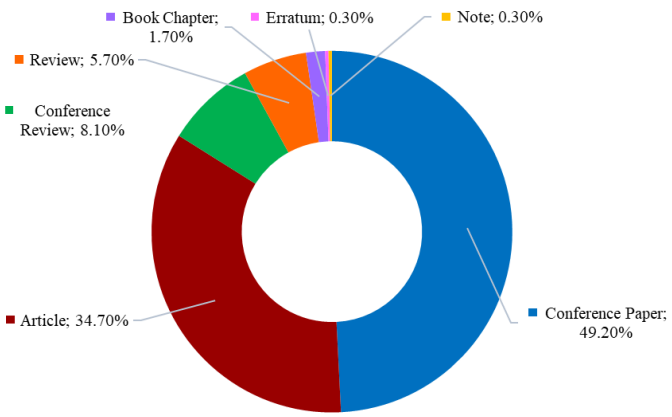


Figure 3: Document distribution by type (2022).

Holistic Maps from VOSViewer Scientometric Analysis

Co-occurrence Keywords

VOSviewer, a scientometric analysis software tool is chosen to construct and analyze the bibliometric network of science due to its unique mining and visualization feature for large amounts of textual data (Eck & Waltman, 2016). Keyword co-occurrence analysis was applied by using VOSviewer and the keywords co-occurrence analysis shows the recent research trends and the core of research. The co-occurrence keyword analysis was performed twice to present a more explanatory and summative result. As a result of this analysis, a holistic map was obtained. The holistic map consisted of nodes of different sizes, links of different thicknesses, and keywords with different font sizes. As the number of times, keywords were repeated, the node sizes and font sizes increased. Also, as the number of keywords used together increases, the link thickness between them increases. Thanks to the holistic map, the most studied and trending study topics in the researched field were displayed.

In the first analysis, bibliometric data from Scopus, unedited raw data, was used in VOSviewer. The ordinary full counting methodology was chosen in the analysis. The minimum number of co-occurrence keywords was selected 1 time to not lose any keywords because there could be typos in the bibliographic data list. Then, the keywords used in this analysis were exported and arranged in an Excel file. A standardization approach was adopted to merge variant terms (e.g. “blockchain”, “block chain”, and “blockchain technology” were merged into “blockchain”). Moreover, some keywords were grouped. (e.g. “cryptocurrency”, “crypto token”, and “central bank digital currency” were merged into “cryptocurrency”) This edited file was used as the Thesaurus file in VOSviewer, that is, it acted as a dictionary file that assists the bibliometric data file to obtain more compact results. After the editing process, the second co-occurrence keyword analysis was applied in VOSviewer using the thesaurus file. As in the first analysis, the ordinary full counting methodology was chosen in the second analysis. To clarify the most trending topics and links, in the second study, the minimum number of co-occurrence keywords was selected 3, 42 out of 646 keywords matched the threshold. The normalization method was selected as Lin/Log Modularity. In VOSviewer, the groups of keywords called clusters are formed according to keywords and their frequency of together usage. In the second analysis, cluster size was selected as 3. As a result of this analysis, 42 keywords created four clusters colored differently in Figure 4. These clusters showed the main study areas of smart contracts and construction.

As can be seen in Figure 4, the clusters were expressed with different colors. The first cluster was represented in red, the second cluster in green, the third cluster in blue, and the fourth cluster in yellow. The first cluster consisted of access control, blockchain, business process management, cloud platform, construction management, cryptocurrency, cyber-physical systems, decentralized applications, decentralized environment, Ethereum, information technology, IoT (Internet of Things), payments, smart contracts, and supply chain management keywords. The second cluster consisted of automated construction, bibliometric analysis, BIM, collaborative process, construction contracts, Distributed Ledger Technology, information trust, lean process, and trust keywords. The third cluster consisted of consensus mechanisms, construction document management, construction quality information, digital contract management, information sharing, privacy protection, security, smart city, and zero-knowledge proofs keywords. The last cluster consisted of Big Data, construction industry, data analysis and management, digitalization, and Industry 4.0 keywords.

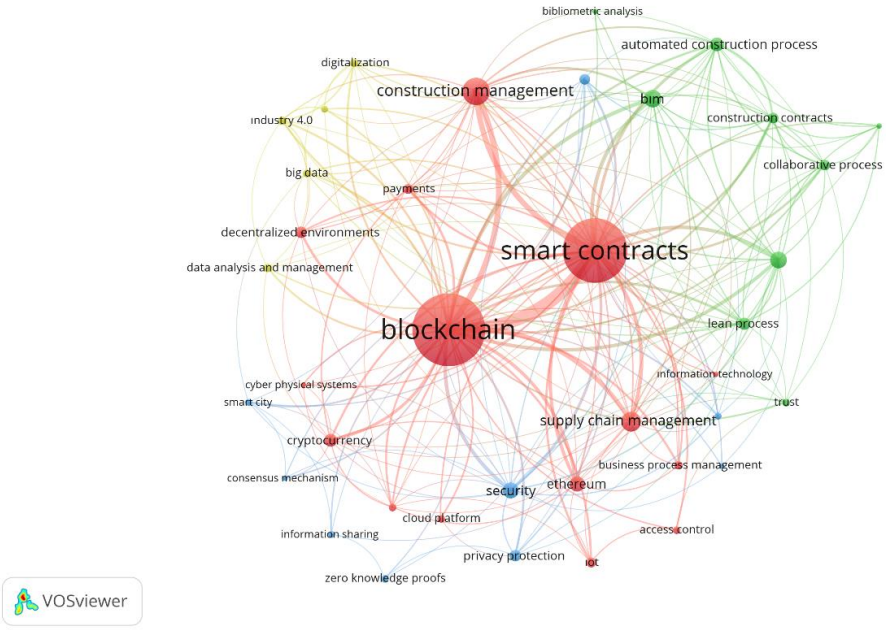


Figure 4: The holistic map as a result of co-occurrence analysis in VOSviewer (2022).

In the holistic map, the main terms smart contract, construction management, and blockchain which were the main topics appeared to be the most repetitive words. Supply chain management was the most pointed out keyword after the main keywords. According to the literature, it mentioned that smart contracts may be beneficial in the supply chain of the construction industry. BIM, which provides great changes and useful opportunities in the construction industry, was one of the prominent keywords. BIM is used actively today and its usage areas in the construction industry continue to be developed. The application of BIM in construction projects together with smart contracts, which are the products of developing technology, has been examined in the literature. The Distributed Ledger Technology keyword was used frequently since the smart contracts are one of the applications of this technology. Another outstanding keyword was security. Smart contracts are based on blockchain technology which provides to secure network for their users. Therefore, the security was a topic frequently included in literature. Ethereum is the platform where smart contracts are created; thus, it is mentioned more frequently in documents. The automated construction process stood out relatively. In literature, it is indicated that the construction processes may progress automatically in projects where smart contracts are combined with other information technologies. The lean process was another pronounced keyword since it referred to that smart contracts provide trustability, transparency, and traceability features to their users in literature. Privacy protection was frequently mentioned in the literature as one of the benefits of the contracts. Decentralized environments are related to the structure of smart contracts, so this was frequently mentioned in the documents. According to documents, the information technologies like the Internet of Things (IoT), Big Data, and Cloud Systems can support smart contracts; however, IoT has been researched more than others currently. Therefore, the IoT node size was bigger in the holistic map.

Conclusion

This study aims to visualize the research topics and gaps in smart contracts and construction industry with a holistic map using the VOSviewer application and to show the current research status on smart contracts and construction industry with graphs from Scopus. The co-occurrence keywords analysis conducted within the scope of this study can help to clarify the topics in the context of smart contracts and construction industry. This analysis also helps to detect areas of interest that have not been touched upon by researchers.

The context of smart contracts and construction industry still needs to be studied and explored considering the publication numbers and types.

According to the holistic map obtained in this study, most current documents focus on the blockchain, Distributed Ledger Technology, and decentralized environments sub-headings which describe the structure of the smart contracts. In addition to these sub-headings, Ethereum, the platform on which smart contracts are created, was mentioned regularly. Moreover, the security, automated construction process, lean process, and privacy protection topics, which are the potential advantages of smart contracts due to their features, were generally discussed. The supply chain management sub-headings, which is the area where smart contracts can be advantageous, were also discussed in the current studies. There is also research that addresses supporting information technologies such as BIM, IoT, Big Data, and Cloud Systems.

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Cardinal Changes: A Comparison of FIDIC 2017 and Turkish Public Procurement Law

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Abstract

Scope is one of the Project constraints and the scope of the contractor's work is defined under contract documents. Yet almost all contracts contain a changes/variations clause that empowers the employer to increase, decrease or omit any part of the work. The cardinal change doctrine developed in the US Court of Federal Claims as a response to change orders fundamentally altering the original contract scope and has recently been introduced into Variations and Adjustments clause of the 2017 editions of FIDIC. As FIDIC forms are frequently used for internationally funded public construction projects in Turkey with Turkish law as the governing law, the mechanisms provided by the law for dealing with changes outside the scope of the contract may have a significant effect on the interpretation of the terms of the agreement. The first section traces the historical background of the cardinal change doctrine. The second section reviews courts' treatment of changes beyond contract scope in the US and UK and the introduction of the concept into the new FIDIC editions. The Public Procurement Law's perspective on limitations to variations is covered in the third section. A critical comparison of the two approaches is presented as the paper's conclusion.

Keywords: *cardinal change, FIDIC, Turkish public procurement law, variations.*

Introduction

Almost all construction contracts have a changes or variations clause that unilaterally allows the employer to modify work defined in the contract documents. A fully developed changes mechanism in a contract describes the types of changes allowed, authority to issue change orders, formal procedures for issuing change orders, time and cost impacts and occasionally the relationship of changes with the critical path through a time extension clause.

There is certainly a deadline for issuing change orders. This is the stage of substantial completion (unless the parties have agreed otherwise), when the contractual conditions for completion of the works have been met and the employer is able to take possession or occupancy of the project. The contractor has to rectify outstanding items and rectify defects during the defect liability period.

Are there other restrictions on the power to issue variations? This issue has been subject to discussion for a long time. The second edition of FIDIC Conditions of Contract, released in 2017, has introduced several adjustments, including a variation mechanism, which entitles the

contractor to object to a variation if the varied work is “unforeseeable” with respect to the scope of work described in the contract. The amendment has been interpreted as “the introduction of the cardinal change doctrine” (The Society of Construction Claims Specialists International, 2017) which limits the employer’s powers to issue variations beyond scope.

FIDIC forms are widely used for internationally funded public construction projects in Turkey where Turkish law generally governs. The choice of law can have a considerable impact on the interpretation of the contract and control the parties’ rights and obligations. Therefore, the mechanisms provided by Turkish law for dealing with changes outside the scope of the contract may have a significant effect on the interpretation of the terms of the agreement.

The present paper shall address the limits to the scope of the work described in the contract documents under Turkish legislation to explore the applicability of the new variation mechanism in FIDIC.

The Cardinal Change Doctrine

The Cardinal Change doctrine was initiated by the United States Federal Court of Claims in the 1960’s. Initially, there were two objectives in the development of the law in federal procurement. The first was to protect the contractors from being compelled to perform work beyond contractual requirements. The second was to prevent government agencies from “from circumventing the competitive procurement process by adopting drastic modifications beyond the original scope of a contract” (King, 2001, p. 119). The argument is that the employer could misuse the advantages of the bidding procedure by using its post-contract negotiation ability to completely alter the terms of the contract (Libor & Sandars, 2001, p. 65).

A key case in the evolution of the doctrine is Air-A-Plane Corporation v. the United States. Air-A-Plane Corporation undertook the production of 1100 smoke generators for the Army Chemical Corps, based on a fixed price agreement. During the execution of the contract, an excessive number of variations were issued by the government, including changes to the design of the product. The court found that the sheer number of variation orders and the transformation of the fixed price production contract into a design and development agreement constituted a cardinal change (U.S. Department of the Army, 1983, p. 10-18). The court not only addressed the number of changes but also the total effect of the change orders, transforming the original project delivery system.

Another case that is frequently mentioned is Edward Marden Corporation v. the United States, in which Marden, the contractor, agreed to build an aviation hangar, which collapsed during the construction phase because the government's specifications were inadequate. Marden was instructed to clean up the debris and reconstruct the building, which, in turn, resulted in huge cost overruns. The court found that the reconstruction work was beyond what was originally bargained for by the parties and could not be rectified under the changes clause of the original contract (Enhada et. al., 2001).

Since then, the doctrine has been adopted by several state courts in the United States and recognized in private construction contracts (Silberman, 2017).

English courts have disallowed modifications that go beyond the terms of the contract as early as the 19th century. In Thorn v. London Corporation, Lord Cairns determined that additional work "so peculiar, so unexpected, and so different from what any person reckoned or calculated upon, that it is not within the contract at all," is to be considered outside of the scope of the variations clause (Davenport & Harris, 1998, p. 107). In Blue Circle Industries v. Holland Dredging Co. UK, the Employer's instruction to transform a dredging contract into an artificial bird island construction contract was considered to be beyond the scope of the original agreement (O'Reilly, 1999, p. 33-34).

Cardinal changes can be additive or deductive. Deductive changes that remove a major part of the original work (also known as *descoping*) upset the balance of the contractor's offer and may be interpreted as "abuse" of changing Powers (Costa, 2020). Reduction of a 99,000 USD nurses' quarters from a hospital contract worth 911,000 USD was held to be a cardinal change (Crowell & Johnson, 1967, p. 557-558).

In McMaster v. State of New York, the employer's removal of 5 of 15 buildings in a state hospital was found to be a cardinal change, entitling the contractor to damages (Callahan, 2005, p. 296).

The decisions generate basically two topics for discussion:

1. What is meant by "beyond the scope of the contract"?
2. What happens when variation orders are beyond the scope of the contract?

There seems to be no exhaustive definition of the scope of the contract. Relevant definitions include "scope of project" and "scope of work". PMBOK defines project scope as "The work that needs to be accomplished to deliver a product, service, or result with the specified features and functions." (Project Management Institute, 2017). "Scope of work", on the other hand, may be a portion of a project. The basic principle appears to be the parties' anticipations because court decisions regarding whether the specified task is inside or outside the scope largely depend on the specific circumstances (Burr, 2016, p.773). A fairer criterion may be "scope of original competition" for both additive and deductive changes, in other words, what all the bidders should have expected to be within the scope of the competition (Cibinic et al., 2006, p. 386).

Contractors' Rights and Remedies

What happens when variation orders are beyond the scope of the contract? Several judicial decisions in the U.S. have established principles (e.g. contract abandonment, breach of contract, cumulative impact) entitling the contractor to recover for material changes. When deciding whether a cardinal change has occurred, the courts have taken several factors into account, including the following: significant changes in the scope of the job, the quality, nature, and type of work envisioned by the original contract (Callahan, p. 53). It is beyond the scope of the present paper to discuss the various theories developed in the U.S. with regard to change orders beyond the scope of the original contract. The term "destruction of the contract" has been proposed as an embracing concept, covering cardinal change, abandonment and material breach theories (White, 2006). In general, the cardinal change and abandonment theories aim to offer redress to those who have been the targets of change-order abuse: the terms of the contract do not apply; hence the changes clause is no longer effective and the contractor is allowed to decline the change. Therefore, the contractors have two

choices if they think the change order is out of scope. The first is to follow the order and then request payment in quantum meruit as the contract's terms (the change order clause) are no longer relevant. The alternative is to reject the order and file a breach of contract lawsuit.

The contracting officer must decide whether the omitted work is a deductive change or a partial termination for convenience under federal contracts, which are controlled by the Federal Acquisition Regulations (Federal Acquisition Regulation, 2022). In order to decide the appropriate clause in the event that a contractor contests the contracting officer's decision, courts and boards will look at the nature of the modification. The contractor is free to negotiate whatever settlement amount where it is judged that the deletion should be handled as a "partial TFC," so long as it is reasonable and the total payments to the contractor won't go beyond the agreed-upon price for that work (Cch Incorporated, 2007).

Under English law, the contractor has rights of reasonable objection to variations beyond the scope of initial work. In Bush v Whitehaven Trustees (1888) 52 JP 392 even though the bid called for summer working, the contractor was still required to work during the winter. Because the court found that the contractor had entered into a distinct contract as a result of the winter working, the contractor was entitled to payment on a *quantum meruit* basis. (Lift & Escalator Industry Association, n.d.) In Costain Civil Engineering Ltd v Zanen Dredging & Contracting Co (1997), the subcontractor was entitled to quantum meruit damages for instructions to turning a casting basin into a marina Project (Moloney, n.d).

The current editions of the FIDIC Rainbow suite include the contractor's rights of reasonable objection. The new clauses provide for the contractor to object to a variation order if “the varied work is Unforeseeable having regard to the nature and scope of the work described in Specification (FIDIC Red Book, 2017, Sub-Clause 13.1a) / the Employer’s Requirements” (FIDIC Yellow Book, 2017; FIDIC Silver Book 2017, Sub-Clause 13.1a).

The introduction of the subclause has been interpreted as a reference to the cardinal change doctrine: “Cardinal change has arrived (sort of!)” (Corbett, 2018). The consequences of objection and potential rejection, however, remain unclear. If the consequences are to be interpreted in terms of governing law, the position of Turkish law is worth considering.

How Turkish Public Procurement Law Deals with Excessive Changes

The Public Procurement Law (Law No. 4734) outlines the rules and guidelines that must be followed in any procurement undertaken in Turkey by institutions and public authorities subject to public supervision, public law, or both.

“General Conditions for Building Works” is the only model contract used in Turkey, establishing the general principles for public construction works regulated by the Public Procurement Law (Law no. 4734). Public Procurement Contract Law (Law no. 4735) governs the legal relationships of public authorities in carrying out public procurement contracts. Both laws came into effect in 2003, following a reform process in public procurement intended to comply with European Union and worldwide procurement practices. However, the original version of the Public Procurement Law prohibited increases or decreases in work. This approach was found to be impractical and both laws were revised by Law No. 4964 to allow for additive changes within reasonable limits (Public Procurement Law, 2003; Public Procurement Contract Law, 2003).

Article 24 of the aforementioned law restricts the employer's flexibility in issuing changes:

ARTICLE 24.- (Amendment: 4964/ Article 46) In case any work increase is inevitable due to unforeseen reasons, provided that;

a) work increase is kept within the project subject to the contract,
b) it is not technically and economically possible to separate additional work from the main contract without burdening the contracting entity,
the contracting entity may have the same contractor perform the work increase up to the amount of 10 % of the main contract's price in turn-key lump-sum works contracts and up to the amount of 20 % of the main contract's price in unit price goods, services and works contracts in accordance with the provisions specified in the original (main) contract and tender documents except the provisions on contract duration.
In case it is determined that the work can not be completed under these circumstances the accounts (of the contract) shall be wound up in accordance with general provisions without any increase. However, under such circumstances, it shall be compulsory that the entire work be fulfilled in accordance with provisions of tender documents and of contract.
(Translation http://www2.ihale.gov.tr/english/4734_English.pdf)

Article 24 describes different procedures for additive and deductive changes. The conditions for increases in work can be summarized as follows:
1. The increase should be unforeseeable (for example, insulation of a facade is not "unforeseeable").
2. The task that is subject to an increase must still be part of the agreed-upon project.
3. The additional work should be an inseparable part of the main contract.

As long as the new work conforms to the aforementioned conditions, the same contractor is permitted to perform it. Otherwise, the contractor and the employer cannot enter into a new contract and therefore, the current contract's accounts must be closed (wound up). The contract conditions are not applicable and the amount payable to the contractor shall be decided in accordance with general principles.

What is interesting is that unforeseeability is a precondition for additional work under Law no.4735, whereas it may be a ground of objection by the contractor in the new FIDIC editions. Two cases demonstrate the position taken by the Supreme Technical Board, a service unit of the Ministry of Environment, Urbanization and Climate Change on the permissible extent of variations. (Recently, the Board's authority was expanded to cover contract dispute resolution).

In the first case, the employer, a public authority applied to the Board for permission to order the construction of an additional warehouse during the execution of an ongoing project. The employer, a governmental entity, applied to the Board for approval to issue variations for an additional warehouse while the project was still being carried out. The Board cited the aforementioned article and determined that the building of a second warehouse could not be considered work "within the same Project" or an integral component of the primary contract. As a result, the Board held that additional work could not be performed by the same contractor (ÇŞB YFK Başkanlığı, 2020, decision 2012/27)

In the second case, when a hospital was being built, the employer, a public university sought to convert the warehouse in the original project to an oncology center and to add an 185 sq. m. radiotherapy unit. The employer's main defense was that an oncology center was required because the closest facility was 180 kilometers away from the city where cancer rates had surged. The Board, once more referred to Article 24 of Public Procurement Contract Law and held that neither the modification of the warehouse into a oncology center nor the addition of a radiotherapy unit was an unforeseeable condition at the tender stage, that the proposed modifications could not be completed without changes in the original design and technical documents in the original contract and that the required modification was not an integral part of the original contract (ÇŞB YFK Başkanlığı, 2020, decision 2010/59).

The same Article also outlines the process for work omissions. The contractor is required to complete the works when it is anticipated that less than 80% of the contract value will be spent on the project. If this is the case, the contractor receives 80% of the contract value in exchange for the actual costs incurred, the contractor's profit, and 5% of the difference between the contract price and the amount of work completed (expressed as a percentage), based on prices as of the provisional acceptance date. This is a problematic issue, particularly with lump sum agreements, where the contractor offers a total project price instead of bidding on each individual item. Thus, the calculation of the difference between the contract price and the amount of work completed may be impossible (İnan, n.d.).

Another issue emerges if the works are not finished despite less than 80% of the contract amount having been spent and there is a deductive change of less than 20% (e.g. in case of a force majeure event). The contractor loses the right to receive the 5 percent payment under these circumstances.

Discussion

The aforementioned rulings demonstrate that Turkish law places limitations on the employer's variation powers: changes that go beyond the terms of the agreement are restricted under the Public Procurement Contract Law and the “General Conditions for Building Works”. When changes exceed the permissible limits defined, the project has to be re-tendered.

With reference to what constitutes changes beyond scope, the first striking difference between FIDIC Conditions of Contract and Public Procurement Contract Law is the interpretation of the word “unforeseeability”. Under FIDIC Conditions, the contractor may object to a variation order if the varied work is unforeseeable in terms of scope and nature of the Works. “Unforeseeability” is now a defined term under the 2017 editions and is defined as meaning “not reasonably foreseeable by an experienced contractor by the Base Date”. The contractor’s right to object is “intended to limit the extent or scope of variations” (Godwin, p.132). Under Public Procurement Contract Law, unforeseeability is a precondition for a valid variation. Insulating the facade, for instance, is not unforeseen, but a latent condition or a change in the law would be considered unforeseeable. It has been found permissible to update the elevator design in order to reflect modifications to the relevant Disability Act, provided that the extent of the adjustments does not exceed 10% of the contract price (ÇŞB YFK Başkanlığı, 2020, decision 2012/30).

A second distinction is the strict application of Public Procurement Contract Law's definition of excessive alterations as a percentage of the contract value, regardless of the nature of the

change. The proportion of variation cost to contract value, expressed as a percentage, serves as the only measure for the degree of modifications. The only metric used to determine completion is the ratio between the amount actually spent (or anticipated to be spent) and the contract value. This approach does not allow for flexibility in evaluating variations that may alter the nature of the original agreement between the parties or impact other operations.

The stance toward negative variations or deductive change orders is the third key distinction. The 2017 editions feature two requirements for the omission of work: either the parties have consented to it, or the contractor has made excessive delays in correcting defects (Sub-Clause 11.4). In a similar vein, Sub-Clause 15.5 of the 1999 editions states that following a termination for convenience, the employer is not permitted to carry out the work itself or make arrangements for any portion of the work to be carried out by a different contractor. The 2017 editions restrict the employer's powers to do so until the contractor has received adequate compensation for its losses (including loss of profit). The question of whether a significant deductive change can count as a partial termination for convenience under FIDIC conditions is, however, uncertain.

It is not entirely clear how substantial deductions are handled under the Public Procurement Contract Law. First of all, there is debate over whether the remedies are equitable within the current method (Gündüz, 2018). The question of whether descoping may be understood as a partial termination for convenience needs to be addressed in light of the Turkish Code of Obligations, which does recognize termination for convenience, provided that the contractor is compensated for the work carried out before completion (Turkish Code of Obligations, 2011, Article 484).

Conclusions

The revised FIDIC variations mechanism has made an introduction to the cardinal change doctrine. However, the new mechanism is silent on the implications of the contractor's rights of objection and significant deductive changes. Are the gaps to be filled by referring to provisions of the applicable law, or to other agreements between the parties? As discussed above, assessing the contractor’s remedies for major deductive changes may prove to be a serious problem under FIDIC conditions.

We've also seen that the employer's ability to issue variations is restricted by the Public Procurement Contract Law in Turkey. Unforeseeability of conditions is a prerequisite for issuing variations under the law. In my opinion, the purpose here is to prevent discretionary variations by the employer. Under FIDIC conditions, on the other hand, unforeseeability of the varied work is a prerequisite for an objection ground by the contractor. Although the intent is essentially the same, there may be disagreements over the interpretation.

The Public Procurement Contract Law primarily has two issues: a confusing omissions mechanism and exclusive dependence on percentages to assess the degree of changes. The biggest challenge in drafting regulations for public procurement is the escalating complexity of construction disputes. It must be admitted that the Public Procurement Law and the Public Procurement Contract Law, both of which were passed in 2003 and only slightly modified by Law No. 4964, may not be able to address the many issues that arise in the administration of international contracts today.

The changes clause is known to be one of the most litigated clauses in public and private contracts. The new variations clause in the new FIDIC editions has unclear implications, and there may be significant differences of opinion over how Turkish law would apply to FIDIC contracts in the event that change orders exceed the scope of the contract.

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Keyword-Based Risk Assessment for Construction Contracts

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Abstract

Risk assessment is essential in contract management because the clauses in the contract may cause claims and disputes in the application. This study aims to support engineers in the risk assessment of construction contracts. In order to achieve this aim, the titles of the clauses that cause disputes in the application were determined by 30 experts from the general conditions of the FIDIC 1999 Red Book. Keywords were extracted using Natural Language Processing (NLP), a branch of Artificial Intelligence (AI), from the sentences in 25 clause titles determined by the experts. Using statistical approaches in keyword extraction, word frequency, word collocations, and co-occurrence results were examined, and 45 keywords were extracted. The extracted keywords were scored by 7 experts using the probability-impact matrix used in risk assessment. As a result of this application, the total risk score was determined for each clause in the contract conditions. These values are expected to assist engineers in decision-making in the risk assessment process of construction contracts.

Keywords: *contract management, FIDIC, keyword extraction, risk matrix, statistical approaches*.

Introduction

Due to unforeseen risks in construction projects, various risks begin to emerge after the application of the project. For this reason, risk management should be done with a proactive approach before starting the application in construction projects (Bakr et al., 2012). However, since risk management requires expertise and knowledge, many employers and contractors cannot correctly manage risk before application. As part of risk management during the bidding of construction projects, the parties must thoroughly review the duties and obligations defined in the contract conditions (Murdoch & Hughes, 2008). In particular, contractors should examine the contract conditions and manage risk. However, due to the contract management teams' limited capabilities, the contract terms cannot be complete and comprehensively examined (Yiğit, 2009). Because the contract conditions are not examined comprehensively, various claims and disputes arise during the application of construction projects. Claims and disputes arising during the application can cause delays, cost overruns, and a decrease in the applications quality, negatively affecting the project's objectives. In addition, construction companies need to rely on the knowledge of the few contract management experts they have (Lee, 2018). Since the complete and comprehensive examination of contract terms in construction projects is open to individual differences or errors depending on the expertise and experience of the expert, the necessary information should be systematized for the review of contract conditions. This study

aims to provide a solution that will systematize the review of contract terms in the tender process, which is among the tasks of contracting and risk management and will support decision-making. For this purpose, it is aimed to calculate the total risk score value as output by making a risk assessment over the keywords determined as a result of the keyword extraction application by using the contract clause as input as given in the main structure in Figure 1.



Figure 1: Keyword-based risk assessment main structure.

Within the scope of this study, the general terms of the FIDIC 1999 Red Book contract were taken as input and used as text data. As an output, it is aimed to make a keyword-based risk assessment to determine the total risk score of the contract article. Although risk assessment is a rather tricky risk management process, it potentially yields valuable results. Therefore, this study examined and applied risk management standards for risk assessment. According to risk management standards (PMBOK, 2004), risk management planning typically proceeds by identifying risks, qualitative risk analysis, planning risk response, and monitoring and controlling risk.

There are various studies on the assessment of contractual risks. In the keyword-based risk assessment applied in this study, keyword extraction, a natural language processing application, was used in the risk assessment of contract clauses. This practice is integrated into the cycle of proactive risk management processes. The keyword-based risk assessment aims to determine the words and word groups that may be related to the risk and the total risk score for each sentence by using these keywords and word groups. With this application, it is foreseen that the contract engineer/manager can evaluate the total risk score values in the review process of the contract by focusing on the contractor during the tender process. Keyword-based risk assessment parameters applied within this study are given in Table 1.

Table 1. Keyword-based risk assessment parameters.

Keyword-Based Risk Assessment Parameters	
Input Data	General Conditions of Contract (FIDIC, 1999)
Tool	Keyword Extraction
Qulitative Risk Analysis	Probility-Impact Matrix
Output Data	Total Risk Score
Target	Contractor
Application User	Contract Engineer / Manager

Literature Review

There are various studies on risk assessment for construction contracts. In the past studies, it has been observed that the effect of the literal meaning of the contract clauses on contract management has been examined very little and mainly focused on the readability of the contract. (Youssef et al., 2018).

Since a keyword-based application is made in this study, keyword extraction applications on contrac management in the construction domain are reviewed in this section. There are few studies on contract management in the construction domain with keyword extraction. Choi et al. (2021) developed the Critical Risk Check (CRC) module, which was developed as an EPC (Engineering, Procurement, and Construction) contract risk analysis tool for contractors during the tender process, using artificial intelligence and text mining techniques. With the CRC module, previous tender documents are analyzed, and risky contract clauses are extracted through the rules developed by the user. It is the Technical Risk Extraction (TRE) module developed by Park et al. (2021) to extract and analyze the risks in the technical specifications of EPC projects based on machine learning algorithms. The TRE module automatically extracts design risk items by analyzing technical specifications. In the TRE module, technical risk keywords were collected and turned into a dictionary (Technical Risk Lexicon-TRL) and extracted through machine learning and natural language processing tecniques. In this study, Choi et al. (2021) conducted contract risk analysis in the tender process, and Park et al. (2021), the keyword extraction application used in modules that perform design risk analysis on technical specifications was made on the contract clauses in the general terms of the standard contract in the tender process.

Data and Methodology

The keyword-based risk assessment research methodology for construction contracts applied in this study is given in Figure 2.

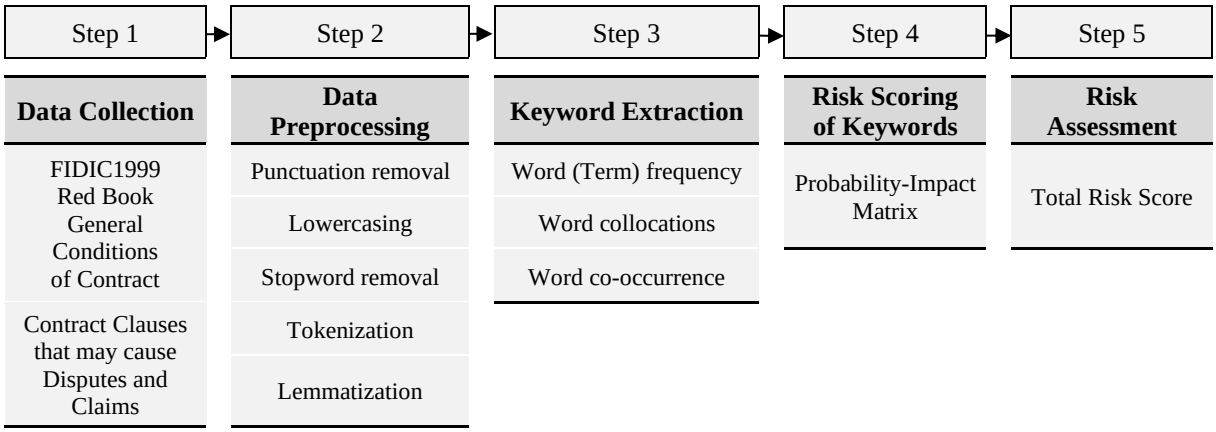


Figure 2: Research methodology.

In this study, FIDIC 1999 Red Book was used as a reference for contract data. All 20 chapters and 163 article titles in the standard contract general conditions for construction in the 1999 FIDIC Red Book have been used. The data set was created by manually separating the sentences in the general terms of the Red Book contract. Various cleanings and syntactic adjustments were made to the completed data set. As a result of the arrangements made, the data set was prepared as 987 sentences of contract clause sentences.

After the data set was created, a survey was conducted to determine which claims and disputes arose in the FIDIC 1999 Red Book applications before making a risk assessment. With the survey conducted, expert participants were asked to mark the titles of the 163 clauses in the Red Book that may cause claims and disputes in practice. A total of 30 responses were received to the survey from different experience levels. Evaluations were made out of 30 responses to

the survey study. After the assessment, it was decided to make a keyword extraction application on 15 markings and over-marking clause titles. For this purpose, according to the results of the survey, the data set, which was previously composed of 163 clause titles and 987 sentences, was narrowed for the keyword extraction application and a new data set consisting of 25 item titles and 178 sentences were created. As a result of the survey, 25 item titles with 15 markings (50%) or more and the number of markings are given in Table 2.

Table 2. Clauses that may cause claims and disputes in application.

Clause Title	Number of Markings
1.5 Priority of Documents	17
1.9 Delayed Drawings or Instructions	22
2.1 Right of Access to the Site	15
3.3 Instructions of the Engineer	16
3.5 Determinations	23
4.12 Unforeseeable Physical Conditions	21
5.3 Payments to nominated Subcontractors	16
8.2 Time for Completion	18
8.3 Programme	19
8.4 Extension of Time for Completion	23
8.5 Delays Caused by Authorities	23
8.6 Rate of Progress	15
8.7 Delay Damages	15
8.8 Suspension of Work	21
8.9 Consequences of Suspension	16
9.2 Delayed Tests	17
10.2 Taking Over of Parts of the Works	16
11.1 Completion of Outstanding Work and Remedying Defects	15
12.3 Evaluation	15
13.1 Right to Vary	15
13.3 Variation Procedure	18
14.8 Delayed Payment	24
14.9 Payment of Retention Money	15
17.3 Employer’s Risks	15
20.1 Contractor’s Claims	19

According to the results of the survey, 15 (50%) and more marked 25 clauses and 178 sentences were used as text data, and keyword extraction was performed. For the keyword extraction application, it was aimed to determine the words and word groups related to the potential risk with the data set narrowed by selecting the clause titles with high marks as a result of the survey. For this purpose, before the keyword extraction application, data preprocessing steps were applied to the text data.

The data preprocessing step was carried out using the Python programming language and the NLTK (Natural Language Toolkit) library. The basic natural language processing data preprocessing steps of the data preprocessing application are the removal of punctuation marks, upper and lower case conversion, separation of the sentence into meaningful units

(Tokenization), removal of ineffective words (Stopword), finding the roots of words that cannot be broken down and are the smallest meaningful form (Lemmatization) steps were applied. The steps applied as an example and the text data are given in Table 3.

Table 3. Example of text data pre-processing.

Pre-processing Step	Text Data
Contract Clause [Raw Data]	Contractor means the person(s) named as contractor in the Letter of Tender accepted by the Employer and the legal successors in title to this person(s).
Punctuation Removal	Contractor means the persons named as contractor in the Letter of Tender accepted by the Employer and the legal successors in title to this persons
Lowercasing	contractor means the persons named as contractor in the letter of tender accepted by the employer and the legal successors in title to this persons
Tokenization	['contractor', 'means', 'the', 'persons', 'named', 'as', 'contractor', 'in', 'the', 'letter', 'of', 'tender', 'accepted', 'by', 'the', 'employer', 'and', 'the', 'legal', 'successors', 'in', 'title', 'to', 'this', 'persons']
Stopword Removal	[contractor, means, persons, named, contractor, letter, tender, accepted, employer, legal, successors, title, persons]
Lemmatization	['contractor', 'mean', 'person', 'named', 'contractor', 'letter', 'tender', 'accepted', 'employer', 'legal', 'successor', 'title', 'person']

The word cloud formed from the words in the data set with the visualization study after the data preprocessing step is given in Figure 3. The sizes of the words in the word cloud are visualized in proportion to the frequency values of the words in the data set.

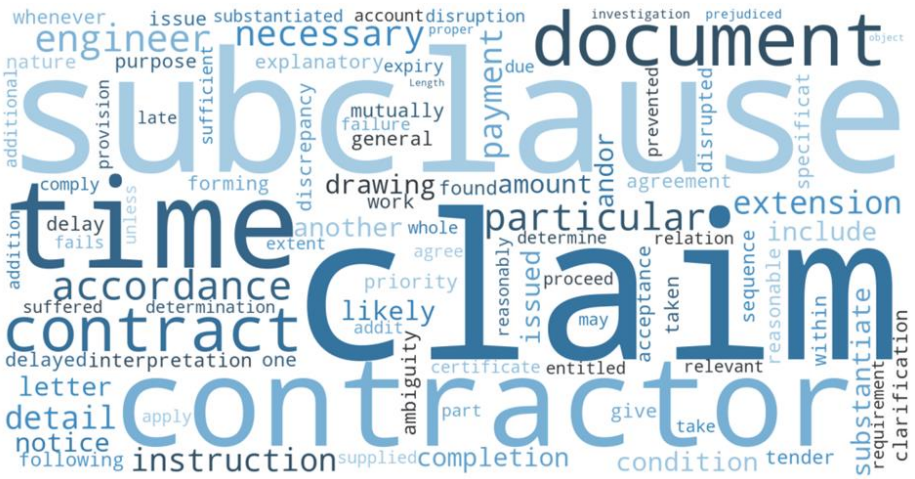


Figure 3: Keyword word cloud.

Keyword extraction is a text mining application that extracts essential words and phrases from a text document (Chang et al., 2022). Generating labeled datasets for keyword extraction is time- and cost-intensive. The unsupervised learning approach, which does not require a labeled data set and is mainly domain-independent, is used more in keyword extraction applications (Vajjala et al., 2020). This study used an unsupervised learning approach for keyword extraction applications. Statistical methods were used in this study, which was conducted using an unsupervised keyword extraction technique. Statistical methods are one of the simplest methods of identifying keywords in text data.

There are different statistical methods, including word frequency, word collocations, and co-occurrence of words, TF-IDF (Term Frequency–Inverse Document Frequency), and RAKE (Rapid Automatic Keyword Extraction) (Sun et al., 2020). In this study, word frequencies, word collocations, and coexistence values of words were used in keyword extraction applications.

In the keyword extraction application, the frequency values of the words in the data set were determined after the data preprocessing step. The CountVectorizer function of the scikit-learn library, also used in the feature extraction step of the model, is used to determine the frequency values, which are the frequency values of the words in the text data. With this function, 178 sentence data in the data set were analyzed, and keyword extraction results were obtained using frequency values. With this application, the data set was analyzed, and the keyword and keyphrase extraction results were obtained by determining the 2-word (bigram) and 3-word (trigram) in the data set.

The keywords extracted from the application were sorted from high to low according to their frequency values before the final evaluation. As a result of the final assessment, 45 words and word groups were determined as keywords with the keyword extraction application. The determined 45 keywords are ranked according to their frequency values. The words and word groups extracted as a result of the keyword extraction application and ordered according to their frequency values are given in Table 4 as unigrams (n=1 words), bigrams (n=2 words), and trigrams (n=3 words).

Table 4. Extracted keywords and term frequency (TF) values.

Uni-gram	TF
employer	34
cost	29
part	26
payment	25
variation	25
instruction	22
section	22
programme	21
however	18
extent	16
period	15
day	14
issued	13
date	13
specified	13
stated	13
appropriate	12
reasonable	12
proceed	12
determination	12
particular	11

Bi-gram	TF
contractor shall	59
engineer shall	19
give notice	16
contractor's claim	15
engineer may	13
if any	13
after receiving	12
physical condition	12
may include	11
contract price	11
delay damage	10

Tri-gram	TF
time for completion	24
in accordance with	23
under sub-clause	20
extension of time	19
shall be entitled	17
rate or price	17
taking over certificate	15
item of work	12
by the contractor	10
by the engineer	10
event or circumstance	10
tests on completion	9
agree or determine	9

As a result of the keyword extraction application, the co-occurrence of the determined keywords was examined. An example word network of keywords is given in Figure 4.



Figure 4: Example of word network.

The distribution of the 45 keywords determined by the keyword extraction application in the data set consisting of 163 item titles and 987 sentences is given in Figure 5 with the lexical dispersion plot. Accordingly, 45 keywords extracted from 178 sentences in 25 article titles were distributed over the entire data set, consisting of 163 article titles and 987 sentences.

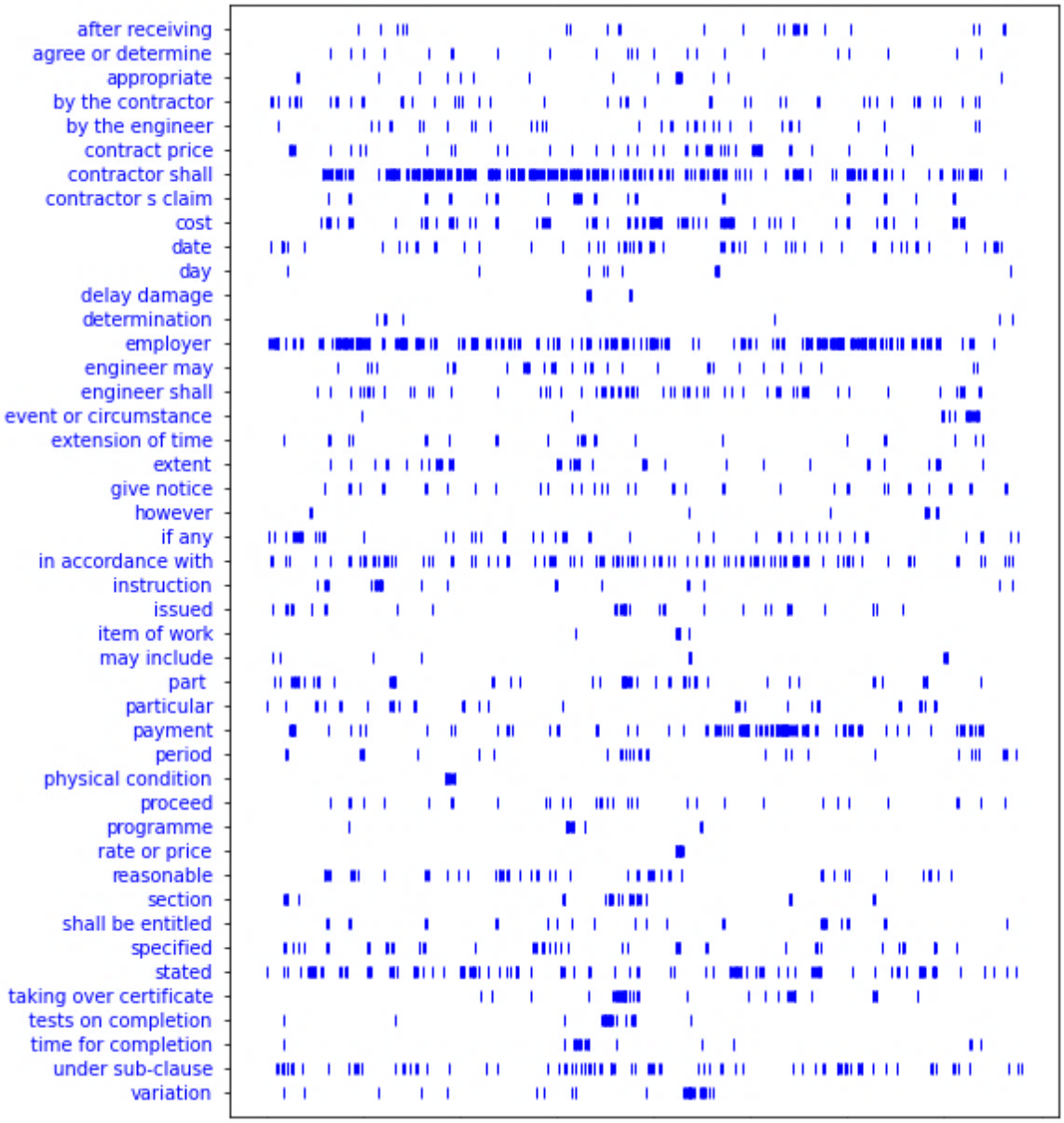


Figure 5: Lexical distribution plot of keywords.

The 45 keywords determined as a result of the keyword extraction application were scored by the experts using the risk assessment matrix with the second survey. The survey was answered by 7 experts with at least 5 years of experience. In the survey, experts were asked to determine a probability and impact value for each keyword using the probability-impact matrix used in risk assessment and given in Figure 6 in the application of Red Book contracts.

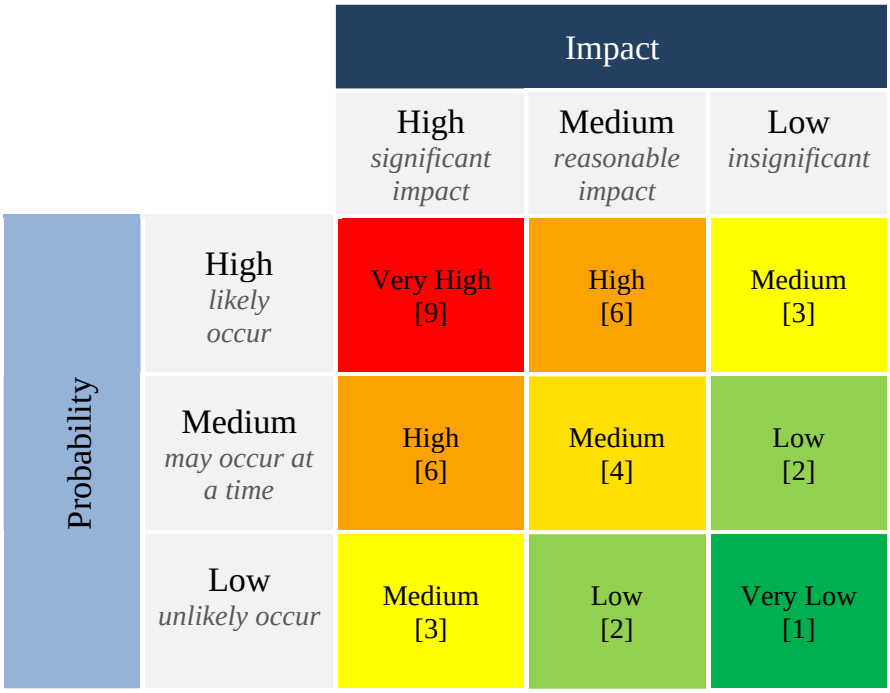


Figure 6: Probability-Impact matrix for scoring keywords.

The probability-impact matrix, which the surveyed experts were asked to use, is one of the widely used qualitative methods for risk assessment. Risk assessment is made by considering specific scales of probability and impact variables of an event. There is a special two-dimensional approach to the assessment of the risk of the event in terms of the probability (probability) of occurrence on the one hand and the effect (impact) of the outcome on the other (Dumbrava & Iacon, 2013). In the survey, experts were asked to determine the probability and impact value for Red Book applications for keywords with this two-dimensional approach.

During the evaluation of the answers to the survey, the average values of the probability and impact values determined by the experts for the keywords were taken and rounded to the nearest integer value. The risk score was calculated for each keyword using the probability and impact values obtained for the keywords as a result of the survey study.

Findings

Based on the first survey conducted for keyword-based risk assessment for construction contracts, 45 keywords related to risk were determined by keyword extraction. A risk score value was calculated with the second survey study conducted for each of the determined keywords. Probability-impact values and risk scores of keywords are given in Table 5.

Tablo 5. Risk matrix results of keywords.

Keywords	Probability	Impact	Risk Score
after receiving	3	2	6
agree or determine	2	2	4
appropriate	2	2	4
by the contractor	3	3	9
by the engineer	3	3	9
contract price	2	3	6
contractor shall	3	3	9
contractor's claim	3	2	6
cost	2	2	4
date	3	2	6
day	2	2	4
delay damage	2	3	6
determination	2	3	6
employer	2	2	4
engineer may	2	2	4
engineer shall	3	2	6
event or circumstance	2	2	4
extension of time	2	3	6
extent	2	2	4
give notice	3	3	9
however	2	2	4
if any	2	1	2
in accordance with	2	2	4
instruction	3	2	6
issued	3	2	6
item of work	2	2	4
may include	2	1	2
part	2	2	4
particular	2	2	4
payment	2	3	6
period	2	2	4
physical condition	2	2	4
proceed	2	2	4
programme	3	2	6
rate or price	2	2	4
reasonable	3	2	6
section	2	2	4
shall be entitled	3	3	9
specified	2	2	4
stated	2	2	4
taking over certificate	2	3	6
tests on completion	2	3	6
time for completion	3	3	9
under sub-clause	2	2	4
variation	2	3	6

After the scoring process on the survey results, the total risk score was calculated by summing the keyword scores in the sentence for each sentence data in the data set. The calculation of the total risk score of the sample sentence data selected from the sentence data set based on the contract conditions is given in Table 6.

Table 6. Example of total risk score calculation.

Contract Clause	Keywords	Total Risk Score
The Contractor shall promptly give notice to the Engineer of specific probable future events or circumstances which may adversely affect the work, increase the Contract Price or delay the execution of the Works.	contractor shall [9] give notice [9] contract price [6]	24
The Employer shall supply, free of charge, the free-issue materials (if any) in accordance with the details stated in the Specification.	employer [4] if any [2] in accordance with [4] stated [4]	14

Keyword-based risk assessment and total risk score results were obtained as an Excel file. For each contract clause sentence, the total risk score values obtained based on the risk score results of the keywords were evaluated. As a result of the evaluation, the total risk score histogram, the number of contract clause sentences, the maximum score, and the average score is summarized in Figure 7.

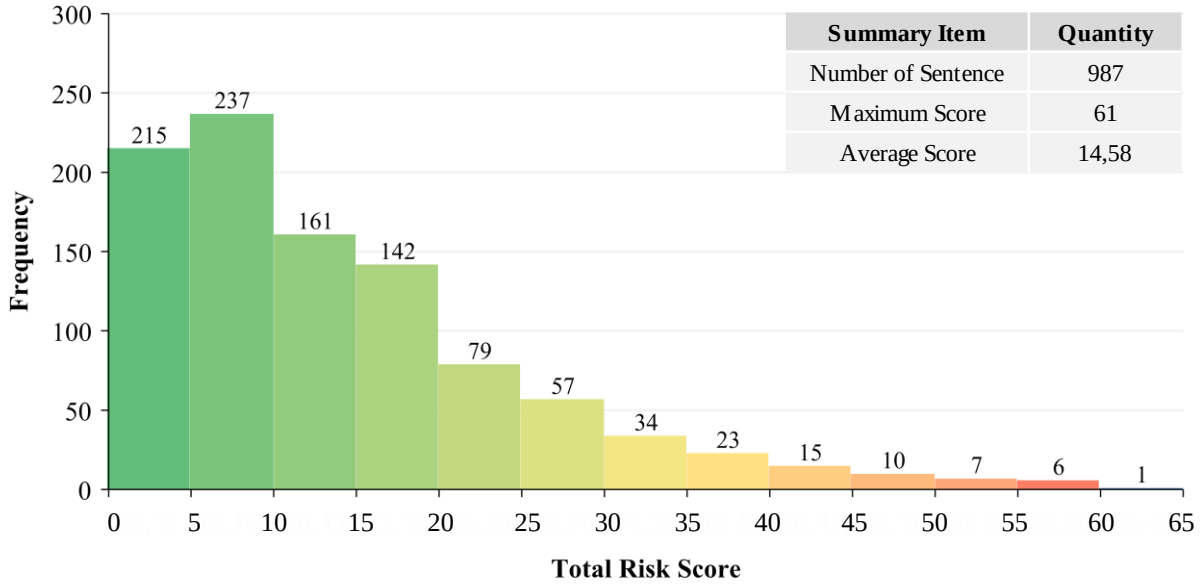


Figure 7: Total risk score result summary.

As a result of the evaluations, more than half of the total risk score value is between 0-15 points. The frequency value decreases as the total risk score value increases to 10 and above.

Results and Discussion

This study it is aimed to provide a technique and solution that can support the risk management task in the contract with a keyword-based risk assessment for construction contracts.

- For this purpose, the first survey study was conducted in order to determine the titles of clauses that have a claim and disputes in the application of the FIDIC 1999 Red Book contract conditinos, which were first selected for the research. By evaluating the results of the survey study, 25 cluse titles in the general conditions of the FIDIC 1999 Red Book were determined.
- It was tried to find the keywords and key phrases that may be related to the risk with the keyword extraction study on the data set consisting of the contract conditions in the specified clause titles. At the end of the keyword extraction application, 45 keywords that may be related to risk were determined.
- A second survey was conducted using the probability-impact risk assessment matrix to determine a risk score for each of the 45 identified keywords. A risk score was calculated for each keyword by evaluating the results of the survey.
- Using the risk scores calculated for the keywords, a risk assessment was made for each sentence data in the data set formed from the clauses in the Red Book general conditions. As a result of the evaluation, the total risk score value was calculated for each sentence of data.

It is expected that the total risk score calculated as a result of the study will be informative to the contract engineer/manager as a qualitative assessment output and supportive in decision making about the risks in the contract. However, this study needs to be expanded considering its limitations in various aspects.

As the output of the keyword-based risk assessment application made in this study, the total risk score value was calculated for each sentence of the contract clause. For this application, high-frequency words were determined as keywords with statistical methods in the extraction of keywords. However, the prevalence of the determined keywords in the contracts caused the probability values to be high. Depending on this situation, the total risk scores determined for the keywords as a result of the survey study using the probability-impact risk assessment matrix were higher than expected. In addition, the general conditions of the FIDIC 1999 Red Book, which is used as text data in this study, are modified according to the needs of the parties by negotiating and negotiating on the terms of the contract. Therefore, the results obtained from this study do not cover all standard contracting applications and risks. To solve this problems and get more accurate results:

- More quality and meaningful keywords and phrases that may be associated with risk can be extracted by examining more contract data.
- In addition, more balanced risk scores for keywords can be obtained by increasing the number of experts participating in the surveys.

A more comprehensive risk assessment can be made with quality keywords to be extracted and balanced risk scores. However, it should not be forgotten that the risk assessment may vary according to the experience of the parties to the contract and their attitudes during the applications process.

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Detection of the Major Problems Concerning Delay Analysis with Unstructured Interviews

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Abstract

Construction industry is prone to disputes resulting in the Extension of Time (EOT). Numerous studies were conducted to improve delay analysis methods; however, the construction industry still suffers from the dispute stemming from EOT. Unresolved dispute concerning EOT ends up in time and cost overrun in projects as well as deteriorate the relationships of the contracting parties. Therefore, resolution of EOT issues in a timely fashion is very crucial. Thus, this study intends to detect the major problems stemming from delay analysis methods. The unstructured interview was conducted with 7 experts and their opinions were evaluated via content analysis to detect the common theme of the experts' views. This study is unique in that it reveals the drawbacks of the existing delay analysis which were not detected by the existing studies. Therefore, it is highly believed that study will pave the way for future study improving delay analysis methods.

Keywords: *construction, delay, delay analysis, delay claim, extension of time.*

Introduction

Claim is an inevitable part of construction projects due to its complex nature. As for the delay in the construction projects, it is considered to be one of the major causes of claims and also one of the most challenging issues to overcome in the construction industry (Bilgin et al., 2018; Kim et al., 2005). For a delay to be settled and equitably segregated as per project parties, the most appropriate delay analysis method considering the characteristics of the project environment is to be adopted. Researchers have made tremendous efforts for developing delay analysis techniques and documents of good practice to guide practitioners instrumentally. Despite the availability of these delay analyses, the projects mostly fail to apportion the project delays to the responsibilities of the project parties due to the disadvantages of current delay analyses and their limited recognition (Asim et al., 2017).

According to a survey conducted with construction consulting organizations in the UK, most practitioners lack recognition of delay analysis methods despite their importance (Braimah & Ndekugri, 2009). The fact that the projects suffer from the catastrophic results of the delays has attracted the attention of researchers and paved the way for the improvement of delay analysis concerning construction projects. In this study, unstructured interviews were conducted with 7 experts experienced in the delay analysis domain in the construction industry to detect the major problems concerning delay analyses. Following the unstructured interviews, content analysis was conducted to release the common themes of the participants' views. In conclusion, it is detected that none of them can detect any improvements or further delays made by the contractor for the delays caused by the employer and force majeure. Additionally, it is detected that existing delay analysis methods necessitate overwhelming number of requirements of the delay analyses. Furthermore, lack of numerical procedure concerning delay analysis result in inconsistent applications in the construction industry.

Delay Analysis

The construction industry is recognized for its notoriety in terms of frequent and costly delays. Delays in projects occur when a delay in an activity surpasses its total float. While distributing the delays to the responsible parties, float ownership comes into prominence. Unless otherwise specified in the contract, the project float is owned by the project parties (AACE International, 2007). Board decisions have confirmed that a party using the float first gains the benefits of float (de la Garza et al., 2007; Wickwire et al., 1988) and most of the delay analyses are based on this approach.

Delays can be categorized as compensatory delays (CD) caused by the owner, non-excusable delays (ND) caused by contractors and excusable delays (ED) which represent other kinds of delays caused by acts of God or a third party (Kraiem & Diekmann, 1988). While non-excusable delays may arise from slow progress, compensatory delays may result from change order, site instruction, disruptions and suspensions; however, EDs may result from the events which are outside the control of contractors and clients, such as strikes, fire, differing site conditions and change in government law, etc. Particular construction contract documents need to be checked to identify EDs in a project. In the case of an ED, the contractor is entitled to EOT. Few amounts of delay analyses have been developed to figure out EDs and CDs and NDs to apportion the delays to the clients and contractors.

Methodology

To detect the major problems concerning delay analyses, unstructured interviews with 7 experts were conducted in addition to the in-depth literature review. Concerning the unstructured interview, the demographic information of participants was tabulated in Table 1 below.

Table 1. Demographic information of experts.

Expert #	Role of Participant	Experience (Year)	Project Budget	Project Type
Expert#1	MEP Planning Chief	7	US$1.17bn	Airport Project
Expert#2	Planning Manager	9	US$450m	Airport Project
Expert#3	Planning Manager	11	606m Euro	Hospital Project
Expert#4	Contracts Manager	18	US$300m	Oil & Gas Project
Expert#5	Contracts Manager	15	US$700m	Metro Project
Expert#6	Project Control Manager	14	US$5000bn	Finance Centre Project
Expert#7	Project Control Engineer	7	US$200m	Embassy Project

Note: Common themes of the participants' views were analyzed via content analysis and represented in the finding section.

Results

In the wake of the unstructured interview, comment theme of the experts' opinions were analyzed via content analysis and drawbacks of the existing delay analysis were detected under three headings which are "Not computing any further delay and improvement made by the contractor on the activities of fragnet", "An overwhelming number of Requirements of the delay analyses", "Lacking the Procedure of the delay analysis".

Computing Any Further Delay and Improvement Made by the Contractor on the Activities of Fragnet

For the determination of drawbacks concerning prospective and retrospective delay analyses, an opinion of Expert#1 that emerge as a result of unstructured interviews is as follows; "*most of the time, the contractor fails to compute the variance between the planned fragnet and actual dates of the fragnet since mostly one of the methods such as prospective or retrospective is adopted in a project. Consequently, for the projects adopting a retrospective delay analysis, it can be claimed by the owner that the actualized fragnet was completed in a very abundant time and delayed the project unnecessarily. Concerning projects adopting the prospective delay analysis, issues such as whether the planned fragnet which is on CP will be on the critical path in the schedule update or not, presence of concurrent delays of the contractor occurring with actualized fragnet, determination of mitigation or further delays made by the contractor during the schedule update can be questioned by the owner. These issues about Time Impact Analysis (TIA) and Windows Analysis (WA) can end up with a dispute between the owner and the contractor*". Giving an example from Expert#1's previous project, he continued his words as follows; "*The Contractor received 450 Site Instructions during the project. To compute the EOT, Windows Analysis Method was conducted. However, the owner didn't agree upon any of the delay analyses until the end of the project by claiming*

that the duration and sequence of fragnet delayed the project more than required and the contractor didn't take any mitigation measurement on the fragnet".

Expert #2 explained the problem arising from the prospective analysis applied in his project with the following words: "*there was an interface between the two main contractors. Time Impact Analysis was conducted to include the interface issues to the schedule and concluded with an impact of 220-days on the project. However, the owner and the Engineer were not convinced by the validity of fragnet and its impact. Settling this debate concerning fragnet took 4 months by conducting several meetings with a remarkable effort. If the type of delay analysis is not defined in the project contract, the owner quite often wants to see the possible effect of the fragnet on the project and the actual status of the fragnet. Therefore, the employer can take necessary precautions in advance thanks to the prospective analysis. Besides, the owner may also want to see the retrospective delay analysis since the fragnet which has a time impact in the prospective delay analysis may not be on the CP during the schedule update due to the contractor's concurrent delay*."

Expert#3 also highlighted a problem experienced in the prospective delay analysis by stating that "*According to the PPP contract of the Main Contractor, the project can be delayed a maximum of 6 months without reducing the operational period. During the project, the owner sent a change order concerning the increase in the closed area by 14%. The contractor requested 1 year EOT through conducting TIA and requested not to reduce the operation period since the delay in the project resulted from a change order. However, the owner didn't accept this request of the contactor by claiming that the contractor's actual delay or mitigation was not reflected in EOT*."

Expert #4 made the following remarks on the prospective delay analysis "*The owner tends to question the prospective analysis by claiming that it doesn't reflect the actual concurrency and actual mitigations. When the fragnet becomes actual, the contractor can conduct an additional analysis by comparing TIA with schedule updates including the fragnet. However, this additional analysis requires additional efforts of experts and new correspondings between the contractor and the owner.*"

TIA and WA are the most acceptable delay analysis methods adopted by practitioners and courts. TIA method may follow up on the project day-by-day from beginning to completion date (Arditi & Pattanakitchamroon, 2006). However, daily tracking of TIA requires plenty of time, cost and expertise. Consequently, in engineering practice, TIA is conducted mostly when a delaying event (Owner or acts of God-related delays) occurs to detect the possible effect of the delay on the completion date (Arditi & Pattanakitchamroon, 2006; Ekanayake & Perera, 2016; SCL, 2017). Therefore, TIA is often preferred for prospective delay analyses. In fact, SCL Protocol 2nd Edition revised its protocol to require the use of TIA for prospective analysis (SCL Protocol 1st Edition suggested to use TIA for both prospective and retrospective under section 3.2.11). "*The conclusions of a prospective delay analysis may not match the as-built programme because the Contractor's actual performance may well have been influenced by the effects of attempted acceleration, re-sequencing or redeployment of resources*" (SCL, 2017). Since TIA doesn't contain actual dates of a concerning delaying event (Calvey & Winter, 2006; SCL, 2017; Vasilyeva-lyulina et al., 2015), it doesn't include any mitigation, acceleration and/or further delays concerning fragnet. However, "*The Contractor has a general duty to mitigate the effect on its works of Employer Risk Events.*" (SCL, 2017); therefore, the potential variance between the planned fragnet included in TIA and the updated fragnet can be questioned by the owner to detect any further delay or

improvement made on activities of the fragnet. Comparing the dates of fragnet in TIA with actualized fragnet opens up an opportunity for overcoming this drawback. However, this method requires additional analysis and consequently much more time, cost and expertise. Like TIA, WA includes only the actualized delaying event since WA doesn't compute any further delays or improvements made by the contractor on the activities in the planned fragnet (Hegazy et al., 2005).

An Overwhelming Number of Requirements of the Delay Analyses

All the experts reached a joint decision that the requirements of time, cost and expertise of delay analyses depend upon the delay amount, delay type and type of delay analysis. Expert 5 stated the following about the subject; "*Although TIA and WA are very useful to some extent, their requirements such as expertise, cost, document control, close site monitoring, record keeping and time obstruct their usage in practice.*" Expert #6 underlined that if the numerical model and algorithm of the delay analysis are given, the analyst spends less time as well as spending less cost. Also, literature support this view as that applications of TIA and WA in practice are very demanding in terms of significant amount of requirements such as time, cost and expertise (Arditi & Pattanakitchamroon, 2006; Calvey & Winter, 2006; Hegazy et al., 2005; Perera et al., 2016; SCL, 2017).

Lacking the Procedure of the Delay Analysis

All the experts stated that the delay analysis applications may differ from project to project. Although the owner and contractor can agree upon the type of delay analysis at the outset of the project, it is quite encountered that the parties have different views concerning the implementation of the delay analysis method when the related procedure is not available. Expert#7 emphasized the importance of the procedure with the following words; "*Project Scheduling Specification which is part of the contract in our project obliges to use TIA for the delay analysis and provides its procedure. When a delaying event resulting from the employer or a delay resulting from force majeure occurs, we conduct TIA and notify the employer. Since we have a procedure, we did not have any technical problems in terms of time claims. However, I believe that lacking this procedure hinders the process.*

Conclusion

In this study, unstructured interviews were conducted with 7 experts experienced in the domain of delay analysis. Mainly 3 major drawbacks encountered during the practices of delay analyses in the construction industry were highlighted during the unstructured interview. These are computing any further delay and improvement made by the contractor on the activities of fragnet, an overwhelming number of requirements of the delay analyses, lacking the procedure of the delay analysis. A new delay analysis computing any further delay and improvement made by the contractor on the activities of fragnet and having a procedure with its algorithm is believed to speed the delay analysis process as well as the reducing the required man-hours.

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Barriers of Disruption Claim Management in Construction Projects

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Abstract

Changes such as change orders and site instructions resulting in resource diversion and work area congestion negatively affect the crew's productivity and thus a disruption occurs. Diminishing labor productivity ends up with an increase in the costs and time needed to accomplish the work and this jeopardizes the owner's return on investment, concluding with serious friction and even litigation among the contracting parties. Although disruption is a highly contentious event in construction projects, systematic disruption claim management (DCM) practices cannot be facilitated in construction projects successfully so that disruption events continue to be a major trigger of dispute among the contracting parties. Thus, in recognition of the problem described above, this study aims to identify barriers of DCM by conducting a comprehensive literature review. Furthermore, a questionnaire survey which was analyzed using the TOPSIS technique was conducted with the participation of 12 construction practitioners to set out the significance of DCM barriers. Besides rigorous theoretical contribution, this study is believed to provide construction practitioners with fundamental DCM knowledge that is necessary to create a DCM road map for their projects.

Keywords: *barriers, disruption claim management, MCDM, TOPSIS.*

Introduction

A construction project is generally recognized as successful when it is accomplished on the dot and within the budget; however, achieving this goal is often difficult due to numerous obstacles such as changes occurring in the construction projects. Any additions, omissions and revisions in the contract are referred to as changes in the construction project (Ibbs, 2013). Due to the dynamic and turbulent nature of the construction projects, changes are frequently encountered (Gibson, 2015; Ibbs, 2013). Such changes cause adjustments in the price and/or duration of projects as well as fluctuations in labour productivity (Ibbs, 2013).

Productivity is defined as the efficiency rate at which a contractor converts labour man-hours and materials to outputs (Park et al., 2005). The productivity loss occurs if the contractor is forced to alter its method statement upon the change order issued by the owner (McGeehin & Spangler, 2021). When the productivity is diminished, the contractor is required to spend more labour man-hours and/or equipment hours to produce the same output (Park et al., 2005). In turn, the contractor's time and cost estimates deviate from the plan substantially, inhibiting its profits and return on investment. The impact of changes becomes even more detrimental for the contractors if many changes occur on a project simultaneously due to the emergence of a special condition called cumulative impact (Ibbs, 1997, 2005). The cumulative impact is the unforeseeable productivity loss caused by synergistic and simultaneous effects of a series of changes (Ibbs, 2013). It can also be considered as an indirect or secondary effect of multiple changes. Hester et al. (1991) also highlighted the significance of cumulative impact by stating that the negative impact of each change compounds in the presence of multiple changes, which, in turn, leads to disruptions that are greater than the sum of all individual changes. In other words, multiple changes disrupt not only the changed work itself but also the whole project. Consequently, the contractor experiences 1 + 1 = 3 result (Ibbs, 2013).

Upon the abovementioned changes triggering disruption event/s, the contractor prepares a disruption claim (Society of Construction Law, 2017). A disruption claim is prepared to obtain the quantum of damages suffered by the contractor due to disruption events that make the construction works more difficult and/or more expensive to undertake (Williams et al., 2003). In the disruption claims, the contractor must present concrete evidence concerning productivity losses resulting from disruption events. Otherwise, the claims are likely to provoke a fierce rejection from the defendant who is usually a project owner (McGeehin & Spangler, 2021). Depending on the contract conditions, a typical disruption claim focuses on various aspects of disruption such as overhead, productivity loss, escalation of labour, escalation of plant, escalation material, loss of profits/profit-earning capacity, finance charges, off-site/on-site storage charges and claim preparation costs (Bramble & Callahan, 1992). The vast majority of these aspects are however sophisticated to be calculated accurately due to the high degree of ambiguity (Best & De Valence, 2002). Additionally, it is extremely complicated to dissociate the effects of various factors such as inclement weather, poor workmanship, poor supervision and the risks that the contractor has taken during the tender preparation stage (Best & De Valence, 2002). Although all these factors might lower the productivity and construction output, their effects are excluded from the disruption claims since these factors are not triggered by owners. In other words, the contractors must demonstrate a quantum of disruptions triggered by the events that are caused by the owner without considering other factors affecting productivity (Society of Construction Law, 2017). Thus, disagreements become inevitable about rates of compensation, the quantity of the individual and/or cumulative impacts of disruption events (Ibbs, 2013).

Cognitive conflict and conflict of interest are other major inhibitors that maximize the complexity of the disruption claims (Ibbs, 2013). Cognitive conflict in disruption claims escalates when the claimant and defendant interpret the disruption-related data differently. Inadequate information, information asymmetry, misinformation, and diverse views on what is convenient are among the major sources of cognitive conflict (Moore, 2003). Cognitive conflict prevails in the vast majority of disruption claims due to disruptions' retrospective nature and poor record-keeping (Gibson, 2015). On the other hand, conflict of interest occurs when the interests of the claimant and defendant extremely diverge from each other (Fenn et al., 1997). Conflict of interest is encountered frequently in disruption claims since the

contractors seek compensation for their losses and tend to favour their interests at an expense of the owners' interests (Ibbs, 2013). For instance, if a serious disruption occurs in a construction project due to an intervention of the owner and the contract administrator validates the disruption claim of the contractor, the contractor is entitled to recover compensation. Otherwise, in the case of the refutation of the contractor's claim by the contract administrator, additional costs spent to balance lower productivity are financed by the contractor. Therefore, disruption claim should be well-prepared by including convincing records related to the project facts to minimize effects of cognitive conflict and conflict of interest.

Information provided above reveals that DCM should be performed systematically to prevent the escalation of conflicts and disputes among the contracting parties. In this way, financial and non-financial losses stemming from prolonged dispute resolution processes could be prevented (Cakmak & Cakmak, 2014; Çevikbaş & Köksal, 2018; Marques, 2018). Despite the significance of DCM, the construction practitioners could not implement this concept due to various barriers that emerged as also stated by HKA (2020), Arcadis (2021). Thus, there is an apparent need to identify the barriers of DCM to provide significant knowledge to construction practitioners for the implementation of DCM practices more effectively. In this way, the practitioners could develop proactive strategies to avoid the impacts of these barriers on the efficiency and effectiveness of DCM. In the initial step, a comprehensive literature review was conducted to extract barriers of disruption claim management. This was then followed by a questionnaire survey. Next, collected data was analysed using TOPSIS to assess the significance of DCM barriers.

Related Works in the Disruption Claim Management Literature

Disruption is one of the major sources of diminishing labour productivity. Since cost and time are the functions of labour productivity, the subject of disruption has attracted various researchers' attention in the construction management literature. Thomas and Napolitan (1995) conducted one of the first researches related to disruption. The authors performed various quantitative analysis techniques to determine the effects of changes on labour productivity and efficiency. The study revealed that disruptions such as lack of materials and information, which lead to performing the work out of sequence, might reduce productivity in the range of 25 to 50%. Thus, the authors pinpointed that these severe effects of disruption should be claimed to prevent the contractor from losing money. Later, Ibbs (1997) investigated the quantitative impacts of changes in construction projects. The results suggested that the amount of change is negatively correlated with productivity. The study also made various recommendations to manage the changes efficiently. Another recommendation was proposed by Aibinu (2009). The study investigated the role of pre-contract negotiation to avoid and mitigate conflicts stemming from delay and disruption claims. The study conducted a questionnaire survey with the participation of the construction practitioners and revealed that pre-contract negotiation has great potential to avoid and/or mitigate disruption-related conflicts. On the other hand, Ibbs (2005) proposed that the timing of the change is also a significant issue due to having various magnitudes of impact on productivity. Thus, the impact of changes on the labour productivity for early, normal, and late timing situations was analysed within the scope of this study. The study showed that late change is more disruptive of project productivity than early change. Various studies also investigated the factors affecting the disruption claims. Norflee (2005) pinpointed that the level of learning and labour productivity tends to increase as the work progresses. Thus, the study highlighted the

significance of the learning curve and recommended that the effect of the learning curve needs to be considered in the disruption claims. Secondly, Ibbs (2013) suggested that the total negative effects of the disruptions are greater than the sum of the individual parts. The study, therefore, proposed that the cumulative impacts of multiple changes in terms of disruption should also be considered in disruption claims. To compute these impacts, multiple changes stemming from the owner and Acts of God should be well-documented and examined to present the project facts thoroughly. Furthermore, several authors such as Jayasena and Alwis (2011) and Kikwasi (2013) analysed the causes and effects of disruptions as per regions to improve the DCM process in the concerning regions.

As elaborated previously in this study, the productivity losses stemming from disruption events should be proved and analysed to prepare sound disruption claims. Thus, many efforts are also devoted to developing disruption analysis methods in the literature. The most common and well-known disruption analysis methods are Measured Mile Analysis, Global Claim, Control Chart Method (Gulezian & Samelian, 2003), Thomas's BP Method (Thomas & Zavrski, 1999), Improved Measured Mile Analysis (Ibbs & Liu, 2005), System Dynamics Modelling (Williams et al., 2003), Disruption Distribution (Finke, 1998), Demonstrated Labour Efficiency (McCally, 1999) and Data Envelopment Analysis (Lin & Huang, 2010). Furthermore, the effectiveness of the disruption method/s in projects was also analysed by several studies (Eden et al., 2000; Zink, 1986).

Various research was also conducted to develop a roadmap for the DCM domain roughly in the construction projects. William et al. (2003) developed an approach that aids decision-makers to prepare disruption claims logically and transparently. The approach is established on three pillars, namely demonstration of causality, responsibility, and quantum for the claim. Lastly, McGeehin and Spangler (2021) investigated the impact of the COVID-19 pandemic on the disruption of construction projects and developed various approaches to prepare disruption claims triggered by the COVID-19 pandemic. In addition to efforts conducted by researchers, organizations also developed/recommended best practices for preparing disruption claims such as AACE International (2011), Hill International (2011), and Society of Construction Law (2017).

Consequently, the in-depth literature review presented above shows that barriers of DCM have been so far, which formed the research question of this study

Methodology

The research methodology followed in this study is presented in Figure 1. As is depicted in Figure 1, the literature review was first conducted to extract barriers of DCM. This was then followed by a questionnaire survey designed to assess the significance of the barriers extracted from the literature. Lastly, the eligible experts were identified by using the systematic decision-making framework given in Figure 1. Following the expert selection process, the TOPSIS analysis was conducted to identify the priorities of the barriers. This step was crucial since developing a proactive solution to each barrier is a challenging task. By identifying the most significant barriers, the decision-makers are provided with barriers that need urgent and utmost attention.

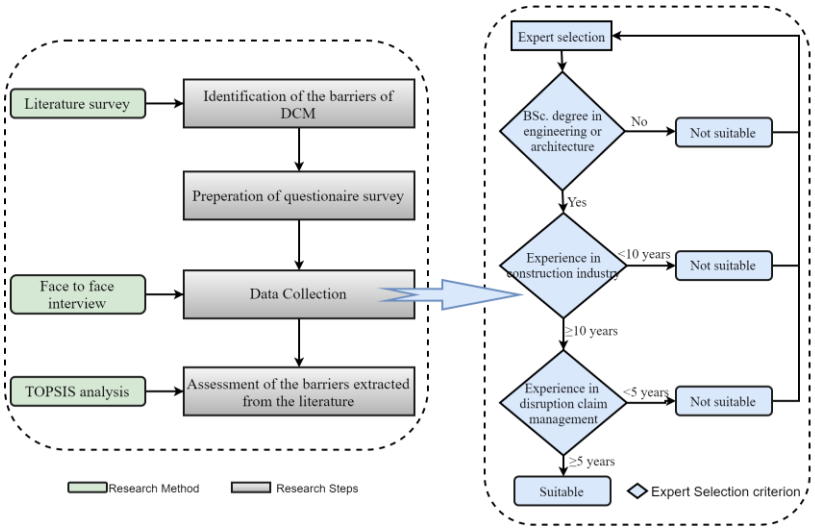


Figure 1. The methodology followed in the study.

Literature Review

As stated above, barriers that could diminish the efficiency and effectiveness of DCM in construction projects were identified by conducting an in-depth literature review. During the literature review, only peer-reviewed articles were initially examined to maximize the reliability of the study. The initial results of the literature review revealed that limited efforts have been devoted to the disruption claim management domain so that scope of the literature review was further widened in a way that includes guidelines published by various institutions. Consequently, 22 DCM barriers were extracted from the literature as shown in Table 1. Point worthy of note is that there is no specific study identifying the barriers of DCM so that barriers presented in Table 1 were identified by reviewing and synthesizing the knowledge related to DCM.

Table 1. The barriers of DCM extracted from the literature.

Barriers	**References**								
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Insufficient communication of project stakeholders in the contract development phase			X						
Lack of knowledge in project scheduling									X
Insufficient human resources for record-keeping			X		X				
Insufficient financial resources for record-keeping			X						
Lack of agreement on the type of records to be kept			X						
Ignorance of project team for tracking disruption events			X						
Improper frequency of programme update			X						
Unclear responsibility assignment of the project for record-keeping			X						
Uncertainty in what and how parts of the works were affected by disruption event		X							
Insufficient site observations to notice a disruption event			X						
Insufficiency in describing events that lead to disruption			X	X					
Lack contract clauses stating disruption analysis and its procedures			X		X				
Lack of expertise in analysis methods			X				X	X	

Lack of project scheduling software			X						
Lack of proper baseline schedule			X			X			
Improper storage and accessibility of the records			X						
Insufficiency of contemporary data			X	X	X	X	X	X	X
Availability of disrupted works which are also impacted by events that are out of owner's control			X		X		X	X	
Over cognitive bias between contracting parties	X								
Over conflict of interest between contracting parties	X								
Subjectivities of analysis methods				X	X	X		X	
Unclear and lack of legal basis under the contract			X	X					X

Note-1: A: Aibinu (2009), **B:** Ibss (2013), **C:** Society of Construction Law (2017), **D:** Zhao and Dungan (2019), **E:** Mikhail and Serah (2019), **F:** Al-Kofahi Z. G. et al. (2020), **G:** San and Nwandem (2020), **H:** Lee (2021), **I:** McGeenhin and Spangler (2021). **Note-2:** The risks named "Loss of confidentiality" and "Lack of knowledge in law and other legal procedures" were eliminated in the FGD sessions.

Data Collection and Data Analysis

Following the literature review stage, the questionnaire survey was designed to assess the significance of the DCM barriers. The questionnaire survey consisted of 3 sections. In the first section, the experts were asked to provide information about themselves. This information was crucial to ensure that experts are convenient for the study. The second section included the fundamental knowledge about DCM and the survey. In the last section, the experts were asked to rate the significance of each barrier with respect to each decision-making criterion. The decision-making criteria that are required by the TOPSIS analysis were determined as Impact on the reliability of disruption analysis, Impact on record-keeping and Impact on the assessment of disruption claims. In other words, each expert completed a decision matrix whose size is 22 by 2.

Next, the eligible experts were identified by following the systematic framework depicted in Figure 1. The demographics of the experts are provided in Table 2. As is seen in Table 2, the experts are capable of providing a substantial contribution to this study.

Table 2. Profile of the participants.

Expert ID	**Personal profession**	**Education**	**Years of experience**
E1	Planning Manager	Civil Engineer	CI: 15 years, DCM: 10 years.
E2	Planning Manager	Mechanical Engineer	CI: 12 years, DCM: 8 years.
E3	Contract manager	Civil Engineer	CI: 11 years, DCM: 7 years.
E4	Quality control manager	Civil Engineer	CI: 16 years, DCM: 8 years.
E5	Technical office manager	Architect	CI: 15 years, DCM: 12 years.
E6	Technical office manager	Civil Engineer	CI: 13 years, DCM: 5 years.
E7	Project manager	Mechanical Engineer	CI: 19 years, DCM: 10 years.
E8	Project manager	Civil Engineer	CI: 21 years. DCM: 15 years.
E9	Project manager	Civil Engineer	CI: 20 years. DCM: 12 years.
E10	Owner	Civil Engineer	CI: 30 years. DCM: 20 years.
E11	Owner	Civil Engineer	CI: 25 years. DCM: 18 years.
E12	Owner	Civil Engineer	CI: 19 years. DCM: 12 years.

Note: CI: International Experience in Construction industry, DCM: Disruption Claim Management.

In the last step, the data collected through the questionnaire survey was analysed using TOPSIS analysis which is one of the most popular Multi-Criteria Decision-Making Methods (Salih et al., 2019). The main reasons behind its popularity are its stability, computational time, and simplicity (İç, 2012). In essence, the TOPSIS method determines the most ideal solution by considering the distances of each alternative from positive and negative ideal solutions (Rao, 2007). The term of positive ideal solution refers to the hypothetical solution which is composed of all the best values attainable from the decision-making criteria while the negative ideal solution is called the hypothetical solution which is composed of all the worst values attainable from the criteria (Rao, 2007; Wang, 2008). Consequently, the following methodology proposed by Rao (2007) was implemented to perform the TOPSIS analysis. The results of the TOPSIS analysis are provided in Table 3.

Results and Discussion of Findings

To interpret these results more precisely, the mechanism of the TOPSIS should be well-comprehended. TOPSIS analysis reveals the relative importance of the barriers of DCM practices. In other words, the barriers having a higher closeness coefficient could be deemed as more significant than those having a lower closeness coefficient. The statements such as barriers having lower weights are insignificant might be controversial to assert (Rao, 2007). Contrarily, in this study, all identified barriers were considered significant since they were extracted from the literature (Budayan, 2019). TOPSIS analysis, however, highlights the barriers that need more and urgent attention from the decision-makers.

Accordingly, the results revealed that "Insufficiency of the Contemporary Data" was rated as the most significant barrier by the experts who participated in this study. The rationale behind this result is that DCM practices are a data-intensive process so that productivity data collected before and after the disruption event is of paramount importance for the disruption claims (Gibson, 2015). Secondly, the barrier named "Uncertainty in what and how parts of the works were affected by disruption event" obtained the second highest result by the experts while "Insufficiency in describing events that lead to disruption" ranked in the fourth order. The loss stemming from disruption events that are triggered by the owner can only be claimable. The damages stemming from other disruption events should be subtracted from the disruption-related claims (Society of Construction Law, 2017)**.** Otherwise, fierce rejection by the defendant who is often the owner is inevitable. Thus, the disruption-related claims should be prepared in a way that includes detailed information about disruption events together with their impact on productivity. In case the owner fails to substantiate the disruption events and their impact, the disruption claim can hardly be negotiated by the owner.

The disruption analysis methods have various subjectivities arising from their inherent mechanisms and assumptions (Hill International, 2011). The subjectivities that exist in these methods could easily complicate the assessment process of the disruption claim since the subjectivities could cause the rejection of the owner. Thus, decision-makers should select the most appropriate disruption analysis methods that meet the needs of construction projects and their stakeholder. Thus, analysis results revealed that the subjectivities of the disruption analysis methods are another barrier in front of the DCM. "Insufficient human resources for record-keeping" was ranked in the fifth order. Record-keeping must be implemented continuously throughout the entire project so that it is not a one-time activity, unlike the other phases (Gibson, 2015). This is a very challenging task and requires significant human

resources. Thus, when the human resources are not sufficient for record-keeping, the entire DCM process could be affected.

Table 3. Result of the TOPSIS analysis.

Barriers	P	Rank
Insufficient communication of project stakeholders in the contract development phase	0.4431	17
Lack of knowledge in project scheduling	0.3791	20
Insufficient human resources for record-keeping	0.6210	5
Insufficient financial resources for record-keeping	0.5841	8
Lack of agreement on the type of records to be kept	0.5620	9
Ignorance of project team for tracking disruption events	0.5377	10
Improper frequency of programme update	0.4298	18
Unclear responsibility assignment of the project for record-keeping	0.3638	22
Uncertainty in what and how parts of the works were affected by disruption event	0.7742	2
Insufficient site observations to notice a disruption event	0.4189	19
Insufficiency in describing events that lead to disruption	0.7147	3
Lack contract clauses stating disruption analysis and its procedures	0.5305	11
Lack of expertise in analysis methods	0.6129	6
Lack of project scheduling software	0.3671	21
Lack of proper baseline schedule	0.4786	14
Improper storage and accessibility of the records	0.6108	7
Insufficiency of contemporary data	0.8042	1
Availability of disrupted works which are also impacted by events that are out of owner's control	0.5216	12
Over cognitive bias between contracting parties	0.4628	15
Over conflict of interest between contracting parties	0.4546	16
Subjectivities of analysis methods	0.6967	4
Unclear and lack of legal basis under the contract	0.5105	13

Conclusions

Disruption in construction projects has widely been seen as a significant problem hindering the productivity of the projects. Given the fact that diminished productivity puts the financial gains of the contractors in jeopardy, the disruption could even escalate the disputes among the contracting parties. Despite this significance, disruption claim management practices are barely implemented in construction projects due to various barriers that emerged during their implementation. Thus, this study aims to identify these barriers that present a roadblock to effective implementation of the disruption claim management practices. Accordingly, an in-depth literature review was conducted to extract barriers. This was then followed by a questionnaire survey designed to measure the impact of each barrier on the DCM. Lastly, the TOPSIS technique was performed to analyse the survey data.

Considering that generating proactive solutions to all barriers extracted from the literature requires significant resources, the decision-makers should focus more on the most significant barriers. In other words, the experts should develop solutions to barriers based on their ranks.

Accordingly, the results revealed that “Insufficiency of contemporary data”, “Uncertainty in what and how parts of the works were affected by disruption event”, “Insufficiency in describing events that lead to disruption”,” Subjectivities of analysis methods”, and “Insufficient human resources for record-keeping” were rated as the most significant barriers. Thus, decision-makers are advised to generate urgent solutions to these barriers. Otherwise, the benefits of DCM can hardly be materialized.

This study has some noteworthy limitations. Firstly, the framework developed within the scope of this study is generic and does not consider inherent differences of the regions and/or countries. Although this issue has a limited effect on its practical implication since it was developed and refined by internationally experienced experts, the decision-makers should be aware of that minimal modifications could be necessary throughout its actual implementation in different countries and regions. Secondly, the use of a small sample size might cause some degree of bias. However, the following systematic procedure during the expert selection is believed to minimize the effects of this issue.

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Civil Engineering Subjects in the Turkish Legal System

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Abstract

Legal processes in the construction industry are shaped in order to solve the problems and to prevent or compensate for all kinds of loss of rights in terms of stakeholders. Engineers and technical personnel, customers, contractors and subcontractors, employees, etc. sector members may encounter these losses of rights, during the construction process. However, legal rights and responsibilities are not limited to only the construction process in the construction industry. Development readjustment share, tender and bidding processes, zoning legislation, construction inspection law, occupational health and safety, compliance with laws, terms of contracts, the debt of loyalty, the fundamental issues such as the clearly reveal the importance of the concept of law in the construction industry. But, legal rights and responsibilities that should be considered in the planning, delivery, and use phase of construction are not taken into account by the stakeholders until a significant problem arises in any concrete case. In addition, many cases are encountered in the construction industry due to the weakness of the inspection mechanism and the fact that some issues do not find their place in the legislation and laws. These litigation processes wear out the parties. In this paper, legal approaches, some deficiencies and relevant laws in the construction industry are examined. It is desired to draw attention to the necessity of basic legal knowledge that concerns stakeholders of the construction industry, especially civil engineers.

Keywords: *building contract, building law, construction law, legal knowledge.*

Introduction

Legal rules are a set of rules that regulate social relations and living conditions, have material sanctions, and are supported by public power (Güriz, 1996; Kalabalık, 2012). Legal rules are about the actions of individuals and deal with human behavior in general. These rules mainly include the concepts of order, prohibition, permission and authorization. By force of these regulations, the rules of law have the sanction power. In addition, the law is dynamic because it can change due to human relations, which is a dynamic process, changing cultures and conditions required by the age. When required, it can be updated (Kalabalık, 2012).

A legal order is formed by classifying the rules of law according to the field they are related to. One of these fields is civil engineering. The civil engineering profession imposes some responsibilities on the relevant parties in terms of resolving disputes and preventing loss of rights during the implementation and execution of the work. Law within the scope of civil engineering is more frequently encountered in the literature with terms such as building law

and construction law. There are a large number of laws in Turkey that deal directly with construction or provisions that also include laws about construction (Daşdelen, 2006). Turkish Laws that contain important regulations *within the scope of civil engineering* are the Turkish Code of Obligations, the Zoning Law, the Occupational Health and Safety Law, the Labor Law, Construction Inspection Law, Public Procurement Law, and the Property Ownership Law. In addition, the Turkish Civil Code, which includes the provisions of the law of property that regulates the issues related to real estate, is one of the laws that can be needed. In addition to all these, there are many regulations prepared based on these laws for the construction sector. One of them is the Planned Areas Zoning Regulation, which regulates the procedures and principles regarding building and construction in accordance with the plan, science, health and sustainable environmental conditions. In addition, Unplanned Areas Zoning Regulation, Energy Performance Regulation in Buildings, Regulation about Site Chiefs, Building Earthquake Regulation, etc. are also sources for *which civil engineers are responsible* (TMMOB, 2011).

It is almost *impossible to have full knowledge* of all these laws and regulations and to know all the provisions, however, the responsibilities arising from these laws are *binding*. In other words, "not knowing" an existing law provision is *not accepted as an excuse* in terms of Turkish law. In this regard, the relevant provision within the scope of the "Law-binding" is as follows in the Turkish Penal Code.

- Not knowing the penal laws is not an excuse (Turkish Penal Code, 2004: 4/1)

However, the same law also included some regulations under the name of “Error” in the provisions regulated by 30/3 and 30/4 clauses. Relevant regulations;

- A person who makes an inevitable mistake regarding the fulfilment of the conditions related to the reasons that remove or reduce the criminal liability, takes advantage of this mistake. (Turkish Penal Code, 2004: 30/3).

- A person who inevitably commits an error that his act constitutes injustice is not punished (Turkish Penal Code, 2004: 30/4).

In accordance with the principle that ignorance of the law in this regard is not an excuse; It is clear that even if the person does not know that there is a criminal sanction for the action he has committed, he will not gain an advantage in terms of criminal law proceedings. However, *unavoidable injustice* is related to the actions that take place despite the fact that the person concerned does his due diligence and attention. It occurs when the person *inevitably believes* that he will not cause an unfair situation, regardless of the provisions of the Law, and therefore commits the criminal act. The *inevitable error* is not here as a fraud but is valid for actions performed in good faith, with the belief that the action that is not thought to constitute a crime will not lead to an unfair situation as well (Öztürk, 2021).

According to these circumstances, it is necessary for civil engineers to know the concerned laws within the scope of professional competence. For this purpose, the Turkish Laws that civil engineers should know directly or indirectly are explained in the following sections.

Turkish Code of Obligations Through the Eyes of Civil Engineers

One of the most common legal issues faced by civil engineers is the *contracts of work* and services. The contract of work is regulated in the Turkish Code of Obligations (TCO), articles 470-486. Conflicts encountered in terms of construction and engineering are more frequently caused by non-compliance with the provisions of this law or a lack of due diligence. A contract of work is a contract in which the contractor undertakes to create a work and the employer undertakes to pay a price for it (Turkish Code of Obligations, 2011: 470).

Without prejudice to the general provisions of the Code of Obligations and other related provisions, it is clearly beneficial for every civil engineer to know at least these provisions regulated by TCO 470-486. *Other related provisions;* (joint liability, the statute of limitations, written form requirement, tort, foreclosure, default in contract, etc.). These provisions, which are regulated by the TCO Part II, Seventh Chapter, start with the definition of the work contract and regulate the Contractor's Obligations and the Employer's Obligations, respectively. Subsequently, the provisions of TCO 482-486 include the cancellation of the contract.

The most common types of lawsuits in terms of the provisions of the TCO are liability due to defects regulated by Articles 474-478 and exceeding the approximate price regulated by Article 482. Another point that concerns civil engineers is construction contracts. Establishing a proxy relationship between civil engineers and the employer is a common situation in the profession. Under article 40 of the TCO, the employer's representative is authorized to act on behalf of the employer. FIDIC contracts and Joint Venture contracts are also a source for more detailed studies on this subject (Çetin, 2022; Tutkun, 2019).

The courts of competent jurisdiction regarding the disputes within the scope of the Code of Obligations may differ according to the content, type, and place of the case. In order to *avoid loss of rights* regarding these issues, it is of great benefit to know the relevant court correctly in terms of duties and competence. Also knowing the period of prescription, and knowing the court of the place where the case will be filed is needed. There are different decisions of the Court of Cassation on this issue (Ruhi & Ruhi, 2018).

Turkish Civil Code Through the Eyes of Civil Engineers

Some issues concerning civil engineering are also regulated by the Turkish Civil Code. Part one of this Code, which is about property law, starts with the right of property and continues with the ownership of *immovable property*. The term immovable is important for civil engineers. This section deals with unlawful construction, especially with articles 722-725, and explains the term "Unjust construction" and "Structural Encroachment" in the literature and law (Atlı, 2017; Erkan, 2014). In addition, the subject of “Building Mortgage” is regulated by articles 892-897 of the law (Turkish Civil Code, 2001).

Unjust Construction

Three different situations can be given as an example of the concept of unjust construction. The first and most common of these; is a type of building that is built on someone else's land with its own material. The second is the structures built on one's own land with someone

else's material. Finally, structures built on someone else's land with still someone else's material are referred to as *Unjust Construction*. There are many examples of lawsuits related to Unjust Construction, but the third type of these cases (someone else's land, and material) is an example that can be seen very rarely. The concept of Unjust Construction is misunderstood and misused generally. There are some factors that would be qualified a structure as an Unjust Construction (Savaşan, 2020). These;

- Privately owned land
- Land register
- Existence of a structure on this land
- The fact that this structure is a permanent structure
- Construction of the structure without relying on a real or personal right
- Material or land belonging to different people

The concept of Unjust Construction; should not be confused with concepts such as structural encroachment, superficies rights, servitude, construction contracts in return for land share, and usufruct rights. Civil engineers should also have sufficient and necessary legal knowledge on these issues.

Structural Encroachment

According to Turkish Civil Code article 725: The part of a building that is moved to someone else's land, becomes an integral part of the immovable belonging to him if the owner of the building has an easement right on the land. *"The part that is carried over to someone else's land"* from the *Structural Encroachment* definition is important. This is the main difference between unjust construction and structural encroachment (Turkish Civil Code, 2001; Öztürk, 2021).

Building Mortgage

One of the other issues regulated by the Civil Code is the subject of *building mortgages*. It is regulated between articles 892-897 of the Law. It is stated that the receivables of the craftsmen and contractors involved in the project, arising from the activities they carry out on a *certain immovable,* by expending labor or materials, can be secured with a building mortgage (Turkish Civil Code, 2001: 893). It is clear that there are problems in the collection of receivables for engineers or laborers due to construction costs and other factors in the construction sector.

According to the Civil Code (892-897) and legal doctrines, the persons who only carry out intellectual work, architects and engineers, and who have given only materials to the construction and oversee the construction do not have legal mortgage rights. However, it is important whether the contract between the owner and these persons is a *contract of mandate* or a *contract of work*. There are also opinions that a person who has a contract of work with the contractor on the subject of building mortgages is the right to mortgage the building in case. Examining the relevant provisions in detail may enable engineers to take precautionary measures against possible disputes in this regard (Akcan, 2018).

Zoning Law

The Zoning Law is a branch of law in which the suitability of construction works is regulated. Therefore, it is one of the *most important legal fields* for civil engineers and other stakeholders. This law was arranged in order to ensure its formation in accordance with the plan, science, health and environmental conditions of settlements and structures in these settlements (Zoning Law, 1985: 1). With the term *"plan"*, the necessity of a legal framework is understood in the planning process and its stages. The benefit of the public and society should not be ignored by the civil engineers who will take part and be responsible in the planning (Kalabalık, 2015).

The term "engineer" is used more frequently in the Zoning Law compared to other laws. The relevant articles, including the direct responsibilities of civil engineers, are regulated in Zoning Law and civil engineers should know the provisions of this law. As a matter of fact, many buildings can be incomplete due to the violation of the Zoning Law, and the concerned and rights holders can have problems. Because the purpose of this law is to ensure compliance with the plan, science, health, and environmental conditions of all public and private structures within the municipality and the adjacent. All article of this law, including the definitions section is important for civil engineers. The following are some of the concepts that are regulated in detail in the law and should be mentioned at least in name by this paper.

- easements,
- parceling and joining,
- partition and registration,
- expropriation,
- building permit,
- permit conditions,
- authorship, technical responsibility, site supervisor, building contracting and records,
- occupancy permit.

These concepts are that civil engineers should know in order not to incur any loss of rights, and lawlessness and not to be affected by natural damages. It should also be known that the laws only are not sufficient. The Planned Areas and Unplanned Areas Zoning Regulations prepared to depend on this law, should be examined together with Zoning Law.

Construction Inspection Law for Civil Engineers

The responsibilities of civil engineers are regulated by laws not only personally but also in relation to the organizations they are affiliated with. There are some legal responsibilities of Building Inspection Institutions which is one of the organizations that some civil engineers work affiliated. For this reason, also civil engineers which work at Building Inspection Institutions have legal responsibilities. Regarding provisions are regulated by Law No. 4708 on Construction Inspection Law. Purpose, scope, and definitions are specified in Article 1 of this law. The purpose of the law is to regulate the procedures and principles regarding "construction of quality buildings in accordance with the zoning plan, science, art and health rules and standards in order to ensure the safety of life and property" and to ensure its supervision (Construction Inspection Law, 2001: 1).

Article 1, also explains some definitions like the owner of the building, construction period, construction area, load-bearing system, *structural damage*, construction inspection institute, building contractor, project owner, the architect, and controller engineer terms. In the next

articles of law, the construction inspection organization and its duties, also responsibilities are explained.

Structural damage is a concept that should be taken into account from the above definitions. Because civil engineers can be held responsible in case of structural damage in accordance with the principle of faulty liability. In order for the fault liability of the building inspection organizations and the engineers or architects in this organization to arise, the damage to the building must prevent the use of the building or cause a loss of value in the building. Who the responsible persons are and in which cases the responsibility will be imposed are specified in the law (Construction Inspection Law, 2001: 3)

However, in order to be able to talk about liability, the *relation of causality* is a legal requirement. What is meant by the appropriate *relation of causality*; It is the cause-effect relationship between the damage that occurs and the event or behavior to which the liability is connected. So, two situations are necessary. The first is the structural damage, and the second is the relation of causality between the damage and the individual responsible (Okan, 2018). Indeed, as stated; also the technical responsibility for the inspection of buildings that are not subject to the provisions of this Law is assumed by the architects and engineers (Construction Inspection Law, 2001: 26-28). If the articles of the law are not taken into account, there are multiple provisions that impose an administrative fine as a sanction on those concerned. So these provisions should also be well known by civil engineers.

Occupational Health and Safety Law for Civil Engineers

Occupational safety specialists have more responsibilities within the scope of the Occupational Health and Safety Law and the obligations regulated by this law. However, the main occupation of these occupational safety specialists is civil engineering generally. Although there is a legal obligation, there is no occupational safety specialist at some construction sites or it is shown as if there was. In such cases, a possible occupational accident is the responsibility of the occupational safety specialist, the site supervisor, and other technical staff and engineers. In fact, the Regulation on Construction Site Managers imposes legal responsibility on contractors and site chiefs in terms of occupational health and safety. Regulation; It contains some explanations regarding the obligations of the construction site supervisor and occupational health and safety.

Civil engineers, whether they are occupational safety specialists or not, are required to have sufficient knowledge of the Occupational Health and Safety Law as part of their responsibility. However, matters related to the provisions of affiliate and the fault of third parties could be seen in occupational health cases. In particular, the care and attention of engineers, tasked with implementing a construction plan are taken into account by Turkish laws. For example, the fact that a construction plan has passed the approval of the administrative authorities *does not eliminate the possible fault of the civil engineer* (Erem & Toroslu, 1994). In occupational health and safety cases, the terms *"negligence", "intention"* and *"gross fault"* are important depending on the way the incident occurred.

Labor Code for Civil Engineers

Labor Code regulates the rights and responsibilities of workers employed on the basis of an employment contract with employers regarding the working conditions and working environment (Turkish Labor Code, 2003). However, whether civil engineers are within the

scope of the Labor Law *depends on the contract terms and working conditions*. Some civil engineers are considered within the scope of the Labor Law, and some are not within the scope of the Labor Law. For example, civil engineers working with a contract of mandate or a contract of work are evaluated according to the Code of Obligations.

In order for a civil engineer to be covered by the Labor Law, the engineer must work for an employer and the contract concluded between them must include the elements of the employment contract. These elements are *works and services debt*, *wage*, and *dependency*. With this contract, *both parties are under the burden of debt*. A continuing relationship is established and *not a contract of instantaneous performance*. It is a contract governed by private law (Sümer, 2019). There are certain conditions for a Civil Engineer included in this scope to benefit from employment security provisions in case of job loss or other negative events (Sümer, 2020). Even if engineers are entitled to benefit from these provisions, loss of rights may arise in cases when certain legal procedures are not followed. Mediator requirement, notice, complaint, objection, notification, etc. topics can be cited as examples of these legal procedures. In addition, it is seen that civil engineers have lost their rights due to reasons such as delays in some matters and ignoring the support of a lawyer. There are many lawsuits related to this issue. Within the scope of the subject, it may be insufficient for civil engineers even if to know the law, and it is useful to investigate sample cases and *Supreme Court decisions.*

Turkish Penal Code for Civil Engineers Working in the Public Sector

So far, important laws for civil engineers working in the private sector and what civil engineers should pay attention to have been emphasized. If in this section, it is aimed to raise awareness about articles 204-207, 235-236, 247-252, 257-262, and 279 of the Turkish Penal Code (TPC), which should be known to civil engineers working in the *public sector*. Within the scope of the Turkish Penal Code, every citizen, regardless of profession, is responsible for every article of the law. However, in law;

- Forgery or Falsification of official documents (TPC 204-207)
- Collusive tendering and the Offense of using fraud or trickery in the fulfilment of execution (TPC 235-236)
- Embezzlement, Bribery, Extortion, Neglect (TPC 247-252)
- Misfeasance in public office, Disclosure of secrets related to duty, Abandon or non-performance of public office… (TPC 257-262)
- Failure of a public official to report the crime (TPC 279)

these provisions, which are regulated under the headings, are the articles of law that civil engineers working in the public sector may encounter by using some privileges they will obtain due to their duties, in an *unlawful manner*. For example, one of these articles, item 257, is regulated under the name of *Misfeasance* in public office. With the offense of misconduct, the situations considered crimes are stated with expressions such as "by acting against the requirements of her duty", and "by neglecting or delaying in fulfilling the requirements of her duty". Misfeasance provisions do not apply to every unlawful act of civil engineers working in the public sector. The moral element of this crime is that it can be committed with *intent*. It should be known that the crime of misconduct cannot be committed with *negligence*, but it is committed with *intent* and the *perpetrator* must commit the crime *knowingly* and *intentionally*. This crime must have included "sufferer" and "unfair advantage" results (Tepe

et al., 2021). For this reason, civil engineers working in the public sector must act in accordance with the laws in the transactions to be made. It is possible to become a competent engineer if only on the condition of knowing and understanding the provisions of the law. Otherwise, if some of the actions are unlawful, difficult litigation processes may be encountered even if there is an *aggrievement situation* in accordance, with the provision "Not knowing the penal laws is not an excuse" (Turkish Penal Code, 2004: 4/1).

Other Laws and Ethical Principles Which Concerning Civil Engineers

It will not be enough for civil engineers to know only the laws explained in previous chapters. The provisions of the Public Procurement Law, the Law on Public Procurement Contracts, and the Property Ownership Law, especially the *Constitution*, should also be examined and known. Although not as much as a lawyer, *at least the professional provisions of laws* such as Civil Procedure, International Arbitration, and Turkish Commercial Code also should be known.



1	12. Ceza Dairesi	2021/5260	2021/8843	14.12.2021	
2	1. Hukuk Dairesi	2021/8380	2021/7412	01.12.2021	
3	1. Hukuk Dairesi	2021/8380	2021/7412	01.12.2021	
4	12. Ceza Dairesi	2018/1565	2021/8028	17.11.2021	
5	7. Ceza Dairesi	2021/5750	2021/14909	10.11.2021	
6	12. Ceza Dairesi	2021/5765	2021/7846	10.11.2021	
7	12. Ceza Dairesi	2018/1566	2021/7340	27.10.2021	
8	12. Ceza Dairesi	2020/31	2021/7166	21.10.2021	
9	12. Ceza Dairesi	2020/1132	2021/6384	29.09.2021	
10	3. Hukuk Dairesi	2020/6674	2021/9095	27.09.2021	
11	12. Ceza Dairesi	2021/3011	2021/6158	23.09.2021	
12	3. Hukuk Dairesi	2021/865	2021/8205	13.09.2021	
13	12. Ceza Dairesi	2020/10977	2021/5567	06.07.2021	
14	10. Hukuk Dairesi	2020/7174	2021/9173	29.06.2021	
15	19. Ceza Dairesi	2020/4366	2021/6709	16.06.2021	
16	3. Hukuk Dairesi	2020/5465	2021/6463	14.06.2021	
17	Ceza Genel Kurulu	2017/1184	2021/257	08.06.2021	
18	Hukuk Genel Kurulu	2017/1031	2021/710	08.06.2021	
19	Hukuk Genel Kurulu	2017/3016	2021/649	01.06.2021	
20	5. Ceza Dairesi	2021/590	2021/2559	01.06.2021	
21	Ceza Genel Kurulu	2019/567	2021/236	01.06.2021	

Figure 1: Supreme Court decisions in which civil engineers are directly a party to the case.

In fact, from a broader perspective, the law is not only a body of Codes with a social aspect but also a necessary tool for the uninterrupted and healthy execution of construction works. With this awareness, long and tiring litigation processes will be encountered less frequently. As a matter of fact, when the cases that directly concern civil engineers are examined, it is seen that these cases are much more than they should A search was made of the Supreme Court decisions, in which civil engineers were directly involved as *defendants or plaintiffs*. The cases examined are only those that have been submitted to the Court of Cassation. Civil engineers who examine cases as experts were not included in the filter. Despite these

limitations, it was seen that there were 21 Supreme Court decisions (Figure 1) in the last six months of 2021 (Supreme Court, 2022).

It should be noted that the Court of Cassation is the supreme court in charge of examining only appeals in the field of judicial jurisdiction. In this case, it should not be forgotten that there are also cases that have not devolved to the Court of Cassation, which resulted in first-instance court decisions or that were concluded in regional courts of appeal. In addition, there are many problems that are resolved through mediation or reconciliation or that are not applied to the legal authorities despite the loss of rights.

Considering all these *constraints*, it should be said that for Figure 1 there is only a small portion of cases that directly concern civil engineers. In these lawsuits, not only the victimization of civil engineers but also the victimization of other stakeholders caused by engineers can be prevented by legal knowledge and the application of this knowledge. As a matter of fact, the rights arising from the law are recognized not only for the protection of the person concerned but also for the protection of other persons. Acting in accordance with *good faith* in the use of these rights is a *requirement of professional ethics and law* (Demirboğa, 2018). This is not just an issue that lawyers focus on. The principles of rights, law, and ethics, which have absolute relevance to all kinds of problems, have been the subject of many studies. In engineering education, it is stated that *not only computational but also behavioral awareness* should be emphasized (Çoşkun, 2007). As a matter of fact, in another study on the subject, it was emphasized that in order for civil engineers to comply with ethical principles, professional ethics principles and codes and legal legislation should be created by taking into account the suggestions of all stakeholders. (Genç et al., 2016). Ethical principles do not have the power of *sanction* like laws. However, it should not be forgotten that all legal rules arise from human behavior and are subsequently accepted as written rules. So, due care should be given to both ethical principles and laws in professional life.

Discussion, Conclusion and Recommendations

Civil engineering is a profession focused on *people, the environment, and technology*. So, civil engineers, who are the practitioners of this profession, have rights and responsibilities in multiple fields. These rights and responsibilities naturally require civil engineers to interact with other stakeholders of the profession in the exercise of rights and fulfillment of responsibilities. The outcomes of these interactions can be positive or negative. Correct planning, implementation, awareness of rights and responsibilities, and healthy communication ensure that this interactions and works are positive and take place in the expected time. However, in other cases; If the laws and regulations are not followed, some problems are caused by the supervisory authorities or by civil engineers. These problems are often the subject of lawsuits and the progress of the works stops. The most common lawsuits are about the *negligence of duty, work accident, or unjust gain* in the construction industry. Financial disputes or the lack of work done as required cause disputes. This is back-breaking both *materially and morally.*

In this paper, some laws and legal provisions that should be known by other stakeholders of the sector, *especially civil engineers*, were mentioned in order to prevent or reduce the negativities in the sector. As it can be understood from the details of the provisions of the law and the number of cases, it has been seen that *it is not a choice but a necessity* for all civil engineers to have legal knowledge. In this context, some studies should be carried out in order

to acquire legal knowledge for civil engineers. These studies can be done with individual demands or courses, as well as by including *compulsory law courses* within the scope of the profession in the *civil engineering departments of universities*. In the civil engineering departments of universities, the Labor Law course is often given as an elective course in undergraduate or graduate education. However, it is recommended that this scope should be *expanded*, made *compulsory*, and not stay as just Labor Law.

Knowing and *applying* the laws directly related to the profession, only some of which are stated in this paper, will provide material and moral gains both in the fulfillment of the works and in the judicial processes. It is a *necessity and also a responsibility* for civil engineers to know their rights and to defend these rights in order to resolve disputes faster during or before judicial processes.

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A Grouping Study of Domain Knowledge Representations in Building Regulations

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Abstract

Building regulations are legal documents written in human language that are interpreted and enforced by people and are often controlled by local governments in the construction industry. Due to factors such as the uncertainty of the expressions in the building regulation clauses, the flexibility of application of the building regulation clauses, and the lack of definitions in the regulation clauses, these documents lack a definite and unambiguous language. In order to avoid this complexity, computerized building regulation representation studies are carried out by experts in the construction industry. With the efforts of professionals, building regulations are transformed into many different, official languages and integrated into existing systems. All kinds of information and data are selected and applied at various levels of accuracy by reasoning. Many works have been carried out for the domain knowledge representations of the building regulations for many years.

The languages and methods in the domain knowledge representations of the building regulations were investigated in this study. These were grouped under the headings: Human Language, Markup Languages, Formal Languages, Semantic Web Languages, Artificial Intelligence Methods, and Hybrid Methods. The languages and methods implemented in the studies were described in great detail.

Keywords: *domain knowledge representations, building regulations, languages and methods, grouping, construction industry.*

Introduction

Building regulations are legal documents written in human language that are interpreted and enforced by people in the construction industry, which is frequently controlled by local governments (Fenves et al., 1987; Sowa, 2006). These documents lack a precise and unambiguous language due to issues such as the ambiguity of the terms in the building regulation clauses, the flexibility of application of the building regulation clauses, and the lack of definitions in the regulation clauses (Lau & Law, 2004; Nawari, 2012b). Experts in the construction industry perform computerized building regulation representation studies to prevent this complexity (Dym et al., 1988; Kumar, 1989; Rasdorf & Wang, 1988; Rosenman & Gero, 1985). Building regulations are being transformed into a variety of official languages and integrated into existing systems thanks to the efforts of experts. All kinds of information and data are selected and applied at various levels of accuracy by reasoning. For many years,

several efforts have been completed for the domain knowledge representations of building regulations (Berners-Lee et al., 2008; Biagioli et al., 2004; Boer et al., 2008; Boley, 2006; Brickley et al., 2014; Brown et al., 1992; Cyganiak, 2005; Dym et al., 1988; Fenves, 1966; Fenves et al., 1969, 1987; Garrett Jr & Hakim, 1992; Gutierrez et al., 2005; Hakim & Garrett, 1993; Hjelseth & Nisbet, 2010a, 2011; Horrocks et al., 2004; Kiliccote et al., 1994; Kiliccote & Garrett Jr, 1998; Kumar, 1989; Lau & Law, 2004; Lee, 2011; Leibniz, 1923; Lupo et al., 2007; Mazairac & Beetz, 2013; Melzner et al., 2013b; Minsky & Papert, 1970; Nawari, 2012b, 2012a, 2012c; Nawari & Alsaffar, 2015; Nyman et al., 1973; Omari & Roy, 1993; Palmirani et al., 2011; Pauwels et al., 2011; Rasdorf & Wang, 1988; Rosenblatt, 1958; Rosenman & Gero, 1985; Rumelhart et al., 1986; Sartor et al., 2011; Sowa, 2006; Walton, 2007; Yabuki & Law, 1993; Yurchyshyna & Zarli, 2009; Zhang & El-Gohary, 2016; Zhang & Issa, 2011).

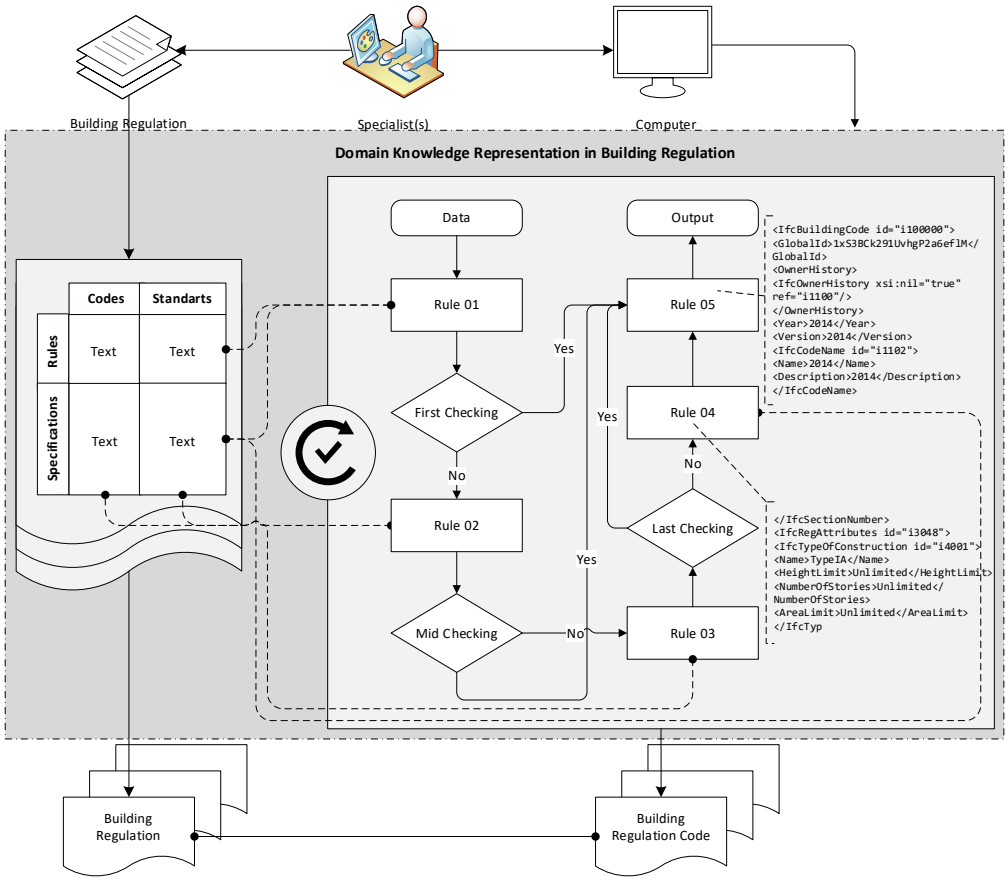


Figure 1: The concept diagram of the domain knowledge representations in building regulations.

The first stage in the automated code compliance checking (ACCC) process begins with the domain knowledge representations of building regulations. Building regulations need to be computably represented in the domain knowledge representations. First, an interpretation process is applied to transform the semantic structure of each building regulation into building regulation rules utilizing specific languages. Then, the ACCC application is begun with the BIM model data that provides data input between the building regulation rules and the software by integrating the building regulations with a particular software or programming language. Therefore, it is important in the ACCC process to represent building regulations in a computer readable format (Aydın & Yaman, 2020; Kiliccote & Garrett Jr, 1998; Minsky & Papert, 1970; Zhang & Issa, 2011).

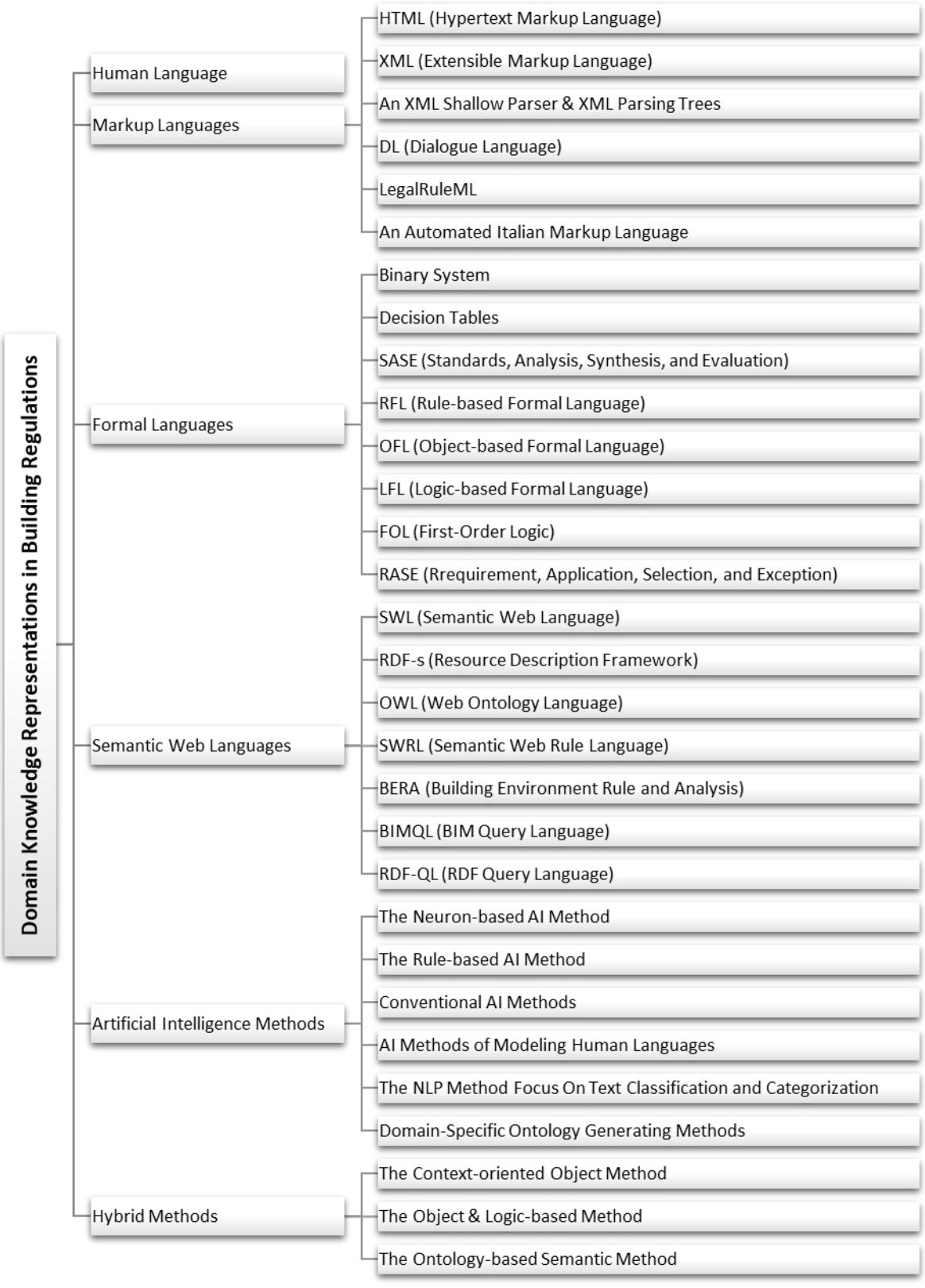


Figure 2: The list of domain knowledge representations in building regulations.

The concept diagram of the domain knowledge representations in building regulations is shown in Figure 1. A building regulation is required for the computable building regulation code representation. The content of the building regulations is parsed into its specifications

through domain knowledge representation languages. Each clause of the building regulation (or only the clauses containing control conditions) is classified within itself before the building regulation rules. The ACCC systems are used to control these rules, which are created in accordance with the relevant building regulations. If the conditions of each rule are met in the ACCC system, the following rule is checked. If not, the rule is re-checked (Berners-Lee et al., 2008; Brickley et al., 2014; Fenves, 1966; Fenves et al., 1969; Omari & Roy, 1993; Yabuki & Law, 1993; Yurchyshyna & Zarli, 2009).

Domain Knowledge Representations in Building Regulations

Figure 2 shows the list of domain knowledge representations in building regulations. The languages and the methods used in domain knowledge representations are grouped under common headings, and detailed information is given under the related headings. These are:

- Human Language,
- Markup Languages,
- Formal Languages,
- Semantic Web Languages,
- Artificial Intelligence Methods,
- Hybrid Methods.

Human Language

A Human Language refers to a language that a child can acquire cognitively in the process of self-expression. A seven-year-old boy is as proficient in human language as his parents in speaking and understanding. When an adult expresses his thoughts, he speaks human language according to the respiratory rate and the limitations of short-term memory. This demonstrates the numerous extensibilities of vocabulary and expressions. Many words in a human language are said to have open-ended meanings, and the ambiguity is unavoidable. The main features of the human language shown in Figure 3 are (Sowa, 2006):

- Phonology shows how words are related to sounds.
- Morphology shows how words are formed from more primitive morphemes.
- Syntax shows how words are ordered to form correct sentences.
- Semantics shows the meaning of words.
- Pragmatics shows how sentences are used in different situations.
- Discourse information shows how it determines the meaning of a sentence.
- Realm knowledge includes perceptions, feelings, beliefs, and local knowledge about the topics in a speech.

Languages have evolved and diversified over time. This situation has made the grammar of each language complex. Language can produce an infinite set of sentences to express any thought. Therefore, it is often difficult to talk about the single meaning of a sentence in human language. Likewise, it is often difficult for a person to understand every text or dialogue in their own language. Therefore, it is also unrealistic to expect a computer to easily understand human language. Difficulties in dealing with human languages come from the way the human brain works or the way languages express information. A significant part of the difficulty arises from the incompatibility of the different words used in the language. Throughout

history, many researchers have focused on this issue and realized that the difficulties experienced are an important component of human languages. They emphasized in their studies that the uncertainties brought about by the difficulties are not a flaw in natural language. They brought up the question of what kind of connection should be established between natural languages and formal languages created by humans.

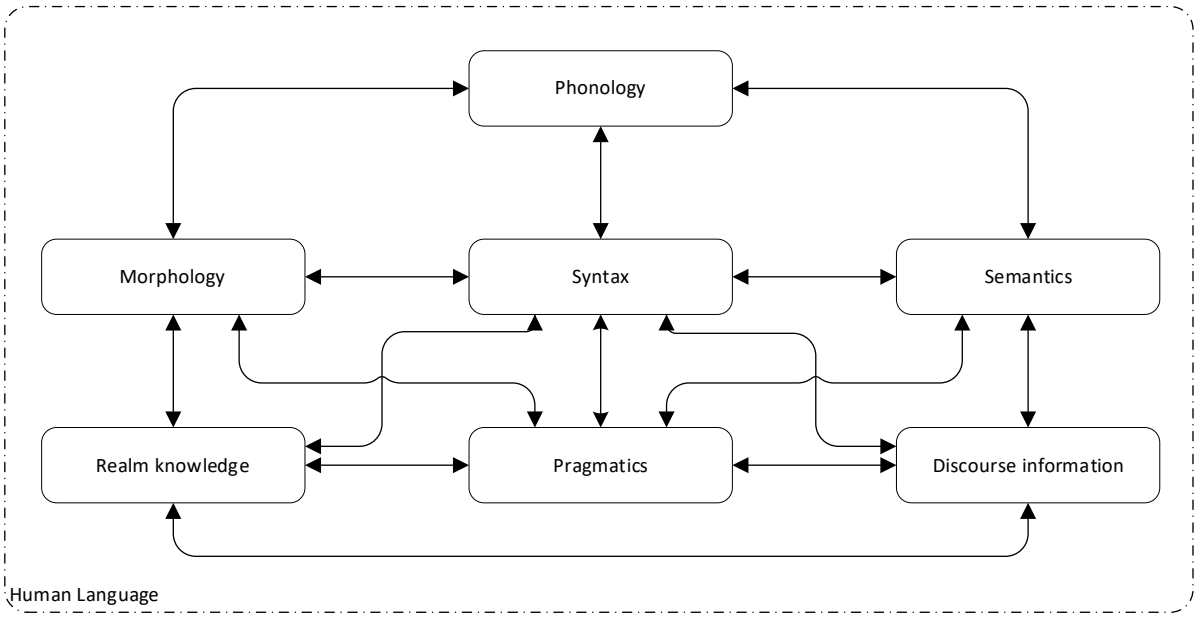


Figure 3: The main features of the human language (Sowa, 2006).

Markup Languages

The researchers used Markup Languages to illustrate and formalize building codes and regulations in their method. Standard markup languages (HTML, XML) are preferred in some studies, while new approaches that refer to standard markup languages have been proposed in others.

HTML (Hypertext Markup Language)

Today, most building regulations and standard documents are available in HTML (Hypertext Markup Language) format in addition to hard copy. HTML is the standard text markup language used to create web pages. HTML cannot be defined as a programming language. However, programs that can run through programs that can interpret this language can be coded.

XML (Extensible Markup Language)

XML (Extensible Markup Language) is a markup language for creating documents that can be easily read by both humans and computing systems. It is a standard defined by the W3C. Besides storing data, it also acts as an intermediate format for data exchange between different systems with this feature. An integrated format into XML was proposed by Lau and Law in 2004 to represent building regulations and codes (Lau & Law, 2004). The format shown in Figure 4 has two features: a markup language for building regulation resources, and a Web standard for digital processing capability.

An XML Shallow Parser & XML Parsing Trees

A combined XML format with XML's ability to handle semi-structured data was proposed by Lau and Law in 2004 to represent building codes (Lau & Law, 2004). An example of the XML representation of the building code is shown in Figure 4. In this study, an XML Shallow Parser was created as a first step in combining different building code rule formats into XML to partially automate the translation process. Semi-structured information from regulations is displayed in an XML schema; for other unstructured information, a feature extractor mechanism is used.

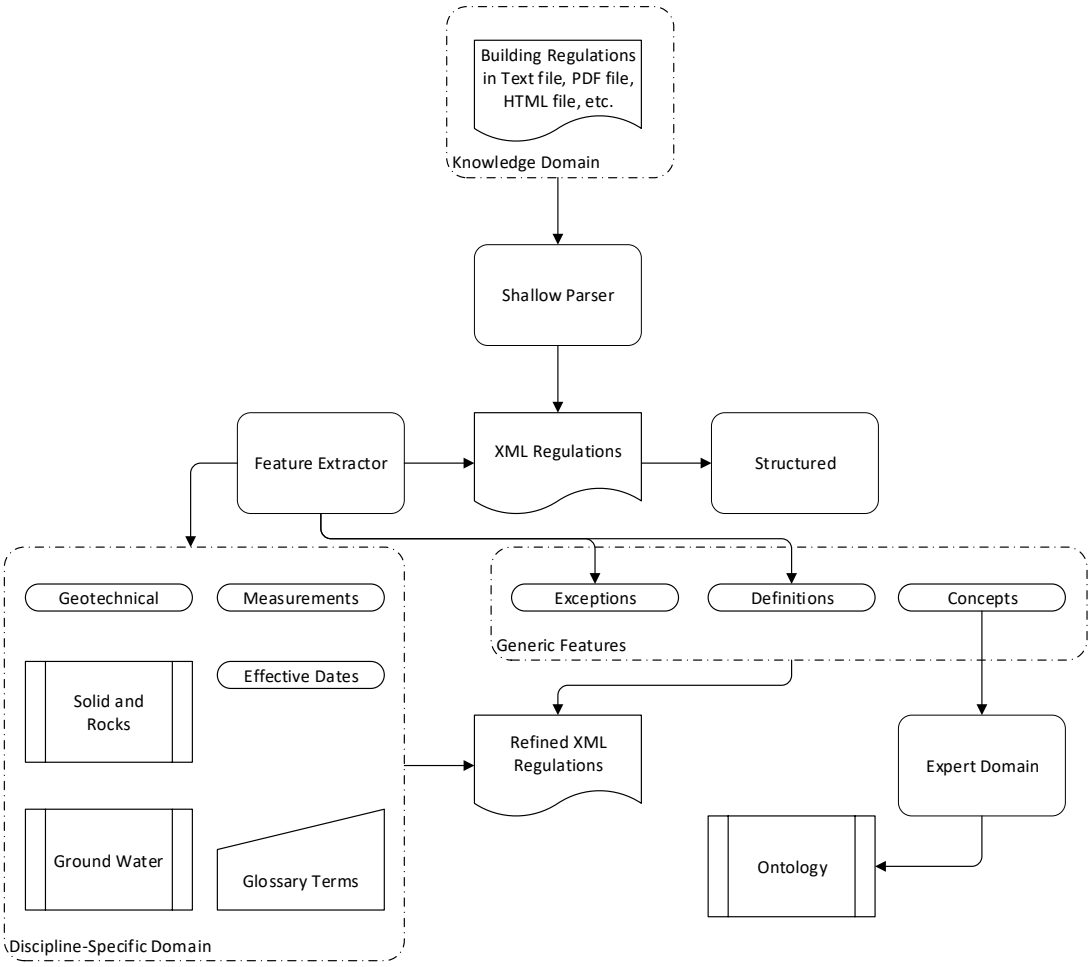


Figure 4: XML representation of a building code (Lau & Law, 2004).

In the study shown in Figure 4, XML Parsing Trees, which mark the contents of building codes with reference tagging, were developed by using the semantic technique, and an example is shown in Figure 5 (Lau & Law, 2004). The hierarchy of XML reference tags in the XML Parsing Trees structure first begins with the regulationID, which marks the building code. Then, elementID is used for the information from the section to the article of the relevant building regulation. Finally, the article is marked with the ID and the text reference tag. An example showing the hierarchy of XML reference tags is seen in Figure 5. In this example, XML Parsing Trees provide users with an easier understanding of building codes through the reference tag of properly extracted building code information.

```
<regulation id="adaag" name="ADA Accessibility Guidelines" type="Federal"> ...
        <regElementid="adaag.4" name="Accessible Elements and Spaces..."> ...
                <regElementid="adaag.4.7" name="Curb Ramps"> ...
                        <regElementid="adaag.4.7.4" name="Surface">
                                <regText> Surfaces of curb ramps shall comply with 4.5. </regText>
                                <referenceid="adaag.4.5" num="1" />
                        </regElement> ...
                </regElement> ...
        </regElement> ...
</regulation>
```

Figure 5: An example of XML parsing trees (Lau & Law, 2004).

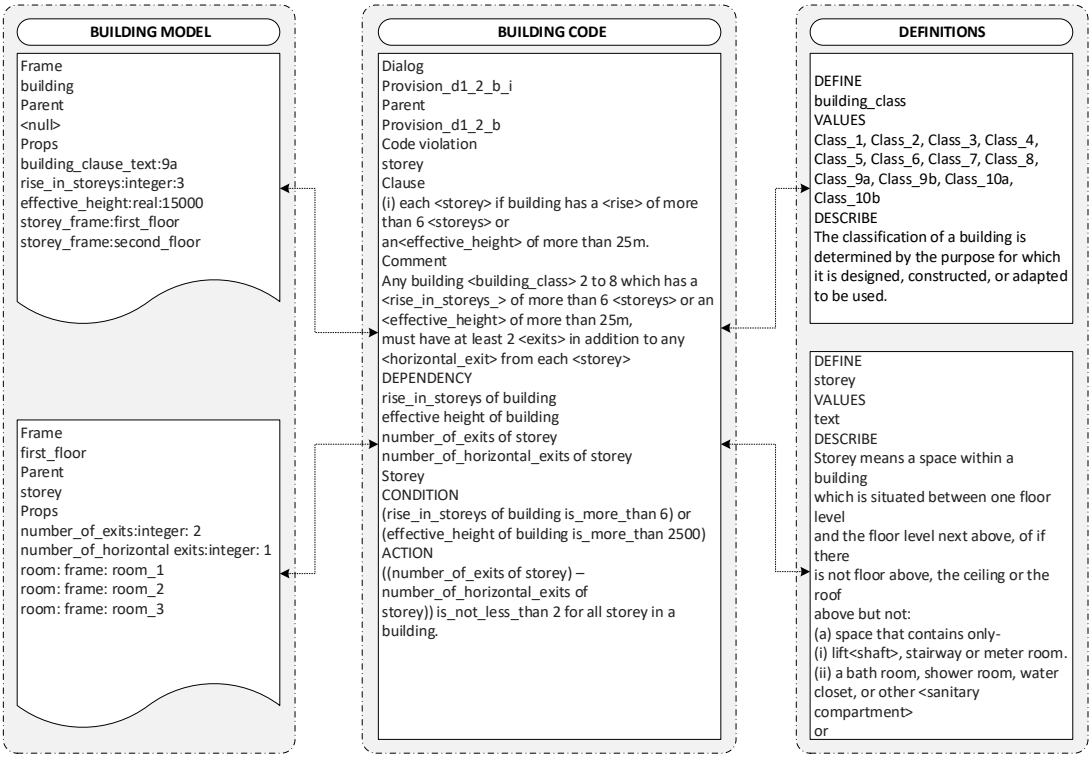


Figure 6: An example diagram of a building code created using DL (Omari & Roy, 1993).

DL (Dialogue Language)

DL (Dialogue Language), which was one of the first studies using markup language for domain knowledge representation of building regulations, was proposed by Omari and Roy in 1993 (Omari & Roy, 1993). DL was developed to interpret the Australian Life Safety Regulations in an expert system. It is used to represent the interactions between users and expert systems as well as the provisions of the regulation. DL provides a framework for the hierarchical organization of building codes, consisting of eight basic items. These items are Dialog ID, Parent ID, Clause, Condition, Code Violation, Action, Comment, and Dependency. DL provides a simple schema structure that allows designers to manage

hierarchical building codes and interactions with building models to create meaningful reports. An example diagram of a building code created using DL is shown in Figure 6.

LegalRuleML

In 2011, the XML-based LegalRuleML standard was proposed by Palmirani et al. for defining and displaying building codes and regulations with rules (Palmirani et al., 2011). The purpose of LegalRuleML is to represent the features of legal building codes and norms in a comprehensive, articulated, and meaningful markup language. For this reason, a customized XML markup language using Semantic Web technology is used within LegalRuleML, which meets the specifications of legal building codes and norms. The LegalRuleML representation of the text in Section 17, Clause 6, Sentence 602b of the US Code regarding copyright infringement is shown in Figure 7. (A) contains the textual expression of the text in the relevant clause, (B) includes the LegalRuleML expression of the relevant text. The LegalRuleML approach has been accepted by many researchers. Researchers have proposed using LegalRuleML modeling languages to express building codes with legal rules (Boer et al., 2008; Lupo et al., 2007; Palmirani et al., 2011; Sartor et al., 2011).

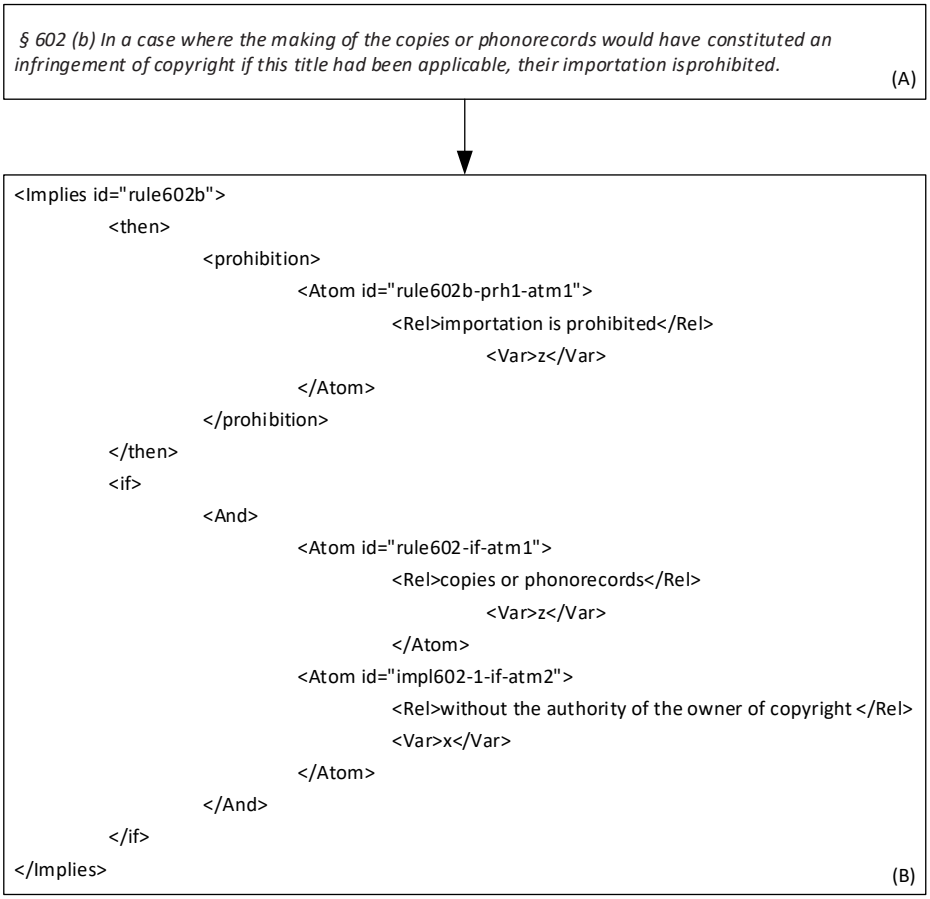


Figure 7: An example of LegalRuleML (Palmirani et al., 2011).

An Automated Italian Markup Language

In 2004, a study was conducted by Baigoli et al. on the automated marking of Italian building regulation texts in XML format (an automated Italian markup language) (Biagioli et al., 2004). In this study, in order to automatically convert the building codes to XML format, first

the content of the regulation is clustered, and then the text of the regulation is tagged. For clustering, the highlighted terms in the building regulation text are captured and transferred into a cluster. These terms are formalized as markup values in the XML representation of the regulation text.

Formal Languages

Many inconsistencies, errors, and abuses occur in the automated building code compliance checking process, which is done manually by humans. Many researchers use ACCC and BIM standardization to solve these problems. It supports the transition to machine-oriented automated processes for more consistent, accurate, and reliable building code compliance checking. The most effective solution to control of building codes is to implement Formal Languages shown in Figure 8, which are capable of creating computer-interpretable building codes.

Binary System

The first computable formal language was Leibniz's Binary System Habilitation Thesis, made by Leibniz in 1666 on automating Aristotle's assumptions (Leibniz, 1923). A sample study of the binary system used by Leibniz in the cover and content of his habilitation thesis is shown in Figure 9. This study was based on the most advanced logic and ontology systems. Reasoning rules based on four sentence order, which relate a subject in Aristotle's assumptions, were created (Nawari, 2012b). The computational probabilities of the four binary systems were analyzed to code these simulations. It is claimed that this system will eventually be utilized to compute logic rules for machine operations.

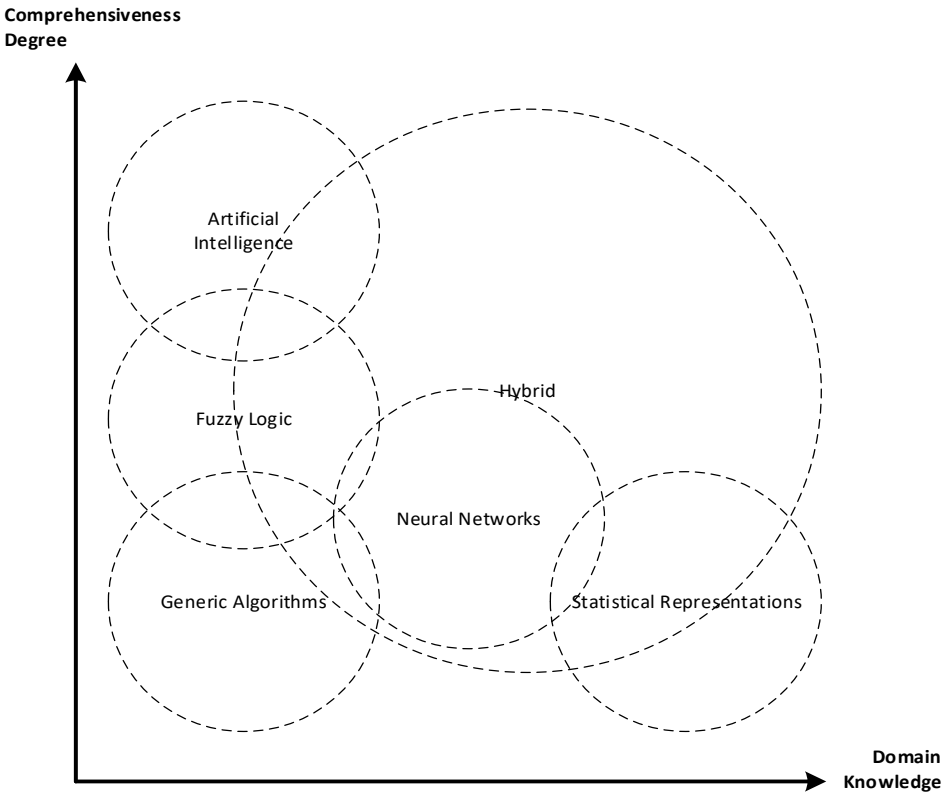


Figure 8: Application areas of formal languages (Nawari & Alsaffar, 2015).

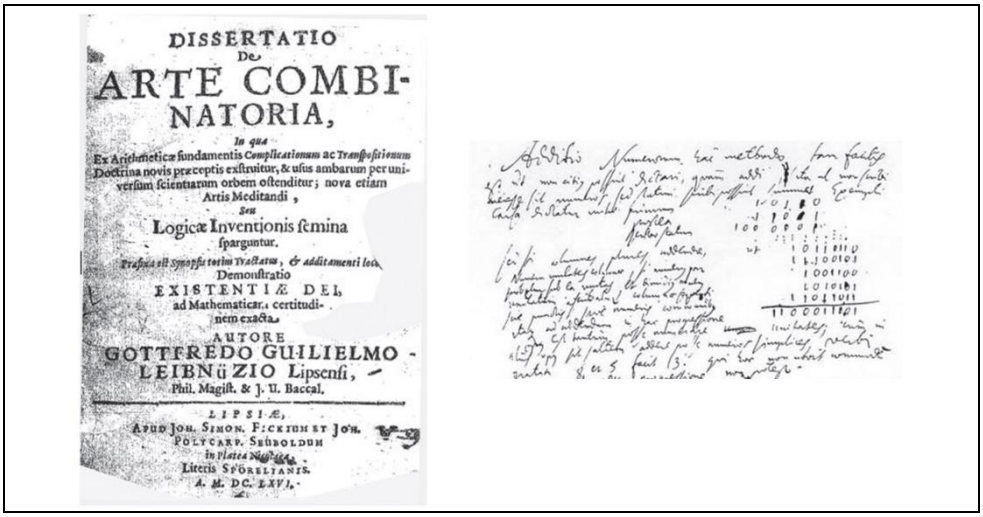


Figure 9: Leibniz's habilitation thesis (Leibniz, 1923).

	Rules Stub	Rules Entry		
Condition	Condition Stub			Condition Entry
	Related space of a door: Entrance	Y	N	N
	Related space of a door: Room	N	N	Y
	Related space of a door: Kitchen	Y	N	N
Action	Action Stub			Action Entry
	Minimum door width: 0.80 m		Y Y Y	Y
	Minimum door width: 0.90 m	Y Y Y	Y	N
	Minimum door width: 1.00 m	Y	N	N N N

Figure 10: An example of a decision table (Fenves, 1966).

Decision Tables

Decision Tables, proposed by Fenves in 1966, were one of the first attempts to represent building codes in a formal language (Fenves, 1966). In this study, building regulation clauses were presented in the form of a definite and clear decision table. Decision tables represent the clauses of the regulation as a set of conditions. The data contains a precise description of the building element information contained in the building regulation clause. The decision table, an example of which is shown in Figure 10, is divided into four parts. The condition stub in the upper left is a list of conditions that have an impact on the result. The condition entry at the top right lists the relevant combinations of conditions in the relevant columns. Each column specifies a clause rule. The lower left part of the decision table lists all the actions to be taken for the condition. The lower right part of the table shows the action entry to be

applied for the condition corresponding to the specified rule. The condition input can have only one of three possible values. Y indicates a true condition, N a false condition, and I an unimportant condition.

In 1969, Fenves, Gaylord, and Goel studied different combinations of decision tables (Fenves et al., 1969). In this study, different combinations of decision tables were created to which the building regulation rules and conditions could be applied. Fenves called this work a new if-then programming technique. He used the clauses of the AISC specification, which include the design criteria for building elements, to represent precisely and clearly with if-then. It has been a practical application in which interrelated decision tables are represented in the AISC specification sample.

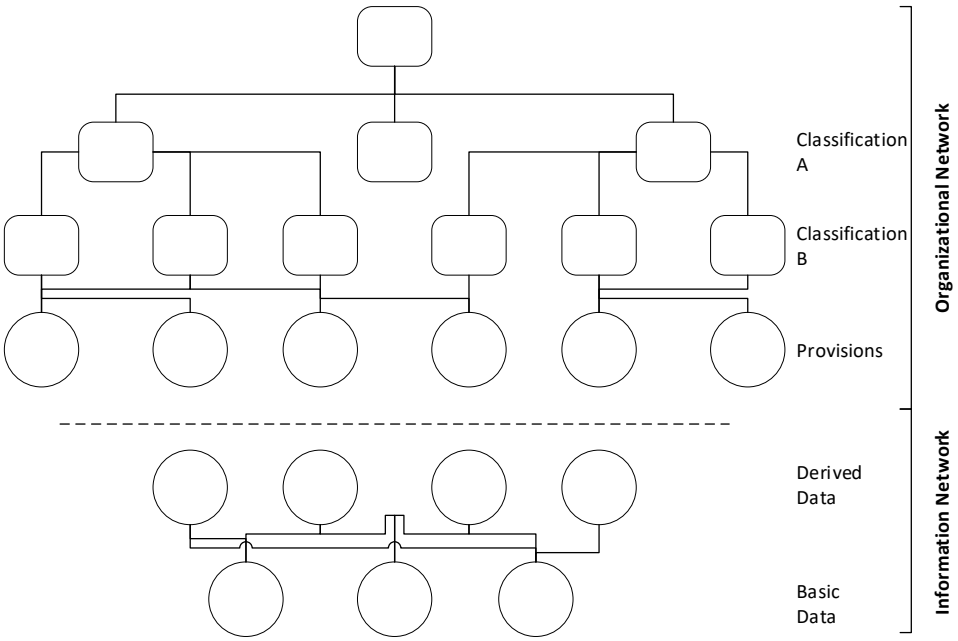


Figure 11: The concept of the SASE formal language (Fenves et al., 1987).

SASE (Standards, Analysis, Synthesis, and Evaluation)

Decision tables can precisely express possible combinations of conditions and actions of building regulation clauses in formal language. However, decision tables cannot respond to the general organization of the building code and the relations between the building regulation clauses. In 1987, the SASE (Standards, Analysis, Synthesis, and Evaluation) formal language was developed by Fenves et al. to represent building codes more broadly (Fenves et al., 1987). The concept of SASE was developed on the basis of the abstract model of the logical structure of building codes developed by Nyman et al. in 1973 (Nyman et al., 1973). Figure 11 shows the concept of the SASE formal language. SASE has four levels of layout to represent individual clauses, relationships between clauses, and building regulation layout. These are:

- The top level represents the outline and organization of building regulations.
- The intermediate level represents the compliance relationship between building regulation clauses.
- The detailed level represents building regulation clauses in the form of decision tables.
- The lowest level represents the basic data specified in building regulation clauses.

In SASE, data is divided into basic data and derived data. Each clause in the building regulations is represented by a decision table. The condition value of each decision table is limited to Y, N, and I. The information network is used to represent precedence relationships among building code data. The information network consists of networks, nodes, and branches. The SASE formal language enables the dynamic classification of building codes based on users' needs.

RFL (Rule-based Formal Language)

Many researchers have applied RFL (Rule-based Formal Language) in their studies to transform building regulations into rules (Dym et al., 1988; Kumar, 1989; Rasdorf & Wang, 1988; Rosenman & Gero, 1985). In the RFL, building regulation clauses are represented as a set of rules in the form of IF (condition) THEN (action) statements rather than decision tables. The IF statement defines the applicability conditions that the rule must meet. The THEN statement describes the actions to be taken. The RFL is considered to be more impressive than other building regulation representation approaches. The main advantage of this approach, which accepts the building regulations as a rule, is the ease of implementation in automated code compliance checking (ACCC) systems. However, as a result of rule-based modeling of building regulations, the problem of managing a large number of rules may arise. Some building regulation clauses may need to be represented by more than one rule. In addition, the user is expected to have expert programming or coding knowledge to create the IF and THEN relationships of the rules in the RFL. Although the rules representing the building regulation clauses are coded via computer, the relevant rules must also be revised due to the updates in the building code.

Figure 12 shows an example of an RFL rule created with the IF and THEN relationship for doors. In the example, three rules were created. Rule definitions are as follows (Hakim & Garrett, 1993):

- Rule 1: IF; If the door is an entrance door,
  THEN; The width of the door should be 1.00 meters.
- Rule 2: IF; If the door is a room or kitchen door,
  THEN; The width of the door should be 0.90 meters.
- Rule 3: IF; If the door is a cellar, wc or bathroom door,
  THEN; The width of the door should be 0.80 meters.

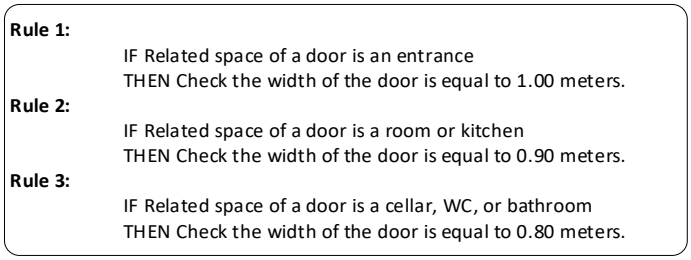


Figure 12: An example of the RFL rule created with IF and THEN relationship for doors (Hakim & Garrett, 1993).

OFL (Object-based Formal Language)

Building regulations contain many types of data in terms of scope. In particular, the building regulation clauses that include the definitions, properties, and conditions of different building elements lead to the definition of complex data types, which are numerous. To solve this problem, OFL (Object-based Formal Language) was proposed by Garrett and Hakim in 1992, which allows easy organization of building codes according to building elements. The OFL shown in Figure 13 consists of four basic object groups. These are (Garrett Jr & Hakim, 1992):

- The design object hierarchy represents subclass relationships between objects in the building code. Objects define design-specific properties and hierarchies such as shape, function, and material.
- The performance limitation hierarchy represents the boundaries of objects in the building code.
- The data item hierarchy represents the data types in all building codes.
- The data item instance network represents instances of the data types in a building code.

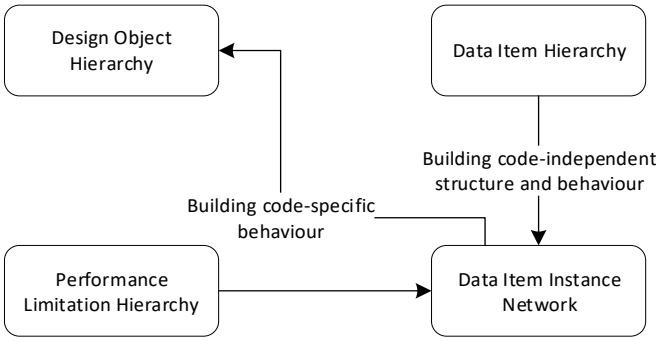


Figure 13: The four basic object groups of the OFL (Garrett Jr & Hakim, 1992).

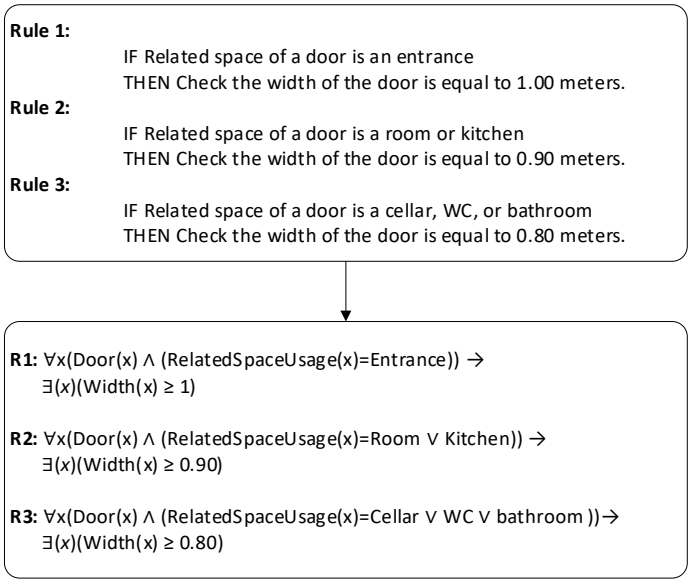


Figure 14: An example of the LFL rule created with predicate logic for doors (Hakim & Garrett, 1993).

LFL (Logic-based Formal Language)

LFL (Logic-based Formal Language), which is preferred in the CORENET e-PlanCheck system, is used to transform building regulations from human language to a more precise, clear, and understandable formal language (CORENET, 2018). During the logic-based interpretation procedure, there are assumptions and expectations that provide an understanding of what needs to be examined. In a study by Hakim and Garrett in 1993, it was emphasized that users should have knowledge of logic and logical predictions in order to understand the system of the LFL (Hakim & Garrett, 1993).

The LFL adopts predicate logic to represent building regulation clauses. Predicate logic provides a formal, well-known, and systematic knowledge representation language for the expressions in well-formed formulas. In Figure 12, the representation of the RFL rules created with the IF and THEN relationship for the doors in the predicate logic is shown in Figure 14. The applicability building element conditions of the rules denoted by the abbreviation R in this example are indicated to the left side of the arrow. The numerical conditions that the building element must meet are indicated on the right side of the arrow, and these are coded with this logic. The rule definitions are as follows (Hakim & Garrett, 1993):

- R1: $\forall x(\text{Door}(x) \wedge (\text{RelatedSpaceUsage}(x)=\text{Entrance}))\rightarrow\exists(x)(\text{Width}(x) \geq 1)$
- R2: $\forall x(\text{Door}(x) \wedge (\text{RelatedSpaceUsage}(x)=\text{Room} \vee \text{Kitchen}))\rightarrow\exists(x)(\text{Width}(x) \geq 0.90)$
- R3: $\forall x(\text{Door}(x) \wedge (\text{RelatedSpaceUsage}(x)=\text{Cellar} \vee \text{WC} \vee \text{bathroom}))\rightarrow \exists(x)(\text{Width}(x) \geq 0.80)$

FOL (First-Order Logic)

In 2012, FOL (First-Order Logic) was proposed by Nawari to code building regulation clauses via computer (Nawari, 2012a). The FOL transforms the written texts into a set of rules by extracting information from the building regulations. But this requires manual effort and technical knowledge. The FOL is built with terms, relations, and functions that describe the building objects. The FOL has two basic mechanisms: syntax and semantics (Nawari, 2012b). The syntax identifies terms with symbols. On the other hand, the semantics controls the meaning of these terms. The FLO is effectively used in building regulation clauses. The conditions are usually described in a sentence. This sentence is separated into its subject (S), predicate (P), and object (O). It is translated into the FLO, which is defined as S+P+O.

RASE (Rrequirement, Application, Selection, and Exception)

A RASE formal language has been proposed by Hjelseth and Nisbet, which directly translates building regulation requirements into building codes using four semantic markup operators (Hjelseth & Nisbet, 2010b, 2011). The RASE is considered a good starting point for generating updatable numerical representations of building codes. In this language, rule sentences are divided into sub-expressions. These sentences are defined in a common structure. In addition, the RASE provides an order that does not require programming knowledge for the creation and updating of building regulation representations (Macit & Günaydin, 2015). The RASE has the potential to be fully applied to building codes as a successful or unsuccessful output. However, it has limitations with cross-references in building regulation clauses and deep hierarchies between clause texts. In the RASE, the formal rules need to be defined manually by AEC experts. The RASE is designed on four operators. These are:

- R (Requirement),
- A (Application),
- S (Selection),
- E (Exception).

R, A, S, and E structures consist of topic, property, comparator and target value (Hjelseth & Nisbet, 2011). The topic and the property are derived from the objects described in the building regulation clause and the restricted properties of the objects. The comparator includes mathematical expressions such as greater, less, equal, not equal, and etc. The target value can consist of numerical or verbal values. Mathematical expressions are easy to apply if the target value contains a numeric value. If it contains a verbal value or object set, comparison expressions are used such as including, not including, excluding, and so on. The RASE formal rules are linked to the IFC sub-scheme. This sub-schema is initialized as an object that qualifies as a regulatory constraint. Figure 15 shows an example of a RASE formal rule of the ICC IECC 2006 moisture control regulation.

Code Clause Source	ICC IECC 2006 502.5 Moisture control
Rule Description	All {A/} framed {\A}{S/} walls, floors {\S}, and {S/} ceilings {\S} {E/} not ventilated {\E} to allow moisture to escape shall be provided with an {R/} approved vapor retarder {\R} having {R/} a permanence rating of 1 perm {\R} (5.7 × 10 –11 kg/Pa s m2) or less, when tested in accordance with the desiccant method using Procedure A of ASTM E 96. The vapor retarder shall be {R/} installed on the warm-in-winter side {\R} of the insulation. Exceptions: {E/} Buildings located in Climate Zones 1 through 3 {\E}. In constructions where {E/} moisture {\E} or its {E/} freezing {\E} will not damage the materials. Where there are other approved means to avoid {E/} condensation {\E} in unventilated framed wall, floor, roof, and ceiling cavities.

Figure 15: An example of a RASE formal rule of the ICC IECC 2006 moisture control regulation (Hjelseth & Nisbet, 2010b, 2011).

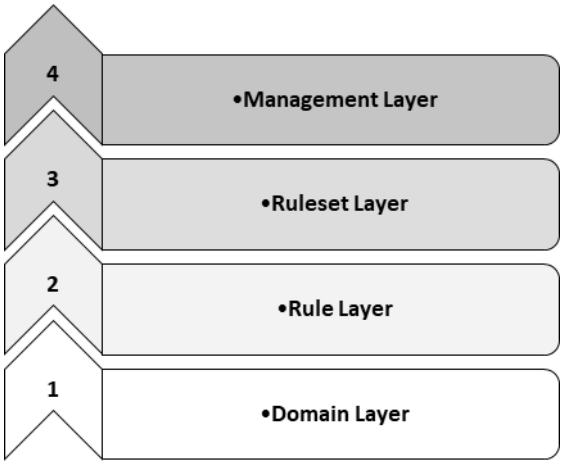


Figure 16: The four-layer structure of the RASE-based model (Macit İlal & Günaydın, 2017).

Another study focusing on the RASE was prepared by İlal and Günaydın in 2017. In this study, a new domain knowledge representation model was proposed in order to represent building regulations in a digital environment. A pilot study was conducted to evaluate the applicability of the RASE formal language in creating numerical representations of building

regulations. Within the scope of this pilot study, the rule statements of the Izmir Metropolitan Municipality Zoning Regulation regarding residential buildings were modeled as rule objects consisting of Requirement (R), Applicability (A), Selection (S), and Exception (E) operators. The RASE was taken as a reference in the new domain knowledge representation model. But it was rearranged with a four-layer modeling approach. A systematic structure consisting of four layers is shown for the new model in Figure 16. These are (Macit İlal & Günaydın, 2017):

- The domain layer defines the terms (concepts, objects, etc.) in the building regulation text.
- The rule layer represents the rule sentences in the building regulation text as rule objects.
- The ruleset layer creates rule sets by defining the relationships between rule objects modeled in the rule layer.
- The management layer represents the overall organization of the building regulation by classifying the rulesets.

Semantic Web Languages

Semantic Web means that web contents can be expressed not only in natural languages, but also in a way that can be understood, interpreted and used by related software. It is an evolving internet add-on that aims to enable this software to easily find, share, and consolidate information (Walton, 2007). Contextual information is added to existing unstructured information on the internet with the semantic web approach. This approach to web markup is a key concept underlying effective web coding, computing, universal usability, search engine visibility, and maximum screen visibility.

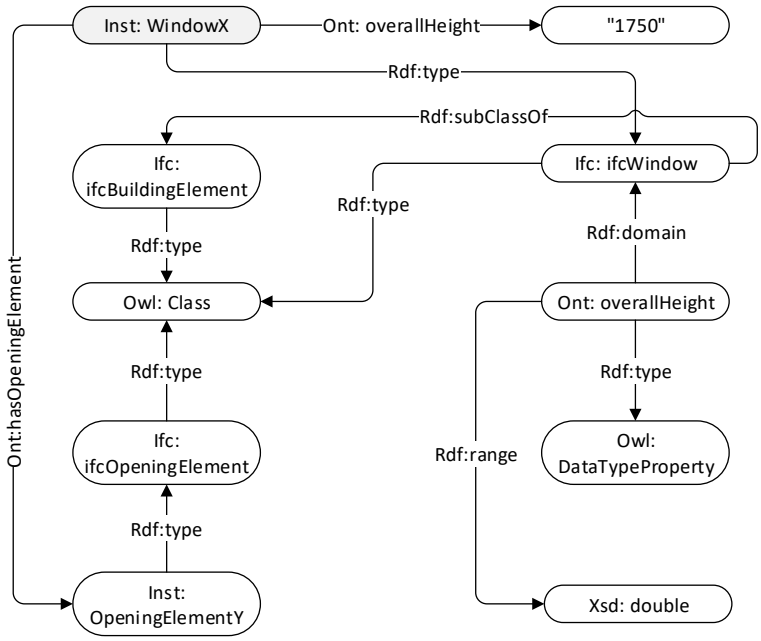


Figure 17: A semantic web language representation of the window building element (Pauwels et al., 2011).

SWL (Semantic Web Language)

One of the earliest studies applied to automated building code compliance checking of SWL (Semantic Web Language) was carried out by Pauwels et al. in 2011 (Pauwels et al., 2011). In this study, it was stated that IFC has limitations such as a limited range of explanation, difficulties in segmenting information, and the possibility of explaining the same information in different ways. This study aimed to provide compliance checking of BIM models according to the building acoustic regulation. The aim of the study was based on the SWL. The SWL defined concepts through a directed, labeled graphic.

In the graph shown in Figure 17, each node represents a concept (or an object), and each arrow represents the logical relationship between these two concepts. Two nodes and an arrow symbolize a sentence in this graph. A combination of logical sentences is created with two nodes and an arrow. Then, the logic of the combination is defined graphically. The SWL has the ability to define rules using logic-based rule language. However, a logic-based approach should be made possible for the implementation of the SWL in the rule-control environment (Pauwels et al., 2011).

RDF-s (Resource Description Framework)

The semantic web is based on XML's ability to define customized labeling schemes and RDF's (Resource Description Framework) flexible approach to representing data. The RDF is defined as a data model for objects and relationships between objects. It also has a graphical representation. An RDF chart is created using a set of logical operators containing objects and their relationships. These expressions, which contain a subject, a predicate, and an object, are called RDF triple. An example RDF triple is shown in Figure 18. Whether each concept described in an RDF chart is an object, subject, or predicate is identified via the URI.

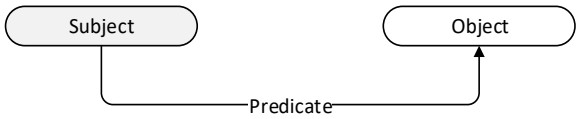


Figure 18: An example of an RDF triple.

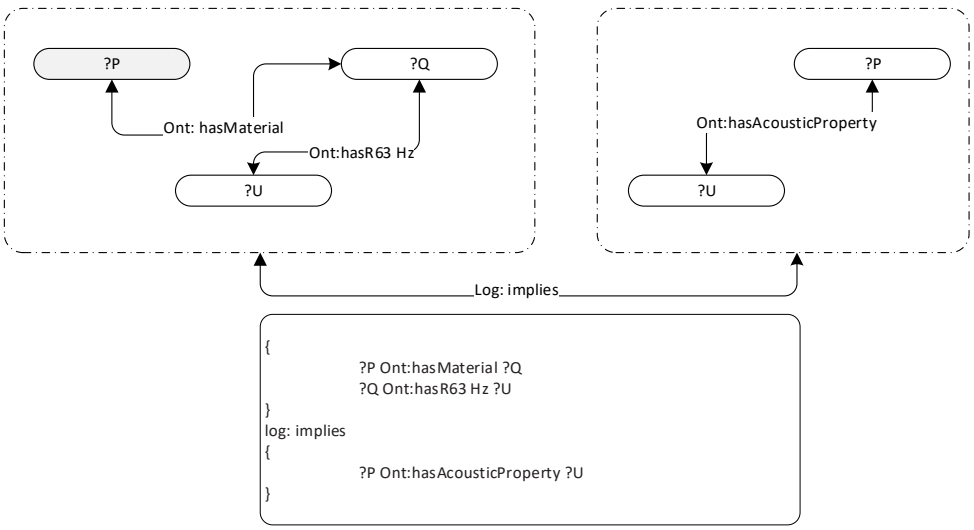


Figure 19: A representation of the N3- Logic rule (Pauwels et al., 2011).

A semantic structure developed using an ontology can be created in the SWL. The RDF-s (RDF words) are used to describe this ontology (Brickley et al., 2014). The RDF-s allows defining classes, subclasses, comments, and data types. For example, the ifc:IfcBuildingElement class, shown in the SWL in Figure 17, is a subclass of the ifc:IfcWindow class. In addition, Pauwels et al. used N3-Logic to define specific rules for the EN1235 Building Acoustic Performance Regulation (Pauwels et al., 2011). A rule in N3-Logic covers hypothetical formulas in general. The hypothetical formula uses brackets in the syntax to identify a subtitle; in other words, it represents a logical combination of expressions between brackets as shown in Figure 20 (Berners-Lee et al., 2008).

If the rule of an RDF triple expression indicates that one hypothetical formula (IF) is true, it means that the other hypothetical formula (THEN) is also true. Moreover, an N3-Logic rule is optimally abbreviated by using the URIs of the concepts. An example of the N3-Logic rule is shown in Figure 19 (Pauwels et al., 2011). This rule requires that a concept have the Ont:hasMaterial (IF) attribute. If it meets this condition, it is required to have the Ont:hasR63Hz (AND) attribute. After satisfying both conditions (THEN), it is understood that the Ont:hasAcousticProperty attribute of that concept has the same URI as the Ont:hasR63Hz attribute.

```
{
        ?BE     rdf:type EN12354:BoundaryElement.
        ?BE     EN12354:elementSurfaceArea ?a.
        ?BE     EN12354:partOfRoomBoundary ?RB.
        ?RB     rdf:type EN12354:RoomBoundary.
        ?RB     EN12354:facadeSurfaceArea ?atot.
        ?BE     EN12354:soundReductionIndex_4000Hz ?R_4000.
        ?a      math:notLess?Than 1.
        (?a ?atot) math:quotient ?value_i.
        (?R_4000 -10) math:quotient ?value_j.
        (10 ?value_j) math:exponentiation ?value_k.
        (?value_i ?value_k) math:product ?value_l
}
log:implies
{
        ?BE     EN12354:directSoundPowerRatio_4000Hz ?value_l
}
```

Figure 20: A rule representation of the EN12354-3:2000 ruleset (Berners-Lee et al., 2008).

inst:WindowX	rdf:type	ifc:IfcWindow.
ifc:IfcWindow	rdf:type	owl:Class.
ifc:IfcWindow r	dfs:subClassOf	ifc:IfcBuildingElement
ifc:IfcBuildingElement	rdf:type	owl:Class
ont:overallHeight	rdf:type	owl:DatatypeProperty
ont:overallHeight	rdfs:domain	ifc:IfcWindow.
ont:overallHeight	rdfs:range	xsd:double

Figure 21: An OWL ontology representation that specifies the IfcWindow class (Zhang & Issa, 2011).

OWL (Web Ontology Language)

Another important language associated with the semantic web approach is the OWL (Web Ontology Language), which enables applications to be used to process the content of information rather than simply presenting it to people (Zhang & Issa, 2011). The OWL facilitates further interpretability of web content by providing additional words along with the XML and the RDF. An ontology is represented as a set of concepts within a domain and a description of the relationships between concepts. It works like an encyclopedia for computers. It connects heterogeneous metadata information, explains all definitions, and lists all synonyms. Thus, it creates a global structure for the data on the web, allowing the data to be understood and shared by more than one application (Zhang & Issa, 2011).

The definitions, explanations, and abbreviations of the ifc properties of the window building element belonging to the ifc:IfcWindow class shown in the semantic web language in Figure 17 are shown in Figure 21. In the example of the OWL representation, the top class is defined with inst. A subclass of owl is created that depends on the top inst class. Ifc is associated with the ifcWindow property of the window, rdf is associated with the type of the window, and ont is associated with the properties of the window.

SWRL (Semantic Web Rule Language)

SWRL (Semantic Web Rule Language) has been defined as a language that combines the OWL and the RuleML (Rule Markup Language) recommended for the semantic web (Boley, 2006). The SWLR was proposed in 2004 by the Rule Markup Initiative, whose members are in industry and academia (Horrocks et al., 2004). The SWLR has a modular and a hierarchical layout for different rule types. The RuleML is an open and independent markup language developed for expressing web rules and performing rule transformations in XML. It cooperates with many software systems by enabling the exchange of rules on the web. The RuleM, shown in **Figure 22,** has a three-layer rule hierarchy. The first layer of the RuleML contains reaction rules. The second layer consists of integrity constraint rules and derivation rules. The third layer customizes the derivation rules according to the facts.

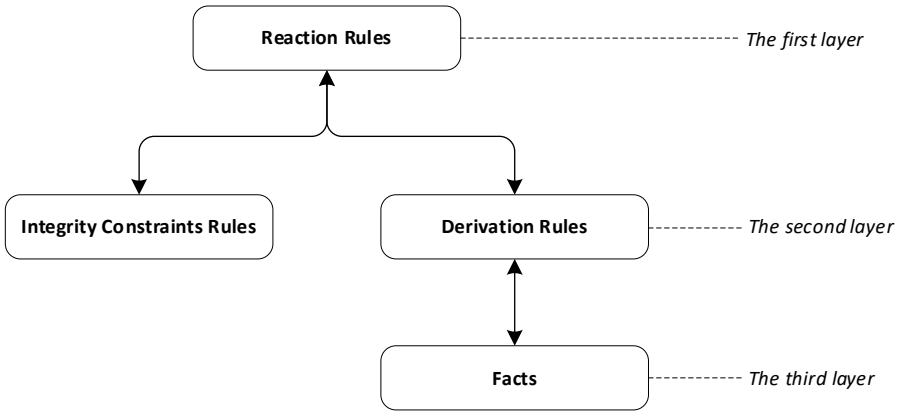


Figure 22: A three-layer rule hierarchy of the RuleML (Horrocks et al., 2004).

BERA (Building Environment Rule and Analysis)

With the expansion of the BIM domain, there has been a need for the development of domain-specific, customized semantic web languages to address the problems of building models in

the construction industry. In 2011, the domain-specific BERA (Building Environment Rule and Analysis) language was designed by J. K. Lee, and it was applied in building restoration works (Lee, 2011). The BERA handles BIM models to define and analyze rules at the design stage. The implementation of the BERA consists of three stages. These stages are defining rules, analyzing rules, and controlling rules.

The BERA allows ad-hoc connection of BIM models owned and operated by various stakeholders in a building project in the context of automated code compliance checking. It can be used as a starting point for the inclusion of software services that enable the conclusion of special operations such as performance calculations, quantity take-offs, spatial programming, energy analysis, and cost estimation. The target users of the BERA are BIM-based software developers, architects, designers, engineers, experts, managers, and students.

The BERA, the concept of which is shown in Figure 23, focuses on two main areas: building circulation and spatial programming. The BERA transforms BIM models into the BOM (BERA Object Model) with its own BERA tools to achieve both purposes. The BOM is a human-centered abstraction of computational building models. Users can easily access BIM data with the BOM. The BOM also has expandable potential. The objects presented in the BOM are not limited to building elements. The derived properties of building circulation, such as type, depth, metric distance, area, volume, walking distance, and number of spaces, are obtained with the BOM.

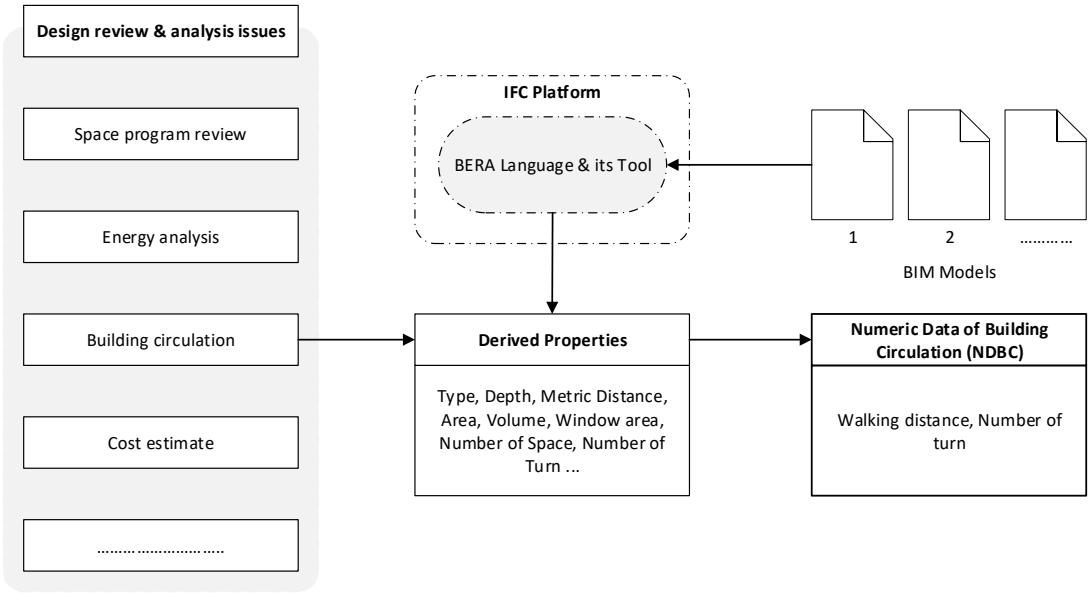


Figure 23: The concept of the BERA (Lee, 2011).

BIMQL (BIM Query Language)

BIMQL (BIM Query Language), a domain-specific, open BIM-based semantic query language for BIM models, was proposed by Mazairac and Beetz in 2013 (Mazairac & Beetz, 2013). The BIMQL is designed to select, update, and delete data stored in the IFC data models. Because the objects contained in the IFC data are often interconnected through a complex web of relationships, the BIMQL enables the IFC data models to simplify these interconnected accesses. The BIMQL is a prototype plugin for the open-source model server platform, bimserver.org.

The structure of the BIMQL consists of three parts. The first part provides an introduction to the problem of information extraction from complex models. It formulates requirements for a query language. In the second part, open problems are identified by reviewing studies at both general and domain-specific levels. In the third part, the query language is designed and applied to the examples. The Backus-Naur Form describing the syntax and grammar of the domain-specific query language BIMQL is shown in Figure 24. The language features of the implemented specification are currently limited to the "select" and "set" sections. For example, deleting a single window in the BIMQL can be accomplished by performing a simple query. The profiles and material properties of the window can also be obtained by query.

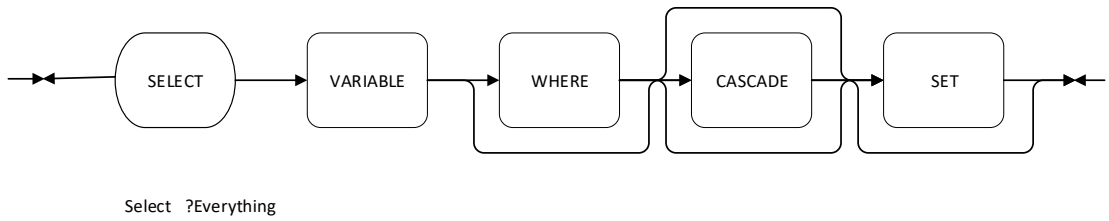


Figure 24: An example of the BIMQL (Mazairac & Beetz, 2013).

```
(?X, type, 21-century-student) ←
(?X, takes, ?C):[?T], (?C, type, Master) : [?T], 2000 ≤?T, ?T ≤ Now.
```

Figure 25: An example of the RDF-QL (Gutierrez et al., 2005).

RDF-QL (RDF Query Language)

RDF is the basic building block of the semantic web. It provides configuration of many queries. Thus, it effectively connects information from different sources (Cyganiak, 2005). The RDF-QL (RDF Query Language), an ad-hoc query language, was suggested for accessing the RDF graphics in a study by Gutierrez et al. published in 2005 (Gutierrez et al., 2005). In this study, temporal RDF graphics were presented by including temporal reasoning in the RDF. To access the RDF graphics, the user can access the desired graphic data using the RDF-QL. Figure 25 shows the RDF-QL format of a sample query: "Find the students who took master's courses between 2000 and the current year and copy these students to the 21st century group-student". In this example query, the group to which the students will be copied is selected before the arrow. After the arrow, the characteristics of the copied students are indicated. If desired by the user, the RDF graphics of temporary queries can be brought along.

Artificial Intelligence Methods

The purpose of Artificial Intelligence Methods is to simulate human intelligence, knowledge, and perception. This simulation is generally focused on two key areas:

- The first area is related to learning styles from a particular data set.
- The second area is focused on succinct explanation and reuse of people's acquired knowledge.

The Neuron-based AI Method

The first biologically inspired Neuron-based AI Method was proposed by Frank Rosenblatt in 1958 in his work simulating the behavior of brain cells (Rosenblatt, 1958). Another study was published as an article by Minsky and Papert in 1970 (Minsky & Papert, 1970). This work is based on the principle that a neuron produces an output with more than one input. This study, which draws the boundaries of the Neuron-based AI Method, remains up to date.

The Rule-based AI Method

The Rule-based AI Method has been a significant research area for many years. In 1986, Rumelhart et al. published a book examining neuronal networks that found the solution to the problem emerging in AI on their own (Rumelhart et al., 1986). In this study, it has been shown that neuron networks can self-learn a certain value, optional and infinity function, and produce solutions.

Conventional AI Methods

Most of the Conventional AI Methods are based on the Neuron-based AI Method work of Minsky and Papert (Minsky & Papert, 1970). In this study, knowledge is defined as a mixture of facts and rules. The facts consist of data items and value pairs. The rules allow new facts to be extracted from within the system. If a data item changes, everything in the system is potentially changed. The Rete algorithm is used for all changes. After the change, all rules and facts are renewed and added to the system. In the event of any change, the system repeats itself constantly.

AI Methods of Modeling Human Languages

Various NLP algorithms are used to extract meaning from natural language texts in the AI Methods of Modeling Human Languages. The NLP algorithms focus on human-computer interaction, allowing computers to extract meaning from building regulation texts and create logic rules. The probability distribution of the semantic expressions extracted in the study by Brown et al. was called an n-gram model in 1992 (Brown et al., 1992). The N-gram model specifies interconnected words as a single term. It estimates the probability of two words forming a term.

The NLP Method Focused on Text Classification and Categorization

An NLP Method Focused on Text Classification and Categorization focuses on the syntactic and semantic features of texts. In this method, text analysis, content source creation, automatic classification for ACCC, and text mining processes are applied. The entity concept is used for the output of the text analysis process. Each entity is classified as building elements such as floors, beams, columns, walls, windows, doors, etc. These classes are named, ordered, labeled, and categorized, and a sensitivity score is assigned to each class (Nawari & Alsaffar, 2015).

Domain-Specific Ontology Generating Methods

Domain-Specific Ontology Generating Methods focus on an ontology creation logic that captures the knowledge of domain-specific content with the NLP algorithms and ensures the

interpretability and intelligibility of the content. Domain-specific ontologies and semantics are used together to achieve the redundancy and complexity of building regulations. Certain rules have been extracted from building regulations using the NLP algorithms. An intermediate stage is used before the rule extraction. This stage results in a triple semantic element in the form of a subject, attribute, and value (Zhang & El-Gohary, 2017).

Preprocessing, feature generation, analysis of the extracted information, rule extraction, and coding implementation stages are performed to create a domain-specific ontology (Melzner et al., 2013). The created ontology is expected to be electronically accessible, computer-readable, represented in a standard format, interoperable, clear, and transparent (Nawari & Alsaffar, 2015). Therefore, domain-specific ontologies should be implemented with the help of consultants and professionals in building regulations.

Hybrid Methods

Hybrid methods are created by combining several building regulation representation approaches. The hybrid methods obtained from the studies are mentioned in the following headings.

The Context-oriented Object Method

In 1994, the Context-oriented Object Method was proposed by Kiliccote et al. (Kiliccote et al., 1994). This method organizes building regulations around contexts and reduces the complexity of the class hierarchies using the object-oriented approach. Context refers to all of the subclasses in the classification hierarchy to which the building regulation clauses are related. Although the contexts are used to describe the conditional parts of the applied clauses, they are insufficient to represent the applicability concepts of building regulation clauses.

```
define Concept {
        name = "Room";
};
define Concept {
        name = "Door";
};
```

```
define Classification {
        name = "Space";
};
define Concept {
        name = "Entrance";
is_a = Space;
}
define Concept {
        name = "Room";
is_a = Space;
}
define Concept {
        name = "Kitchen";
is_a = Space;
}
define Concept {
        name = "Bathroom";
is_a = Space;
}
```

```
define Relation {
        name = "related_space";
        domain = Door;
        range = Space;
}
```

```
define Instance {
        name = "kitchenDoor";
        instance_of = "Door";
        related_space = "Kitchen";
}
```

Figure 26: The four basic objects used in the SPF-CL (Kiliccote & Garrett Jr, 1998).

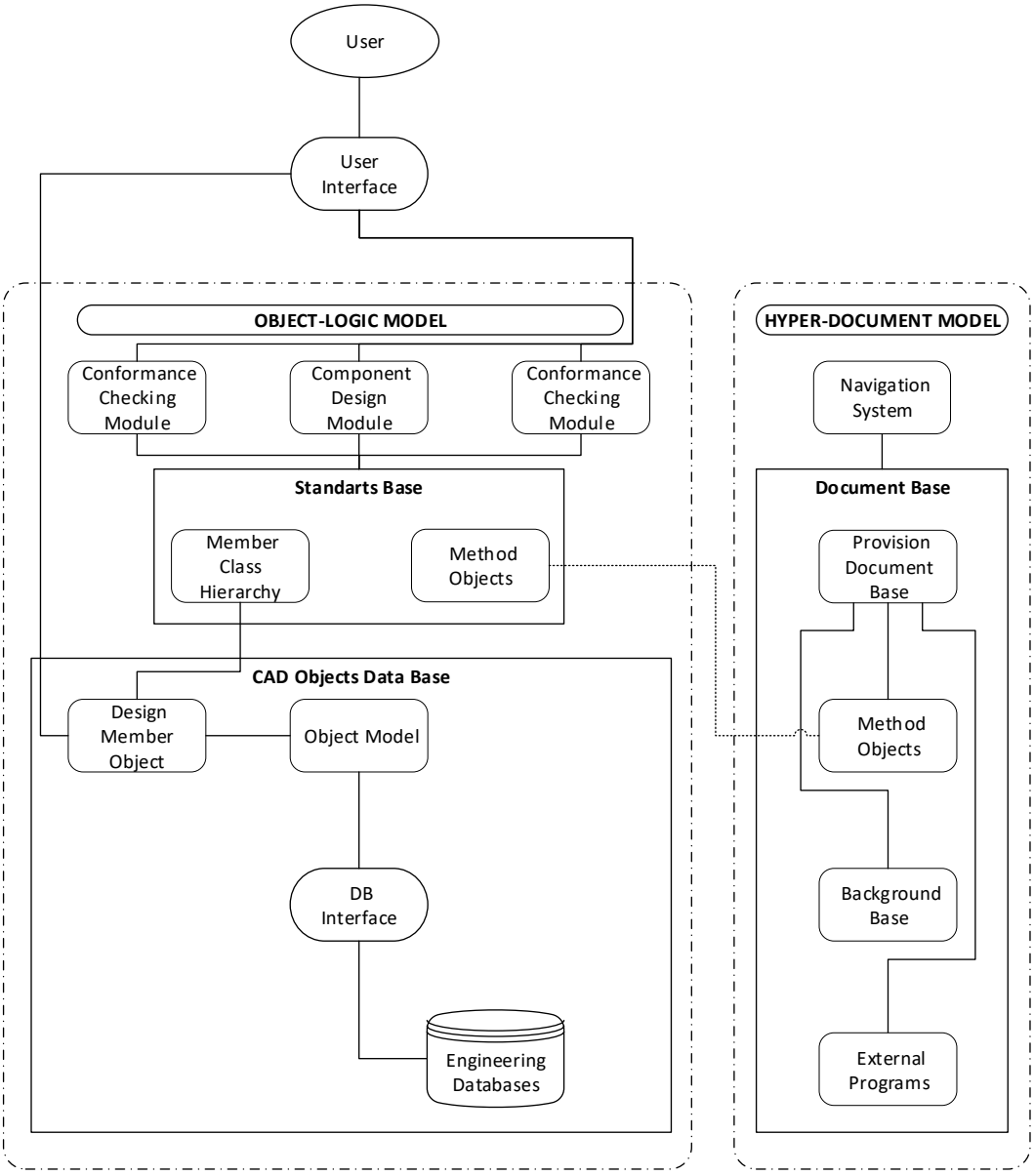


Figure 27: The structure of the object & logic-based method (Yabuki & Law, 1993).

Because of this lack, the SPF (Standards Processing Framework) was proposed by Kiliccote and Garrett in 1998 to represent building regulations, focusing on the Context-oriented Object Method (Kiliccote & Garrett Jr, 1998). SPF-Agents are independent entities that communicate through messages expressed in a common language. The SPF-CL (SPF Communication Language) was developed to allow interaction between various SPF-Agents. The SPF-CL consists of three languages. These are the ADL, the SML, and the SUL. As seen in Figure 26, the SPF-CL needs four basic objects to represent building regulations. These are:

- Concepts used to represent building elements such as a building, a room, a door, and so on.,
- Classifications that differ from each other,
- Relationships that define the relationship between a concept and another concept,
- Examples that represent assets that exist physically or conceptually.

The Object & Logic-Based Method

In 1993, the Object & Logic-based Method was proposed by Yabuki and Law, which combines object and logic-based approaches to represent building regulations (Yabuki & Law, 1993). The proposed method allows for formal procedures to be developed to check the integrity of the building regulations and to reduce conflicts between building regulation clauses. The Object Logic Method shown in Figure 27 consists of two sub-models. These are the object logic model and the hyper-document model. These two models integrate objects from building regulation clauses. The hyper-document model functions as a document store for generating building regulation clauses. It contains building code information, external programs, and objects. In the object logic model, building regulation clauses are stored in a standard database as object logic statements. The properties of this model are taken from the CAD object database.

The Ontology-Based Semantic Method

Some researchers have suggested using the Ontology-based Semantic Method, which combines the usage of ontology and semantic web formal language, to transfer building regulations to the computer environment. It was applied in the 2009 study by Yurchyshyna and Zarli to extract information from building regulation texts and match semantics with industry-specific ontologies (Yurchyshyna & Zarli, 2009).

Conclusion

Aristotle's assumptions historically show how intelligent categorization and verification systems developed 2000 years ago. In order to automate Aristotle's assumptions, Leibniz created the first computable binary system in 1666. Since 1950, a number of formal languages have been suggested for studying building regulations written in human language. These weren't enough to cover all of the building regulations, even if they were useful for processing and interpreting some areas of knowledge of the building regulations. Markup languages are required to address this issue by converting building regulations into logically applicable expressions that make them easier to understand in computer language. Markup languages serve as an intermediate format for data exchange between different systems that is simple for both people and computers to understand.

Today, in addition to human language, many building regulations are represented in computational markup language. Studies on domain knowledge representations of building regulations have emerged with the advancement of computer technology. Semantic languages that enable the contents of building regulations to be understandable, interpretable, and usable not only in human language but also by software have been proposed in light of the importance of the internet in computer language. These make it possible for software to easily find, share, and consolidate building regulation data. In addition to semantic languages, the concept of AI, which focuses on human intelligence, has begun to be used in the computable representation of building regulations. Many studies have focused on expert AI methods to easily translate and code building regulation clauses. Research is still being performed today on the automated or semi-automated extraction of information from building regulation clauses, its translation into a rule, and its implementation using AI methods. However, the manual update of building regulations in human language hinders the implementation of AI

methods. Therefore, the researchers propose hybrid methods, in which a variety of languages are combined and used as a combination.

As a result, efforts are underway to create a computable representation of the current building regulations and standards. In order to represent building regulations and standards in the AEC industry in a way that can be effectively calculated, researchers are looking for a more long-lasting answer. Various national and international ACCC systems are being created in the AEC industry as a result of BIM, allowing automated or semi-automated compliance checking with building regulations and standards.

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Resilience in Construction Projects: A New Approach to Manage Disruption

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Abstract

Construction project management literature is replete with numerous research studies on managing disruptive events during the life cycle of a project to avert failure. The conventional strategies to deal with disruption focus mainly on predicting all possible threats and managing them to reduce vulnerability. Nevertheless, construction projects' current high failure rate indicates the insufficiency of those proactive strategies in managing today's dynamic and complex projects. Therefore, considering the promising concept of resilience, a new approach is needed to improve the project performance and ensure bouncing back during or after a disruptive event by focusing on recovery besides reducing vulnerability in projects. This study intends to introduce a conceptual model to illustrate resilience in dealing with disruptive events in construction projects; therefore, to achieve this aim, a comprehensive literature review is conducted on disruption management strategies. The developed model may provide a bedrock for further studies on project resilience and disruption management.

Keywords: *resilience, disruptive event, disruption management, construction project.*

Introduction

Projects are temporary organisations that need multi-disciplinary people and different resources to create a unique product, service or result within time and cost constraints in an uncertain environment. Significant interferences or disruptions in projects can precipitate shock, raising project vulnerabilities and leading to a failure (Burr & Castro, 2016; Loosemore et al., 2005). Failure is described as one of the fundamental problems in construction projects. Disruptions that are integral parts of the projects are among the main causes of failure. Disruptive events can deviate projects from their primary objectives. The longer a project is exposed to disruptions, the lower the likelihood of success (Zhang, 2007) in achieving the project's objectives.

Construction project management literature is replete with abundant research studies on how to enhance the performance of projects to avert failure. Numerous research streams addressed this problem from different perspectives, which led to a wide range of approaches to enhance project

performance, such as risk management, opportunity management, change management and crisis management. Distinctive methods have been developed to decrease the impact and/or the exposure duration of disruptive events in projects and, therefore, increase the projects' success rate by concentrating on the source of those events. Finding sources of disruptions has been identified as one of the crucial tasks in disruption management to reduce the duration of the project's exposure to the disruption (Sears et al., 2015). The sources of disruption can be categorised into two different groups, namely known and unknown sources. Risk and opportunity management have been used to deal with known sources of disruption. In contrast, crisis and change management have been used to deal with unknown sources of disruption (Loosemore et al., 2005; Ward & Chapman, 2003). The former intends to predict and handle threats to avoid disruption, while the latter intends to decrease the project's vulnerability level prior to the disruption.

These proactive approaches provide brilliant guidance on managing disruption to avoid failure; however, the construction projects' current high failure rate indicates the insufficiency of those approaches in managing today's dynamic and complex projects (Dvir et al., 1998; Eden et al., 2000; Shenhar et al., 2001). It clearly shows that further research studies are still required to understand "why construction projects fail?" and "how projects can reach their objectives successfully even after experiencing severe disruption?".

Although the conventional approaches have differences in nature, they aim to protect projects from failure by predicting all possible threats for the whole life cycle of projects during project preparation and therefore reducing vulnerability (Qazi et al., 2016). In layman's terms, they intend to provide “fail-safe” projects. However, regardless of how hard project management teams work to identify all potential threats, reality shows that the likelihood of happening an unidentified (unexpected) threat is still high (Eden et al., 2000; Flyvbjerg, 2007; Shenhar et al., 2009; Williams, 2005) and there will always be significant unpredictability in construction projects (Cruz & Marques, 2013). It can be claimed that this common denominator (predicting all possible threats) makes these approaches insufficient for managing today's dynamic project. Thus, a paradigm shift is needed to resilience-based approaches, which intend to provide “safe-to-fail” projects by enabling recovery during or after a disruptive event (Naderpajouh et al., 2020; Park et al., 2011). To date, few research studies address project resilience, and there is a significant gap in knowledge pertaining to project resilience and how to guarantee project success.

This paper is an overview of four different conventional disruption management approaches (risk, opportunity, change and crisis management) and a preliminary attempt to introduce the potential of resilience concept in managing disruptions in projects. This paper is divided into four sections. The first section briefly explains risk and opportunity management and their used mechanisms to cope with disruption. Change and crisis management are discussed in the second section. The third section introduces the concept of resilience and presents the different definitions of project resilience available in the literature. The discussion section compares the pros and cons of these approaches for managing disruptions to draw a conceptual model, which may provide a bedrock for further studies in project resilience and disruption management.

Risk and Opportunity Management

Risk, known as a threat (Carr & Tah, 2001), an uncertainty that matters (Hillson, 2014) or a measurable uncertainty (Hillson, 2003), is a potential event that may or may not happen in the

future. If it happens, it may lead to a disruptive event which can positively or negatively affect the project's objectives (PMI, 2021; Tomanek & Juricek, 2015; Ward & Chapman, 2003). Reducing the negative severity of disruption is the main aim of risk management. It intends to achieve this aim by identifying those threats, predicting their occurrence and developing strategies to reduce their negative impact on the project's objectives (PMI, 2021; Qazi et al., 2016). The primary step in the risk management process is risk identification, which is predicting the possible future events that may alter the project's objectives and mostly rely on an individual's experiences, skills, interests and perception (Ward & Chapman, 2003; Zhang, 2007). The challenge is that individuals with different experiences and interests may have different perceptions of risks in a project and consequently identify and prioritise risks differently. The following steps in the risk management process, risk analysis, response strategies and monitoring during the project's life cycle (Qazi et al., 2016) entirely rely upon risk identification. Thus, any unknown threat could challenge the whole risk management and considerably affect the project. Risk management intends to create value in a project by mitigating disruptions or reducing their impact (Sanchez et al., 2009; Ward & Chapman, 2003). Some scholars, however, criticised its performance and effectiveness and described it as a check-the-box process rather than a process for creating value (Erol et al., 2020).

In contrast to risk management which targets the repercussions of a threat, opportunity management focuses on its positive consequences. In other words, opportunity can be described as a positive perception of risk (Olsson, 2007). Although the steps of opportunity management are similar to those of risk management (identification, analysis and responding) (Ward & Chapman, 2003), their responding methods are entirely different. As discussed earlier, there are four different responding strategies in risk management, including avoiding, transferring, mitigating, and accepting. In contrast, opportunity management responds by exploiting, sharing, enhancing and ignoring (Hillson, 2003). Contrary to avoiding strategy in risk management, which tries to reduce the probability of occurrence by eliminating uncertainty, exploiting strategy in opportunity management aims to raise the likelihood and make the opportunity happen (Hillson, 2001). Analogous to transferring strategy in risk management, sharing strategy seeks to allocate an opportunity to a party best able to manage it. Moreover, opposing mitigating strategy in risk management, enhancing strategy tries to increase the probability of occurrence and/or severity of impacts of an opportunity. Like accepting strategy in risk management, the ignoring strategy will be used when an opportunity cannot be exploited, shared, or enhanced (Hillson, 2001).

Both risk and opportunity management suffer from the inability to cope with disruptions fully and ensure project recovery after experiencing a shock. These approaches mainly concentrate on increasing the ability to identify the potential threat or opportunity to avoid shock; however, in the face of unidentified threats or opportunities, these approaches might be incapable of managing them and their consequences appropriately.

Crisis and Change Management

A crisis has been defined as "a breakdown of familiar symbolic frameworks legitimating the pre-existing sociopolitical order" (Hart, 1993). In simple words, it is an extraordinarily challenging situation (Boin & McConnell, 2007) that leads to a menace to the functioning of a system (Rosenthal et al., 2001) and disturb its balance. A threat, the element of surprise, and short response time have been described as three inseparable properties of a crisis (Seeger et al., 1998). Crisis management, in projects, fixates on handling issues that disturb the balance of

a project and tries to keep the project from being further disrupted. Crisis management approaches employ a pre-developed plan, command centre and training (Kerzner, 2013). After facing a crisis in a project, the pre-developed plan can be applied to buy some time for the command centre, which is responsible for assessing the situation and developing a strategy to reduce the initial impact of the disturbance. While training strategies try to predict the crisis's repercussions and response precisely (Boin & McConnell, 2007). Current crisis management approaches have been criticised for oversimplifying the crisis's severity, making projects more vulnerable to crisis (Kerzner, 2013). Moreover, most of these approaches ignore issues generally created during a crisis, such as behavioural instability, conflict and information problems (Love & Smith, 2016).

Change in construction projects generally refers to work status, processes, or methods altering the initial planned or specification (Park, 2002). Change management seeks to handle these alterations by constantly monitoring and modifying the direction and structure of a project (Chen et al., 2015; Motawa et al., 2007). Change management tries to ameliorate the consequences of an already happened change, but its first attempt is to predict potential changes that are likely to occur later and reduce their impact on the project (Hayes, 2018; Motawa et al., 2007). The current literature on change management primarily aims to discern the essential factors for the success of a change process and provide practice instructions for handling change (Cox et al., 1999; Ibbs et al., 2001; Motawa et al., 2007; Stocks & Singh, 1999). Moreover, there are research studies assessing change impact on particular project parameters. For example, the impact of a change order on labour productivity in a construction project (Hester et al., 1991), the effect of the change size and its impact time on a project (Ibbs et al., 2007) and the risk of safety regulations changes during projects (Williams, 2000). Another study developed an integrated change management system for the lifecycle of changes within the construction project. This generic change system aims to manage change scenarios and evaluate change effects on projects. It consists of four main stages: "start-up", "identify and evaluate", "approval and propagation", and "post change" (Motawa et al., 2007). In the first stage, proactive requirements are defined to manage change effectively, enabling the project team to respond readily to change. Then, in addition to identifying and evaluating change causes, types and effects, the relevant and/or involved project processes and departments in the change decision are defined in the second stage. Client approval will be taken in the third stage after reviewing potential changes against the project baseline using tangible and intangible criteria. Finally, when a dispute resolution is applicable, it needs to investigate change's direct and indirect causes (Motawa et al., 2007). Although the change management system can reduce the aftereffects of disturbance in a project by employing the provided requirements in the "start-up" stage, the requirements are not explicitly delineated. Change management may go wrong, especially when the sources of shock are beyond those perceived or permitted (Ward & Chapman, 2003).

All approaches discussed above intend to either avoid shock or reduce the project's susceptibility to shock-induced disruption. What is ignored here is the capability of the system to handle the shock and bounce back to an equilibrium state after a disruption, which is called recovery. Ponomarow & Holcomb (2009) claimed that vulnerability reduction approaches are insufficient to deal with project disruption and played readiness and response up to guarantee recovery. Some researchers support the idea that recovery may reduce exposure to future disruption. (Blay, 2017; Holling, 1973; Raco & Street, 2012). The concept of resilience has a solid history of ensuring recovery in many domains and can benefit construction projects.

Project Resilience

The concept of resilience was introduced by Norman Garmezy (Coutu, 2002; Geambasu, 2011) more than half a century ago. Since then, it has been extensively employed in a wide range of disciplines, including but not limited to ecology (Holling, 1973), organisational management (Al-Abrrow et al., 2019; Chen et al., 2021; Ortiz-de-Mandojana & Bansal, 2016; Sapeciay et al., 2017), supply chain (Sheffi & Rice, 2005; Tang, 2006), psychology (Coutu, 2002; Luthans et al., 2006), disaster management (Paton et al., 2000; Paton & Johnston, 2001), climate risk management (Hallegatte & Engle, 2019), urban planning (Wilkinson et al., 2010) and infrastructure (Giezen, 2013). Consequently, many definitions of the word resilience are presented by scholars in different contexts (Bhamra et al., 2011; Linnenluecke, 2017), showing the context-specific nature of resilience (Blay, 2017). Regardless of the significant differences among the definitions of resilience, those definitions include terminologies such as ability, capability, anticipate, monitor, resist, respond to, adapt to, learn, recover from and bounce back (Hollnagel, 2010, 2015). Those definitions are categorised into two fundamental perspectives: engineering and ecological resilience (Holling, 1973). From the engineering perspective, resilience is the system's ability to resist force, withstand disruption and improve its rigidity, while ecological resilience is defined as the system's capacity for renewal to maintain its performance under disruption or shock (Aven, 2011; Blay, 2017; Holling, 1973). The former lays emphasis on efficiency, stability, and predictability, while the latter focuses on persistence and flexibility (Blay, 2017). These perspectives differ so fundamentally that they serve as alternate paradigms for researchers (Geambasu, 2011).

There is a broad body of knowledge on organisational resilience (Bhamra et al., 2011; Hollnagel, 2010; Linnenluecke, 2017; Naderpajouh et al., 2020; Thomé et al., 2016); however, little is known about project resilience, and there is no consensus on project resilience theoretical definition. It might be claimed that the same concept of organisational resilience can be applied to projects since projects are a kind of organisation. This claim is partially valid because a project is defined as a temporary organisation (Sydow & Braun, 2018); however, resilience in an organisation is enabled by the long-term established relationship and challenged by the short-term transactional relationship. Whilst relationships in a project are generally transactional (Blay, 2017). Therefore, a clear conceptualisation and definition of resilience in a project is needed.

To the best of the authors' knowledge, few studies on project (as temporary organisation) resilience exist. The scarcity of research studies on project resilience strongly indicates the concept's novelty. Geambasu (2011) introduces project resilience as "the project's capacity to maintain positive adjustments when confronted with critical events inherent in its lifecycle". She claimed that project resilience should be seen from the ecological perspective rather than engineering resilience (Geambasu, 2011). Schroeder and Hatton (2012) interpret it as "the capacity of a project to evolve successfully in the face of unexpected threats or risks". Similarly, Hillson (2014) explains project resilience as "the capacity to maintain core purpose and integrity in the face of external or internal shock and change" and rephrases it as the "bounce-back-ability" of a project. In a like manner, Giezen et al. (2015) express it as "the ability of the decision-making process to deal with unexpected and the ability to entertain flexibility and preparedness to cope with uncertainty". Resilience in complex construction projects has been defined as "the ability of project systems to cope with uncertainty" (Zhu, 2016). Finally, Blay (2017) provides a comprehensive definition as "the capability of a project to prepare for, respond to, and reduce the impact of disruption caused by the drifting environment and project

complexity" and proposed recovery from a disruptive event as the consequence of project resilience.

After reviewing the studies mentioned earlier, it can be concluded that although what is known from project resilience is largely based on organisational resilience, those scholars make a distinction between these two concepts. Whilst organisational resilience, built upon the organization's permanent feature, follows the engineering resilience definition and focuses on reducing vulnerability, project resilience follows the ecological perspective and focuses on recovery (Blay, 2017). Moreover, they agree that project resilience is the ability/capability of the project to provide recovery. However, there is a disagreement about the type of event (shock, disruption, uncertainties, change, ...) that resilience is attempting to handle in a project. This disagreement and the novelty and vagueness of the project resilience concept indicate that researchers should debate this concept more. (Naderpajouh et al., 2020; Thomé et al., 2016; Zhu & Mostafavi, 2017).

Discussion

In this section, the authors intend to develop a conceptual model (Figure 1) within the construction project management context among the abovementioned approaches, risk, opportunity, change and crisis management, and project resilience by underlying the differences and similarities between these concepts.

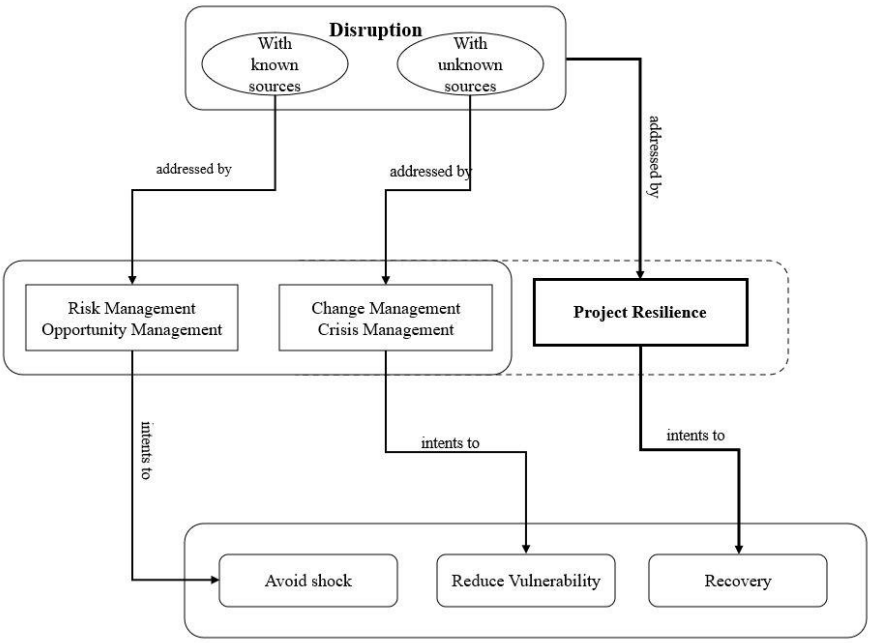


Figure 1: Delineation of proposed model among project resilience and conventional disruption management approaches.

Risk and opportunity management are successful approaches when there is a low level of uncertainty in a project and the sources of disruptive events are easily identifiable and analysable (Besner & Hobbs, 2012). It has been claimed that less risk or opportunity management is used when the uncertainty is high in a project (Besner & Hobbs, 2012). It could be because of their low productivity in a highly uncertain environment. A project's high degree

of uncertainty and ambiguity makes disruption source identification difficult or even impossible (Thamhain, 2013). These proactive approaches are commonly used to deal with disruptions with known (identified) sources. Simply, they intend to protect the project from failure by preventing disruptions from happening or reducing their impacts on the project. Both can be interpreted as a shock-avoiding mechanism in a project (Blay, 2017).

They pay more attention to the source of disruption rather than managing its consequences if it happens. It makes them incapable of handling disruptions with unknown (unidentified) sources. The reason is that predicting a disruption's consequences and impact on a project is extremely difficult because of the complexity and drifting environment of the project (Blay, 2017). However, On the other hand, identifying all threats, which are sources of disruptions, is almost impossible. Hence, more flexible approaches are required to deal with a disruption's consequences in a project after occurring, even if its source is unknown or unidentified at the beginning.

Change and crisis management approaches are also proactive approaches which take disruption from unknown sources into consideration. These approaches try to predict potential disruption, but they mainly focus on managing disruptions and reducing the susceptibility of the project to the consequences of disruptions. Therefore, they are praised for being more prosperous in coping with disruptive events with unknown sources (Blay, 2017), specifically where there is a medium to a high degree of uncertainty in a project. These approaches intend to protect the project from failure by reducing its vulnerability to disruptive events during its life cycle.

Given the high degree of complexity and uncertainty in construction projects which makes disruptive events unpredictable, the approaches mentioned earlier are not flexible and effective enough to provide an acceptable response and ensure success in the project (Schroeder & Hatton, 2012). Those proactive approaches intend to provide "fail-safe" projects; nevertheless, resilience, as a new-born concept in project management, targets recovery and tries to provide "safe-to-fail" projects. It may supply insight into responding better to disruptive events. Resilience allows for both proactive (adjustments before a disruptive event happens) and reactive (adjustments after a disruptive event happens) practices (Hollnagel, 2015; Klein et al., 2015). From the project management perspective, it adds a “thinking in action” mindset and increases the improvisation among project management team (Klein et al., 2015). Resilience intends to retain the project’s function by absorbing, adapting to or restoring from disruption. The absorptive function seeks to alleviate the impact of disruptive events before they arise. The adaptive function tries to adjust and transform the project to avoid failure and keep the project running during a disruption. Finally, after facing disruption, the restoring function returns the project to an equilibrium state (Zhu & Mostafavi, 2017).

Aven (2011, 2018) believes that the resilience concept has the potential to eliminate the need for other proactive approaches, such as risk management. However, we believe project resilience is still a very new and immature concept to reach that target and negate the importance or need of the conventional approaches. It can currently be considered an accompaniment to other approaches for increasing project success.

Conclusion

This study has provided a delineation of resilience concept within a project together with risk, opportunity, change and crisis management. As discussed earlier, risk and opportunity

management are proactive approaches that mainly focus on the source of disruptions and intend to protect the project by either preventing the disruptive event or reducing its negative consequences. These approaches have been criticized for their low efficiency and effectiveness in dealing with disruptive events with unknown or unpredictable sources. Therefore, more flexible approaches such as crisis and change management are introduced to cope with disruptions coming from unknown sources. These proactive approaches intend to predict potential disruptions and handle their consequences. Thus, they focus more on managing disruption within the project by reducing the project's susceptibility to disruption. Although all these approaches aim to avoid failure in a project, none of them can guarantee the project's success in the end. The high failure rate in construction projects is proof of this claim.

The successful results of applying resilience in other domains make this concept more attractive for the project. However, project resilience is still immature and a relatively new topic of study. Therefore, there is a need for further qualitative and quantitative research studies to complement and develop this theory in projects. What is understood from the current literature is that project resilience may provide projects with the ability to adapt themselves to any disruption. It keeps the project running during a disruption or returns it to an equilibrium state after experiencing a disruption. Recovery ensures success after experiencing disruption and strengthens the project to overcome future disruptive events easily.

This study has gone some way toward enhancing our understanding of project resilience in comparison with conventional approaches to deal with disruptive events in projects. Research into evaluating and enhancing resilience in public-private partnership projects is already underway. We are confident that this paper will serve as a base for future studies on project resilience. More broadly, further studies are needed to define the dimensions of resilience in a project more clearly, identify potential resilience activators, and propose indicators to measure a project's resilience level.

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Quantum Analysis Approaches for Construction Claims and Disputes

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Abstract

Multidisciplinarity and complexity of construction projects generally keep them prone to encounter disputes between parties. In some cases, these disputes remain unsolved and parties verge their requests into more official forms in order to pursue compensation from the opposing party. This situation often necessitates a thorough, even forensic analysis of the course of events and all evidential documents in order to allocate disruptions and discrepancies with the liable party. As the expected remedy can be both monetary and time-wise; the main concern of Quantum Analysis is to correlate financial data with the events, consider contractual obligations and find the fair amount to be paid as indemnification to the affected party. Since the process involves the evaluation of financial data on a timeline with a series of events and their causal links; this endeavor necessitates the use of several renowned formulas. Based on the literature review this paper aims to investigate the use of Quantum Analysis formulas for EoT claims and prolongation cost estimations in construction projects. This paper is expected to be helpful for new researches on Quantum Analysis in the future.

Keywords: *construction claims, construction disputes, Eichleay formula, quantum analysis.*

Introduction

As one of the largest industries in the world with a significant share in economies of countries, construction industry maintains to be complex intrinsically due to participation of multiple stakeholders (Musarat & Ahad, 2016). Mills (2001) attributes the riskiness of construction projects to being ever changing and emphasizes on infamy of the industry for finishing projects over-budget due to poor risk management stemming from unforeseen changes. Sun and Howard (2004) put the complexity of the projects down to excessive amounts of project data. Furthermore, fragmentation of project teams due to the nature of construction projects make it difficult to communicate (Anumba et al., 2002). As a result, these factors cause turmoil, time and cost overruns, which often lead to disputes (Jallow et al., 2014).

Based on Blake Dawson Waldron (2006)'s report on Australian construction projects, the survey results show that changes in scope, misunderstanding of contract clauses and Extension of Time (EoT) claims are the top three reasons that gave rise to disputes. On the other hand, Mitropoulos and Howell (2001) presented the main three reasons as obscureness of construction projects, exploitive conduct of parties and contractual complications.

In order to avoid conflicts, a contract is prepared where general and technical conditions of the project, possible delay and dispute scenarios and several conditional measures are predetermined (Ahmed et al., 2003). Nevertheless, in despite of all precautions and conditional measure clauses in the contracts, it is quite common for a construction project to be delayed and finished in over budget (Koushki et al., 2005) due to many unforeseeable factors stemming from various sources (e.g., resource scarcity, weak performance, interrelations of parties) (Assaf & Al-Hejji, 2006). Eventually these issues build up and verge into conflicts and disputes that affect the project and relations of parties negatively (Sinha & Wayal, 2007). Moreover, Cheung et al. (2004) emphasize that unless being resolved quickly; these disputes often intensify and snowball into a claim or even litigation, which are both costly procedures.

Shah et al. (2014) state construction claims as an ex-parte or reciprocal atonement demand of parties to each other, which often stems from a failure to meet an engagement of work as specified in the contract and is expected to be compensated in means of time extension, additional payment or both. On the other hand, claims do not directly connote to an award; by conducting a forensic delay analysis on project records and diverse data with appropriate analysis method, all the events and responsibilities are displayed in order to settle an argument on the pillars of causality, liability and pricing calculations (Sanchez et al., 2019). After revealing the cause-and-effect relationship and presenting the delayed amount, quantum analysis is conducted to calculate the financial impact of delaying events (Mehany & Grigg, 2015).

Claims, delay analysis and quantum analysis are rarely embedded and questioned as topics of academia and university education, which compels these notions in shadows. In comparison with other subjects, there are just very few numbers of articles that examine the formulas of quantum analysis holistically. Therefore, this paper aims to present differences and similarities of formulas used in Quantum Analysis procedures based on the literature review.

Quantum Analysis – Definition and Types

After identification of delaying events and presentation of cause effect relationship between the parties and delaying events, various methods of delay analysis are used to find out the amount of time delayed and the cost of these delays are calculated accordingly (Khekale & Futane, 2015). This procedure is called a Quantum Analysis where after nature of events and their temporal repercussions are identified by a delay expert's work, a quantum expert processes number of financial records in various forms in order to calculate the impact of the affecting events and damages (Thompson, 2021). A quantum analyst's calculations should be based on contractual and project information and should be made with certain methods meticulously (DAC Consulting, n.d.)

In the academic literature a quantum analysis can be made in several claim situations;

- EoT Claims – after investigation of events and their impacts, if awarded by EoT, Contractor may claim the costs that would incur during this added time period (Hewitt, 2011)
- Prolongation Costs Claims - where a number of delayed days and responsible party are presented after running the forensic delay analysis and considering concurrent delays of parties in the calculation (SCL Protocol, 2017)
- Disruption or Loss of Productivity Claims – which cannot be easily but measured and proved in different forms to calculate the impact of wasted labour and productivity because of method or work sequence change (Cushman et al., 2000; Finke, 1998)
- Acceleration and Mitigation Claims – Costs that incur due to Contractor's preventive actions to avoid delays are calculated (Trauner et al., 2009)
- Variation Order Claims – Costs caused by variation or change of a deliverable (Cushman et al., 2000)
- Loss of Profit Claims – Claims based upon deprivation of parties' profit by failure of the other party's fulfilment of obligations (Cushman et al., 2000)

Contractual clauses have a significant importance on quantum analysis procedures as it puts the whole process through a "go/no-go" test. Cushman et al. (2000) claim that liquidated damages clause overrules the quantum analysis and deems all calculations as void. Djanett and Guitera (2019) state that unless there is a specific contractual clause on calculation methods and assumptions, Contractor can claim two outcomes from quantum analysis; direct monetary losses and expenses that happened due to the affecting incident and the amount that is supposed to be earned as a profit but lost due to the affecting incident.

There are a plethora of formulas and approaches under each claim type and in order to focus on a group of quantum calculations, this academic writing is limited to present the formulas, methodologies and approaches of EoT claims and prolongation costs.

EoT Claims and Prolongation Costs

Although EoT claims and prolongation costs seem similar, there is an apparent difference between these two concepts in the literature. Furst et al. (2021) draw attention to this misconception and declares that entitlement to EoT does not directly give entitlement to monetary compensation for the impacts of delay. In furtherance, SCL Protocol 2nd Edition (2017) under Clause 12.2 clearly states that EoT and prolongation events should be stated and investigated separately under the contract. Furthermore, "non-compensable Employer risk events" where costs are at Client's risk and delayed end date is Employer's risk; for instance, delays caused by unforeseen weather conditions are given as an example where Contractor is awarded by EoT but is not entitled to any monetary compensation. Nevertheless, in case Contractor is also entitled to compensation of costs incurred during the EoT, the quantum analysis considers a number of construction cost titles where main idea is to cover all reasonable and exigible expense (SCL Protocol, 2017).

In order to calculate the impact of delay, costs should be presented under several categories. Senogles and Raneda (2016) describe these costs categories as: direct costs (any cost that can be related to and substantiate the event that caused the claim); project overheads (site office costs) (any costs that is not directly related to any event but is necessary in order to run the project); staff costs (staff costs that would not incur if the claim event would not happen); head office overheads (HOOH) (a reasonable calculation of head office overheads that are related with this event); profit margins (a reasonable margin rate that would be earned if the

claim event would not happen). Additionally, Hewitt (2011) mentions two more categories to be considered while calculating EoT claims; contractual costs (e.g., letter of guarantee, insurances) and finance costs (e.g., loans and credit) which eventually builds up as the project proceeds. Similar to these aforementioned classifications, Trauner et al. (2009) elaborate the direct costs as labour, equipment and material costs. Similary, Zack and Badala (2016) make the same classification with an additional category as "subcontractor costs". Other than site office overhead, head office overhead, and machinery and equipment costs, rest of these costs categories are calculated with basic accounting methods. Therefore, only these three categories and formulas on these topics will be explained and rest will be excluded from this paper. Furthermore, methods such as total cost method or jury verdict will be excluded from this article.

Overhead Costs

There are several different definitions to the overhead costs. While Cilensek (1991) describes it as expenses that are not directly a part of the project but caused by the contractor to conduct the project and beared by all contractors. With a different point of view, Coombs and Palmer (1989) defined it as costs that are neither relatable to a construction project/project element nor can be appended to one. Nevertheless, different descriptions overlap at this cost category to be counted as an indirect cost (SCL Protocol, 2017; Trauner et al., 2009), since it is not related to project directly but incur during the construction procedure.

Site Office Overheads (SOOH)

CIOB New Code of Estimating Practice (2017) defines SOOHs as project expenses that are peculiar to the construction site, which cannot be associated with site activities or included in the cost of any services. SOOHs are expenses that incur on the site due to the management of the prolonged project (Trauner et al., 2009). Some of these costs can be classified as salaries, site office rent, heating, electricity, services taken by site office, office stock, etc. (Smith & Gray, 2001).

Zack and Badala (2016) state that there are two methods to calculate site office overheads; "Average Site Office Overhead for Project" and "Average Site Office Overhead for The Period of Delay"; where the first one considers all office costs and non-time related costs throughout the entire project with a retrospective approach while the latter considers these aforementioned costs in a time window with a prospective one. After calculating the average SOOH, in both cases, the number of delayed days is multiplied with this cost to calculate the total claimed SOOH (Zack & Badala, 2016). Another method for calculation of SOOH is proposed by Leśniak and Juszczyk (2018) where authors came up with an artificial neural network-based model that can predict SOOH by correlating specs of SOOH with SOOH index.

Home Office Overheads (HOOH)

HOOH are described as costs that incur in the headquarters of construction company to run the project which cannot be directly related solely to the project but is essential, such as salaries, office utility costs, rents, travel expenses, etc. (Schwartzkopf & MacNamara, 2000; Cilensek, 1991).

Similar to Zack and Badala (2016)'s statement on SOOH, Zack (2000) also states that there are no standard formulas or strict limitations on which formula to use other than several limitations on governmental projects by Federal Acquisition Regulations and other governmental bodies; therefore, many companies prepared different formulas since only reasonability and provability was expected. It has been stated that having more than one project simultaneously makes the HOOH calculations more complex as this would necessitate allocation and division of costs between projects (Trauner et al., 2009).

There are two types of HOOH that should also be considered in calculations, namely: Unabsorbed and Extended HOOH (Golnaraghi, 2011). While Extended HOOH defines the amount that will be claimed as HOOH for every owner-caused delay day, Unabsorbed HOOH purports to the amount that had to be beared by another project due to decrease in cash flow in the first project (Zack, 2000).

To calculate HOOH, there are plenty of different formulas in the literature such as Eichleay, Modified Eichleay – Variation 1 & 2, Hudson, Ernstrom, Burden Fluctuation, Manshul, Carteret, Canadian, Allegheny and Emden formulas (Singh & Taam, 2008; Zack, 2000). In this proceeding, only Eichleay, Modified Eichleay – Variation 1 & 2, Hudson, Emden and Canadian formulas will be examined.

Eichleay Formula and Modified Eichleay Formula – Variation 1 & 2: The original form of Eichleay formula is; in order to calculate the sum of all the overhead relatable to the project first the ratio of contract invoices to total invoices for actual contract period is calculated and multiplied with the entire overhead of company for that actual contract period (Zack, 2000). Then, total overhead relatable to the project is divided to actual days of contract performance, which gave the daily overhead relatable to the project and subsequently this number is multiplied by the number of days delayed by the faulty of owner (Zack, 2000). Limitations of Eichleay formula oblige that there must be a delay event that is entitled for a reimbursement, which cannot be mitigated and causes a loss in revenues (Cushman et al., 2000). Modified Eichleay Formula – Variation 1 is also quite similar to the original formula; instead of actual contract period and actual days of contract performance, original contract period and original days of contract performance are used which purports to the assumption of the calculated HOOH for the original contract is the same throughout the entire project regardless of prolongations and delays; which would add up to a higher HOOH amount in result (Singh & Taam, 2008). The second variation is similar to the first variation; the only difference is also expenses made over the prolonged time interval is also included in the calculation to remunerate these costs (Zack, 2000). The original formula has a retrospective approach as it considers all the "actual" data while the modified versions tend to consider everything at the contract preparation stage with a prospective method (Trauner et al., 2009).

Hudson Formula: Hudson Formula's HOOH calculation starts with a significant assumption that there is a predefined HOOH and profit rate that remains the same throughout the project; simply finding the daily contract cost and multiplying it with this rate and the number of days delayed by the faulty of owner gives the claimed HOOH amount (Zack, 2000). On the other hand, Donohoe (2000) states that the formula should be used carefully, and the extents of these formula should be considered as it would cause ingeminate payments; which is also remarked by the owner of Hudson Formula per se. Moreover, based on Davenport (1991)'s research on uses of Hudson formula, it is presented that there are two distinct versions; "Extra Cost Formula" which is used for entitlement to a compensation of HOOH for owner caused delay and "Lost Chance Formula" is used for calculating the owner caused delay's aftermath

– to calculate the HOOH that would be generated if the Contractor would not be delayed and produce more outcome and eventually more HOOH (Davenport, 1991).

Emden Formula: While Zack (2000) finds Emden formula's methodology similar to Eichleay formula, Davis and Watson (1999) infer the formula as an improvement of Hudson formula, where the formula neglects the project profitability and calculate predefined HOOH rate from the ratio of total overhead costs to total revenue.

Canadian Formula: Canadian formula is quite similar to the Hudson Formula; where Hudson formula includes a predefined rate that includes both HOOH and profit while Canadian formula only considers HOOH and no profit is included in that rate (Nagata, 2018).

Cost of Idle Machinery and Equipment

In the SCL Protocol 2nd Edition (2017) under clause 1.26 (a) equipment costs are presented as a direct cost. Cushman et al. (2000) state that these claims are often Contractor's demand for a compensation of expenses of idle machinery and equipment due to owner related delay events. Hewitt (2011) classifies the idle equipment costs that incur due to time extensions as either hire or amortization costs that includes fuel and maintenance costs as well and does not include full expense of obtainment of an equipment since it may be used in more than one project.

Stojadinovic (2018) considers with a rather different perspective where idle equipment costs are defined as expenses of depreciation, interest and insurance. Cushman et al. (2000) add taxes, warehousing charge and remoulding to these cost categories and suggest that because of difficulties in calculation and data collection, cost estimations can be based upon industry manuals prepared by trade groups and governments, which incorporates large sets of historical data.

Since interest rate and insurance calculations are performed with basic accounting methodologies, these two topics will be neglected and only depreciation formulas will be presented in this academic writing.

Depreciation is the decrease in the current price of a construction equipment over time due to wear and attrition and being outdated (Petronijević et al., 2012). There are four types of depreciation calculation; straight line, units of production, sum of years digits and declining balance method (CFI Team, 2022).

Straight Line Method: By using this simple method, the yearly depreciation rate is assumed as a constant and market value of the equipment is directly related to the number of years equipment or machinery is in use (Petronijević et al., 2012). There are also modifications to this formula where a fuzzy approach is taken to overcome the obscurity of attributed useful life and final salvage values (Khalili et al., 2014).

Units of Production Method: This method defines a number of units to be produced before the end of useful life span and calculates the depreciation over the units produced (CFI Team, 2022).

Sum of Years Digits (SYD) Method: Also as known as Accelerated Depreciation Method, SYD method calculates the maximum depreciation rate on the first year and then depreciation annually (Petronijević et al., 2012). First an assumption is made on total life span and salvage rate of machinery; in order to calculate the depreciation after a specific number of used years, remaining economic life is divided to the SYD of total life span and this value is multiplied by first value of equipment – salvage value (CFI Team, 2022).

Declining Balance Method: Also as known as "Constant Percent Formula" or "Matheson Formula", this method relies on a constant amortization value that is predefined and decreases annually (Giudice et al., 2016). Although it is a rather easy method to apply, different annual amortization constants and the fact that salvage value would always be more than zero are the downsides of this formula (Giudice et al., 2016).

Conclusion and Discussion

Notions of complexity and contingency in the essence of construction projects make disputes and claims inevitable. This proceeding aimed to show several quantum analysis formulas that are widely accepted and being used for proving the monetary impacts of delays. In order to maintain the focus on the subject, claims are classified and only the quantum analysis formulas regarding EoT and Prolongation Cost estimations in construction claims are investigated. Moreover, since many of the estimations were basic accounting calculations, only the cost categories that include complex and specific formulas are presented.

In the course of literature review and research, it has been noticed that the majority of books, papers and academic writing were belonging to at least 10 years or more. There were only a few recent articles and even less researches on the cost estimations of construction claims.

Several articles (e.g., Zack, 2000; Trauner et al., 2009) on SOOH and home office overhead calculations showed that although there are plenty of different formulas, the results of formulas on the same case are inconsistent; therefore, method selection phase is the key and the subject of which formula should be chosen in which situation is still vague. Furthermore, it has been noticed that there are quite a lot of depreciation cost calculations but none of these calculations consider legislations and account codex of different countries, which keeps these calculations susceptible to be void or conflicting with local law codes in international projects.

Quantum analysis in construction claims and disputes is a detailed subject with numerous clusters and subtopics. It has been suggested that further investigation on this subject will help to fill the gap in the literature in this field.

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Examination of Organizational Perceptions on Risk Status of Events of Contractors' Claims and Key Control Measures on Construction Projects in Turkey

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Abstract

Construction projects are exposed to a lot of contractor's claims due to many factors. Project performances are significantly affected as a result of contractors' claims. Either contractor or owner involved in the project may have to cover the monetary value of the claim. The reasons for the claim may differ with respect to the project parties, the project region, and the project characteristics. This study aims to identify the top risk factors that lead to the contractors' claims and on the other hand, aims to identify the most effective measures with respect to controlling the claims in construction projects based on the views of contractors, consultants, and owners in Turkish Construction Industry. In this context, the causes of contractors' claims and mitigation measures have been examined based on a survey with construction professionals in different organizations in Turkey. Research findings have shown that in accordance with organizations characteristic features, organizations have exhibited different views with respect to the top risky events leading claims, together with the most effective measures that can control claims. According to the contractors, the top risky claims are "Design-Technical" flaws, while according to the consultants and project owners, the top risky claims are "Construction" flaws. On the other hand, according to the contractors, it was emphasized that the improvement of "technical document" components is the most effective measure, while the improvement of the "Construction implementation" based applications is stated as the most effective measures by the consultants and project owners. This study aims to raise awareness regarding contractors' claims in Turkey.

Keywords: *contractors' claims, changes in construction, mitigation measures.*

Introduction

Simon (1979) defined that, "claim is the right to the party who deserves a request for compensation of damages incurred by the other party". Adrian (1993) stated that claim is ''a request by a construction contractor for compensation over and above the agreed-upon contract amount for additional work or damages supposedly resulting from events that were not included in the initial contract''.

It becomes rare to complete the projects within the contract time (Katham, 1999), and contract cost (Harris et al., 2006), due to lots of variations and uncertainties in construction projects. Today, many construction projects combat cost and timeouts and quality deterioration (Sun &

Meng, 2009). Wu et al. (2005) referred that design changes occurring in many public projects lead to an increase in project duration and cost, as well as demoralization and legal disputes and moral disturbances among project stakeholders. Completing a project on a timeline has become a difficult task to complete in an uncertain, complex, multi-party, and dynamic environment of construction projects (Zaneldin, 2006).

Problem Statement and Aim of the Study

Jergeas and Hartman (1994) have referred that 72 percent of all contractors' claims are due to change orders in construction projects. Patil (2005) stated that when one of the parties denied the other party's claim in construction projects, a dispute arose between the parties. Crowley and Hancher (1995) have referred that the contractor's financial damage can be compensated by change orders to be made to claim extra financial resources throughout the construction process.

Zaneldin (2006) revealed that the most frequent claim causes in construction projects in Dubai and the Abu Dhabi Emirates are change orders. Diekman and Nelson (1985) analyzed 427 construction claims to identify types, frequencies and the average cost of claims. Authors were emphasized that 46% of contract claims were originated from design errors and design changes in construction projects. Hassanein and Nemr (2007) emphasized that the most common causes of construction claims are due to the "change orders" and "modification of the Project by owner party" in the projects. On the other hand, 54% of the causes of claims were due to change orders in the Egyptian construction sector. In 57 % of the project in Egypt, change orders are comprised due to poor documentation practices by the contractor's team (Hassanein & Nerm, 2007).

In another study, Semple et al. (1994) examined 24 construction claims in the Canadian construction industry to specify the causes and effect of claims on cost and time parameters. "Increase of scope of the work", "weather" and "Acceleration of project" are the most common factors that cause claims in Canada.

At the end of the comprehensive literature review, it has been realized that the most significant causes of claims vary depending on the organizational, regional and project characteristics, as the organizations and regions have their own characteristics, construction law, cultures, economies, and construction technologies. Within this context, based on a survey of construction organizations in Turkey, this paper aims to identify the top risky claim factors for a lump sum and design-bid-build contract building projects according to the construction organizations located in Turkey.

One of the important tasks to resolve the contractor's claims is to analyse the types and causes of claims (Ren et al., 2003). Diekman and Nelson (1985) stated that the construction industry should develop methodologies and techniques to reduce or prevent claims because project participants are becoming more aware of the high costs and risks associated with claims. Kululanga et al. (2001) developed a framework to handle claims to improve strategies for construction business processes in the Malawian construction sector. Besides, the performance of contractors was measured on the construction claim framework process. It has been noted that contractors have low awareness of the construction claim process framework in Malawi (Kulungana et al., 2001). It is revealed by past studies that, in order to achieve

success in the project, problematic events that lead to claims in projects should be recognized and controlled.

In past studies, it has been realized that various methods and measures were discussed to control the claims of the contractors according to the characteristics of projects, parties, and regions of the construction projects. For the success of the project, the most appropriate measure should be applied to eliminate the factors that cause the claims. In this context, to develop a strategy for the construction industry in Turkey the most effective measures were identified based on the views of organizations.

In thıs respect, in the second phase of the research, it is aimed to examine the measures of contractors' claims. In this context, the existing knowledge on claim management is comprehensively examined in the literature and presented as below.

Research and Analysis Method

In the first phase, factors influencing contractor's claims in construction projects were identified based on the validity of the literature. Hereby, a total of 21 different factors were defined (See Table 2).

In the next step, potential mitigation measures that can prevent the contractor's claims conditions in construction projects are determined by the literature review. In this regard, the identified mitigation measures are presented in Table 3 below.

In further step, factors of contractors' claims and mitigation measures were examined based on the survey of professionals in the construction industry in Turkey. Civil engineers and architects were interviewed on behalf of their organizations. A participant from each organization was included in the survey to make an organizational evaluation. Participants were asked to carry out the survey based on the organization's experience, as they participated in the name of the organization. The survey document was provided to the organizations as a hardcopy. A total of 103 organizations participated in the survey. The distribution of organizations and participants' profiles were presented in Table 1.

Table 1. Distribution of organization and respondents' professions.

	Architect	**Civil Engineer**	**Total**
Contractor	21	45	66
Consultant	8	16	24
Owner	5	8	13
Total	**34**	**69**	**103**

The research results were classified according to two types of organizational characteristics. Here the organization is meant the parties involved in the construction projects, namely contractors, consultants, and owners. The first type of organization was considered to be a contractor representing the party that undertakes the implementation of the construction projects and who claims and receives a financial benefit in return. Consultant and owner, both of them are the authority to produce technical and administrative decisions in throughout the

project. In this way, the negativity caused by a low number of owners participated in the survey was compensated. The data collection and the analysis methods are explained in the following. The research findings are classified and compared to emphasize the differences and consensus of the organizations' opinions regarding the contractor's claims.

In the survey, factors of contractors' claims were examined according to three parameters such as frequency of occurrence, impact on cost-time and frequency of disagreement between contractors and owners. On the other hand, claim mitigation measures were assessed in terms of effectiveness on preventing the occurrence of claims and, cost and time overruns.

Factors weighting method was chosen to measure how the participants think about the claim and measure factors. A five-point Likert scale was used to evaluate the factors in the evaluation parameters explained above. The factor's level of significance was determined by calculating factors relative Importance Index scores (R.I.I.) according to the Frequency Index (F.I.), Cost - Time Impact Index (C.T.I.) and dispute index (D.I.). On the other hand, Claim Prevention Index (C.P.I.), Cost Prevention Index (C.P.I) and Time Prevention index (T.P.I.) were calculated to determine the level of significance of the factors of mitigation measures. Factors Relative Importance Index scores were calculated using Equation (1):

$$R.I.I.(\%) = \frac{\sum W_i \times X_i}{A \times N} \quad (1)$$

Where,

R.I.I. (%): Relative Importance Index for Frequency of Occurrence (F.I.); Relative Importance Index for impact on project cost and time (C.T.I.); Relative Importance Index for the frequency of disputes (D.I.)

Wi: The weight assigned on Likert scale given to each factor by the respondents and ranges from 0 to 4, where; 0: Never, 1: Less, 2: Moderate, 3: High, 4: Very High

Xi: Number of choices of the (i) th weight in the Likert scale for the claim factor.

A: is the highest weight (i.e., 4 in this case) and;

N: is the total number of respondents

Risk Significance Index of Factors of Contractors' Claims

The risk levels of the claim factors were determined by calculating the Risk Importance Index (R.S.I.) of the claim factors. In this study, the risk score factors that contribute to contractors' claims were valued as the combination of the two components; the probability of the claim (frequency) and its impact after its occurrence (severity).

Factors Risk Significance Index (R.S.I.) scores were calculated by considering the frequency index as multiplier effect and by aggregating the cost- time impact index (C.T.I.) and dispute index (D.I.) (See Equation 2 and 3).

$$R.S.I.(\%) = \frac{F.I. \times AV.S.I.}{100} \quad (2)$$

Where;

F.I. = Frequency Index; AV.S.I. = Average Severity Index (Equation 3)

$$AV.S.I.(\%) = \frac{C.T.I. \times D.I.}{2} \quad (3)$$

Where;

C.T.I. = Severity Cost-Time Overrun Index; D.I. = Dispute Index

The highest risk significance index refers to the top risky factor, while the lowest refers to the minimum risky claim factors in construction projects.

The Benefit Index of Claim Mitigation Measures

The benefit levels of mitigation measures were determined by calculating the Benefit index (B.I.) of mitigation measures factors. The Benefit Index of measures (B.I.) was calculated by considering the claim prevention effectiveness index as the multiplier effect and aggregating cost- time overrun prevention indexes (See Equation 4 and 5).

$$B.I.(\%) = \frac{E.I. \times AV.C.T.P.I.}{100} \quad (4)$$

Where;

E.I. = Claim Prevention Effectiveness Index; AV. C.T.P.I. = Average Cost-Time Overrun Prevention Index (See Equation 6)

$$AV.C.T.P.I. = \frac{C.P.I. + T.P.I.}{2} \quad (5)$$

Where;

C.P.I. = Cost Overrun Prevention Index; T.P.I. = Time Overrun Prevention Index.

The highest score refers to the most beneficial factors, while the lowest refers to the least beneficial claim mitigation measure. The higher the benefit index score, the greater the effectiveness of preventing claims.

Project Success Rate

The likelihood of rate of the construction project was determined by establishing the link between the risk index of claim factor and benefits index of mitigation measures. In this regard, the success rate of the project was determined by the combination of the risk index of the claim and the benefit index of mitigation measures.

In order to have a high success rate, the claim factors should effectively be mitigated with the potential measures. The higher of this rate implies that the project is more likely to be completed successfully. In other words, greater of mitigation of claim factors means that the project still could be completed with a higher success rate. The project success rate has been determined for the types of claim factors. The project success rate is calculated with Equation 6 and given in Table 4.

$$P.S.S.(i) = \frac{1}{R.S.I.(i)} x \frac{\sum_{j=1}^{j} N.O.S.* B.I.}{n} \quad (6)$$

Where;

P.S.S. (i) = Project Success Rate for (i) th factor of claim,

R.S.I. (i) = Risk Significance Index of (i) th factor of claim,

N.O.S. (j) = Number of a choice of (j) th factor of mitigation measure for (i) th factor of claim,

B.I. (j) = Benefit index of (j) th factor of mitigation measure,

n= Number of Participants

Results

Top Risky Claim Causes

The Risk Significance Index of factors of claims is shown in Table 2. “Contractors” and “Consultant-Owner” were stated that “Errors/Insufficiencies in Design Documents” are the top risky factors of claims. The risk index score in the “Consultant-Owner” assessment has been relatively low compared to the contractors. Besides, the contractors highlighted that the “inconsistencies between different designs” and “lack of supervisor’s experience” as other major risks in construction projects. Consultants and owners stressed that subcontractors' mistakes and faulty organizations are the top risky demand factors in construction projects. Contractors referred that the factors that the consultants and owners have more responsibilities lead to more claims. However, according to the consultants and owners the factors related to the obligations of the contractors are referred to as the main reasons for the claims.

The highest risk score average was obtained by the contractors (See Table 2). According to the opinions of the contractors, it was emphasized that construction projects have become more prone to claims. In other words, according to the contractors, the necessity to claims more due to defects in construction projects in Turkey. Contractors have been observed to be more concerned concerning claims in construction projects.

Table 2. Risk significance index of factors of contractors claims according to the organizations.

Claim Factors	**Contractor**	**Consultants - Owners**	**All Participants**
Inadequacies in Contract Drawings	0.58	0.44	0.54
Low Constructability Design	0.37	0.27	0.33
Inadequacies in Specification	0.51	0.26	0.43
Inconsistencies between different designs	0.54	0.28	0.46
Changes in Scope	0.47	0.35	0.4
Inadequacies in Contract	0.46	0.36	0.43
Inadequate knowledge of client	0.51	0.29	0.43
Inadequate Experience of Consultants	0.53	0.31	0.46
Low contract price	0.36	0.37	0.36
Inadequate time in tendering	0.39	0.39	0.39
Inadequacies in Organizations	0.37	0.40	0.38
Lack of Communication between parties	0.37	0.21	0.33
Changes in Construction Method	0.34	0.28	0.32
Errors of subcontractors	0.36	0.41	0.38
Inclusion of Shop Drawings	0.49	0.38	0.45
Inadequate Experience of contractor	0.38	0.36	0.37
Inflation in Resources Cost	0.38	0.38	0.38
Natural Disasters	0.36	0.20	0.32
Subsurface Problems	0.44	0.30	0.41
Shortages of Materials	0.43	0.38	0.41
Changes in Law and Standards	0.33	0.20	0.3
Average Score	**0,43**	**0,32**	**0,39**

Top Effective Mitigation Measures

The benefit rate of mitigation measures according to the organization types is shown in Table 3. Contractors were emphasized that “detailed design and specifications”, “qualified architect/engineer” and “easy constructability design” are the most effective methods that could reduce claim risks in construction projects. On the other hand, “effective site management”, “qualified architect/engineer” and “awarding of the right contractor” in the tender process were determined as the most effective mitigation measures according to consultants and project owners. According to contractors, requests can be controlled by mitigation methods to be applied to problems related to the improvement of the design process and design documentation. However, according to consultants and owners, it has been stated that claims can be controlled strongly by improving the construction process works. The highest of the benefit index scores average was observed in the assessment of contractors

(See in Table 3). This result has revealed that there is a greater need for mitigation measures according to the contractors.

Table 3. The benefit index for claim mitigation measures according to the organizations.

No	Mitigation Measure Factors	Contractor	Consultant - Owner	All Participants
1	Standard form of Drawings	0,55	0,32	0,42
2	Detailed Drawing/Specification	0,63	0,50	0,59
3	Advanced Design Software (BIM)	0,42	0,37	0,41
4	Front-End Planning (Feasibility)	0,51	0,40	0,48
5	Qualified Architect-Engineer	0,59	0,55	0,58
6	Easy Constructability Design	0,59	0,45	0,53
7	Effective Communication	0,49	0,35	0,45
8	Sharing Historical Data	0,50	0,31	0,45
9	Qualified Project Manager	0,55	0,42	0,51
10	Detailed Contract	0,57	0,50	0,55
11	Staff training	0,50	0,47	0,49
12	Contractors well bidding organization	0,51	0,57	0,52
13	Risk sharing philosophy	0,56	0,33	0,49
14	Awarding Right Contractor	0,50	0,54	0,51
15	Effective Site Management	0,52	0,57	0,53
16	Pre investigation of site	0,49	0,53	0,50
17	Effective Quality Control	0,46	0,51	0,49
Average Score		**0,52**	**0,45**	**0,50**

Results of Project Success Rate

The project success rates according to the claim factors are shown in Table 4. According to the contractors, the project can be completed most successfully by the measures to be applied by the contractors to prevent the errors of subcontractors. In this respect, it was denoted that, construction projects can be managed most successfully by the measures to be taken in case of claims related to the construction process. In other words, it was stated that construction projects suffer less in the case of contractor originated claims in construction projects. However, according to consultants and owners, it is implied that construction projects can be completed most successfully through mitigation measures to overcome “Complex Design”, “inconsistencies between different designs” and “lack of supervisor experience”. In other words, these findings have revealed that construction projects suffer less in the case of consultant-owner originated claims in construction projects. In this context, the consultant-owner were indicated that the projects can be managed most successfully with the measures to overcome “technical related” problems.

In general, organizations implied that construction projects can be managed most successfully with the measures to be taken to address the problems under their responsibility. In other words, it was implied that the project could be completed unsuccessfully because of encountering claims events related to the other party's obligations.

Table 4. Project success rate relative to claim factors according to the organizations.

List of Claim Factors	Contractor	Consultants - Owners	All Participants
Inadequacies/Errors in Contract Drawings	1,18	1,17	1,12
Complex/ Low Constructability Design	1,66	2,71	2,00
Inadequacies/Errors in Specification	1,12	1,89	1,19
Inconsistencies between different design disciplines	1,03	1,90	1,18
Changes in Scope of Project	1,17	1,50	1,42
Inadequacies/Errors in Contract	1,27	1,30	1,10
Inadequate knowledge of client about construction projects	1,23	1,56	1,33
Inadequate Experience of Consultants/ Supervisors	1,24	1,74	1,21
Low contract price	1,57	1,55	1,36
Inadequate time in tendering process	1,71	1,37	1,55
Inadequacies / Errors in Organizations	1,60	1,00	1,40
Inadequate Communication between project parties	1,70	1,98	1,63
Changes in Construction Method	1,82	1,46	1,76
Low Quality/ Errors of subcontractors	1,96	1,19	1,67
Effects of Construction/ Shop Drawings	1,26	1,69	1,22
Inadequate Experience of Contractors	1,60	1,56	1,51
Inflation/ Rises in Resources Cost	1,57	1,27	1,44
Natural Disasters	1,68	1,26	1,63
Subsurface/ Ground Problems	1,36	1,50	1,34
Lack of Material in Market	1,61	1,59	1,44
Changes in Law /Regulations/ Standards	1,32	1,26	1,3
Average Score	**1,46**	**1,59**	**1,42**

Conclusion

Project performances are significantly affected due to contractor claims. Any organization involved in the project may be obliged to cover the cost of claims. It has been observed that organizations exhibit different approaches for claim factors and mitigation measures according to their organizational characteristics. This paper emphasizes that organizations exhibit a stance based on their interest concerning claim causes and mitigation measures. This paper reveals that more importance should be given to detailed project scope and comprehensive project preparation in the pre-execution process as well as to effective site management during the execution phase for construction projects in Turkey.

Construction projects in Turkey are extremely susceptible to the claims of the contractors. Many factors allow contractors to ask claims, thereby construction projects are exposed to a lot of contractor's claims. One of the most important factors affecting the claims is called "insufficient project documents" and "lack of party organizations during the pre-construction phase of the projects". Such activities are carried out in the design and tender processes in

common. In general, consultants and project owners play more active roles than contractors to build the technical and administrative structure of the project.

This study has revealed that construction projects may be subject to fewer claims if all organizations fulfil their responsibilities during the project stages. In this context, additional budget and time will not be required due to fewer claims in construction projects. The projects will be able to complete at the planned budget and time, thereby this result will be counted as a success for all parties involved in construction projects.

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New Approaches in Civil Engineering Education

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Abstract

The spread of the digital transformation, which started with Industry 3.0, along with the developing technology, has affected the construction and education sectors as well as different professions and industry groups. It is seen that the use of technologies such as building information modeling (BIM), cyber-physical systems (CPS), laser scanners, virtual reality, augmented reality and artificial intelligence has increased with Construction 4.0, especially in the design and construction management stages. It is inevitable that students, who are in these technological and digital transformations, need different methods in terms of perceiving information compared to other generations. While traditional methods are effective for the Y generation and the old, traditional methods lose their effect in the Z and future generations. This situation necessitated a change in education methods and revealed the concept of Education 4.0. In this study, new methods used in civil engineering education, especially in the last 10 years, were investigated. The results obtained from the use of the methods found as a result of the research in civil engineering education, and the advantages and disadvantages of these methods were examined.

Keywords: *civil engineering education, education 4.0, educational technology, industry 4.0.*

Introduction

Industry 4.0, which first came to exist in 2011, is a new industrial revolution based on robotics, the internet of things (IoT), real-world virtualization, big data storage, nanotechnology, energy storage and artificial intelligence (Mogoş et al., 2018; Esmer & Alan 2019). Technologies brought by the Industry 4.0 revolution have revealed many 4.0 concepts such as marketing, logistics, health, management, construction and education (Schircks et al., 2017). Each of these concepts refers to digital transformation and technological progress in its own field. With construction 4.0, it is seen that the use of technologies such as building information modeling (BIM), cyber-physical systems (CPS), laser scanners, virtual reality (VR), augmented reality (AR) and artificial intelligence (AI) has increased, especially in the project designing and monitoring stages. The size and complexity of the construction projects built with these technologies cause the need for technical personnel who can adapt to the

developing technology. This situation makes it inevitable to use the developing technology in engineering education. In order to train qualified personnel in the field of civil engineering, as in every field, there is a need for a project-based, life-long learning, developmental, innovative, technology and internet-using education system. Nowadays, the education system that aims to meet this need is called Education 4.0.

Education 4.0 has nine goals besides integrating high technology and digital data into education (Fisk, 2017):

- To ensure that education is not limited to classrooms and learning anywhere and asynchronously.
- To enable the student to choose the appropriate tools and programs for learning.
- To provide education with a personalized curriculum according to the student's abilities.
- To enable the student to learn by herself/himself, to gain independence in learning, and to ensure that the teacher takes a guiding role in the learning process.
- To ensure that practical training is included in the curriculum, to provide opportunities for students such as internships and industry cooperation projects.
- To provide project-based thinking, learning and working principle.
- To provide students with organizational, collaboration and time management skills.
- Determining student and sector needs in education.
- Using assessment methods such as data interpretation, questioning and answering instead of traditional exams.

It is also seen that the technological and methodological goals of Education 4.0 are compatible with the learning style of the Z generation living with technology. Young people (Generation Z), who grew up with technology, have difficulties in adapting to classical materials and techniques. Generation Z youth focus on first-hand access to information (Kuleto et al., 2021). Therefore, this generation of young people prefers web, computer, phone, tablet, etc. environments to access information, unlike the classical library environment. Educating civil engineering students with an appropriate pedagogical and technological approach will increase the capacity of universities to train engineers at a professional level. In addition, it is foreseen that students will gain a systematic perspective, lifelong learning, intergenerational experience exchange, interdisciplinary cooperation, and increase the entrepreneurship and innovation culture of students (Samaka & Ally, 2016). Due to the aforementioned reasons, it is thought that the blackboard and chalk system should be abandoned in universities, technological developments should be followed and Education 4.0 should be integrated into university education (Almeida & Simoes, 2019; Boz, 2019).

This study is aimed to investigate new methods and technologies used in civil engineering education that emerged with Industry and Education 4.0. For this purpose, new technologies used in civil engineering education have been obtained by researching studies in the literature in recent years. The results obtained from the use of the new methods found in civil engineering education, and the advantages and disadvantages of these methods were examined.

Methodology

Since the mention of Industry 4.0 in 2011, it is seen that studies related to educational technologies have increased in the literature. In this study, the keywords "Engineering Education" and "Education Technologies" were used to search for new technological approaches. The related studies conducted in the last 10 years were searched in the databases of “Scopus”, “Google Scholar” and “Thesis Center” with the determined keywords. In the investigations, seven technologies have been identified. These are “Audio-Visual Materials”, “3D Printers”, “BIM”, “Games and Animations”, “VR”, “AR” and “Mixed Reality (MR)”. Then, the usage of these technologies in "Civil Engineering Education" was searched in the same databases. In the following stages of the study, these technologies are examined in detail. The research methodology is given in Figure 1.

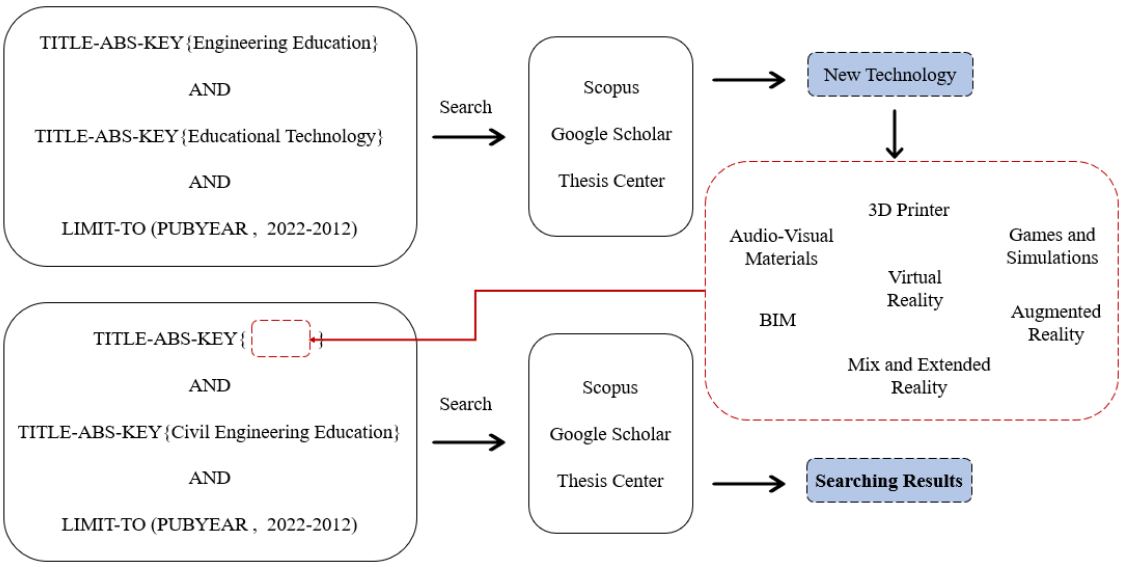


Figure 1: Research methodology.

In this study, a systematic literature review such as meta-analysis, bibliometric analysis, and statistical analysis of publications was not carried out. By using these keywords, new technologies were tried to be determined and these approaches' usage in civil engineering education was investigated.

Audio-Visual Materials

The invention and use of audio-visual materials, which were used before Industry 4.0, have changed considerably until today. The high quality of audio-visual materials used these days (videos, animations, simulations, animated presentations, audio slides, etc.) and their easy accessibility (mobile phone, television, computer, tablet, etc.) have greatly increased the use of these materials. The widespread usage and increasing speed of the Internet, the satisfactory video quality and the easy sharing of videos in the digital environment have made videos, one of the audio-visual materials, quite successful in education. The videos, which are used frequently during the Covid-19 pandemic period, have made a great contribution to the continuation of education regardless of place and time (Liu, 2021).

In the literature, it is seen that videos also contribute to the spreading of educational services, increase the quality of education, ensure memorability and attract the attention of students in education (Stefanova, 2014). In addition, the benefits of videos are stated as saving the time and cost of teaching the subjects, showing the details to the students by zooming the image in professional fields and providing practical education more easily (Boz & Toğan, 2021). It is also emphasized that audio-visual materials allow students to learn the subjects faster than written texts and to concentrate on the subject by stopping their education whenever they want (Kay, 2012). It has been demonstrated through surveys, observations and experiments that educational documentaries or practice videos about subjects that cannot be shown directly in the lessons are useful in education (Bétrancourt & Benetos, 2018) and that course materials supported by real-life pictures, simulations, animations and interactive narrations provide advanced benefits in education (Bikçe et al., 2011).

Bauer et al. (2021) stated that the necessity of using technology in civil engineering education is more understood in the Covid-19 period. In order to support distance education, the team of professors has prepared comprehensive training videos on environmental, geotechnical, transportation and structural engineering issues. They stated that the students who were educated with videos found it interesting and that the videos helped the students to understand the course content.

Boz (2019) argued in their study that practical training is necessary for civil engineering students to fulfill their professional responsibilities well after graduation, but internships, which cover a large part of applied education, cannot fully accomplish this task. For this reason, they explained the production of stone walls, which is in the professional practice of civil engineers, to civil engineering students using audio-visual materials. The videos include the designing phase of the stone wall, the technical terms in the projects and the real video on site under construction (Figure 2). As a result of the study, they determined that audio-visual materials can be used especially in practice training.

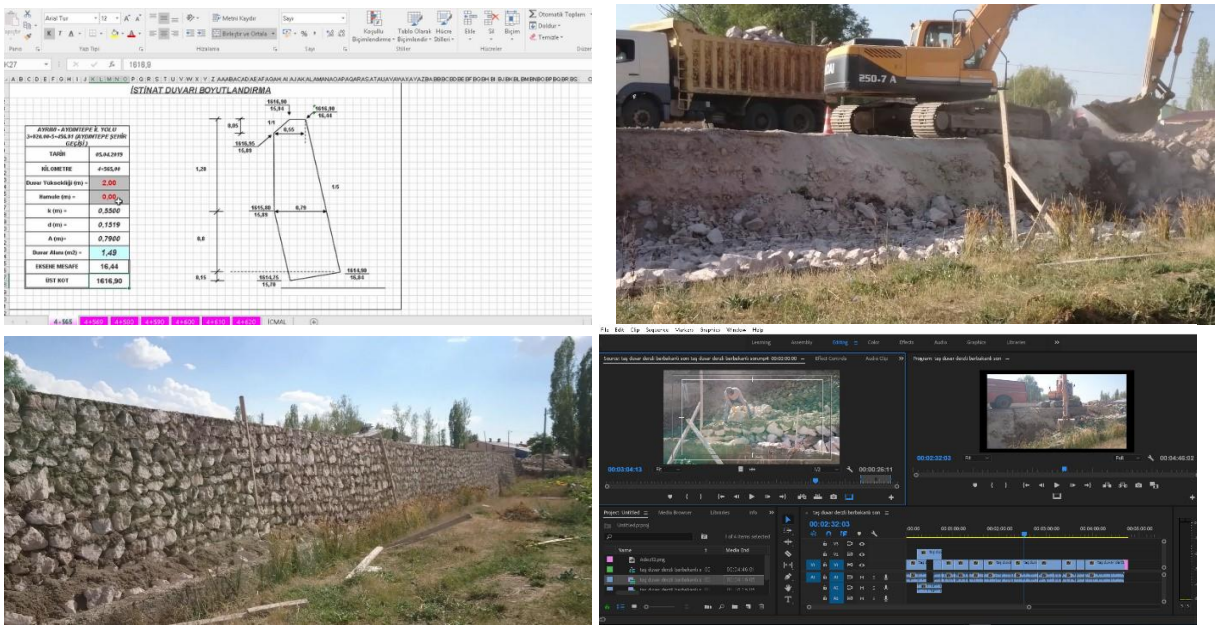


Figure 2: Stone wall video (Boz & Toğan, 2021).

Stefanova (2014) divided engineering students taking electronic measurement courses into two groups. They taught the lesson to one of the groups using audio-visual materials and the other group with traditional methods, and as a result of the study, it was determined that the students who were educated with audio-visual materials learned the lesson better.

3D Printers

3D printers, which became widespread with Industry 4.0, have managed to become a trend in the field of prefabricated manufacturing with their contributions to speed, design possibilities, economy and engineering. Today, it is used in many areas other than manufacturing and it has different usage areas day by day. It is thought that small-sized 3D printers, which can also produce 3D course materials, will create significant changes to engineering education (Kökhan & Özcan, 2018).

3D printers, which can be used in the education of fields such as architecture, art, biology, chemistry, geology and construction, are seen as an important tool for increasing creativity in mechanical and technical courses. With the effective use of this technology in the educational environment, students can quickly see their designs in 3D, improve their perspective vision skills (Lantada et al., 2010), find the opportunity to create physical objects (Syed, 2012) and learn by showing more interest in the lessons and having fun (Schelly et al., 2015).

While Tehrani et al. (2017) taught civil engineering students the working principles and necessary programs of 3D printers to make multidisciplinary designs, Katrenicova et al. (2020) used 3D printers in education to increase the geometric perceptions of civil engineering students. In addition, Kazemiroodsani and Kamat (2021) used 3D printers to better understand the land conditions and cut/fill works in the road project design in the civil engineering transportation department.

Building Information Modeling (BIM)

BIM is the process of producing digital models for the design, construction and operation of projects and using these models throughout the project lifecycle (McGraw Hill, 2009). This process includes stages such as static, architectural, machine and energy elements of the building can be modeled in three dimensions (3D), creating planning and scheduling documents and showing the construction phases. BIM is also becoming a new generation learning method in terms of pedagogy, thanks to the ability to see two-dimensional building components in 3D and the simulation features. From another perspective, BIM technology can provide an environment for students who have not seen the construction phase of a building to think and practice all building processes and behaviors close to digital and physical reality. Owing to these advantages of BIM, it is seen in the literature that BIM is used especially in architecture and civil engineering education (Bozoglu, 2016; Sampaio, 2018; Pomares Torres et al., 2017).

Meterelliyoz and Özener (2017) developed the operation of the Construction Technology course by using BIM technology. As a result of the case study, they have identified positive changes in the improvement of students' knowledge levels and also the design and development of building elements.

Lassen et al. (2018), in the Introduction to Civil Engineering course at Akershus University in Oslo, gave the students the task of designing a two-story wooden structure in the BIM-based Autodesk Revit program. As a result of the task, the students reported that they understood the design, implementation and construction details better. In addition, students have gained collaborative working experience. As a result of the study, it was determined that BIM supports students in understanding professional civil engineering. In Figure 3, there are images from the models created in the study.

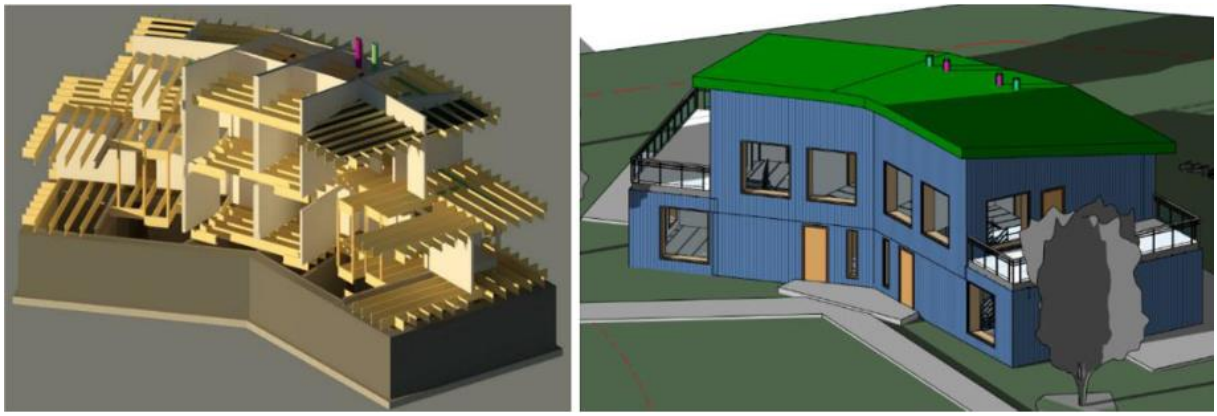


Figure 3: Images from the study (Lassen et al., 2018).

Games and Simulations

It is getting harder and harder to motivate Z generation students in the classroom with traditional methods for a long time. This generation, growing with technology, is looking for a more flexible and interactive educational environment (Proserpio & Gioia, 2007). It is thought that digital tools such as games and simulations will meet this need (Poole et al., 2014). Game-based learning, which is one of the new generations learning methods, creates high motivation and habits in individuals (Huang & Soman, 2013). In game-based learning, features such as virtual rewards, achievement badges and displaying students' success rankings according to various characteristics increase participation in education, create competition and improve learning (Alanne, 2016). It is also mentioned in the literature studies that the fun learning brought by games and simulations is better understood than the lessons presented as text or oral presentation (Chen & Wu, 2015). It is seen that the advantages of digital game-based education increase with the rise in the frequency of use of devices such as computers, tablets and phones (Sera & Wheeler, 2017). While this method provides the opportunity to present information without requiring a large investment, it also relieves students of the obligation to devote intensive time to classes (Kapp, 2012).

Fatahi and Khabbaz (2015) used a computer game to teach civil engineering undergraduate students about soil behavior. In the study, it was observed that game-based learning contributed to students' information gathering methods, creative thinking, problem-solving and lifelong learning skills. In addition, a fun competitive and collaborative learning environment was provided in the course, and students' motivation and critical thinking skills increased.

Sousa (2020) organized suitable games for two civil engineering courses and added them to the course curriculum. In the study, it was seen that game-based learning contributed to the

student's learning of transportation costs and construction terms. However, it was also stated that a lack of seriousness in the lesson may occur in game-based learning.

Zechner and Ebner (2011) applied the game-based learning method in the civil engineering structural analysis course. 159 students used the games and as a result, they found that the learning outcomes of the students who used the application increased. Although the learning outcomes of the students who played the game increased compared to those who did not, there was no difference between the students who played the game more and those who played less.

Virtual Reality

VR is a technology that allows a person to observe or do events in a virtual environment that may occur in the real world by isolating them from the real environment. This technology, which has a slow spread rate due to the expensive required equipment and the difficulty of preparing materials, has started to be used in fields such as health, engineering, military, automotive and tourism in recent years. It is thought that VR technology, which is preferred for personnel training in many areas that may pose a danger to humans and the environment, can make it possible to learn subjects and concepts that are difficult to understand at other levels of education in a more interesting, memorable and effective. Especially in civil engineering education, it is thought that the opportunity to gain experience without going to the construction site and the ability to visualize and interact with the 3D materials in the theoretical courses will both contribute to the practical training of the students and contribute to a better understanding of the theoretical knowledge and increase the academic success of the students.

VR applications are becoming more popular daily with developing technologies and various field-specific VR applications and simulators are being developed. The integration of VR into education has increased the potential of students to access education (Balak, 2019; Kılıç, 2020). Piovesan et al. (2012) stated that 3D virtual learning environments can improve spatial knowledge, facilitate impossible or impractical experiential learning, enable the transfer of knowledge and skills learned in virtual environments to real situations, and increase learning motivation and participation. Mikropoulos and Natsis (2011) stated that VR makes it easier to understand the basis of a subject, can transform intangible ideas into tangible representations, and offer users more situations than they can normally experience. Çoruh (2011) investigated the effect of using VR applications as a learning model in Art History courses in Fine Arts and Architecture Faculties on student achievement. At the end of the study, it was stated that the majority of the students were in favor of the use of VR applications and technologies both as a learning model and as a complementary element in Art History courses.

Sampaio et al. (2010) pointed out that VR technology can be used as a complement to 3D modeling in civil engineering vocational education and practice. They emphasized that the VR models developed for the construction process can provide a visual simulation of the physical progress of each type of work, can help to examine the necessary equipment and learn information about the operation in the field, and can evaluate the knowledge gained by the students in their professional practices.

Özel (2019) created a VR application to measure the ability of construction workers to recognize hazards at construction sites. The dangers that the workers may encounter in real

life were placed in the application and the workers were expected to walk around the virtual construction site and detect the dangers by wearing VR glasses. Thanks to this training, workers experienced dangerous behaviors and substances without going to the real construction site. An example of a virtual construction site is shown in Figure 4.

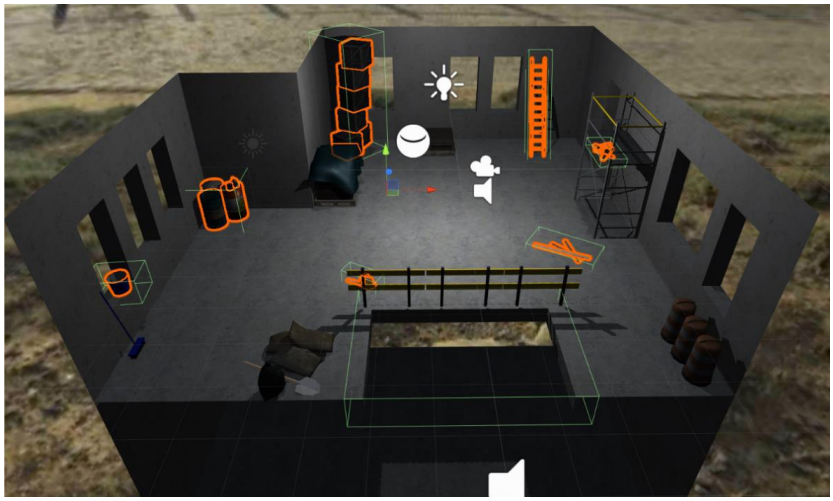


Figure 4: Virtual construction site environment with various dangers (Private, 2019).

İçten (2021) designed an educational virtual environment so that pedestrians and driver candidates can learn traffic rules in a virtual environment based on real traffic rules. It has been argued that VR can be a solution tool in eliminating the problems that pedestrians and driver candidates will encounter in traffic, with the training in this application in which natural hand movements are followed and vehicles move. Figure 5 demonstrates the images of the designed program and its use.

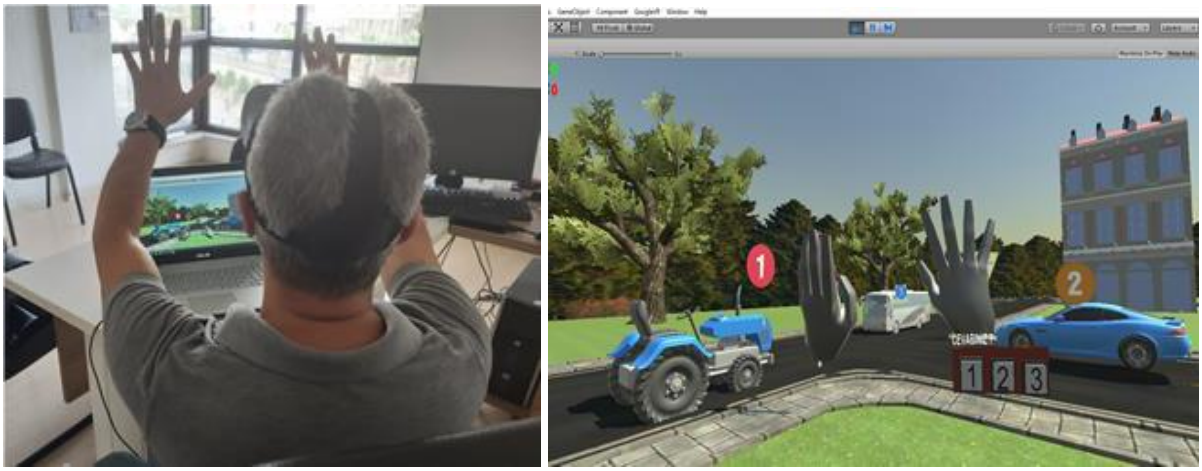


Figure 5: Interactive 3D virtual environment (İçten, 2021).

Kılıç (2020) mentioned that students have difficulty in understanding application issues such as finishing structure details, material, space and object scale in lessons. As a solution proposal to this problem, a VR application teaching model with an immersive effect and representing a virtual construction site, has been developed to be used in interior architecture education. In this study, the author revealed that VR application has an effect on accelerating

the interior architecture teaching process and increasing the quality of teaching. The designed VR application is shown in Figure 6.

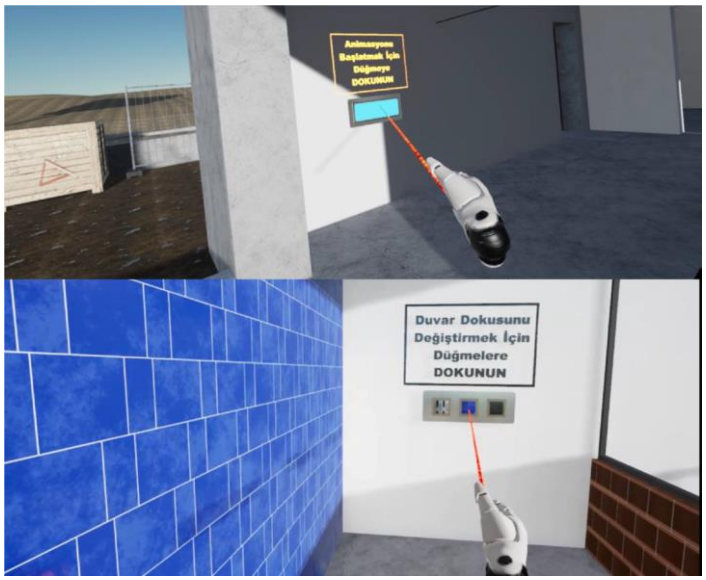


Figure 6: Interior architecture virtual training application (Kılıç, 2020).

In the above-mentioned studies, it has been determined that VR technology, adapted from real life, mainly helps students to understand and learn the information better because it opens new ways for learning and offers an interesting method.

Augmented Reality

The general purpose of AR and VR is to strengthen, support and enrich reality by providing information that people cannot see but can imagine under normal conditions. However, AR does not create a completely artificial environment, unlike VR. With the AR glasses, opportunities such as viewing the situations of objects in different environments, the details of machine parts and the process-result steps of the construction work guides are provided. These possibilities have made AR a new technology that can be used both in the sector and in education (Albahbah et al., 2021).

Nesterov et al. (2017) claim that AR is replacing expensive laboratory equipment and that students' interest level has increased due to the interaction of these technologies with students. Somyürek (2014) expresses some of the usage areas of AR for educational purposes as adding a 3D to 2D books, training on cognitive and psychomotor maintenance/repair tasks, and providing information/skills about tools and materials in engineering education. Balak and Kısa (2016) investigated the use of AR technology with smartphones in technical drawing education and emphasized that AR has critical importance for engineering students in the technical drawing course. Li et al. (2017), on the other hand, state that visualizing accurately and effectively using an AR platform for analysis and simulations involving engineering data types reduces false learning and interpretation.

Theodossiou et al. (2018) developed an AR application for hydrology education in civil engineering. Thanks to the application, the students gained the ability to better understand the effects of floods and structures on the flow regime, rainfall intensity and evaporation-

transpiration. Louis and Lather (2020) used an AR to teach excavation planning. As a result of this study, it has been suggested that AR virtual spaces can support planning and managing large-scale construction projects. It is also mentioned that the application can be used by excavation construction teams and professional engineers. Also, Waters et al. (2021) created an AR application for the Foundations, Soil Mechanics, Hydraulics and Hydrology courses in the civil engineering undergraduate curriculum of Villanova University. For the planning and implementation of these modules, faculty members from more than one discipline (geotechnical, water resources and structural engineering) worked in the department. It is aimed to support education with 3D materials for other courses at the university, as positive feedback is received on the 3D visualization and application skills of the students who use these modules.

Mix and Extended Reality

Nowadays, it is seen that the concept of MR is used as a term that covers both VR and AR applications (Sherman & Craig, 2018). The MR concept, which uses wearable technology instead of hand-held devices, provides the opportunity to interact with virtual objects in the real world (Künüçen & Samur, 2021). While the user is experiencing MR with these devices, they can interact with virtual menus or objects with their hands without the need for any additional device and can be more involved in the experience process than the classical AR concept (Langstone, 2021). Extended reality (XR) is a concept that brings all other realities together. With XR, which is less common in the literature, people will be able to feel as if they are anywhere in the world thanks to wearable technologies (Künüçen & Samur, 2021). These technologies require expensive equipment and are more complex technology than AR and VR, therefore, the possibility of using these technologies in civil engineering education reduces.

Discussion

Civil engineering education should not be limited to subjects such as the response of load-bearing elements under various loads and various environmental conditions, how the bearing elements are designed, and how the materials that make up the structural elements are produced. Civil engineering is a generally field-studied profession. When the theoretical knowledge taught in universities cannot be combined with field studies, the efficiency of the students' vocational education decreases. Civil engineers taking responsibility in many areas such as bridges, roads, tunnels, industrial structures, prefabricated structures, infrastructure works, dams and ports in their working life, cannot gain the necessary experience with traditional education methods. When it comes to the training of field applications, the use of current technologies is of great importance. It is much more practical and faster than traditional methods for students to learn, manage and develop the design processes and construction stages by using technology.

Within the scope of this study have been researched new technologies that can contribute to applications such as internships, technical trips and laboratories used in civil engineering practice education. Audio-visual materials, 3D printers, games, simulations, BIM, VR, AR and MR are some of these technologies. Audio-visual materials are very useful in providing asynchronous learning, transferring the experience acquisition that takes a long time to the student in a short time and in showing the construction stages. However, audio-visual

materials have some disadvantages such that they cannot be filmed under all conditions, some dangerous works cannot be recorded on video recordings, and the students feel a lack of perception of reality in animations. Although 3D printers increase imagination, design skills and perspective vision, the inadequacy of 3D design elements in crowded classrooms is one of its disadvantages. Although games are very advantageous in providing fun learning and keeping information in mind, the lack of seriousness while playing games in the classroom is one of the difficulties brought by this technology. Interdisciplinary BIM studies contribute to the collaborative learning of students, to have knowledge about design and development of building elements, and to examine the details of design and construction stages. The environment provided by VR technology to students and the opportunity to interact with objects can offer students unlimited experience, especially in practice training. The cost of the design of VR environments and the used materials slows the spread of this technology. AR technology, which can be easily accessed by tablets and phones used today, can be used in education with simple coding and 3D models. MR is a mixture of VR and AR technology. Similar to VR, it requires expensive equipment.

Conclusion

The expectation of Industry 4.0 and Education 4.0 is to train human power integrated with technology. In order to fulfill these expectations, new technologies should be integrated into education. For this purpose, educational technologies that can be used in civil engineering education, together with their advantages and disadvantages, are examined. It has been shown with examples from Turkey and the world that these technologies can be integrated into civil engineering education. It is thought that the technologies mentioned in the study, in addition to traditional methods, will contribute to the training of qualified and technology-skilled civil engineers with application knowledge. Nowadays, when the virtual classroom and Metaverse have become widespread, it is obvious that traditional methods are insufficient.

Future studies can investigate different new technologies that can be found by systematic literature review. Educational approaches other than engineering education can also be included in these studies. In addition, new pedagogical approaches used for the Z generation can also be explored for engineering education.

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From War to Peace: How Public Space Contributes – The Case of Barcelona

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Abstract

Most post-war reconstruction initiatives consider revitalizing public places an appealing starting point; much effort is focused on guaranteeing a new phase and transitioning from conflict to peace, which has a different influence on maintaining peace. Barcelona was one of the cities affected by the conflict and the political transition from Franco dictatorship to democratic Spain; urban planning played an essential role. In the mid-1980s, the recovery of public spaces, the recreation of new parks, and the revitalization of the city centre were critical in translating a new culture and value into the city system. This study aims to learn from Barcelona about the process of revitalizing the city center and its influence on the city's transformation from war to peace. The study conducts a literature review of Barcelona, scanning the public space design process using the timeline, followed by an assessment of the function of public spaces in post-conflict rebuilding to determine the success and failure of the public space design process. The paper also aims to provide a point of reference that may serve as an example for nations experiencing or at risk of experiencing civil war.

Keywords: *Barcelona, civil war, post-conflict reconstruction, public space.*

Introduction

Public spaces were designed as a sign of democratic practice in Barcelona city; for this reason, almost two hundred parks were designed after the democratic election of the mayor in 1979 as a response to the citizens' demands to ensure their rights to political and civic participation. In addition to rebuilding a new culture and identity that emphasizes the local authority of the public spaces and provides the international community's recognition of the local claims and role.

The public spaces also played a significant role in building the connection between the segregated areas, as well as building the bridges between the different cultural groups through cultural activities and providing spaces for each of them to show their culture and identity. (Bollens, 2006; de Balanzó & Rodríguez-Planas, 2018). Understanding the Barcelona city

experience in developing the public spaces as a critical urban tool for democratic transformation and building a place-based identity that managed to gather groups from different ethnic groups. Assessment of the public spaces design process will provide a list of dynamics and references that can serve other cities experiencing conflict and recovery planning. Emphasizing that there is no recovery blueprint and understanding the internal and external context is essential for developing the recovery plan. The paper answers the following questions: How can public spaces play an essential role in recovering the cities experiencing conflict? And what are the requirements and conditions needed to ensure the effectiveness of the public space's recovery role?

The paper answered the designed question through the following methodology:

- A literature review by looking at the Barcelona case study, using the timeline tool to document the main event.
- Analyzing the public spaces' design process in Barcelona.
- Providing a point of reference for the role of the public spaces and the dynamics need to be considered as a part of the recovery work.
- The conclusion part of the paper will consist of several questions defined along the reviewing process of the current practices in Syria.

Background of Barcelona Public Spaces Design

Barcelona's city story with public spaces started as part of urban regeneration local policy and making the public spaces in the 1980s. Their policy had international recognition for its way of improving the city, where more than three hundred qualified inter-connected public spaces and facilities were created. The objective behind it is to respond to people's claims to develop their neighborhoods and to fulfil their need to play an active role in the civic and political realm (de Balanzó & Rodriguez-Planas, 2017). This policy was implementable because it resulted from the 1970s grassroots movements' proposals on urban rehabilitation, where the political parties found it acceptable within the political environment after a long-contested dictatorship that lasted for forty years. The reconstruction of Barcelona focused on the local urban interventions, including the public spaces, that participated in connecting the diverse areas to establish a network of democratic gathering spaces (di Masso, 2015).

The Olympiad in 1992 had a significant influence on the Barcelona public spaces journey; it is considered an important milestone where the city went through structural crises to fulfil the needs of hosting the Olympiad. For this purpose, a new public-private partnership established and guided the spatial dynamic and priorities of the design of the public spaces and negatively affected the role of the public spaces as a place of citizenship because the global dimension dominated the preparation needed for the Olympiad and became a tourist-centered designed process. This phase resulted in a higher level of exclusion and developed policies against migrants and minorities, in addition to the oppression and low freedom of expression (di Masso, 2015). in addition to another international event in 2004, the forum of universal culture participated in shifting the focus to global and going beyond the local political conflict. (Bollens, 2012). Such events put the urbanist in the dilemma of market-driven design versus citizenship and local community needs-driven design, where they manger with those global events to reinforce the relationship between national, regional and local policies (Bollens, 2012), which ensured the global sustainability of the city.

One of the events mentioned could explain the conflictivist relationship over the public spaces, in one of Barcelona's neighborhood, in late of 2000 there were a vacant placed as a result of demolition work planned to be a public space as part of the 1985 urban development plan for the people in one of the marginalized neighborhoods in the city, the people decided to take the action and shows their unacceptance for the long time passed and not designing the public space as well there were a plan for gentrifying the neighborhood by the council and the private sector, as a result of this circumstances, the people decided to reoccupy their public space and make as it was planned (garden) for the neighborhood, they plant a tree in the middle of the empty space which faced with a refusal from the municipality and several back and forth action took place ended with the municipality took over the planet trees and sieged the area, but the activist and the citizens took over the area and planted trees and flower as well established a playground and opened theater, the conflict lasted till 2007, and became a symbol of a public demands for a public spaces that's fulfil local communities needs and priorities, where the municipality designed the public spaces according the measures and responds to the public claim.

This event shows a un ended story where the conflict over spaces will never end, but at least having the community's culture and structure could ensure community-based urban interventions. The public spaces could be considered an indicator of the healthy implication of the urban interventions; as long as the public spaces reflect people's lives, diversity, cultures and needs, we are on the right track.

Another fact in Barcelona's case is the role of the architects and urbanists; they were in the street with the people and engaged in the political discussion because they believed that the city's role was to ensure the rights of the people to their streets and public spaces. The city's function and design reflect the more extended political situation, and that’s what the urbanist of Barcelona focus on as part of criticizing the franco city and applying the urban justifications as an indirect way to come for a democratic city (Bollens, 2012). Understating the historical and cultural relationship between the people and their city’s public spaces was essential in the development role of the architects and urban planners in transferring the city and standing against the policies developed during the Franco years, as shown in table 1, which affected the heritage and the authenticity of the city (Bollens, 2012). As well it's important to mention the dependency between urban peacebuilding and the political peace process. The death of Franco opened the space for the administrative entities to apply the changes of urban peacebuilding in public spaces. But still, the urban approach is essential for sustainable peacebuilding at the national and local levels (Bollens, 2006).

Table 1. Comparison between Franco’s planning and what the urbanist worked on.

Barcelona city during Franco's years (Wynn, 1979)	What the urbanist worked on
- It was an overbuilt landscape and shaped by private power - City of limited public spaces - Working class neighborhoods were under-serviced	- Helped neighborhood-based-movement associations to analyze their local problems and define possible solutions. - Provided a political-civic education on the needs for local democracy.

The establishment of the neighborhoods based-movement association was essential in requesting the design of more than 200 parks, where the demands at the urban level connected to the brooder movement for democracy. The public space at the neighborhood level developed

as part of the extensive work with the people; they defined their problems and solutions and were educated on what democracy means (Bollens, 2012).

In addition to the role of urban planners at a local level, the use of urban tools at the planning level managed to put together all opposition parties around one shared project, at a time when each party had their political agenda and vision of developing the community and transferring to democracy. Keeping in mind that the planning tools were guided by the community (neighborhoods associations), which ensured the focus of the urban interventions at the neighborhoods level played a crucial role in building trust and had a direct result of the community participation that's reflected in the provision of their urgent needs and the public spaces. In addition, implementing public spaces and parks in neighborhoods was an educational approach for the community.

In conclusion, the case of Barcelona is a case where they managed to transfer from in-group conflict and take stable steps in peacebuilding through urban governance and policy.

Public Spaces' Roles as Part of Peacebuilding

The public spaces' role in grounding the citizenship implication as part of promoting democratic practices through emphasizing the rights and responsibilities of the citizens on a practical and small-scale level, ultimately shaping the city's political frame (di Masso, 2015). How the dynamics taking place in the public spaces could participate in grounding the construction of citizenship at the community level. What are the criteria of those public spaces that can participate in the construction of the sense of citizenship, such as belonging, recognition, rights, and ownership, and where citizenship is experienced, performed, challenged, and demanded daily? That's called locational citizenship, which the paper explores in-depth as part of the Barcelona case study (di Masso, 2015).

Public streets and spaces are a living culture that shows the various identity in the city, for it should belong to the people, not to the state, where the people all people can raise their voices on the issues of their concerns through public spaces and streets (Bollens, 2012).

The urban spaces reflect the macro-political structure of the city, where each of the urban spaces has the ability, among others, to influence the city's order and political dynamic. Ultimately, the social and cultural life of the urban spaces is part of the broader state attitude, political structure and economic systems. And vice versa, they constitute a place's defining elements as a social context for political and other forms of social behavior (Parkinson, 2012.)

Based on the viewpoint of considering the public spaces as a conflictive space where the ongoing conflict is reflected on them, as well, it's a place where the various groups meet and are introduced to each other. They manage their differences to create a unique identity that belongs to the space and all of them simultaneously. Owning the public spaces and ensuring the inclusivity of all citizens and participating in the daily democratic life of the city, considering the public spaces as a place for citizenship from the social-psychological and political terms (di Masso, 2015). It is also regarded as a must right at the neighborhood level, regulated by the guidelines and policies of the neighborhood (Acebeillo & Gracia-Bragado, 2000).

Public spaces have a two-way effect; the value and the process of their development influence the community and the city act, and vice versa; the community's behavior and willingness for changes will influence the role of the public spaces.

Based on this two-way role, the public spaces present new values in the community, which educates the people about democratic and collective action in the city's daily life, which is a critical factor in democratic practice (Bollens, 2006). the urban design was an opportunity for joint planning across the different ethnicity, which brought them together and ensured equal participation. The public spaces were considered connecting areas between those groups from different ethnic backgrounds (Bollens, 2006), where post-war reconstruction aims to deal with the war causes and the issues raised during the war.

Guiding values for public spaces are summarized in the following (Bollens, 2012):

- Public access: is reflected in stakeholders who participated in the design that influenced the urban design and access.
- Equality: is reflected in working with most marginalized groups and improving across all neighborhoods.
- And democracy: is reflected in the process design, ensuring participation and the interventions' priorities.

Those values helped establish and reinforce urban-based identity, which included all ethnicity In other cases, the peace agreement might maintain segregation and ensure the power balance between the conflicted groups and communities and cannot transfer the city to act and progress as one body for a shared future. The urban intervention needs to develop spaces and policies that support democratic practices and ensure daily diverse group interaction. Ultimately, the city will be able to deal with the conflict that could lead it to creative development (Bollens, 2006).

The power of planning comes from its ability to translate democratic and civic objectives into concrete actions. Where in the Barcelona case, urban planning translated the economic and social program into action through 1) the process of developing and designing the urban spaces and 2) what the urban design focused on and had a priority based on the result of the participatory process. For this reason, this authority from urban design needs to be used in a way that supports the democratic transfer of the city and ensures equal opportunity and access for all groups (Bollens, 2006).

The urban has another role in educating the people on what the democracy terms mean in practice and how they can be applied daily and manage the relationship between the people and their city daily. Urban planning ensures a breath moment for the city to deal openly with challenges and problems of the city and paves the way for a shared future of the people in the city by connecting the spatial design with the social and civic objectives of the city (Bollens, 2006).

Working on the public spaces as part of the regeneration projects participates in the effectiveness of those projects, where the public spaces play a critical role in developing the low-income groups' situations which open space for their participation and defining their priorities. Otherwise, it is just a "renewal program" that works on the physical level (Arbaci & Tapada-Berteli, 2012).

Based on the above, we can conclude the success factors of public spaces' role in democracy and sustainable peace as following

1. Community participation and political education
2. Role of architects as activists and working with people
3. Implementing local thinking global
4. Planning's justification for claiming political issues
5. Ongoing process.

People in public spaces feel absorbed by what's happening around them. Those spaces take them to a unique dynamic where they gradually become part of it and have a memorable experience just by crossing through it. Public spaces create opportunities for all social groups to exchange and express themselves and protect people's rights to participate appropriately in urban spaces. As urban planners and designers, we must understand that democratic public spaces evolve through the processes and practices of times. We must focus on the functions and procedures that enhance democratic public spaces' roles (Sezer, 2020).

In conclusion, the public spaces are the symbolic presentation of the diverse" group, preserving the memory and identity and defining the political order of the city as well the economic system. Where those democratic streets can play an essential role in the democracy of the city, and the need to pay attention to what extent and how might streets' functions limit democratic action. Through understating the reciprocal role of the influence of physical on its social, cultural, and political structures (Parkinson, 2012). Dewey (1916) stated long ago, "a democracy is more than a form of government; it is primarily a mode of associated living".

Results

Urban design plays a significant role in building bridges between conflicted communities and a connection between them. It might also create barriers between those communities and divide the city by acting in a fragmented way, which will lose growth and development opportunities. That shows the critical role of urban intervention in defining the future shape of the city and how the people will act based on this shape.

For this reason, a set of criteria developed to assess the urban intervention that participates in playing the peacebuilding role of the urban interventions are (Bollens, 2006):

- Porosity and flexibility of the urban structure ensure a comprehensive option for the future development.
- Planning should participate in ensuring equity and dealing with the root causes of the conflict. Where all groups have equal access, opportunity, and spaces to be presented, and all are empowered to play an active role in the city's development.
- The sensitivity of urban land usage ensures respect for different ethnic groups, religions, and histories. As well as create spaces for interaction between all those groups. This raises the need for an urban-sensitive approach to conflict and ethnic differences.
- Promotion of the public shared spaces and sphere, which should include all ethnic, religious and people from different backgrounds, where people can deal with their differences and conflicts and find their way collectively to move forward as part of their right to the city. At the physical level, planners should carefully deal with the design of the public spaces to play this vital role, which ensures the city's resilience and disseminates the culture of citizenship and its transfer to democracy. At the institutional

level, those spaces should be run and managed by the people and aligned with the political will that ensures everyone's rights.

- Working in partnership with all actors from all sectors at all levels is essential for an urban role in peacebuilding, considering the bottom-up approach that ensures local grassroots participation and engagement in the urban planning process. And that need to be started in parallel with the negotiation meeting of the peace process, where practitioners, urban planners, politicians, conflicted groups, diplomates and peacebuilders all work together at the early stage of the peace-building process (Bollens, 2006).
- Leadership at the urban and architectural level played a significant role in the political and urban future of the city (Bollens, 2012), wherein sometimes we are looking for a political leader to do the democratic change, which could be found within urbanist professions.
- Building on the local assets (the neighborhood associations in the Barcelona case) played an essential role in building trust with the communities and ensuring their active role as active actors in claiming their rights in the public spaces (Astor, 2019).
- Urban is always in a dynamic position that raises the need not to wait for a peace agreement or settlement. Because it might be too late and used to ensure the policies of dictatorship; if we don't intervene, others will do; urban intervention is not waiting.
- Starting small at the neighborhood level is essential to practice the process with the community and showcase the benefit they got from their participation; urban equity intervention is a critical criterion for public spaces at the neighborhood level approach.
- The connection between public spaces to form a network as a step toward a general plan for the whole city is considered an essential factor for success. In addition, it ensured the connection between the various communities.

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"Learning by Doing" Approach using Grid-shell Structures as Sustainable Construction Technology in Architecture Education

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Abstract

One of the main problems of architectural education is the difficulties experienced by students in establishing the relationship between form and structure and limitations to illustrate the relationship between form and structure in an integrated manner. However, today, instead of design approaches in which only form is considered, integrated design approaches with multi-purpose performance goals such as structure, facade, and performance are preferred. The innovative approaches in materials, construction and informatics are being guided by the Industry 4.0 and its reflections in the construction industry. In this context, the evaluation of grid-shell structures, which is one of the innovative approaches are aimed to be integrated in architectural education in terms of form finding and structural optimization. The methodology consists of literature review and a framework proposal based on grid-shell structures for a construction technology course in architecture. The main objective of this study is to provide flexibility in the form-finding process, explain the form-structure integrity, and provide the necessary environment for an ambiguous and creative design exploration in the early design stages.

Keywords: *computational design, construction technology, design exploration, form-finding, grid-shell.*

Introduction

Last century the mainstream architectural design approach was mainly based on form. Even though there were some limited trials such as Bauhaus, to reach holistic way of thinking, the common process of design was generally fragmented (Uluoğlu, 1990). This situation causes limitations to illustrate the relationship between form and structure in an integrated manner. This challenge reflects to the architectural education as one of the difficulties experienced by students in establishing the relationship between form and structure. One of the reasons of this gap, the disconnection between design studios and building construction technology courses. Moreover, the traditional approach of building construction technology courses involves theoretical lectures and repetition of 2D drawings (Seyman Guray & Kismet, 2021) which limits the student's perception and realization of form structure and their connection.

Today, architectural field is required to increase collaboration with various disciplines such as engineering, information technologies and materials science. This strong collaboration leads to design and construction of complex and high technology buildings & structures. Accordingly,

innovative construction technics and materials are being explored. These contemporary approaches in materials, construction and informatics are being guided by the Industry 4.0 and its reflections in the construction industry which is coined as Construction 4.0. (Sawhney, 2020) In this regard, to obtain current architectural requirements and performance objectives, integrated design approaches are providing certain advantages of multi-purpose performance goals such as structure, facade, aesthetics and sustainability.

This study focuses on grid-shell structures which potentially guide to sustainable building construction by allowing large spans with less material usage. On the other hand, these structures provide flexibility in form finding process which leads to exploratory and ambiguous environments in early design stages (D'Amico et al., 2015; Mesnil et al., 2018). In addition, form-structure integrity can be established effectively. In this context, the evaluation of grid-shell structures, which is one of the innovative approaches are aimed to be integrated in architectural education in terms of form finding and structural optimization. The main objective of this study is to be a response to the digital era of Construction 4.0, by integrating form and structure in early design stages in architectural education. Along with this aim, building technology course is developed to evaluate the potentials of grid-shell structures in terms of integrated design approach.

Theoretical Background

According to Schön (1985), what makes architectural education special is the learning system based on experience and doing. At the beginning of the 20th century, the Bauhaus School established the education model based on learning by doing. The education system was studio-based, in which design and production were carried out, and it liberated design education from the limited form-order bondage and opened it to practice and experimentation. Architectural education has transformed into a participatory workshop environment based on the sharing of the tutor and students (Özkar, 2009). Furthermore, starting from 1960s, informatics has begun integrating virtual and digital concepts to design studios (Cagdas, 2000). In the 1990s, information technologies became widespread all over the world rapidly (Cagdas & Tong, 2005). This has shifted learning away from traditional face-to-face, didactic lectures and tutorials to self-direction, collaborative peer learning, technology-enhanced teaching and learning through multiple technology delivery modes (Birt & Cowling, 2018). On the other hand, as a reflection of Construction 4.0, the development of skills in the AEC industry impacts the required approaches of educators, employers and sector leaders to enable a phase shift in terms of digitalization (Sawhney et al., 2020). In this regard, building construction courses need to be adapted and supported by the digital transformation to fulfill the industry demands. Also, there various studies about digital modelling, 3D representations, simulations increase student perception on construction techniques, materials and details (Arashpour & Aranda-Mena, 2017; Chan et al., 2019; Messner & Horman, 2003; Olawumi & Chan, 2018). Additionally, innovative construction technologies and materials are being adapted to curricula of building construction courses. In this regard, grid shell structures are one of them in which applied on courses for form finding and structural optimization objectives in different universities such as MIT, Princeton University, Aarhus University, University of Bath, Anhalt University, Edinburgh Napier University (Adriaenssens et al., 2015). Moreover, as the expectation of reaching sustainable construction techniques, grid shell has significant advantages on this topic by providing minimum material and structural optimization (Adriaenssens & Block, 2014).

Shell structures are one of the construction techniques used since ancient times. Since 1950s, it has been handled by pioneering researchers such as Isler, Frei Otto, Fuller, Candela who developed shell structures through hand-based drawings and physical models. However, especially since the second half of the 2000s, both the development and spread of computer-aided design (CAD), computer-aided manufacturing (CAM) and importance of optimization shifted architectural and engineering practices into computational and parametric design. Additionally, pioneering architects such as Zaha Hadid, Frank Gehry, Bjark Angels, Calatrava, Shirigu Ban are generating much more innovative architectural designs with these approaches. Computational design aims to achieve numerical and generative designs based on a certain rule, an algorithm (Singh & Gu, 2011; Menges & Ahlquist, 2011). In this regard, it is possible to extend the context of grid shell structures as a construction technology whose potential has been realized with the development of both computational design approaches and digital fabrication methods. Additionally, it is seen that researchers have shown increasing interest in grid shell systems in the last ten years (Adriaenssens & Block, 2014; Dimcic, 2014; Menges, 2016; Ochsendorf & Block, 2014). On the other hand, since sustainable construction techniques are extremely urgent and on the world's agenda, designing with optimum material, optimum energy and optimum form comes to the forefront in Europe, UK and the USA in the field of research as well as grid shell systems.

Methodology of the Proposed Framework

The proposed framework based on grid-shell structures is planning to be applied on a building construction technology course in architecture department. The course is re-designed to adapt Project Based Learning (PBL) since it targets students becoming active learners by the help of Dewey (1938)'s "learning by doing" approach. It provides advantages of internalized learning for the students. In the PBL, the active learning occurs through applying the knowledge of formal courses to a specific project by sharing informal learning experiences through groupwork (Adriaenssens et al., 2015). The targeted group of students taking the course are 3rd year undergraduates who had background courses of Building Science and Materials I, II, III, Digital Media in Architecture I, II. Thus, the students have knowledge and skills about building elements, construction techniques, building materials, building systems, structural systems together with digital knowledge and skills. The design and fabrication of grid shell structured pavilion will be conducted in 10 students per group.

The project component of the course formulated by the authors. It involves a semi-open, semi-closed pavilion design as grid shell structure. The design requirements of the grid shell pavilion given to the students as follows; 3m x 4m (12 m^2) layout area, with a maximum height of 3 meters. Initial shape to apply grid shell is selected as penci arch. Penci arch is a type of low pointed arch and had been used widely used in traditional Turkish architecture such as Mimar Sinan's mosques. It is formed by the intersection of circular archs drawn from two points of the middle section by dividing the stirrup line into five (Özyalvaç, 2017). The distance between two centers over the span equals to 1/5 (Figure 1).

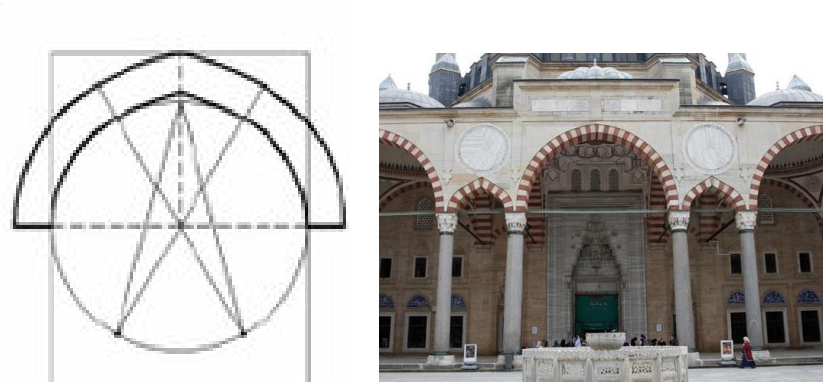


Figure1: Penci arches of Selimiye Mosque by Mimar Sinan.

Penci arch gives the opportunity to re-interpret the traditional architectural element with computational approach through digital skills. In this study it is found important to rethink the traditional arch & vaults and it is aimed to design their transformation into a contemporary non-linear shell structure. Besides their formal relation, vaults and pavilions have similarities in function such as being a passage and a shading element.

The proposed framework has two stages; first is digital workflow and second stage is physical prototyping (Figure 2). The proposed framework aims to extend the borders of form-finding to represent properly the complexities of scale, digital design systems and delivery workflow of grid shell structures. It investigates the cooperation of architecture, structure and manufacturing from file to fabrication process.

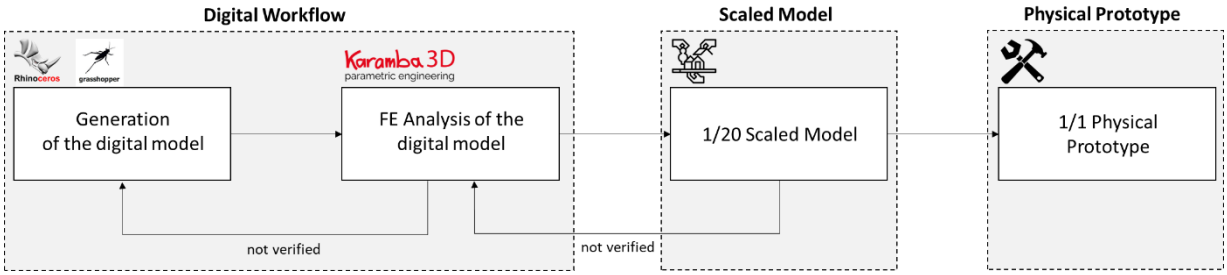


Figure 2: Process of proposed framework.

Digital Workflow

Digital workflow elaborates form finding process which relies on computational design approach. This process involves complexity, network, emergence, patterns, biomimetics, and non-Euclidian geometries (Akipek, 2010), which are highly challenging to be designed without computational tools. To model free forms, the Non-Uniform Rational Basis Spline (NURBS) function is selected as it is one of the most common ways. NURBS can be easily extended to allow more design freedom (Xia et al., 2019). The design alternative of grid shell pavilion is explored and modelled parametrically in the Rhinoceros 7 3D geometric modelling software and Grasshopper plugin. Firstly, the layout is modelled in 3x4 grids in Rhinoceros 7, then the penci arch is modelled accordingly. A series of surface operations - extrude, sweep, loft, boolean, trim- are used in the Rhinoceros 7 to generate forms. Finite Element Analysis (FEA) analysis is conducted to explore the structural behavior of the form alternatives through Karamba 3D which is a FEA add-on into Rhino-Grasshopper environment. According to the

result of FEA, optimal form is selected to be used in the second stage, prototyping. Digital workflow is shown in Figure 3.

Scaled Model

This is a stage between digital workflow and physical prototyping. 1/20 scaled model is made by students to verify the constructability of the 1/1 grid shell pavilion. Manual model making experience, provides better perception - a larger scale amplified the limitations of fabrication and material features, to understand the complexity of grid shell in the early design stage. 1/20 scaled model covers the dimensions of 60cm x 80cm layout area with the maximum height of 80cm; the material is 1mm corrugated cardboard, and students are guided to use pins for joints. Corrugated cardboards are planned to be laths for grid shell. Scale model making involves evaluation of mechanical behavior of the corrugated cardboard and evaluation of assembly details, including joints and connections (Figure 3).

Physical Prototype

1/1 physical prototype is produced according to the form alternative that is generated through digital workflow process and tested in scaled model production (Figure 3). Physical prototype as the material and tactile mode of prototypes help to evaluate the tectonic aspects as the structure, shell performance, material and system behavior in the physical world (Akipek, 2010). 1/1 physical prototype covers 3m x 4m layout area, with the maximum height of 3 meters. The material is selected as 5mm corrugated cardboard to form laths of structural grid elements. The corrugated cardboard is chosen as it is recycled material and cost-effective. Also, it can be renewable and reusable in further implications. It is lightweighted, easily carried and can be processed easily such as cutting, gluing, attaching. In addition, placement of corrugated boards according to the direction of internal structure increase the strength of the system. In this regard, boards can be attached to each other one-directional or bidirectional respectively.

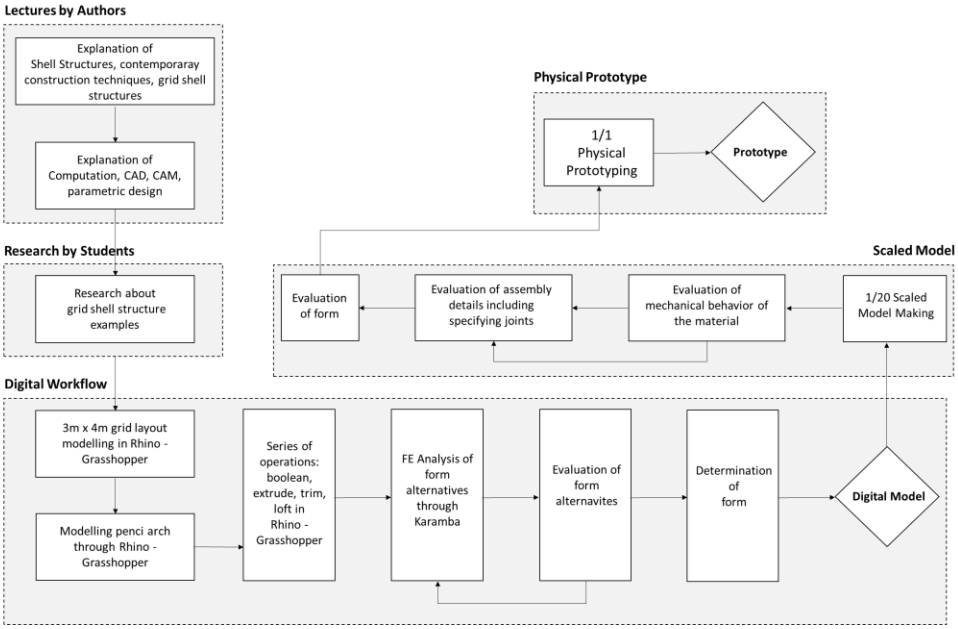


Figure 3: Process of proposed framework.

Conclusion

"Learning by doing" is a significant education approach in architecture as it transforms students to active learners and participants while designing, modelling and constructing. This approach increases learning outcomes of the courses as students experience the whole process. Additionally, PBL offers an environment to conduct concrete experiments. From this perspective, the proposed framework explores beyond the borders of theoretical construction courses by integrating project components. In this study, project component is designed to produce a grid-shell structured pavilion through form finding process. Combining grid shell structure and PBL in curricula provide opportunities for students to experience innovative techniques and technologies which is considered highly beneficial.

One of main contribution of this study is creating an integrated design environment for students in which form and structure are interrelated. It makes students to understand the behavior of form and structure. Also, this study can be considered as introducing the logic of computational thinking which is becoming much more important for the professionals of construction industry in today's digital era. Additionally, students are focused on the importance of planning, simulating and then fabricating which make them increase the management skills as well as provides a sophisticated experience. This process improves the perception of students on integrated design. On the other hand, re-interpreting the traditional Turkish penci arch provides valuable contribution on cultural heritage. Also, it is an example of interdisciplinary work between heritage and computation. Moreover, it offers social sustainability understanding for students. In addition, for the environmental sustainability, grid shells have less material consumption and are flexible to be designed in wide range of materials. The material that is chosen for this study is corrugated cardboard that is both recycled and reusable for future implementations.

For future studies, the proposed framework is planned to be applied. Students' experience will be taken into account to evaluate the effects of this framework to understand form-structure relation, mechanism of grid-shell structure and logic of prototyping.

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