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A SYSTEMATIC APPROACH TO INVESTIGATE BIM IMPLEMENTATION IN TURKISH CONSTRUCTION INDUSTRY

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SUMMARY: *Architectural, engineering, and construction (AEC) industry is currently in a transition process that deeply affects the long-established way of collaboration and building information modelling (BIM) is at the centre of this transition. Achieving the smooth integration of BIM in construction projects requires companies to spend great effort and resources. In that sense, it is crucial to generate a comprehensive list of critical success factors (CSFs) of BIM adoption. This study aims to systematically identify the CSFs of BIM implementation in the construction phase and evaluate their effectiveness on real projects for Turkish construction industry. Within this context, an extensive literature review was conducted and CSFs were identified. The number of times each factor had been cited in the literature was recorded as the frequency. A comprehensive framework with 6 components was utilized including drivers, inputs, enablers, barriers, benefits and impacts. The identified CSFs were assigned to relevant components based on their contents. In an attempt to distinguish the responsibilities of the industry, firms, and project teams; each factor was categorized into three levels of influences (industry-, firm-, and project-level). A case study was employed to examine the effectiveness of each factor in practice through conducting interviews with the practitioners of 18 different construction projects. The interviewees were asked to specify the effectiveness of each factor in a 1-5 Likert Scale based on their experience in that particular project. This study is expected to promote BIM implementation in the construction industry and inform the industry professionals about the most significant factors to focus on. Further research may utilize the framework to conduct similar studies in different countries.*

KEYWORDS: *Building Information Modelling (BIM), BIM Integration, Critical Success Factors, Case Study*

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1. INTRODUCTION

Architecture, engineering, and construction (AEC) industry has been experiencing a transition process to integrate building information modelling (BIM) into the projects (McGraw-Hill Construction, 2012). BIM is one of the most fascinating improvements in the construction industry within the last decade. Traditional design communication methodology is based on project specifications and two-dimension (2D) layouts, however the traditional method creates ambiguities within project parties (Chelson, 2010).

Nowadays, construction projects have a wide range of information that needs to be managed in a systematic way. Thus, the traditional method of collaboration is inefficient for today's construction projects since it brings lot of clarifications, change orders and re-works that consequently results in time and resource waste. At this point, BIM enables the AEC companies to manage all the project information via a single model. BIM models can be described as the digital simulations of not only the building itself but also the construction and facility management process as a whole.

AEC industry encounters a gradual decrease in the productivity of labour since early 1960s (Hergunsel, 2011). One of the reasons for this decreasing trend is lack of communication among the project parties. BIM is considered as a solution to enhance productivity in the AEC industry (Qian, 2012). Moreover, integrating occupant feedback in BIM provides benefits for facility management by indicating most problematic areas (Artan et al., 2022). In addition to that, there is a pressure on companies to decrease their costs (Demirbilek, 2021). In an attempt to gain competitive advantage, construction companies seek to develop BIM capabilities (Eastman et al., 2011) and the trend is becoming popular in the industry (McGraw-Hill Construction, 2012). The increasing rate of BIM adoption and the need to ensure a smooth transition process require a vast amount of issues to be clarified (Ozorhon et al., 2018).

Studies focusing on BIM integration in certain countries imply very high adoption rates (Ghaffarhouseini et al., 2017) and BIM implementation has been gaining momentum in these countries (Smart Market Report, 2014). However, the rate of adoption isn't still at the desired level in the global scale (World Economic Forum, 2018; Smith, 2014). One of the main reasons for the slow adoption is that there is not a clear path for the BIM implementation. It is not possible to just decide and implement BIM in the project. Companies has to spend an effort to implement the BIM process.

BIM has become an attractive topic both in academia and industry due to its undeniable influence on the construction process (Aladağ, 2022). Majority of the studies have focused on investigation of its effectiveness (Kovacic and Filzmoser, 2015; Coates et al., 2010) and many other studies have concentrated on its philosophy (Barlish and Sullivan, 2012; Arayici et al., 2012). A limited number of studies have investigated the components of BIM and critical success factors (CSFs) of its implementation (Ozorhon and Karahan, 2016; Shang and Shen, 2014). Thus, there is a gap in the literature regarding the determination and evaluation of CSFs on real case projects and this research is expected to bring crucial information regarding the issue.

This study aims to identify the CSFs of BIM implementation and assess the impact of each factor through collecting data from real construction projects in Turkey. The sub goals can be described as;

- To create a list of CSFs through conducting an extensive literature review.
- To evaluate the CSFs by obtaining data from the BIM executives of real case projects.
- To shed a light on the BIM implementation process and give industry professionals a lead.

In this context, the main research aim is to determine the most critical factors affecting the BIM implementation. In this direction, a list of CSFs was created by conducting a comprehensive literature review. The factors were categorized into three levels, namely industry-level, firm-level, and project-level. Interviews were collected with construction professionals from 18 different construction projects. The professionals rated the effectiveness of each factor in a 1-5 Likert Scale based on their observation in that specific project. The most significant factors were discussed based on the evidence from the literature.

2. RESEARCH BACKGROUND

BIM implementation has been a trending topic in academia. Various research has been conducted to promote BIM implementation across the world. Research on BIM implementation have mainly focused on identifying the CSFs, which were evaluated under five headings as the drivers, barriers, inputs, enablers, and benefits.

The drivers of BIM implementation have been examined in a number of studies. Kassem et al. (2012) conducted a study for 4D BIM implementation within the UK AEC industry and identified an internal push force by clients and an external push force by governments" as driving forces. Eadie et al. (2013) demonstrated the correlation of the driving factors with the experience of the respondent. Although non-users of BIM ranked the pressure (pressure of government, client or competition) as the top driver, users of BIM ranked the clash detection and reduced rework as the top drivers.

Another group of studies have concentrated on the barriers. Newton and Chileshe (2012) detected lack of understanding and awareness as the major barriers of BIM implementation in South Australia. Gerrard et al. (2010) also supported this finding as they revealed lack of BIM knowledge and expertise as the greatest barriers. Based on a study that analyzed 4 case studies, Migilinskas et al. (2013) argued that data transfer among the particular tools (software and hardware) was limited due to incompatibility and transmission of the consistent information to other participants.

Certain studies have investigated the inputs, which are the resources sacrificed for BIM implementation. In a previous research study, a remote construction project was analyzed as a case study by Arayici et al. (2012) and decision on utilized software was found as an important input. Alazmeh et al. (2017) examined a knowledge exchange partnership with a case study project for level 2 BIM implementation and identified developing a BIM implementation strategy and staff trainings as the crucial inputs. In the report published by World Economic Forum (2018), investment, qualified staff and leader, and company know-how were mentioned as the essential inputs for BIM implementation.

The enablers, the factors that facilitate BIM implementation, have been at the center of another group of studies. Abbasnejad et al. (2016) tried to identify key enablers for an effective BIM implementation. Based on an extensive literature review, they identified the enablers for different tasks that had to be achieved during the implementation period and considered BIM as an organizational innovation. Another research conducted by Syazwani et al. (2017) identified 24 factors influencing the adoption of BIM. According to the results, "standards and accreditation" and "collaboration and incentives" were found to be the top two mentioned enablers in the literature. Based on case study research, Arayici et al. (2011) emphasized internal capacity as a requirement for an effective BIM adoption.

The benefits of BIM implementations have been discussed in another group of studies. Ghaffarianhoseini et al. (2017) discussed the reality of BIM by reviewing the literature and grouped the clear current benefits of BIM into 9 different components as technical, knowledge management, standardization, diversity management, integration, economic, planning /scheduling, building LCA, and decision support benefits. They expected BIM to have transformational impact on the AEC industry. Stanley and Thurnell (2014) designed a cross-sectional questionnaire to investigate the benefits of 5D BIM and reported advantages in quantity surveying by improving the efficiency and visualization together with earlier risk identification. Moreover, the leading benefits were identified as improving multiparty communication and 3D visualization by Jin et al. (2017).

The literature lacks a systematic approach to review previous studies on CSFs of BIM implementation. This study fills the gap by investigating the CSFs through an extensive literature review and evaluating their influences through analyzing data obtained from industry experts of various case projects. For this purpose, a comprehensive literature review has been conducted to come up with a detailed list of CSFs. The impact of each factor has been assessed by 25 experts from 18 different construction projects. The results of the assessment have been compared with the frequency of being cited in the literature.

3. RESEARCH METHODOLOGY

The methodology is composed of three main phases. The first phase is the description of the utilized framework. A previously developed framework was subjected to some modifications and used to evaluate BIM implementations in the Turkish construction industry. The second phase is the creation of the list of CSFs. An extensive literature review was conducted to draw up a list of CSFs of BIM implementation. 45 different literature sources were investigated, the CSFs were listed, and the number of times each CSF had been mentioned in the sources was stated. The third phase is the explanation of the data collection process. How the interviews were conducted and how the interviewers were selected are expressed.

3.1 UTILIZED FRAMEWORK

In an attempt to cover all aspects of the BIM implementation process, a comprehensive framework generated by Ozorhon (2013) was utilized following certain modifications. The framework was expected to help the researchers systematically investigate the process. The BIM implementation framework was primarily developed to investigate the innovation process in the construction industry. The framework defines innovation as a system with several components related to the participating organizations and project-specific factors.

Utilization of the framework for purpose of the study required some modifications. Even though the original framework had also been developed for utilization in semi-structured case studies, it included the effect of project participants as a 3rd dimension. In the modified framework, the 3rd dimension was removed to focus directly on the implementation process and make the framework simple. In addition, the impacts component had been associated with the benefits in the original framework and it was adjusted to be directly affected by the process. Thus, the original framework was subjected to a couple of adjustments and was simplified.

The resultant framework includes a total of 6 components including drivers, inputs, enablers, barriers, benefits, and impacts. Drivers are the motivation factors that push a company to implement BIM. Inputs represent the main resources that company utilizes. Barriers imply the main challenges encountered during the process. Enablers are the factors that facilitate the process. Benefits indicate the short-term project level gains. Impacts are the long-term company level outputs. All these components are in a direct relation with the BIM implementation process. The framework addresses almost all aspects of the BIM implementation process and can be seen in Fig. 1.

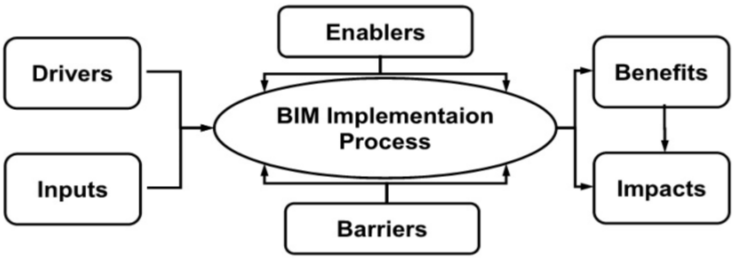

FIG. 1: The BIM implementation framework.

3.2 LIST OF CRITICAL SUCCESS FACTORS

A total of 45 journal papers and conference proceedings were reviewed. All the mentioned CSFs were noted, and an initial list CSFs was established. Then, the initial list was modified to obtain a more refined list of factors by grouping/merging similar factors and deleting some irrelevant ones. The frequency was counted for each CSF in the final list, where the frequency indicated how many sources had referred to the corresponding factor. It implied the significance of each factor in the literature. Table 1 and 2 present the components of the framework together with the assigned CSFs.

TABLE 1: List of drivers, inputs, and barriers.

Critical Success Factor		Source
Drivers	Improving corporate performance	5,7,10,17,22,25,26,30,39,40,41,42
	Improving project performance	2,3,5,6,7,10,11,16,17,18,19,20,22,23,25,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45
	Improving building's energy performance	1,2,10,14,16,17,18,19,20,22,23,26,27,28,30,31,32,33,34,36,37,38,40,41,43,45
	Improving collaboration and coordination	2,3,4,5,6,10,16,17,18,19,20,21,22,23,24,25,26,28,29,31,32,33,34,35,36,38,39,40,41,42,43,44,45
	Client requirement	4,7,9,10,11,17,19,20,23,25,41

Critical Success Factor		Source
	Governmental push	4,5,7,9,10,17,20,27,30,35,41,42
	Design improvement	1,2,3,5,6,7,10,12,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40, 41,42,43,44,45
	Improving construction productivity	4,6,10,12,18,19,20,21,23,25,26,28,30,31,32,33,34,35,36,37,38,39,40,41,43,44,45
	Improving HSE activities	10,18,37,43,44
	Reducing life cycle cost of the building	2,5,17,19,22,23,28,32,33,35,37,39,40,41,42,43,45
Inputs	Human resources	4,9,11,13,15,17,18,19,20,21,22,23,26,27,30,34,35,36,37,38,39,41,42,43,44
	Financial resources	1,2,3,4,5,9,11,12,14,15,17,20,23,38,39,40,41,42
	Technological infrastructure	1,2,4,5,6,8,9,10,11,13,14,15,16,18,19,20,21,22,23,24,25,26,27,28,29,30, 31,32,33,34,35,36,37,38,39,41,42,43,44
	Software and hardware	1,2,3,4,5,6,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24,25,26,27,28,29,30, 32,33,34,35,36,37,38,39,41,42,44
	Custom 3D library	3,6,13,17,21,22,25,27,30,33,37,42
	Internal knowledge	4,6,9,13,15,17,19,20,22,23,34,35,39,40,42
	External knowledge and consultancy	9,15,17,18,19,20,23,38,39,41
	Project information	3,6,9,12,14,15,18,20,27,39,40,43
	Project BIM execution plan	4,6,12,13,16,17,18,20,22,32,34,36,37,38,41
	Company's BIM policy	5,6,9,10,15,17,18,23,25,29,32,34,36,38,41
	BIM guideline	2,8,9,10,11,13,14,17,20,28,29,30,31,32,35,38,39,41,42
	Training and education	1,2,3,4,5,6,8,9,11,12,15,16,17,19,20,22,23,25,26,29,30,34,35,36,38,39,40,41,42
Barriers	Availability of knowledge based on experience	2,4,5,7,11,13,17,18,19,20,21,22,23,25,26,27,28,29,33,35,38,39,41,42,45
	Unclear benefits	4,17,20,21,23,25,28,30,35
	Lack of best practices	1,4,5,9,11,17,20,21,22,25,26,27,28,32,33,35,36,39,41,45
	High costs	1,2,3,4,5,11,13,17,18,19,20,21,22,23,24,25,26,27,28,29,30,32,33,35,39,41,42,45
	Technology related problems	2,3,4,5,7,8,11,13,17,18,19,20,21,24,25,26,27,28,29,32,33,35,36,38,39,40,41,42,43,45
	Change process problems	1,2,3,4,7,8,11,13,15,17,18,19,20,21,24,26,27,28,29,30,32,33,35,36,38,39,40,41,42,44,45
	Legal and protocol problems	2,3,4,5,8,9,11,13,17,18,19,20,21,26,27,30,33,35,38,39,41,42,44,45
	Fragmented nature of the industry	2,3,11,19,20,21,23,33,39,40,41
	Interoperability problems of different parties	4,6,7,8,11,13,17,18,19,20,23,35,38,40,41,42,43
	Project specific problems	1,2,3,4,5,6,7,11,13,18,19,20,21,23,24,27,28,33,35,36,38,39,40,42,45
	Lack of government support	21,23,35,41

Sources: 1) Yan and Damian, 2008. 2) Sun et al., 2017. 3) Stanley and Thurnell, 2014. 4) Kassem et al., 2012. 5) Ghaffarhouseini et al., 2017. 6) Arayici et al., 2012. 7) Cao et al., 2017. 8) Shang and Shen, 2014. 9) Ozorhon and Karahan, 2016.10) Eadie et al., 2013. 11) Newton and Chileshe, 2012. 12) Barlish and Sullivan, 2012. 13) Chien et al., 2014. 14) Suermann and Issa, 2009. 15) Abbasnejad et al., 2016. 16) Coates et al., 2010. 17) Hancock et al., 2017. 18) Migilinskas et al., 2013. 19) Broquedas et al., 2013. 20) Gu and London, 2010. 21) London et al., 2008. 22) Arayici et al., 2011. 23) Karahan, 2015. 24) Alder, 2006. 25) McGraw-Hill Construction, 2014. 26) McGraw-Hill Construction, 2008. 27) Tulenheimo, 2015. 28) Marshall-Ponting et al., 2009. 29) Kovacic et al., 2015. 30) Smith, 2014. 31) Giacomo, 2015. 32) InfoComm International, 2013. 33) Eastman et al., 2011. 34) Krygiel and Nies, 2008. 35) Luo et al., 2018. 36) Kovacic and Filzmoser, 2015. 37) Kymmell, 2008. 38) Alazmeh et al., 2017. 39) World Economic Forum, 2018. 40) Liu et al., 2013. 41) Nanajkar and Gao, 2014. 42) Syazwani et al., 2017. 43) Singh et al., 2017. 44) Mostafa and Leite, 2018. 45) Tereno et al., 2018.

TABLE 2: List of enablers, benefits, and impacts.

Critical Success Factor		Source
Enablers	Corporate and academic level collaboration	4,6,9,15,17,18,19,20,23,29,30,34,38,39,41
	Project level collaboration	4,6,8,9,11,15,17,18,19,20,21,22,23,25,26,28,29,30,32,33,34,35, 36,37,38,39,41,42,44,45
	Managerial and technical abilities	9,11,15,17,18,20,22,23,27,28,29,33,35,39,41,42
	Supportive organizational culture	2,4,5,6,7,8,9,11,13,15,17,18,19,20,21,22,23,27,30,32,33,34,35, 36,37,38,39,41,42,44,45
	External grants, incentives, and promotions	2,5,7,9,10,11,12,13,17,19,20,22,27,30,31,32,33,35,38,39,41,42
	Global standardization	17,21,23,30,31,33,35,39,41,42
	IPD type contracts	4,17,18,19,33,35,39,40,41,42,44
	Planning of BIM execution process	4,15,17,20,21,32,33,38,39,41,42
Benefits	Project financial benefits	1,2,4,5,6,8,12,13,14,16,17,18,19,22,23,25,26,30,31,32,33,34,35, 36,39,40,41,42,43,45
	Right and accurate construction activities	1,2,3,4,5,6,8,12,13,14,15,16,17,18,19,22,23,25,26,27,28,30,31, 32,33,34,35,36,37,38,39,40,41,42,43,44,45
	Right and accurate technical office works	2,3,5,6,8,12,13,14,16,17,18,19,21,22,23,24,25,26,28,30,31,32,33, 34,35,37,38,39,40,41,42,43,44,45
	Improve staff performance	1,2,5,6,12,17,19,20,21,22,23,24,30,32,33,34,35,39,40,41,42,43,44,45
	Knowledge management benefits	1,2,5,6,17,18,19,20,21,22,23,24,25,26,32,33,34,35,37,39,40,41,42,43, 44,45
	Claim management benefits	2,3,5,12,13,14,17,19,22,25,26,28,29,31,32,33,35,36,40,41,42,43,45
	Reduction of facility management costs	5,8,12,17,18,19,20,21,25,31,32,33,34,35,40,41,42,43,44,45
	Client satisfaction	4,5,6,19,41
	Improve communication and collaboration	1,2,4,5,6,12,16,17,18,19,20,22,23,25,26,28,29,31,32,33,34,35,36,39,40, 41,42,43,45
	Improve energy savings	5,19,26,28,29,32,33,34,36,37,39,40,41,42,43,45
Impacts	Company's productivity improvement	2,4,5,6,12,14,17,19,21,22,23,25,26,28,29,30,32,33,34,35,36,37,40,41,43, 44,45
	Corporate management improvement	6,19,22,23,25,28,33,34,35,42,45
	Expanding company's scope of services	22,25,31,32,39,41
	Enable new businesses	5,7,16,19,22,23,25,27,31,32,34,41
	Improve corporate financial performance	5,6,19,22,23,25,30,31,32,41,42
	Generate corporate knowledge	1,6,7,22,33,44

Sources: 1) Yan and Damian, 2008. 2) Sun et al., 2017. 3) Stanley and Thurnell, 2014. 4) Kassem et al., 2012. 5) Ghaffarhouseini et al., 2017. 6) Arayici et al., 2012. 7) Cao et al., 2017. 8) Shang and Shen, 2014. 9) Ozorhon and Karahan, 2016.10) Eadie et al., 2013. 11) Newton and Chileshe, 2012. 12) Barlish and Sullivan, 2012. 13) Chien et al., 2014. 14) Suermann and Issa, 2009. 15) Abbasnejad et al., 2016. 16) Coates et al., 2010. 17) Hancock et al., 2017. 18) Migilinskas et al., 2013. 19) Broquedas et al., 2013. 20) Gu and London, 2010. 21) London et al., 2008. 22) Arayici et al., 2011. 23) Karahan, 2015. 24) Alder, 2006. 25) McGraw-Hill Construction, 2014. 26) McGraw-Hill Construction, 2008. 27) Tulenheimo, 2015. 28) Marshall-Ponting et al., 2009. 29) Kovacic et al., 2015. 30) Smith, 2014. 31) Giacomo, 2015. 32) InfoComm International, 2013. 33) Eastman et al., 2011. 34) Krygiel and Nies, 2008. 35) Luo et al., 2018. 36) Kovacic and Filzmoser, 2015. 37) Kymmell, 2008. 38) Alazmeh et al., 2017. 39) World Economic Forum, 2018. 40) Liu et al., 2013. 41) Nanajkar and Gao, 2014. 42) Syazwani et al., 2017. 43) Singh et al., 2017. 44) Mostafa and Leite, 2018. 45) Tereno et al., 2018.

3.3 DATA COLLECTION PROCESS

This study followed a case study-based data collection process in order to evaluate the CSFs based on real experiences. The case study selection criteria were based on a better representation of the data. Thus, it was decided to select cases from different types of projects (airport, metro, hospital etc.) and different types of project parties (designer, contractor, consultant) as well. In this way, a better representation of the real world was achieved. An interview transcript was developed to systematically collect the data. The transcript was aiming to gather vital info regarding the project, the company, and the interviewee(s). A sample of the interview transcript can be found in Appendix A.

Face-to-face interviews were conducted to obtain data. In order to gain a better understanding of the evaluations regarding the CSFs, 18 projects were investigated in detail. Interviews constitute an important part of the case study methodology and allow to obtain the target information. Case studies have an exploratory nature rather than developing a hypothesis and testing the theory (Thies and Volland, 2010). The case study's strength comes from its wide variety of evidence including documents, interviews and observations (Yin, 2003). During the interviews, rather than just evaluating the CSFs, interviewees were also asked to share their own experience for that particular project and allowed the researchers to access related project documents.

There are four main criteria to ensure that the case study is credible and persuasive (Yin, 2003): (i) construct validity (quality of operationalization of the concept being investigated); (ii) internal validity (a specific event led to another, a causal relationship between two events); (iii) external validity (the extent to which the findings can be generalized); and (iv) reliability (repeatability with the same results). In order to enhance the validity of the research, various evidences obtained from the case studies were achieved, a framework was established and multiple case studies were performed. Lastly, a database was constructed within the scope of this study to allow replication of the study and ensure reliability.

In order to assess the significance of the identified CSFs and obtain a more realistic result, the framework has been evaluated with the industry experts working in BIM implemented projects. In this way, it is aimed to reveal the real process of BIM implementation and to compare the industry facts with the literature. 25 Industry experts from 18 projects were accepted to make a face to face interview. The details regarding the case projects can be seen in Table 3.

TABLE 3: Information about the case studies.

#	Type	Interviewed Party	Area (m^2)	Contract	Budget	Duration (Months)	Savings	BIM Investment	Size of BIM Team	BIM Level
1	Retail	Consultant	150K	Unit Price	-	24	2 M TL	3%	7	5D
2	Airport	Consultant	12M	Lump Sum	-	24	-	< 1%	35	7D
3	Interior	Consultant	6K	Unit Price	-	6	15%	< 1%	7	4D
4	Airport	Contractor	76M	Unit Price	35 B TL	42	-	-	15	7D
5	Industrial	Designer	60K	Lump Sum	-	6	-	-	5	5D
6	Airport	Contractor	700K	Lump Sum	2 B USD	60	-	-	40	-
7	Airport	Contractor	60K	Lump Sum	200 M EUR	24	-	-	15	-
8	High Rise	Contractor	350K	Lump Sum	500 M USD	36	-	-	-	4D
9	Building	Contractor	113K	Unit Price	600 M TL	25	-	< 1%	7	5D
10	Medical	Consultant	12K	Lump Sum	-	4	-	-	8	4D
11	High Rise	Designer	430K	Lump Sum	> 2 B TL	36	-	< 1%	5	4D
12	High Rise	Designer	-	Lump Sum	-	-	-	-	5	-
13	Medical	Contractor	1M	BOT	1.5 B USD	36	20-25%	1%	9	5D
14	Industrial	Designer	650	Lump Sum	-	8	10%	-	8	-
15	Industrial	Designer	-	Lump Sum	-	24	10%	-	3	-
16	Building	Contractor	-	Lump Sum	-	-	-	-	3	4D
17	Retail	Contractor	200K	Lump Sum	-	36	-	< 1%	10	4D
18	Infrastructure	Consultant	-	-	2.3 B TL	36	-	-	10	-

During the interviews, multiple interviewees were participated in order to obtain different perspectives and to prevent biases regarding the process. Different experience levels of the respondents were also important to obtain different perspectives. Interviewees were chosen from top management level to project engineer level and mainly had an engineering or architectural background. Each face-to-face interview took almost an hour. The collected data were processed into a comprehensive excel spreadsheet and mean values were calculated for each CSF based on specific criteria such as influence levels, project types, or BIM application.

4. FINDINGS AND DISCUSSION

The results of the case study interviews are presented in Table 4 and 5 for various components of BIM implementation. The findings show the influence level, frequency, and rating for each CSF. Presentation of the frequency and rating of each factor enables comparison of the significance of each factor in the literature and in real case projects.

TABLE 4: Findings for the drivers, inputs, and barriers.

#	Component	Factor	Influence Level	Frequency	Rating
1	Drivers	Improving corporate performance	Firm level	12	4.44
2		Improving project performance	Project level	34	4.78
3		Improving building's energy performance	Project level	26	2.83
4		Improving collaboration and coordination	Project level	33	4.72
5		Client requirement	Project level	11	3.61
6		Governmental push	Industry level	12	1.44
7		Design improvement	Project level	38	4.56
8		Improving construction productivity	Project level	27	4.50
9		Improving HSE activities	Project level	5	1.61
10		Reducing life cycle cost of the building	Project level	17	2.78
1	Inputs	Human resources	Project level	25	4.67
2		Financial resources	Project level	18	4.17
3		Technological infrastructure	Industry level	39	4.28
4		Software and hardware	Firm level	40	4.50
5		Custom 3D library	Industry level	12	3.56
6		Internal knowledge	Firm level	15	4.72
7		External knowledge and consultancy	Project level	10	2.89
8		Project information	Project level	12	4.50
9		Project BIM execution plan	Project level	15	4.61
10		Company's BIM policy	Firm level	15	4.06
11		BIM guideline	Industry level	19	4.22
12		Training and education	Firm level	29	4.50
1	Barriers	Availability of knowledge based on experience	Firm level	25	3.83
2		Unclear benefits	Project level	9	2.56
3		Lack of best practices	Industry level	21	2.67
4		High costs	Project level	28	2.39
5		Technology related problems	Industry level	30	2.22
6		Change process problems	Industry level	31	3.83
7		Legal and protocol problems	Industry level	24	1.67
8		Fragmented nature of the industry	Industry level	11	2.61
9		Interoperability problems of different parties	Project level	17	3.00
10		Project specific problems	Project level	25	2.78
11		Lack of government support	Industry level	4	2.22

TABLE 5: Findings for the enablers, benefits, and impacts.

#	Component	Factor	Influence Level	Frequency	Rating
1	Enablers	Corporate and academic level collaboration	Industry level	15	3.22
2		Project level collaboration	Project level	30	4.61
3		Managerial and technical abilities	Firm level	16	4.50
4		Supportive organizational culture	Firm level	31	4.39
5		External grants, incentives, and promotions	Industry level	22	2.44
6		Global standardization	Industry level	10	3.94
7		IPD type contracts	Project level	11	2.67
8		Planning of BIM execution process	Project level	11	4.68

#	Component	Factor	Influence Level	Frequency	Rating
1	Benefits	Project financial benefits	Project level	30	4.17
2		Right and accurate construction activities	Project level	37	4.72
3		Right and accurate technical office works	Project level	34	4.56
4		Improve staff performance	Project level	24	4.67
5		Knowledge management benefits	Project level	26	4.83
6		Claim management benefits	Project level	23	4.28
7		Reduction of facility management costs	Project level	20	2.44
8		Client satisfaction	Project level	5	4.28
9		Improve communication and collaboration	Project level	29	4.17
10		Improve energy savings	Project level	14	2.78
1	Impacts	Company’s productivity improvement	Firm level	27	4.61
2		Corporate management improvement	Firm level	11	4.28
3		Expanding company’s scope of services	Firm level	6	4.11
4		Enable new businesses	Firm level	12	4.67
5		Improve corporate financial performance	Firm level	11	4.17
6		Generate corporate knowledge	Firm level	6	4.67

4.1 Drivers

Drivers can be described as the forces that push a company to implement BIM. According to the evaluations the industry experts (ratings), “improving the project performance” emerges as the most important one. With a slightly lower rating, “improving the collaboration and coordination” was found as the second most important driver. The least significant factor is identified as “governmental push”. Based on the literature analysis, “design improvement”, “improving project performance”, and “improving collaboration and coordination” have been identified as the most frequently referred drivers. In parallel, Eadie et al. (2013) have identified "improving design quality" as one of the most important drivers. Another study conducted for 4D BIM implementation within the UK AEC industry shows that "an internal push force by clients" and "an external push force by governments" are the driving forces (Kassem et al. 2012). Since the study conducted for UK, the local legislations may strengthen the importance of those factors when compared to Turkey. During the interviews, it has been observed that although the importance of “improving HSE activities” is evaluated as one of the lowest, there is a high potential for combining BIM with safety tools. Industry professionals indicated that “coordinating HSE discipline with BIM would be great to identify potential risks”. In addition, it is clear that the construction industry is developing new ways to enhance the safety performance (Demirkesen ,2020). A previous research conducted by Kiral et al. (2015) argues that V-SAFE can improve the risk recognition capability and the spatial awareness of the users.

4.2 Inputs

Inputs can be described as the utilized resources for the BIM implementation. Among the 12 identified inputs of BIM implementation, “internal knowledge” is evaluated as the most important resource. In addition, “human resources” and “project BIM execution plan” are the second most significant resources based on the ratings of the industry professionals. Except the “external knowledge and consultancy”, all the inputs are evaluated as significant factors for the case projects. Thus, identifying the resources and investing on the right ones are crucial for a successful BIM implementation. The factors that have highest literature frequency are “softwares and hardwares” and “technological infrastructure”. Arayici et al. (2012) reported that decision on utilized software is very important. Technology is essential for BIM implementation in both firm level and industry level. Findings of this study showed that combination of BIM implementation with the most recent technology is highly significant. Laser scanning of existing structures are getting popular and especially using unmanned aerial vehicles (UAVs - Drones) for the laser scanning may be a good development for BIM implementation.

4.3 Barriers

Barriers represent the challenges encountered during the BIM implementation process. Among the barriers, "availability of knowledge based on experience" and "change process problems" are the most significant ones according to the ratings. Newton and Chileshe (2012) revealed that lack of understanding and awareness acting as a barrier to BIM. Gerrard et al. (2010) also supported this finding as they revealed lack of BIM knowledge and expertise as the greatest barrier. Moreover, Aladağ et al. (2016) identified "organizational structure and culture" as the most important obstacle faced in Turkish construction industry that complicate using BIM. The least significant barrier was identified as "legal and protocol problems". Erpay (2021) stated that stakeholders' legal concerns arising from the BIM integration can be eliminated by integration of all parties into the contract preparation phase. According to the frequencies, "change process problems" and "technology related problems" are the most frequently referred barriers. In a case study, Migilinskas et al. (2013) argued that data transfer among the particular tools (software and hardware) was limited due to incompatibility and transmission of the consistent information to other participants. In addition, Cecchini (2019) conducted a study to overcome the interoperability issues regarding the BIM and GIS integration to achieve a spatial relational database aimed at information management on historical city centres.

4.4 Enablers

Enablers can be described as the factors that facilitate the BIM implementation process. Based on the ratings, it is observed that "planning of the BIM execution process", "project level collaboration", and "supportive organizational culture" are the most significant enablers. The most frequently mentioned enablers in the literature are identified as "supportive organizational culture" and "project level collaboration". Similarly, in the literature, Abbasnejad et al. (2016) argued that knowledge sharing and communication could play a vital role for BIM implementation. On the other hand, "global standardization", "IPD type contracts", and "planning of BIM execution process" are the least frequently mentioned factors in the literature. However, "global standardization" and "planning of BIM execution process" have been identified as one the most important factors by the industry experts. Since IPD type contracts improve the project level collaboration, BIM implementation in IPD projects is expected to give better results.

4.5 Benefits

Benefits are the short-term gains from the BIM implementation. Among the 10 previously identified benefits, "knowledge management benefits" have been evaluated as the most significant short-term outcome of the BIM implementation. Since this study aims to investigate the BIM implementation for the construction phase, the second most important benefit has been evaluated as "right and accurate construction activities". The two least significant benefits of the BIM implementation are revealed as "reduction of facility management costs" and "improve energy savings". Considering the frequency, "right and accurate construction activities" and "right and accurate technical office works" are the top mentioned factors in the literature. Yan and Damian (2008) indicated reducing time and cost and improving quality as the most important benefits of BIM in UK and US construction industries. Stanley and Thurnell (2014) investigated the 5D BIM implementations in New Zealand and revealed that utilizing BIM improved earlier risk identification compared with the traditional approaches and it is known that construction industry is vulnerable to the risks (Demirkesen, 2020). In addition, it has been argued that BIM provides significant input for digital twin applications especially in the new projects (Madubuike, 2022).

In terms of benefits, literature frequencies and industry evaluations are almost parallel except "client satisfaction". The least mentioned benefit of the BIM implementation is "client satisfaction" in the literature even though it has been identified as one of the most important benefits. Broquetas et al. (2013) claimed that owner received a big injection of confidence in the GC when the PM showed how design decisions impacted cost and schedule. Moreover, it has been observed that significances of "improve energy savings" and "reduction of facility management costs" are highly dependent on the BIM objective of a particular project. If a company targeted 6D BIM implementation, then energy savings became an important benefit. Similarly, if a company focused on 7D BIM implementation, then reduction of facility management costs became an important benefit.

4.6 Impacts

Impacts can be described as the long-term outcomes of the BIM implementation. Industry professionals have evaluated the “enable new businesses” and “generate corporate knowledge” as the most significant impacts of BIM implementation followed by “company's productivity improvement”. In parallel “company’s productivity improvement” is the most frequently mentioned impact. The identified impacts have an average rate greater than 4, implying that industry professionals find the long-term outcomes of the BIM implementation highly significant. According to a research based on a case study, Arayici et al. (2011) emphasized the requirement of internal capacity in case a company desired improvement in efficiency and effectiveness. Nevertheless, “enable new businesses” should also be addressed as a crucial impact. Ghaffarianhoseini et al. (2017) stated maintaining relationships with past clients for new businesses as a major impact of BIM. From the industry experts’ perspective, all the CSFs of the impact component is highly significant.

4.7 Comparison of CSFs for Different Project Types

For the high-rise building projects, “client requirement” and “improving construction performance” have been identified as the most significant drivers. When it comes to the inputs, “training and education” has been evaluated as the most important input for the airport projects. In terms of barriers, airport projects differentiate from the overall ratings. The most significant barriers have been identified as “project specific problems” and “fragmented nature of the industry” for the airport projects. Since governments frequently get involved in airport projects, the least important barrier has been evaluated as “lack of government support”. For medical building projects, “improving corporate performance” has been identified as a crucial driver and “client requirement” as the least significant driver. Different than the overall average ratings, “availability of knowledge based on experience” and “lack of best practices” have been identified as the most important barriers and “interoperability of different parties” as the least important barrier for medical building projects. In contrast with the overall average ratings, “fragmented nature of the industry” has been evaluated as the least significant barrier for industrial building projects.

4.8 Discussion Based on BIM Application Level

When the driving factors are examined, it can be interfered that in contrast to 4D and 5D BIM implemented projects, “improving building's energy performance” found as the most significant driver with an average rating of 5 out of 5 in 7D BIM implemented projects. Although “BIM guideline” has been evaluated as highly significant for 4D and 5D BIM implemented projects as an input, it has been evaluated very low (1 out of 5) for 7D BIM implemented projects. Since the 7D BIM application has a relatively low adoption rate within the industry, most of the guidelines may not cover 7D implementations. When it comes to barriers, “availability of knowledge based on experience” and “lack of best practices” have been differentiated for 7D BIM implementation with a low level of significance.

As an enabler, “corporate and academic level collaboration” has been evaluated as highly significant for 5D and 7D BIM implemented projects whereas it has been evaluated to have a low level of significance for 4D BIM implemented projects. Except the factor “reduction of facility management costs”, all of the benefit factors have almost been evaluated as highly significant. Since 7D BIM implementation is more about facility management, “reduction of facility management costs” has a very high average rating (5 out of 5) for 7D BIM implemented projects and very low (2 out of 5) for 4D and 5D BIM implemented projects. All of the factors within the impacts have been almost evaluated as highly significant.

In summary, it has been observed that 7D BIM implemented projects differentiate from the 4D and 5D BIM implemented projects in terms of significance of the CSFs. Regardless of the BIM function utilized within a project, is has been observed that collaboration is crucial for a successful BIM implementation and IPD approach enhances the BIM implementation. It can be argued that implementing BIM together with the other related concepts such as IPD, lean, sustainability or agile fosters the BIM implementation.

4.9 Discussion on Influence Levels and Comparison of Components

It can be deduced that impacts represent most significant component of the framework. Since the impacts can be defined as the long-term firm level effects of BIM implementation, this result indicates that utilizing BIM is highly significant for the companies. In addition, benefits and inputs are also differentiated as highly significant. Table 6 shows the average case study ratings for the components based on the influence levels.

TABLE 6: Ratings of the components based on the influence levels.

Component	Influence Level	Average Rating	Overall Rating
Drivers	Industry	1.44	3.53
	Firm	4.44	
	Project	3.67	
Inputs	Industry	4.02	4.22
	Firm	4.44	
	Project	4.17	
Barriers	Industry	2.54	2.71
	Firm	3.83	
	Project	2.68	
Enablers	Industry	3.20	3.82
	Firm	4.44	
	Project	4.02	
Benefits	Industry	N/A	4.09
	Firm	N/A	
	Project	4.09	
Impacts	Industry	N/A	4.42
	Firm	4.42	
	Project	N/A	

On the other hand, the table indicates the least important component of the framework as the barriers. This situation might result from the fact that all the interviewed projects have utilized BIM and therefore, they have already overcome most of the identified barriers. Only some of the specific barriers are encountered for some particular projects. For the drivers, project and firm level factors are considered as significant whereas industry level factors are evaluated to have a lower significance. It can be deduced that firm level factors are the most important drivers for the BIM implementation. When it comes to inputs, it is observed that project, firm, and industry level factors have almost equal average ratings evaluated as highly significant.

For the barriers, the firm level factors are evaluated as more significant than the project and industry level factors. When the enablers are examined, similarly, it can be deduced that the firm level factors are more significant than the project and industry level factors. However, it is also obvious that industry level factors are not very significant as an enabler. It might stem from the lack of industry level BIM initiatives in Turkey. By the definition, benefits contain only project level factors and impacts contain only firm level factors. When the overall influence level ratings are compared, it is observed that the most important influence level is the firm level. This finding indicates that companies invest in BIM for themselves rather than the project itself.

5. CONCLUSION

Although the BIM adoption rate has been increasing by the time, the adoption process is quite slow. Due to the lack of guidelines for BIM implementation process, companies mostly have no idea about what they might encounter during the implementation process. Identifying the components of BIM implementation process with the underlying CSFs would be an essential guide for the companies at the beginning of the process. Unlike the other studies in the literature, this research has identified the CSFs based on a comprehensive framework and evaluated their significances based on data collected from case studies. In addition, the identified factors have been categorized into the influence levels and compared with each other.

This study fills an important gap in the literature by identifying the CSFs of BIM implementation process and assessing them on various real case projects. Moreover, different than the other studies, this research has investigated a large number and various types of case studies. This helped researchers compare the results for different types, sizes, and functions of projects. In addition to the previous study findings, this study has revealed that significance of the CSFs can depend on the BIM implementation objectives of the industry professionals. If a company or project does not aim at utilizing BIM for facility management, then the factors regarding the facility management become inefficient.

Further studies might analyze the BIM implementation process based on the research findings and develop a BIM implementation roadmap for the industry. They may investigate different kind of innovations within the construction industry based on the followed methodology. As the combination of BIM implementation with the recent developments in the technology fosters its benefits, future studies might focus on developing a model based on the laser scanning of existing structures. Especially, scanning of on-going constructions via using unmanned aerial vehicles (UAVs - Drones) may provide a better construction monitoring process.

This research was limited to new construction projects that were on the construction phase. However, since Turkey has an enormous number of existing building and infrastructure stock, investigation of BIM implementation for existing structures with the help of laser scanning and big data technology can also be a great field of research. Although the number of examined case studies were very high compared to similar researches, this research was limited to Turkish construction industry. For further studies, this framework may be used in different countries and with different case studies for comparisons. Turkey, as a developing country, is at the initial stage of BIM adoption. In recent years, BIM implementation become widespread within the Turkish construction industry. Since this research has been conducted for Turkish construction companies, the results may be applicable for companies at other developing countries.

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APPENDIX A

GENERAL INFORMATION (Respondent)

1) Your profession :
2) Your experience in construction industry (years) :
3) Your position in your company :
4) Your Age (Optional) :

GENERAL INFORMATION (Company)

5) Company name (not obligatory) :
6) Field of operation : ☐ ENGINEERING ☐ ARCHITECTURE ☐ CONSTRUCTION ☐ PROJECT MANAGEMENT ☐ CONSULTANT
7) Your company's expertise areas : ☐ BUILDING ☐ INFRASTRUCTURE ☐ TRANSPORTATION ☐ OTHER:
8) Annual turnover of your company (Optional) :
9) Total number of employees of your company :
10) Number of countries that your company has been operating :
11) Number of years that your company has been operating (general / in Turkey) :
12) Total number of projects that your company involved in Turkey :
13) Year that your company adopted BIM :
14) Projects utilized BIM in Turkey (specify function (Design, Construciton, Facility Management)) :

GENERAL INFORMATION (Project)

15) Project name :
16) Project type : ☐ BUGILDING ☐ INFRASTRUCTURE ☐ TRANSPORTATION ☐ OTHER:
17) Project ownership : ☐ SOLE ☐ JOINT VENTURE ☐ CONSORTIUM ☐ OTHER:
18) Your company's role in the project :
19) Total construction area of the project (m2) :
20) Contract type of the project : ☐ UNIT PRICE ☐ LUMP SUM ☐ TURNKEY ☐ COST PLUS FEE ☐ OTHER:
21) Contractural budget of the project :
22) Total amount of cost savings (if possible, %) :
23) Duration of the project :
24) Total amount of time savings (if possible, %) :
25) Total amount of BIM investment for the project (%) (Specify type if possible) : AMOUNT (%): ☐ HR ☐ SOFTWARE ☐ CONSULTANCY ☐ TRAINING ☐ OTHER:
26) Number of employees in your BIM team :
27) Softwares / Tools to utilize BIM : OTHER:

☐ Revit ☐ 3D Studio Max ☐ Dynamo ☐ ArchiCAD ☐ V-Ray ☐ CorelCAD ☐ Bentley ☐ Naviswork

☐ SAP2000 ☐ ETAPS ☐ AutoCAD ☐ GIS ☐ Plaxis ☐ Geodin ☐ Micro Station ☐ Tekla BIMsight

☐ BIM360 Glue ☐ Naviswork ☐ Synchro ☐ Maximo ☐ ARCHIBUS ☐ Primavera ☐ Eco domus

☐ BIM360 Docs ☐ BIM Track ☐ Prolog ☐ Aconex

28) DRIVERS (Pushed you to utilize BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
To Improve Corporate Performance	Company image, competitiveness, gain experience					
To Improve Project Performance	Efficiency, quality, speed, cost, risk reduction					
To Improve Building's Energy Performance	Sustainability, LEED, lean implementation					
To Improve Collaboration & Coordination	IPD, collaboration, coordination,					
Client Requirement	Contractual obligation					
Governmental Push	Law enforcement					
For Design Improvement	Clash detection, visualization, simple revision process					
To Improve Construction Productivity	Site logistics, optimized schedules, prefabrication					
To Improve HSE Activities	Safety measurements					
To Reduce Life Cycle Cost of The Building	Maintenance & usage costs					

29) INPUTS (Resources used to utilize BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Human Resources	Qualified staff & leader					
Financial Resources	Investment					
Technological Infrastructure	Technological developments enhancing the scope of BIM					
Softwares & Hardwares	Modeling & managing programs, computers					
Custom 3D Library	Open family libraries					
Internal Knowledge	Company know-how					
External Knowledge & Consultancy	Outsource know-how, consultancy					
Project Information	Drawings, specifications, project data					
Project BIM Execution Plan	BIM implementaion routeway					
Company's BIM Policy	BIM implementation approach					
BIM Guideline	BIM implementation rules					
Training & Education	Internal & external staff trainings					

30) BARRIERS (Problems encountered during the process)- Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Availability of Knowledge Based on Experience	Lack of experience, awareness					
Unclear Benefits	Lack of tangible benefits					
Lack of Best Practices	Lack of cases, benchmarks, universal use					
High Costs	Time, HR, software & hardware investment					
Technology Related Problems	Licensing, data interoperability, reliability					
Change Process Problems	Resistance to change, company culture, fear of failure					
Legal & Protocol Problems	Lack of legal protocols, ownership, responsibilities					
Fragmented Nature of the Industry	Number of parties getting involved to the process					
Interoperability Problems of Different Parties	Low collaboration, interoperability					
Project Specific Problems	Delivery method, contract type, unique requirements					
Lack of Government Support	Lack of incentives, initiatives					

31) ENABLERS (Things that facilitates BIM adoption)- Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Corporate & Academic Level Collaboration	Academic partnership, research teams					
Project Level Collaboration	Communication, involvement of parties					
Managerial and Technical Abilities	Experience level, right decisions					
Supportive Organizational Culture	Commitment, internal support					
External Grants, Incentives & Promotions	Industry level commitment, governmental support					
Global Standardisation	Common standards, protocols					
IPD Type Contracts	Integrated delivery system					
Planning of BIM Execution Process	Making an implementation plan					

32) BENEFITS (Project level gains from BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Project Financial Benefits	Cost and time reduction					
Right and Accurate Construction Activities	Less rework, better site planning, reduce risk, high quality					
Right and Accurate Technical Office Works	Minimize errors, better estimates, clear results					
Improve Staff Performance	Staff understandig and awareness of the project					
Knowledge Management Benefits	Better documentation, easy tracking					
Project Management Benefits	Reduce RFIs, claims, change orders					
Reduction of Facility Management Costs	Reduced maintenance & usage costs					
Client Satisfaction	Happy client					
Improve Communication & Collaboration	Low number of meetings, effective communication					
Improve Energy Savings	Better energy analysis					

33) IMPACTS (Company level gains from BIM) - Please indicate the importance level of the relevant critical success factor in your project (1 Lowest - 5 Highest)

	Description	1	2	3	4	5
Company's Productivity Improvement	Improved business value					
Corporate Management Improvement	Better administration, marketing, organizational structure					
Expanding Company's Scope of Services	New services					
Enable New Businesses	Competitiveness, reference projects					
Improve Corporate Financial Performance	Increased ROI					
Generate Corporate Knowledge	Archive of knowledge and information					