IDENTIFYING CRITICAL SUCCESS FACTORS FOR SUCCESSFUL BIM-FM IMPLEMENTATION IN CONSTRUCTION PROJECTS

by

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ABSTRACT

IDENTIFYING CRITICAL SUCCESS FACTORS FOR SUCCESSFUL BIM-FM IMPLEMENTATION IN CONSTRUCTION PROJECTS

The use of BIM (Building Information Modeling) in FM (Facility Management) is becoming increasingly common around the world, but despite a large number of studies focusing on BIM implementation success in design and construction, there is still no consensus on how to evaluate BIM-FM integration success. The primary goal of this research is to identify and prioritize BIM-FM related CSFs and offer an Analytic Network Process (ANP) model to evaluate factors in construction projects carried out by Turkish contractors. Its purpose is to provide some guidance on how to make BIM-FM deployment more efficient. It also intends to acquire insights on the state of BIM-FM integration in Turkey from professionals working in the Turkish construction sector who are specialists in BIM-FM processes, as well as interpret the CSFs listed. To achieve these objectives, identified CSFs are grouped into stakeholders-related, technology-related, design-related, and handover process-related factors. The focus group sessions are used to collect data on interrelationships and relative importance ratings. ANP is then used to compute the priorities and importance weights. “BIM education and training for employees”, “Top leadership backing and motivation”, “Availability of capable/experienced personnel (both in FM and AEC)”, “Early involvement of Facility Managers in the BIM process”, “Using BIM to maximize potential cost savings (return on investment of built assets)” success factors and “stakeholders related factors and “design process-related factors” groups are among the essential findings of this study. Interviews are used to evaluate the final CSFs list and obtain input on the current status of BIM-FM integration in the Turkish construction sector and assess the advantages and barriers to BIM-FM integration indicated in the literature. This model gave industry representatives a way to analyze the effectiveness of their BIM-FM integration. The suggested model’s findings may help FM and AEC organizations review their projects and take the required steps to ensure project success.

ÖZET

İNŞAAT PROJELERİNDE BAŞARILI BIM-FM UYGULAMASI İÇİN KRİTİK BAŞARI FAKTÖRLERİNİN BELİRLENMESİ

FM'de (Tesis Yönetimi) BIM (Yapı Bilgi Modellemesi) kullanımı dünya çapında giderek yaygınlaşmaktadır. Tasarım ve yapım aşamasında BIM uygulama başarısına odaklanan çok sayıda çalışmaya rağmen, BIM-FM uygulama başarısının nasıl değerlendirileceği konusunda fikir birliği yoktur. Tezin birincil amacı, BIM-FM entegrasyonu ile ilgili CSF'leri belirlemek ve önceliklendirmek ve Türk müteahhitler tarafından yürütülen projelerde faktörleri değerlendirmek için bir Analitik Ağ Süreci (ANP) modeli sunmaktır. Ayrıca tezin bir başka amacı BIM-FM uygulamasının nasıl daha etkili hale getirilebileceğine dair bilgi sunmaktır. Son olarak, BIM-FM süreçlerinde uzman olan Türk inşaat sektöründe çalışan profesyonellerin Türkiye'deki BIM-FM durumuna ilişkin bakış açılarını elde etmek ve listelenen faktörlerin yorumlanması amacıyla mülakatlar yapılmıştır. Bu hedeflere ulaşmak için, literatür taraması ve odak grup yardımıyla tanımlanan kritik başarı faktörleri paydaşlarla ilgili, teknolojiyle ilgili, tasarımla ilgili ve devir teslim süreciyle ilgili faktörler olarak gruplandırılmıştır. Bu çalışmada karşılıklı ilişkiler ve göreceli önem dereceleri hakkında veri toplamak için odak grup toplantıları yapılır. Daha sonra ANP methodu öncelikleri ve önem ağırlıklarını hesaplamak için kullanılır. BIM-FM entegrasyonu için en önemli beş faktör "Çalışanlar için BIM eğitimi", "Liderlik desteği ve motivasyonu", "Yetenekli/deneyimli personelin mevcudiyeti", "Tesis Yöneticilerinin BIM sürecine erken katılımı" ,"BIM'i potansiyel maliyet tasarruflarını arttırmak için kullanmak" ve en önemli iki kategori "paydaşlarla ilgili faktörler" ve "tasarım süreci ile ilgili faktörler" olarak bulunmuştur. Türk inşaat sektöründe BIM-FM uygulamalarının mevcut durumu ve literatürde belirtilen avantaj ve engellerini değerlendiren bu model, sektör temsilcilerine BIM-FM entegrasyonunun etkinliğini analiz etmeleri için bir yol sağlamaktadır. Önerilen modelin bulguları, tesis yönetimi ve yüklenici firmalarının projelerini gözden geçirmelerine ve proje başarısını sağlamak için gerekli adımları atmalarına yardımcı olacaktır.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS/ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
4D	Four Dimensional
5D	Five Dimensional
6D	Six Dimensional
7D	Seven Dimensional
AEC	Architecture Engineering Construction
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BAS	Building Automation System
BEP	Building Information Modeling Execution Plan
BIM	Building Information Modeling
CAS	Communication Automation System
CAFMS	Computer-Aided Facility Management Systems
CEM	Construction Engineering Management
COBie	Construction Operations Building Information Exchange
CMMS	Computerized Maintenance Management System
CSFs	Critical Success Factors
FAHP	Fuzzy Analytic Hierarchy Process
FAS	Firefighting Alarm System
FM	Facility Management
GIS	Geographic Information System
IAI	International Alliance for Interoperability
IBM	International Business Machines Corporation
IDP	Information Delivery Plan
IFC	Industry Foundation Classes
IFMA	International Facility Management Association

IoT	Internet of things
ISO	International Organization for Standardization
KPIs	Key Performance Indicators
LOD	Level of Development
MCDM	Multi Criteria Decision Making
O&M	Operations and Maintenance
OIR	Organizational Information Requirements
ROI	Return on Investment
SAS	Security Automation System
US	United States
QA	Quality Assessment
QC	Quality Control

1. INTRODUCTION

The introduction covers the background of the research, problem statement, research questions, aim and objectives, methodology, and organization of the thesis.

1.1.Background

Owners and project stakeholders are frequently concerned with the project's early construction expenses. Nevertheless, a building's later operating and maintenance expenditures during its lifetime might be several times greater than its initial cost of construction (Becerik-Gerber *et al.*, 2012). BIM implementations in design and construction have progressed beyond the research phase and are now extensively used; nevertheless, BIM implementations in facility management (FM) are still evolving, so studies on the subject are still in their infancy (Pishdad-Bozorgi *et al*., 2018). However, FM should receive greater attention because it is the most significant aspect of the building life cycle. The data gathered during the BIM modeling process may be helpful since it is a database that corresponds with the physical building (Becerik-Gerber *et al.*, 2012). Although the benefits of using BIM in FM are well known, and some FM organizations strongly encourage this use, it is still controversial how and how much BIM can be used for FM and what are the conditions for BIM in FM to be successful (Becerik-Gerber *et al.*, 2012). According to Oluleye *et al.* (2021), BIM implementation in FM has been gradual and insufficient due to a lack of knowledge about the critical success factors (CSFs) required for performance.

The performance management topic associated with FM is a hot research area in academia where prominent researchers emphasize the necessity for further research. Worryingly, no measurement matrix or indicator of the Facility Management performance exists inside the BIM-governed design and construction. Without these critical performance indicators, no way exists to correctly measure or grasp whether the facility manager can improve the design and construction process (McAuley *et al*., 2015). Organizations may use these feedback procedures and systems to enhance FM performance and establish data needs for future capital projects, such as building performance (Asare *et al*., 2022). One of the methods used for this is developing success parameters and creating a framework. For this purpose, this thesis serves to establish the critical success factors required for BIMenabled-FM to be successful.

1.2.Problem Statement and Research Questions

There is a significant gap in the literature for evaluating BIM-FM integration performance, and no research specific to the Turkish construction industry exists. This thesis focuses on the critical success factors of BIM-FM integration and makes recommendations for how to improve success. So, this research makes a significant contribution to the literature. Construction projects carried out by Turkish contractors were chosen for this study to evaluate critical success factors for successful BIM-FM.

The research questions of this study are;

- What are the critical success factors (CSFs) for BIM-FM integration?
- From the perspective of the AEC practitioners in Turkey, what is the relevance of critical success factors in order of priority?
- What is AEC representatives' feedback on BIM-FM integration in Turkey?

1.3. Aims and Objectives

The aim of this thesis is to identify CSFs based on BIM-FM integration and to prioritize these factors by focusing on national and international projects undertaken by Turkish contractors.

The following research objectives have been developed in order to reach the aim.

- Review the literature and identify CSFs relevant to successful BIM-FM integration and classify the CSFs and determine interrelations among them through literature review and focus group sessions.

- Construct an analytic network process (ANP) model, which is a decision-making method to assess the CSFs of BIM-FM integration and reveal the level of importance of CSF and determine which CSFs are the most and least essential.
- With the help of interviews, learn about AEC experts' views on the current state of BIM-enabled FM applications, get expert feedback on the final list of CSFs, and evaluate BIM-FM practitioners' satisfaction with BIM-FM's benefits and barriers.

1.4. Methodolody

This chapter covers the research methodology. First and foremost, to fully address the research questions and objectives, an extensive literature review was undertaken using keywords such as BIM, Facility Management, FM-enabled BIM, etc. A mixed-method methodology (a combination of qualitative and quantitative approaches) was selected to answer the research questions better.

In the second phase, the CSFs list was gathered with the help of the literature review and expert opinions. The ANP method is chosen as the most appropriate approach for factor prioritization, taking into consideration the interrelation of the factors. An ANP model was constructed for the survey preparation based on expert feedback on the interrelation and pairwise comparison matrices. After, the questionnaire survey was performed and administered through the internet. The participants were chosen based on their expertise with BIM FM integration on projects. "Super Decisions" software tool was utilized to calculate importance weights and priorities.

In the third phase, semi-structured interview questions were created with the help of experts. The purpose of the interview is to understand the current state of BIM-enabled FM applications in Turkey, evaluate BIM-FM practitioners' feedback on BIM benefits and barriers, and seek for interpretations of the survey results and final CSFs list. Hence, discussion and conclusions will be presented according to the data results and the interview. The flow and phases of the research technique are depicted in Figure 1.1.

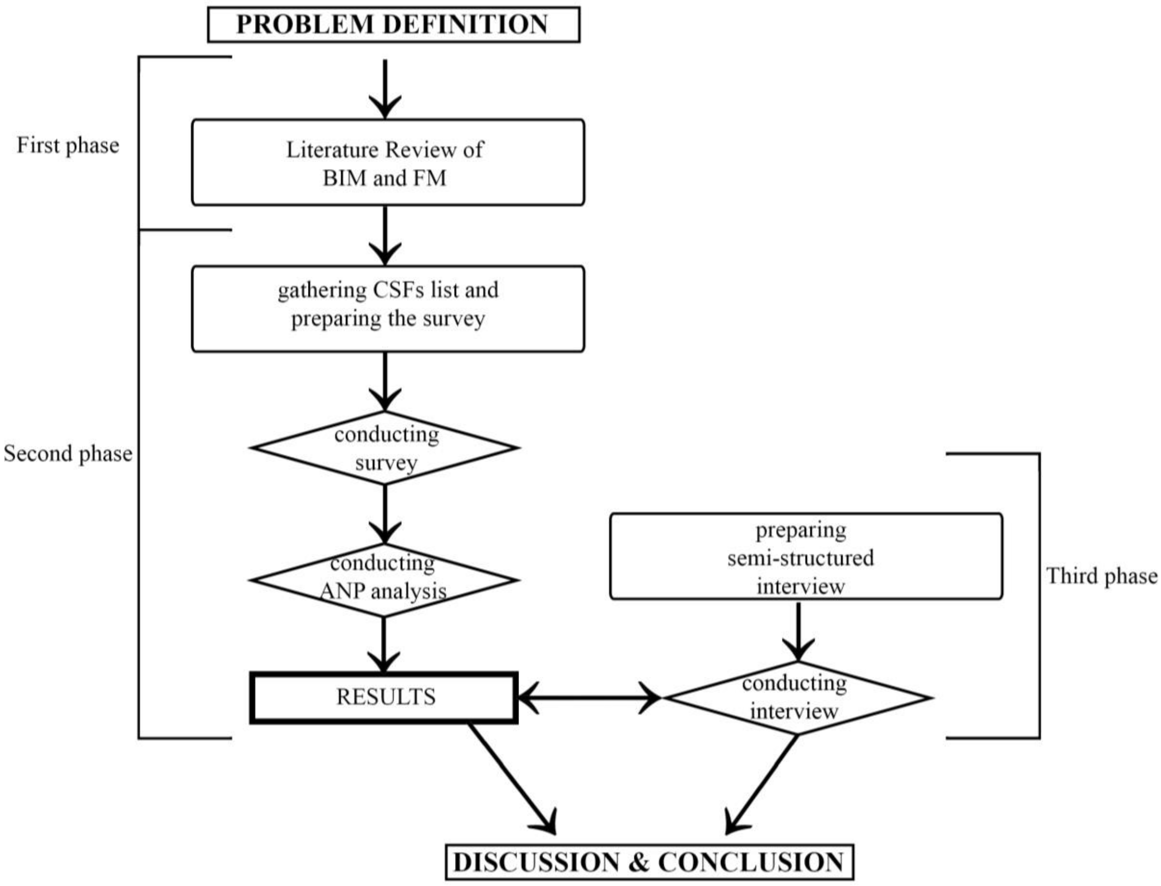

Figure 1.1. Methodology of the Thesis.

1.5. Organization of the Thesis

Chapter 2 provides a detailed review of the relevant literature on Building Information Modeling (BIM), Facility Management (FM) and their integration, the benefits and barriers of this integration, previous studies of the relevant literature, and gap.

In chapter 3, the research methodology is explained in detail, including the theoretical background of AHP and ANP. This chapter presents the final CSFs list, "Super Decisions" software, interrelation matrix, model formation, web questionnaire survey, and pairwise comparison matrices.

In chapter 4, CSFs are mentioned with references and thoroughly addressed. The demographic structure of the respondents is thoroughly investigated. The priorities of the clusters and nodes are obtained, and also importance weights are given. The opinions obtained from the interviews are collected and presented together with the findings.

In chapter 5, the discussion section based on the research findings is presented, and the study’s limitations are given.

Chapter 6 presents the study’s conclusion and includes recommendations for further research.

2. LITERATURE REVIEW

In this section background of the research is provided through the literature review. BIM, the definition of FM, the integration of BIM-FM and, benefits and barriers of this integration, facility performance assessment are covered consecutively. Subsequently, previous studies and the gap in the literature are addressed.

2.1.Building Information Modeling

For decades, BIM has been a hot topic in the construction engineering management (CEM) industry. Liu and Zettersten (2016) stated that building information modeling (BIM) had proved its return on investment in design and construction in recent years. With digital representations of building products and processes, Building Information Modeling (BIM) provides a new approach to design, construction, and facility management and is employed to allow digital information interchange and interoperability (Eastman *et al*., 2008). BIM is a digitalized procedure of designing, building, and operating a facility with a data-driven 3D model that includes physical and functional characteristics, and it allows for the smooth flow of information in the digital environment throughout the building life cycle (Eastman *et al*., 2011). BIM offers the possibility to enhance building life cycle assessment performance through relational databases, reducing complexity, increasing adaptability to modifications, and boosting communication and cooperation (Nwodo *et al*., 2017).

There are several possible dimensions of the 3D BIM model; Smith *et al*. (2014) asserted that using 3D data enhanced with information about construction time (BIM 4D), cost estimation (BIM 5D), and life-cycle management (BIM 6D). According to Charef *et al*. (2018), there was also uncertainty between academics and practitioners on the 6D and 7D BIM dimensions. 86 percent of professionals that use 6D assign Sustainability to 6D, whereas 85 percent of professionals who use 7D use it for Facility Management (Figure 2.1).

In a 3D BIM model, all objects called families, which are parametric components, can have non-geometric and geometric information, containing all of the quantity, cost estimation, and project schedule. Many industry proponents say that BIM technology increases the capacity to integrate all project team members by more effectively expressing ideas and gives competitive benefits to innovative construction firms (Eastman *et al*., 2008). The fragmented structure of the AEC (Architecture, Engineering, Construction) sector necessitates a massive interchange of information. As Kunz and Fischer (2012) stated, this problem is solved using exchange protocols such as Industry Foundation Classes (IFC); computer-based integration enables a project team to transfer data among diverse modeling and analytic tools safely.

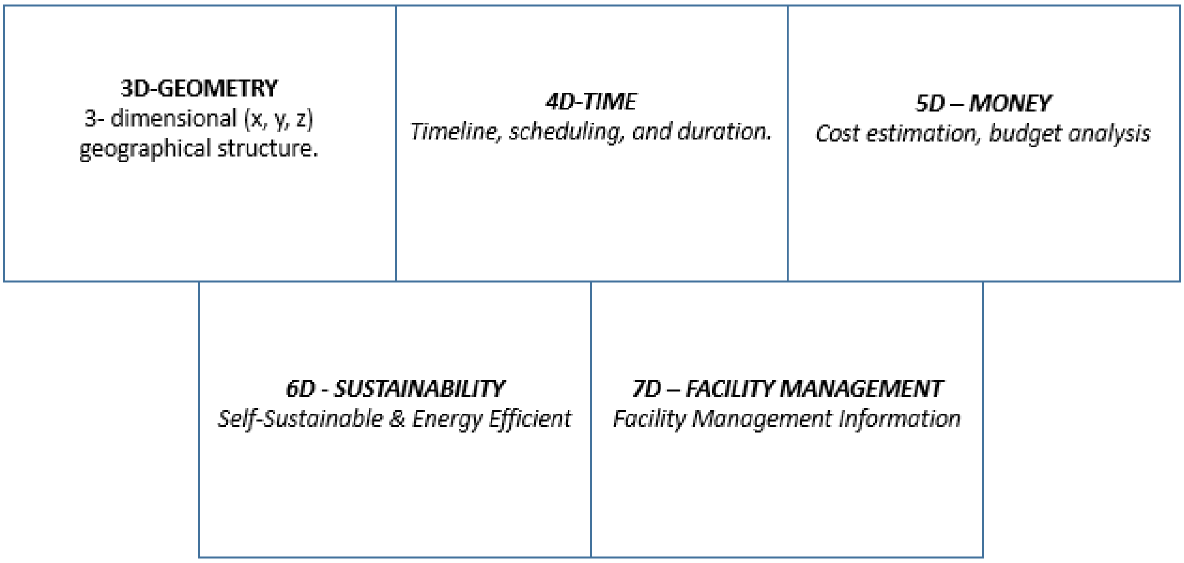

Figure 2.1. Possible dimensions of 3D BIM model (adapted from United-BIM (2021)).

BIM also has parametric features, which allow for real-time interactive adjustments (Lee *et al*., 2006). According to Dixit and Yan (2012), by using application programming interfaces (APIs), embedded building information may be retrieved, updated, and returned to the model. BIM can improve handover since data can be transferred from the model in a manner suited for FM needs (Wu and Issa, 2012). Professionals AEC and FM increasingly view BIM as a mindset for the complete built environment rather than a technology or a process.

Figure 2.2 depicts the assumption that the requirement for visuals is more significant during the design phase. BIM models were utilized during conceptual design to depict areas and generic items; as engineering study of various types progresses from conceptual to detailed design, more data are required. During construction, more data and detail (cost, procurement, installation, etc.) are required (IFMA, 2013).

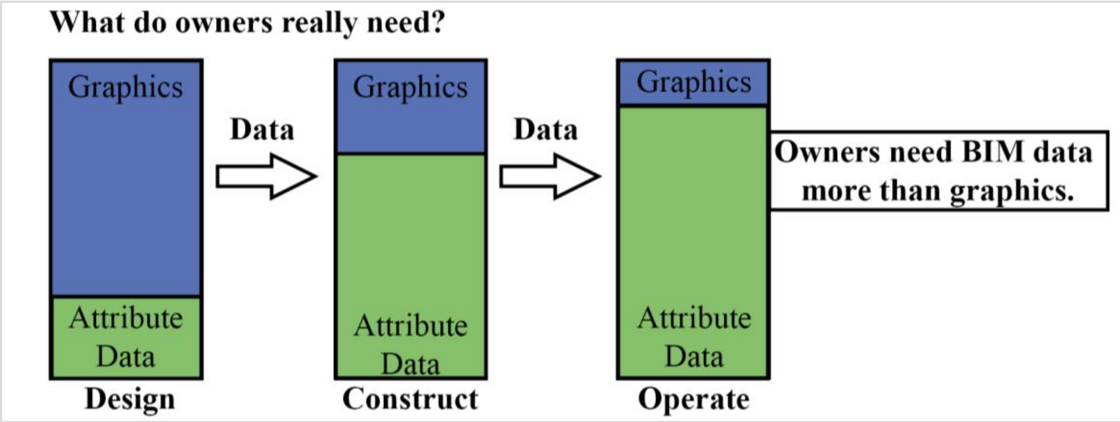

Figure 2.2. Graphics and data change over the life cycle of a facility (adapted from IFMA (2013)).

2.2.Facility Management

The International Facility Management Association (2021) identifies FM as "A profession that encompasses multiple disciplines to ensure functionality, comfort, safety, and efficiency of the built environment by integrating people, place, process, and technology". ISO (2017) defines FM as an "Organizational function that integrates people, location, and process within the built environment to improve people's quality of life and fundamental business productivity".

According to IBM (2021), FM is responsible for:

- Lease management, including lease administration and accounting,
- Capital project planning and management,
- Maintenance and operations,
- Energy management,
- Occupancy and space management,
- Employee and occupant experience,
- Emergency management and business continuity,
- Real estate management.

Throughout the last three decades or more, intelligent facilities and their management have seized the foundation of FM discussion, particularly in the long-running and contentious debate over the smart building and intelligent buildings (Xu *et al*.,2019). Advanced FM technology, software, and systems sparked a surge of 'intelligent' efforts and inventions (Xu *et al*.,2019). The widely used CMMS (computerized maintenance management system), CAFMS (computer-aided facility management systems), BAS (building automation system), CAS (communication automation system), SAS (security automation system), FAS (firefighting alarm system), extensively debated BIM technology, and intelligent public transportation systems are examples of these technologies and methods.

BIM is commonly used throughout the architectural, engineering, and construction phases, but it has been sluggish to catch on among FM experts (Edirisinghe *et al*.,2017). BIM is widely used for design & construction phases; however, facility management is the last regarded dimension of BIM; as Nordstrand (2000) stated, the facilities management phase is the final but by far the most extensive step in the lifetime of a building.

Typically, building owners and other construction project stakeholders focus on the initial design and construction expenditures of a structure since these occur in a relatively short period with potentially severe consequences compared to the facility's whole existence (Edirisinghe *et al*., 2017). However, it is estimated that design and construction account for less than 15% of a typical facility's life-cycle cost, whereas FM accounts for more than 85% (Teicholz, 2004). In terms of both time and expense, FM covers around 70-80 % of the whole life cycle of a structure (Lewis *et al*., 2010; Akcamete *et al*., 2010); as we can conclude, FM covers a non-negligible part of the life-cycle cost.

2.3. Facility Management -BIM Integration

Traditional facility management approaches lead to ineffective management (Durdyev *et al*., 2021). Because of the inherent environment of the AEC sector, various significant stakeholders contribute to the construction phase; as a result, data loss may occur during the operation and maintenance phase between those sophisticated systems. According to a study by the US Department of Commerce Technology Administration, annual losses in the US capital facility business due to insufficient interoperability are amount to $15.8 billion (Gallaher *et al*., 2004). The industry must first examine the financial benefits of BIM for FM, then define the FM-related data that should be included in BIM for various types of companies, and then review the tools, workflow, and best practices, among other performance measurements, criteria, and standards (Pishdad-Bozorgi *et al*., 2018). Because most construction innovation is co-developed at the design stage, it is vital to analyse BIM implementation by gathering multi-party viewpoints (Keskin *et al*., 2020).

FM-enabled BIM deployment digitally captures, maintains, and shares critical facility information in a set of linked BIM models (Pishdad-Bozorgi *et al*., 2018). Interoperability refers to transferring digital information across and inside firms' design, construction, maintenance, and business process systems (Lavy *et al*., 2019). Many academics agree that data loss upon handover is a significant issue for FM, which BIM might assist in overcoming (Patacas *et al*., 2015; Parsanezhad and Dimyadi, 2014; Wu and Issa, 2012). Space management, maintenance management, asset management, renovation/retrofit planning, energy analysis & management, security and emergency management, inventory management, personnel training and development, occupancy planning, and performance monitoring are some of the FM domains that can benefit from the 3D BIM model (Alvarez-Romero, 2014; Nical and Wodynski, 2016; Hosseini *et al*., 2018; Becerik-Gerber *et al.*, 2012). Embracing FM to BIM from the early design stage might potentially minimize maintenance efforts throughout the operating phase of facilities (Wang *et al*., 2013; Ashworth *et al*., 2018).

The two open-source formats used for this sort of information transmission in BIM-enabled FM are industry foundation classes (IFC) and construction operations building information exchange (COBie) (Patacas *et al*., 2016). The buildingSMART (2021), formerly known as the International Alliance for Interoperability (IAI), is an international organization dedicated to improving information sharing across software systems used in the construction sector. It created Industry Foundation Classes (IFCs) to serve as a neutral and open specification for BIM, Building Automation Systems (BAS), and Geographic Information System (GIS). IFC, or "Industry Foundation Classes", is a standard digital description of the physical environment, including facilities and civil infrastructure. It is a vendor-neutral, international open standard (ISO 16739-1:2018) that may be used across a wide range of hardware devices, software products, and interfaces for various use cases (buildingSMART, 2021).

> *"COBie or Construction Operations Building Information Exchange is a modern data format that is used to streamline the handover process to the operators or owners of a building. COBie is essentially an information exchange specification that can be viewed in the form of simple spreadsheets or within sophisticated design, construction and maintenance software. COBie is specific information set in the form of a simple spreadsheet that offers consistent and structured information about an asset that is useful in post-occupancy facility management and decision making" (United-BIM, 2022).*

The open standard COBIE format is designed to make the transfer of facility data into CMMS as simple as possible (Pishdad-Bozorgi *et al*., 2018). A digitized handover file containing all the building information is prepared for the client using BIM integration through the FM team's in-house software and the Construction Operations Building Information Exchange (COBie) and IFC data (McAuley *et al*., 2015).

The BIM-FM integration process may be separated into three steps: (1) modeling, (2) BIM model connection with the BIM-FM platform and CMMS system, and (3) operation and maintenance (Kula and Ergen, 2021). Level of development (LOD) is a critical issue, which should be determined in the early design stages according to the project type concerning COBie (Ashworth *et al*., 2018). LOD is a term used in architecture and construction to classify the level of detail of a model, which determines the level of information it conveys to the client and contractor (Jang and Collinge, 2020). Instead of including useless information, the LOD should ideally only include critical information needed for construction and facility management (Sacks *et al*., 2018). LOD is divided into five levels: LOD 100 to LOD 500 (Latiffi *et al*., 2015). These layers are conceptual, as-built, and facility management (Reddy, 2012). While designing a project, the LOD level is determined based on the needs of the construction players. LOD 100 is roughly akin to conceptual design, whereas LOD 200 is comparable to schematic design (Weygant, 2011; Reddy, 2012). Furthermore, LOD 300 is expanded to include construction documents, while LOD 400 is extended to include fabrication drawings (Weygant, 2011; Reddy, 2012). LOD 500 represents the as-built drawing and facility management data (Latiffi *et al*., 2015; Weygant, 2011; Reddy, 2012).

In 2018, Pishdad-Bozorgi *et al*. mentioned a pilot study for FM-enabled BIM for a public university building. The FM information in the BIM model was helpful on this project in a variety of ways, including verifying the design solution against the program, providing scheduled building equipment/component lists, determining construction submittal register requirements, identifying installed equipment, and all tagged building products and specifying close-out deliverables. BIM may also be used in conjunction with other FM technologies, such as Internet of things (IoT) sensors, to provide a virtual environment for managing real-time information. The internet of things (IoT) is defined as a network that connects over the internet and specifies processes through data exchange and communications (Dahanayake and Sumanarathna, 2021). Sensor-based automation is a crucial contribution of IoT technology to FM services such as; energy management, operations, maintenance management, space management, emergency management, FM project management, and quality management are all examples of IoT-BIM-based smart FM (Dahanayake and Sumanarathna, 2021).

2.4. Benefits and Barriers of BIM-Facility Management Integration

BIM adoption across FM is still in its early stages; however, it can integrate and bridge digital technologies already in use in various FM organizations. Like CMMS and CAFM, two of the most widely used FM software, it can store embedded asset information for responsive and preventive maintenance as well as monitoring activities, enabling process and work plan optimization; when integrated with BIM, they enable real-time communication of facility information with all stakeholders (Ghadiminia *et al.*, 2021). In this part, we will look at several studies conducted to examine the advantages and disadvantages of BIM adoption in FM in the literature.

2.4.1. Benefits of BIM-FM Integration

BIM establishes a practical budget management and control mechanism and cost control for facility managers (Naghshbandi, 2016). The design and construction industries have greatly embraced BIM as it can save significant time and money in a short period. In contrast, facility management is a much longer process over the entire life of a facility, and the benefits of new technologies may take longer to be evaluated (Lavy *et al.,* 2019). The advantages of using BIM in FM, from initial planning to the lifecycle stage, are also critical factors to project success (Terreno *et al.*, 2015).

Due to cost and time restrictions, FM practitioners face issues that result in lost productivity, efficiency, and effectiveness, which BIM aims to help them overcome (Arayici *et al.,* 2012). Cost savings and efficiency advantages associated with BIM-FM integration are based on a data-rich BIM model that automatically generates ready and reliable FM data (Arayici *et al.,* 2012).

The BIM model gives an accurate and up-to-date view of all facility elements. This data can be used to minimize operational problems during relocation and obtain more effective furniture placement. It helps define functional space thanks to the parametric and geographic information in the BIM model (Arayici *et al.*, 2012; Becerik-Gerber *et al.,* 2012). The BIM model shows the cleaning requirements and helps to identify hazardous areas and safe paths within a structure (Arayici *et al.*, 2012). Projected average waste per functional area can be viewed in the BIM interface and waste disposal monitored (Arayici *et al.*, 2012). BIM is a powerful tool for detecting vulnerabilities as it allows instant visualization of 3D spaces (Arayici *et al.,* 2012). If the model is constantly updated, it can give accurate inventory information about products and services.

The BIM model assists facility managers and engineers by providing data on building maintenance. In the BIM model, each lock in the building is identified; using this information, FM personnel will be able to identify precisely, place, and replace defective locks promptly (Arayici *et al.,* 2012). Information from BIM about the asset’s history and perceived deterioration can help determine if the asset needs to be repaired or replaced (Arayici *et al.,* 2012; Becerik-Gerber *et al.,* 2012; Ghadiminia *et al.,* 2021).

In Table 2.1, various studies have been conducted to investigate the benefits of BIM-FM integration. For this table, three latest studies that covered the literature extensively were used. In 2015, Terreno *et al*. used a case-study technique in order to elicit qualitative statements of benefits and listed 13 benefits as; notable advancements in teamwork, more in-depth strategic planning with a holistic approach, and more in-depth design assessments in order to achieve a more seamless lifecycle integration, design and construction requirements for FM are more clearly defined, the model includes specifications in contract papers, obtaining more precise data from a data-rich asset, model is automatically updated, improved compatibility with no changes to the existing data system, employee productivity, and efficiency have increased, data retrieval is simplified, shorter operational reaction times, more proactive maintenance and increased emergency preparation. The listed advantages highlight the value of BIM and the valid potential return on investment (Terreno *et al.*, 2015). In 2016, Aziz *et al.* asserted that the quality of life in the space would improve when BIM in FM is used to enable better functioning of the built environment. According to Aziz *et al.* (2016), the benefits of using BIM in FM for a better quality of life are 1) lower operating costs; 2) faster decision-making; 3) more decision-making resources; 4) improved documentation; 5) cooperation and working flexibility, and 6) up to date information and clash detection. In 2021, Ghadiminia *et al.* grouped BIM-FM benefits into three tasks financial asset management, space management, and operational management, and listed 18 benefits under these topics.

Table 2.1. The Benefits of BIM-FM Integration.

Financial asset management	enhancing productivity and efficiency (Ghadiminia *et al.*, 2021; Aziz *et al.*, 2016; Terreno *et al*, 2015).
	improving forecasting cost estimations (Ghadiminia *et al.*, 2021).
	informed decision-making (Ghadiminia *et al*., 2021; Aziz *et al*., 2016) .
	process optimization (Ghadiminia *et al*., 2021).
	real-time information is available for cost estimates (Ghadiminia *et al*., 2021).
	visual representation for project elements that must be estimated (Ghadiminia *et al*., 2021).
Space management	enhancing the efficiency of a facility’s assigned spaces (Ghadiminia *et al*., 2021).

Table 2.1. The Benefits of BIM-FM Integration (cont.).

Space management	process optimization for building uses (Ghadiminia *et al*., 2021).
	space, component, and event planning that is efficient (Ghadiminia et al., 2021).
	monitoring space used to make improvements (Ghadiminia *et al*., 2021).
	effective management of safety and security of facilities (Ghadiminia *et al*., 2021).
Operational management	creating and visualizing multiple scenarios in order to enhance the performance and functioning of a building (Ghadiminia *et al*., 2021; Terreno *et al*., 2015).
	the availability of accurate real-time information enables successful disaster management (Ghadiminia *et al*., 2021; Terreno *et al*., 2015).
	access to up-to-date, reliable information about MEP components and equipment (Ghadiminia *et al*., 2021; Aziz *et al*., 2016; Terreno *et al*, 2015).
	access to information needed for operations and maintenance (Ghadiminia *et al*., 2021; Aziz *et al*., 2016; Terreno *et al*, 2015).
	availability of accurate quantity take-off (Ghadiminia *et al*., 2021).
	model updates in real-time to reflect changes (Ghadiminia *et al*., 2021; Terreno *et al*., 2015).
	maintenance scheduling, monitoring, and management optimization to save time, money, and labor (Ghadiminia *et al*., 2021; Aziz *et al*., 2016; Terreno *et al*., 2015).

Table 2.1. The Benefits of BIM-FM Integration (cont.).

Between FM&AEC industry	collaboration and work flexibility (Terreno *et al.*, 2015; Aziz *et al.*, 2016).
	a better definition of FM requirements for design and construction (Terreno *et al*, 2015).
	incorporation of requirements into contract documents (Terreno *et al*, 2015).
	better interoperability that does not necessitate a change to the present data system (Terreno *et al.*, 2015).

2.4.2. Barriers of BIM-FM Integration

Regarding the apparent advantages of superior FM through BIM adoption, there is considerable reluctance to include the Facility Manager earlier in the design process (McAuley *et al*., 2015). However, despite the numerous advantages of BIM, specific barriers have been noted in the literature that appears to play a significant role in BIM's lack of application in FM. Volk *et al*. (2014) described the barriers as identifying the critical information needed, the high degree of work necessary to construct and maintain the BIM, and information interchange between the BIM and FM systems.

Dixit *et al*. (2019) held a study to find out what is preventing facilities management from being fully integrated into BIM technology. After conducting an extensive literature review over 54 papers, they grouped BIM-FM barriers into four subcategories; "(1) BIM execution and information management (confusing BIM procedure, inaccurate data collection, inability to update BIM data, and a lack of client desire); (2) technological (big files sizes, software problems, long adjustment durations when using new technology, file exchange conflicts, presence of numerous software, interoperability issues among BIM–FM); (3) cost-based (BIM people training expenses, information management costs, and unrealized cost advantages of implementing BIM) and (4) legal and contractual (Contractual and compliance difficulties, cyber confidentiality, and custody and accountability for BIM data)". In the category of BIM execution and information management, the study findings show that the most significant barrier to BIM–FM integration is that FM specialists are not included in the early BIM process to collect critical O&M data (Dixit *et al*., 2019). However, in the existing literature, the failure to update BIM information is the most severe problem in this category (Dixit *et al*., 2019). The study's findings confirmed that the most significant barrier to BIM–FM integration is the absence of engagement of FM specialists in the pre-design, design, and construction phases. Additionally, another significant barrier to BIM–FM integration may not be cost, technology, or legal difficulties but rather the inability to gather the necessary information correctly and completely (Dixit *et al*., 2019). Hence, this study also highlights the importance of the guidelines of FM data in the BIM model, including LOD, structure, and type should be determined (Dixit *et al*., 2019).

Table 2.2. Barriers to BIM adoption in FM (adapted from Durdyev *et al*. (2021)).

Code	Barriers
B1	BIM FM may not be compatible with existing methods of contracting
B2	Interoperability issues with existing software used by FM stakeholders
B3	Proof of effectiveness is required to sway conservative thinking/use of traditional methods
B4	Potential benefits of BIM for FM are unknown
B5	BIM marketing is targeted at design and construction, not FM
B6	Privacy concerns around use of digital software
B7	BIM is only likely to be used for FM if it was used during design and construction
B8	Facility mangers unfamiliar with BIM and associated technology will struggle
B9	Lack of legal framework for FM phase
B10	Research and development of BIM FM is far behind design and construction phases
B11	High cost for training
B12	High cost of software and hardware
B13	Info quality issues
B14	Limited best practice guidelines
B15	Multiple private software providers – which one should be used
B16	Fragmented systems, data is not stored in one location
B17	Lack of regulatory promotions/incentives from policy makers
B18	Unavailability of proper BIM training
B19	Lack of interest/reluctance to change as existing methods of operation are reliable
B20	Lack of experience in BIM FM
B21	BIM models work only in the software they were created on
B22	Lack of organizational (top management) support
B23	High cost of BIM implementation process in FM
B24	The construction industry is not sufficiently clear on what BIM is yet
B25	Not many opportunities to apply the BIM technology
B26	Late involvement of key stakeholders including FM

Durdyev *et al*. (2021) focused on barriers to BIM-FM integration in a rigorous literature review, identified 26 barriers (Table 2.2), and conducted a semi-structured interview in New Zealand to prioritize the barriers. The fuzzy AHP (FAHP) method was deployed for data analysis. Findings revealed that the top ten barriers in New Zealand are: "high cost of software and hardware, high cost for training, facility managers unfamiliar with BIM and associated technology will struggle, multiple private software providers who are confusing, lack of experience in BIM FM, lack of interest/reluctance to change as existing methods of operation are reliable, fragmented systems, data are not stored in one location, info quality issues, BIM is only likely to be used for FM if it was used during design and construction, research and development of BIM FM is far behind design and construction phases" (Durdyev *et al*., 2021).

2.5. Previous Studies and Gap in the Literature

In this section, considering the research questions, the gap identified in the literature will be reviewed, and past studies will be mentioned.

CSFs are described as "the few key areas of activity in which favorable results are necessary for a particular manager to reach his or her goals" (Rockart,1982). There are many studies regarding the success factors of BIM implementation on projects. Won *et al*. (2013) performed an international survey with 52 respondents from four continents, and they identified 56 CSFs from four topics: criteria for selecting BIM services, selecting BIM software, selecting BIM-based projects, and technical and organizational challenges in BIM adoption. Worth of BIM adoption, needs from corporate goals, demands from clients, and a degree of existing BIM system that enables the BIM-based services of interest were the top four CSFs for choosing BIM software. Sarkar *et al*. (2015) attempted to determine the Key Performance Indicators (KPIs) that influence the use of BIM as an FM tool, and 41 KPIs were discovered based on a primary data questionnaire survey completed by 69 respondents who were involved in the BIM industry in India and reduced them to 15 KPIs with factor analysis. According to the research findings, BIM is currently mainly used in the conceptual, design, and development stages (50 percent) of projects, followed by construction (30 percent) and operations (20 percent) stages in India. Also, 74% of respondents said it was beneficial to adopt BIM for FM. Giel and Issa (2016) sought to identify what critical factors should be measured in the assessment of building owners' BIM qualifications, as well as the salience of those factors by foremost experts in the study field, and to create a framework for aiding owner organizations in assessing their BIM competencies. In the study of Giel and Issa (2016), the importance of top management's buy-in and having a written quality control (QC) to review BIM outputs stand out as the first two factors in the prioritization phase of the research. In 2017, Ozorhon and Karahan surveyed public and private 96 practitioners in Turkey to prioritize 16 CSFs for BIM implementation. The findings reveal that the most essential five factors are "the availability of skilled personnel, strong leadership, access to information and technology, collaboration among project participants, and employee training", while the most critical CSFs groups for a successful BIM implementation found as "resource-related and human-related factors". Pishdad-Bozorgi *et al.* (2018) investigated a real-world FM-enabled BIM application in a five-story university building project in the US to evaluate the information required for FM-enabled BIM, expressing the process of collecting and managing, and exchanging FM-related BIM data. Finally, they have proposed FM-enabled BIM deployment success criteria. Three criteria must be met for a successful BIM-FM integration; a thorough understanding of what FM-enabled BIM entails, a streamlined and practical method for gathering FM-enabled BIM data throughout the project development process, and an interoperability plan for sharing data between BIM products and FM. In 2018, Ashworth *et al.* aimed to discuss creating and testing an employer's information requirements template and guide document designed to suit client and FM demands during the BIM process. During the interviews, the research findings assisted in identifying critical success factors. These findings reveal that facility managers generally believe that BIM can significantly benefit the FM sector. For the BIM process to achieve the benefits, clients and facility managers should have objectives tied to the organization's asset management plan from the beginning of the project. FM and clients must learn to actively engage in the BIM process and create an employer's information requirements that describe the process. According to the research, practitioners are looking for good reference examples and support when building an employer's information requirements template. Farahaneza *et al.* (2018) used content analysis methodology and an inductive coding approach to develop CSFs of BIM implementation in facilities management among selected 33 articles and listed 15 factors. Farahaneza (2018) examined the number of citations of these factors in the literature and revealed that the top five factors are: "top management commitment and support, training, and education, change management, product information sharing, the framework of BIM standards and guidelines, motivation". In 2019, Badrinath and Hsieh published a list of 38 CSFs and 13 operational critical success factors based on the perspectives of BIM professionals in Taiwan for the effective adoption of BIM projects. "Top management support, clash detection, 3D detailing, handover and commissioning, BIM-FM integration" ranked as the top 5 CSFs, and "Physical and knowledge infrastructure, technical tasks, general model use, BIM project management, stakeholders and project teams' roles and responsibilities" ranked as top 5 OCSF in BIM projects in Taiwan. From a literature review, Darwish *et al*. (2020) identified 51 CSFs of BIM implementation in construction projects and surveyed 345 participants. Only four research dealt with the CSFs of BIM deployment in underdeveloped countries prior to 2018. As a result, Egyptians and Saudis were selected to analyze the CSFs. Among the 51 criteria examined, 15 factors stood out. Among the factors, "collaboration among all project partners" ranked first, "training and development" ranked second, and "awareness level of the industry for BIM" ranked third. Ashworth (2020), in his PhD thesis, focuses on the United Kingdom market. The study's ultimate goal was to develop an "FM-BIM Mobilisation Framework" to assist people in better engaging with the BIM process and optimizing building assets in use. First of all, he described ten critical success themes as groups. The results of the questionnaire analysis were analyzed with descriptive and inferential statistics to establish a CSF list. 100 CSFs were listed under ten theme groups. In 2021, in Nigeria, Oluleye *et al*. seek to incorporate BIM to improve FM through a fuzzy synthetic evaluation technique for analyzing CSFs, which are gathered from a literature review. According to the findings (Oluleye *et al.,* 2021), FM leaders and employees have the most critical BIM knowledge management capabilities found as the first important category and followed by the FM organization's engagement with BIM, FM leaders and staff engagement with BIM, available BIM products, FM managers and employee commitment towards BIM, investing in BIM, and organizational preparedness for change are all followed.

For example, airport construction demands more sophisticated BIM design and implementation than building construction since airport design and construction integrate various combinations of infrastructure and services such as terminals, runways, passenger gates, car parks, and transportation systems, including railways and roads. Therefore an airport construction project must encompass all areas of those diverse structures (Keskin *et* *al*., 2019). One of the airport's research studies asserted that the biggest impediment to airport BIM adoption is the presence of highly siloed airport systems combined with a technology-averse workforce, which impedes data transfer processes. At the same time, the leading enabler is the use of more transparent BIM platforms in conjunction with an integrated project delivery approach (Keskin *et al*., 2019). It can also be shown that the perceived consequences of successful BIM implementation for an airport project are of great significance to a large number of stakeholders since they have considerable commercial value (Keskin *et al*., 2019). Another criticism raised by both the owner and the consultant is that the magnitude and complexity of the airport project, which resulted in a vast asset pool, is posing a challenge for BIM adoption throughout the facility management phase (Duncan *et al*.,2019). Still, there is no accepted standard for BIM integration since every airport has exceptional project scope items and procedures for the project delivery, although the use of BIM in aviation projects is expanding at a much higher rather than in other types of transportation projects (Keskin and Salman, 2020).

In 2013, Meng asserted that owners and facility managers of physical facilities had emphasized early FM engagement in recent decades, particularly in healthcare facilities. For a hospital in Sweden, BIM technology was used with a life cycle management system to simulate component degradation and justify extended maintenance policies (Hallberg and Tarandi, 2011). In 2021, Kamal *et al*. proposed a framework for BIM-based maintenance of healthcare facilities, the created BIM model delivers precise and trustworthy data for effective maintenance management in healthcare facilities as contrasted to 2D drawings, enhances the maintenance system by giving accessibility to accurate information, visualization of data, and data access time savings.

The facilities management sector is still in its early stages of implementing and utilizing BIM, and its business worth has yet to be determined (Lavy *et al*., 2019). When it comes to possible direct and indirect cost reductions in FM, the implementation of BIM for FM is critical for sustainable and profitable facility management. In 2015, Terreno *et al.* stated that future studies should focus on identifying CSFs generated from a benefits analysis and creating a structured model for calculating ROI (return on investment) throughout project lifecycle phases. The issue of performance management in connection to FM is now a developing and very dynamic field of study, with famous academics stressing the requirement for additional studies (McAuley *et al.*, 2015). To use BIM, the FM team will need to establish criteria for assessing operational efficiencies and cost benefits (Kiviniemi and Codinhoto, 2014). In 2022, Asare *et al.* conducted a study to identify research gaps related to the initiation and implementation of BIM for FM in large capital projects and eventually uncovered that one of the research gaps was “the development of value realization evaluation metrics for application/adoption of BIM for FM”.

There is a gap in the literature on this issue of standardized performance evaluation measures such as CSFs in BIM-enabled FM. Furthermore, no study is based on the Turkish construction sector to determine CSFs for BIM-FM integration exists. Hence, this thesis aims to contribute to the determination and prioritization of CSFs based on BIM-FM integration, focusing on international-national construction projects undertaken by Turkish contractors. CSFs will be derived from literature review and focus group sessions.

3.RESEARCH METHODOLOGY

3.1. CSFs Determination Process for BIM-Facility Management Integration

Various BIM standards and guidelines are in place to ensure that BIM technology and workflows are appropriately distributed. Unfortunately, only a few project objectives serve as guides or standards for appropriate BIM-FM integration. In this part, the CSFs for BIM-FM integration will be identified with the help of a literature review and focus group's opinions.

The CSFs for BIM-FM are searched with the keywords such as building information modeling (BIM), facility management (FM), BIM-enabled FM, FM enabled BIM, key performance indicators (KPIs), and critical success factors (CSFs), and operational critical success factors (OCSFs). Over 80 articles were investigated by academicians and practitioners who deal with the BIM environment. After reviewing studies in the literature, it was discovered that the substance of the studies is relatively similar. In addition, relative references have been utilized in the studies. Because these studies used similar CSFs and similar references, they contained similarities. As a result, several success factors with similar meanings are integrated and removed by combining their definitions. The first CSFs list was created by selecting 19 out of 80 studies published in the last nine years. In Appendix A, the first list of CSFs, which consists of 57 factors, was presented. Subsequently, before the focus group session, with the help of the literature review, CSFs reduced from 57 to 31. Then, these 31 factors were grouped into four subcategories: people-related, policy-related, technology-related, and process-related factors (Appendix B).

Different subgroupings in 19 studies were considered before grouping. For example, for his doctoral thesis, Ashworth (2020) categorized 112 CSFs under ten main themes of 'FM-BIM Mobilisation Framework', regarding optimizing built assets, under four categories: people, process, technology, and digitalization and policy. Sarkar *et al.* (2015) divided 41 KPIs of the BIM-FM integration into six subgroups; input-related, organization-related, process-related, project-related, BIM-related, and output-related indicators. In 2021, Oluleye *et al.* subcategorized the 23 CSFs for BIM-FM integration into six groups: adequate knowledge management of BIM in the FM industry, FM leaders and staff commitment to BIM, availability of the metric, model, and affordable technology for BIM, BIM investment and organization readiness for change, accessible BIM hard and soft packages, stakeholders' awareness and commitment to BIM. In 2016, Giel and Issa defined 66 critical BIM competency factors of facility owners and classified them as; strategic competencies, administrative competencies, and operational competencies. Badrinath and Hsieh (2019) defined 38 CSFs for successful BIM projects in Taiwan and divided these competency areas into six subgroups such as; operational, technical, functional, administrative, implementation, and managerial. In 2017, Ozorhon and Karahan defined 16 CSFs of BIM, with public and private sector participants in Turkey grouped as; human-related, industry-related, project-related, policy-related, and resource-related factors.

For the validation of the factors, a focus group session was held. The focus group consists of two academicians, one BIM Engineer, and one BIM Coordinator (Table 3.1) who have experience in BIM projects in Turkey at least five years. Expert opinions are taken to verify the adequacy, suitability, and categorization of the factors constituted from literature. According to experts' opinions, some factors were merged, four new factors were added, and subcategories were reorganized. Finally, revised 24 CSFs were grouped into four subcategories: stakeholders-related, technology-related, design process-related, and handover process-related factors. The final list of CSFs is shown in Table 3.2. Detailed explanations about the factors will be given in the results section.

Table 3.1. Focus Group Demographic Structure.

No	**Level of education**	**Current role**
Expert 1	Master's Degree	BIM Engineer
Expert 2	Master's Degree	BIM Coordinator
Expert 3	Bachelor's Degree	Academician
Expert 4	Doctorate	Academician

Table 3.2. Categorized Final Critical Success Factors List of BIM-FM Integration.

Sub Categories	**CSFs**	**CSFs for BIM enabled FM**
stakeholders related	S1	General commitment to BIM adoption for FM
	S2	BIM education and training for employees
	S3	Availability of capable/experienced personnel (both in FM and AEC)
	S4	Top leadership backing & motivation
	S5	Stakeholders (architecture, construction, engineering, facility management) collaboration on the project
	S6	Perceived ease of use
	S7	Government support and incentives for BIM in FM industry
technology related	T1	Design of well-executed 3D model and as-built data
	T2	Hardware and software for BIM-FM are readily available
	T3	Databases for BIM are readily available.
	T4	Cybersecurity for stored data
	T5	Cost of keeping system (continuous investment)
design process related	D1	BIM execution plan (BEP)
	D2	BIM standards and guidelines
	D3	Early involvement of Facility Managers in the BIM process
	D4	Project type/size/complexity
	D5	Determining Information Delivery Plan (IDP) (space, asset, energy, management data requirements)
	D6	QA/QC (quality assessment/quality control) plan for checking BIM deliverables
handover process related	H1	Well-executed interoperability plan for exchanging data between BIM tools and FM systems
	H2	Using BIM to maximize potential cost savings (return on investment of built assets)
	H3	Populating COBIe spread sheet from the model

Table 3.2. Categorized Final Critical Success Factors List of BIM-FM Integration (cont.).

Sub Categories	**CSFs**	**CSFs for BIM enabled FM**
handover process related	H4	Defining the mapping rules between shared parameters and COBIe parameters
	H5	Preparing a critical assets list
	H6	Tracking asset history

3.2. Theoretical Background

The primary purpose of this thesis is to identify factors for successful BIM-FM integration. For this purpose, all success factors were listed and categorized. The secondary aim is to evaluate the effects of these factors on construction projects in the Turkish AEC industry. The significant effects of these factors on successful BIM-FM integration will be calculated. This section will give detailed information about AHP and ANP, which are multi-criteria decision methods in the literature, to be used for this purpose.

There are several MCDM (multi-criteria decision-making) methods in the literature. AHP and ANP are the most relevant methodologies for this thesis. The theoretical underpinnings of AHP and ANP will be provided in the next part, and the justification for choosing ANP for this research.

3.2.1. Analytic Hierarchy Process and Analytic Network Process

Analytic Hierarchy Process and Analytic Network Process are theories based on individual and collective values and judgments (Saaty, 1996). These approaches rely on ratio scales to help establish objectivity by transferring values and judgments of qualitative human nature into a quantitative synthesis (Saaty, 1996). In 1980, Saaty first described the Analytic Hierarchy Process (AHP). El-Abbasy *et al*. (2013) summarized that AHP breaks down the decision issue hierarchically, which generally ends with scenarios or alternatives; after AHP assigns weights to items using pair-wise comparison and produces global weights for the last level evaluation by using a ratio scale, each pair-wise comparison assesses the relative importance or strength of the items inside criteria. However, AHP has a shortcoming as it neglects the interrelationships between nodes. This shortcoming is solved with the ANP method.

In 1996, Saaty developed the Analytic Network Process (ANP) as an advanced version of the AHP that considers interrelationships. In Figure 3.1, the differences between hierarchy and network structure are provided.

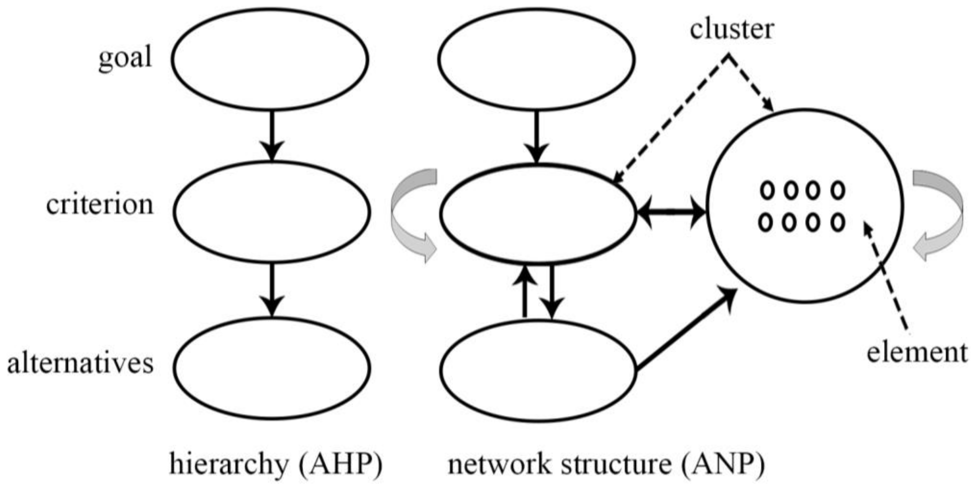

Figure 3.1. Differences between hierarchy (AHP) and network (ANP) structure (adapted from Chou (2018)).

According to Saaty and Vargas (2013), the ANP method consists of several steps:

- Create a network model for the problem, including interactions between goals, clusters, nodes, and alternatives.
- Perform pair-wise comparisons on the node level to build the unweighted supermatrix that contains local priorities.
- Perform pair-wise comparisons on cluster level to build a weighted supermatrix.
- Compute the limit supermatrix by multiplying the weighted matrix by itself.
- In the end, priorities and relative importance weights will be observed.

To perform pairs evaluations, we will need a numerical scale that shows how much more significant or dominating one element is over another in terms of the criterion or attribute against which they are compared (Saaty, 2008). A score of 1 indicates that the two elements contribute equally to the goal, whereas a score of 9 shows that one element is extremely important than the other. The numerical scale is shown in Table 3.2.

Table 3.3. The numerical scale of judgments (Saaty, 2008).

Importance	**Definition**
9	Extremely important
7	Very strongly important
5	Strongly important
3	Moderately important
1	Equally important
2,4,6,8	Intermediate values between the two adjacent judgments

For pair-wise comparisons, the aforementioned non-zero integers are always entered in the appropriate location, and its reciprocal is automatically entered in the transposition position(Saaty,2008). For pair-wise comparisons, the consistency ratio should be less than or equal to 0.10 (Saaty and Vargas, 2013). The inconsistency is a necessary correction to increase the comparability of results (Saaty and Vargas, 2013).

The ANP is a valuable tool for predicting and expressing a range of competitors' interactions and relative strengths to exert influence in a decision-making process (Saaty,1999). The ANP method was preferred over AHP because it is a MCDM method that allows pairwise comparisons and takes into account the interrelationships between factors. More sophisticated methods like structure equation modeling (SEM) may be preferred. However, considering the low adoption rate of BIM-FM in Turkey and the small sample size in the Turkish market, the ANP method was chosen because the study will be conducted with a limited number of participants. As Robinson (2014) mentioned, the ANP method can be conducted with a minimum of 3 participants. Although ANP has drawbacks such as being a subjective approach, it was determined to be the most accurate method for this study under these conditions. To reduce subjectivity, literature reviews and focus group sessions were employed. Using the ANP method will also contribute to the literature because there is no study in the literature that uses the ANP method to analyze the CSFs of BIM-FM integration. Table 3.3 presents the previous studies, the purpose of use, and the number of participants in the construction sector in which the ANP method is used. The ANP method is a preferred method in risk assessment and factor assessment.

Table 3.4. Previous Studies in the construction sector in which the ANP method is used.

Authors who used ANP Method	**Purpose of study**	**Number of participants for ANP Method**
Yi, 2014	Construction project risk evaluation	10
Aydoğan and Köksal, 2013	Construction risk factors on partner selection	8
Çomu *et al.*, 2021	Risk assessment of commercial real estate development projects	5
Bayesteh *et al.*, 2022	To evaluate factors influencing construction labor productivity	9
Erdem and Özorhon , 2015	Assessing real estate project success factors	8

ANP should be utilized whenever there are interdependencies among items (criteria and nodes). As a result, considering the interrelationships between the CSFs, it was decided that the ANP method would give more precise and realistic results for this study.

3.3. ANP Model Development

This study uses the Analytical Network Process (ANP) approach to prioritize CSFs in the successful BIM-FM integration process. The ANP model is based on the principle of defining the problem components, classifying them into classes that impact the goal, and discovering the relationships between them. Pairwise comparisons allow for the estimation of the weight of the classes on the goal as well as the calculation of the priority value of the factor interaction (Saaty and Vargas, 2013). As a result, the importance weight of all system elements are determined. In this section, the design steps of the ANP model will be explained.

3.3.1. Software

The program is known as "Super Decisions" and is commonly utilized in implementing ANP. Thomas L. Saaty was the founder of this network decision software. Super Decisions's user interface enables decision-makers to enter all data as input, compute, and acquire assessment results in only a few steps.

When you identify the internal and external dependencies and design your model in the Super Decisions software, the program automatically creates pairwise comparisons for your model. After collecting input data from experts and inserting it into the program, the software automatically calculates unweighted, weighted, and limit super matrices. While entering the inputs, the consistency ratios of the pairwise comparisons calculated automatically by the software should be reviewed. In the end, priorities and importance weights are obtained from the software.

3.3.2. Interrelation Matrix

Because the project success model includes several connected variables, ANP was chosen as the most appropriate approach in the research study. The ANP-based model consists of three steps: data gathering and model development, pairwise comparison matrices of connected variables, and supermatrix generation and importance weights of nodes and clusters. Once the list of CSFs has been created, the next step is data collection to reveal the interrelationships between the factors. Pairwise comparisons were created with the help of the interrelation matrix. The early mentioned focus group, which consisted of two academicians, one BIM Engineer, and one BIM Coordinator, was used for forming the interrelation matrix. In Super Decisions Software each CSF called a node, and subcategories called a cluster. Each node was examined to reveal interrelationships. To obtain a more reliable interrelation matrix, factor relationships were first examined through literature. Afterward, the consensus was achieved through brainstorming at the focus group meetings, and the final interrelation matrix was created.

Badrinath and Hsieh (2019) conducted a research study to identify operational CSFs for BIM projects and performed relationship mapping of CSFs in a spreadsheet matrix. As

Badrinath and Hsieh (2019) point out, “modeling effectiveness and productivity” is associated with “stakeholder skills and competencies”; nodes S2, S3 and S5 affect node T1. As Badrinath and Hsieh (2019) determined that there is a relationship between “general model use” and “stakeholder skills and competences”; node S3 affects node S5. As Badrinath and Hsieh said, there is a relationship between “quality management” and “skills and competencies of stakeholders”, that is node S3 affects node D6. Since Badrinath and Hsieh (2019) suggest, “integrated BIM meetings, model progress specifications, common data environment” and “project coordination and collaboration” are related, node S5 affects node D5. As Ashworth *et al*. (2018) asserted, the active participation of facilities managers early in the BIM process is critical for defining and managing what they need at handover. Many possible benefits and cost savings may not be fully achieved in operation if customers and facility managers do not participate in the BIM process and express their expectations properly (Ashworth *et al*., 2018). This is shown in the interrelation matrix as D3 influences D1, D5, and H2. BEP provides a means for project stakeholders to work together to negotiate, coordinate, and meet client demands (Ashwort *et al*., 2018). This is shown in the interrelation matrix as D1 affects S5. According to Ozorhon and Karahan (2017), “training of employee” and “availability of qualified staff” have a significant correlation. It is represented in the interrelation matrix as S3 affects S2.

The backing of senior management is essential to the success of BIM adoption (Arayici *et al.*, 2011). According to the literature on information technology adoption, the construction industry is dependent on leadership to overcome organizational and technological barriers (Dossick and Neff, 2010), which demonstrates the relation between S4 and S1, S2, T4, T5, D3. As a developing technology, industry participants from various backgrounds may have considerably varying experiences with BIM, resulting in solutions with variable accuracy (Farahaneza *et al.*, 2018), which demonstrates the relation of S2-BIM education and training for employees and S1, S5, T3, D5, D6, H1. Successful adoption of BIM requires a framework in which all BIM standards and data definitions are required (Howard and Bjork, 2008), showing that D2 influences D1 and H4.

Given this prior information from the literature, meetings were conducted with the focus group. Apart from the things imported from the literature, they have suggested some additional relationships. As mentioned, some relationships were examined through the literature, and the rest were revealed through focus group meetings, and the resulting interrelation matrix (Table 3.5) was created. For example, they have stated that S5-Stakeholders collaboration on the projects affects the whole of the handover process-related factors. S8- Government support and incentives for BIM in FM industry affects S1, S2, S4, T2, T5, and D2. Furthermore, T1-well executed 3D model affects H1, H2, H3, H4, and H5. D5- Determining Information Delivery Plan affects H1, H2, H3, H4. Additionally, H1- Well-executed interoperability plan for exchanging data between BIM and FM affects H3, H4, H5, and H6. H4- Defining the mapping rules between shared parameters and COBIe parameters affects H1, H2, and H3.

Table 3.5. Interrelation Matrix.

INTERRELATION MATRIX		**STAKEHOLDERS**							**TECHNOLOGY**					**DESING PROCESS**						**HANDOVER PROCESS**					
	CSFs	S1	S2	S3	S4	S5	S6	S7	T1	T2	T3	T4	T5	D1	D2	D3	D4	D5	D6	H1	H2	H3	H4	H5	H6
STAKEHOLDERS	S1					+										+									
	S2	+			+	+	+		+		+	+		+				+	+	+					
	S3		+			+			+		+	+		+				+	+	+		+	+	+	
	S4	+	+									+	+			+									
	S5								+									+		+	+	+	+	+	+
	S6	+																							
	S7	+	+		+					+			+		+										
TECHNOLOGY	T1																		+	+	+	+	+	+	
	T2												+							+					
	T3								+																
	T4												+												
	T5									+		+													
DESIGN	D1					+			+						+										
	D2													+									+		
	D3													+				+		+	+			+	
	D4								+					+				+	+	+		+			
	D5								+					+					+	+	+	+	+		
	D6																	+							
HANDOVER	H1																					+	+	+	+
	H2				+																			+	+
	H3																			+	+		+		
	H4																			+	+	+			
	H5																				+				+
	H6																				+				

As mentioned, some relationships were examined through the literature, and the rest were revealed through focus group meetings, and the resulting interrelation matrix (Table 3.5) was created. Matrix is generated from nodes in both column and row. Experts are asked for each row whether it affects the column. The interrelation matrix means that if the row has a plus (+) sign, the item in the row affects the item in the column.

3.3.3. Network Model

After obtaining the interrelation matrix, the further step is to design the network model. In Super Decisions software, a network model consisting of clusters and nodes and internal and external dependencies is created following the CSFs list and interrelation matrix given before. Internal dependencies are used for dependencies between components in the same cluster, while external dependencies refer to dependencies between elements in separate sets. Figure 3.2 below shows the network model created in the software.

After the network model is completed, the software automatically generates the pairwise comparison matrices for nodes and clusters. The next step is to create a questionnaire for experts to evaluate these matrices.

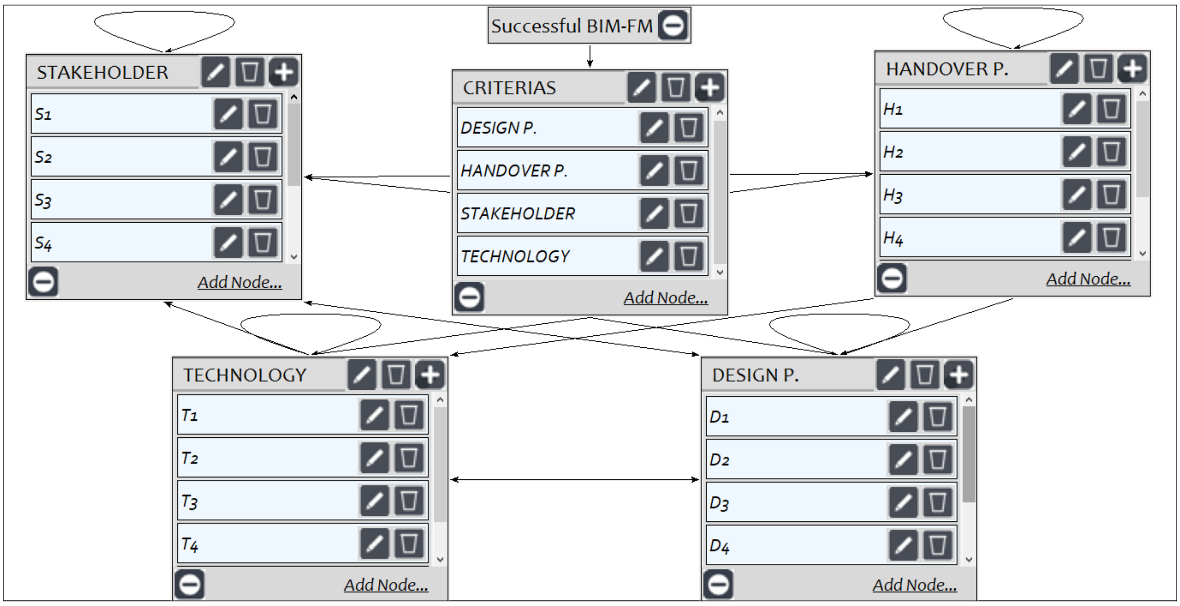

Figure 3.2. Network Model Created in Super Decisions Software.

After the network model is completed, the software automatically generates the pairwise comparison matrices for nodes and clusters. The next step is to create a questionnaire for experts to evaluate these matrices.

3.4.Web Questionnaire Survey

An online questionnaire was prepared from pairwise comparisons extracted from the model to be shared with the experts. This survey included questions to identify the participants' demographics, the types of projects and budgets they have worked on, and the final CSF list and pairwise comparison of nodes and clusters. The survey was validated with the focus group before sharing with the respondents.

Nine experts participating in the survey consist of Turkish people who have participated in national and international construction projects undertaken by Turkish contractors. Experts working on projects with BIM-FM integration were asked to fill in pairwise comparisons with Satty's numerical scales for successful BIM-FM integration. The web questionnaire survey takes place in Appendix C.

3.5. Pairwise Comparisons

To determine priority scales, it uses pairwise comparisons and depends on expert judgments(Satty,2008). For the judgments, the 9 points numerical scale of judgments is always inserted in the appropriate location for pairwise comparisons, and their reciprocal is automatically placed in the transposed location (Saaty, 2008).

For example, in Table 3.4, X is given as a parent node, and other nodes Y, Z, and W are compared with respect to X. They are asked to answer the question, "What is the impact of Y on parent element A when compared to Z and W?". Regarding the parent node X, if we want to read row Y, Y is three times more important than Z and 1/4 times less critical than W. One is written in the place where the nodes are compared with themselves.

Table 3.6. Example of a pairwise comparison matrix.

X	**Y**	**Z**	**W**
Y	1	3	1/4
Z	1/3	1	1/7
W	4	7	1

Experts were given an online link to evaluate the matrices. Subsequently, all pairwise comparisons on node level and cluster level were completed by the experts with the help of the web questionnaire survey. After conducting the questionnaire with experts, the final data were defined as the geometric mean of the experts' assessments (Aydogan and Koksal, 2013) because the Super Decisions software does not allow multiple data entries. The obtained data was entered into the Super Decisions software. Consistency ratios were checked for each pairwise matrix. A brainstorming session was conducted for the matrix with two high consistency ratios, and a consensus was achieved. Some screenshots from the program are presented in the figures below. All pairwise comparison matrices are included in Appendix D.

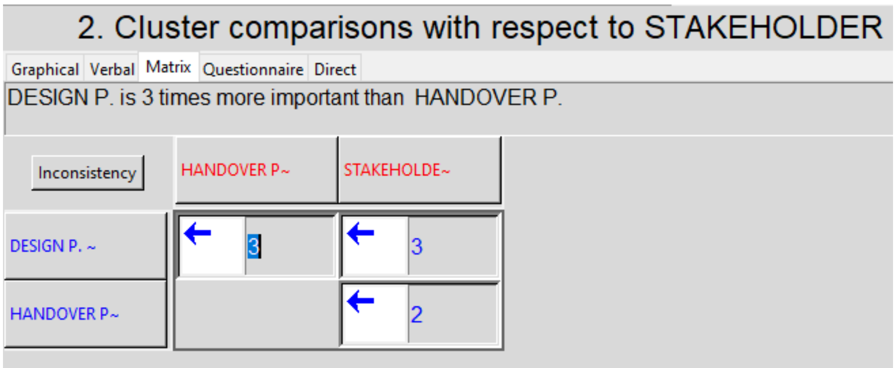

Figure 3.3. Cluster comparisons with respect to Stakeholder Cluster.

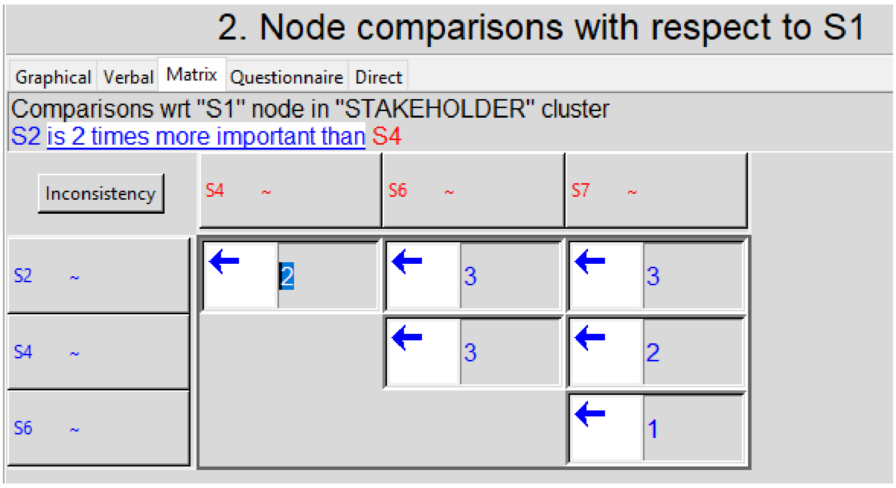

Figure 3.4. Node comparisons with respect to S1 node.

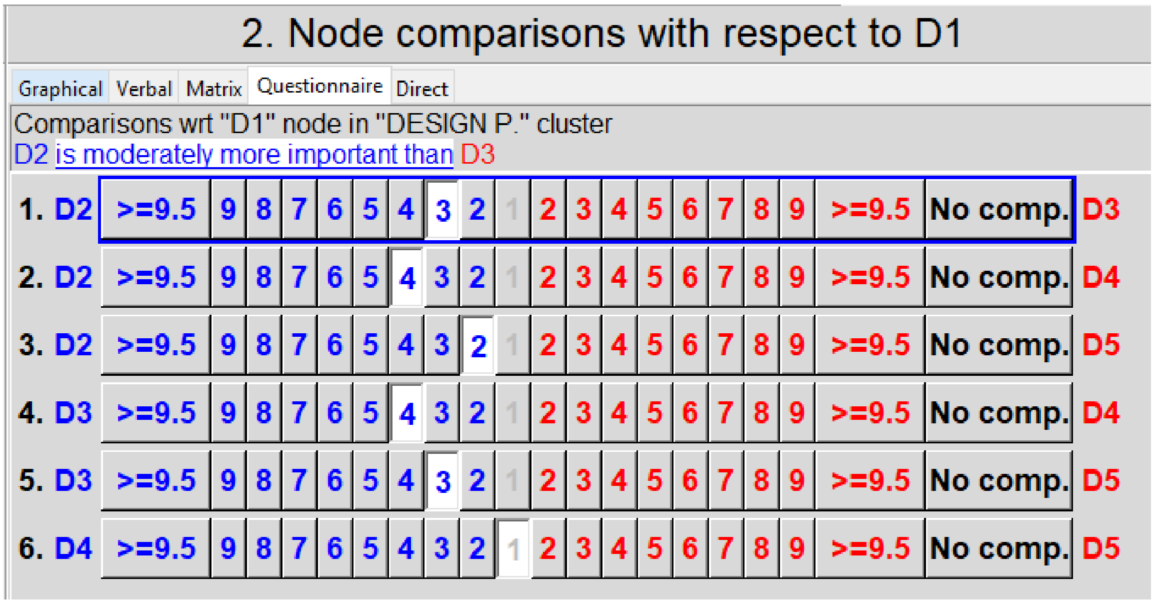

Figure 3.5. Node comparisons with respect to D1 node.

3.6. Interviews with Industry Representatives

It was planned that an interview would be held to assess the final CSF list and obtain expert input from the sector. The goal of the interview is to better understand the present state of BIM-enabled FM applications in Turkey, obtain expert comments on the final list of CSFs, and assess BIM-FM practitioners' contentment with the benefits and barriers of BIM-FM. Benefits and barriers have been sought to be assessed since they are the foundations that produce critical success factors and also feed them. In addition, clarifying how much they are affected by the benefits and barriers mentioned in the literature can be a guide for companies that will adopt BIM-FM in the future. There are academic studies that recommend obtaining critical success factors or critical information by performing benefits and barrier analysis (Volk *et al.*, 2014; Terreno *et al.*, 2015; Yudatama *et al.*, 2017).

The interviews were done with three separate specialists, in addition to the survey participants, because it is critical to analyze the survey results and the final list objectively. In this manner, the survey findings will be validated in a more objective manner. Experts were chosen from among those who had worked on Turkish contractor BIM-FM projects. The interview questions were developed with the aid of the literature and the final CSFs list. Then, the questions were examined with the pre-formed focus group. Comments and feedback from the interviews will be explored further in the results and discussion section.

4.RESULTS

In this section, the list of CSFs will be explained in detail. Then the survey results will be shared. Finally, the interviews for validating the survey results will be explained.

4.1. Explanation of Critical Success Factors

The broad scope of the factors, which have been simplified to 24 factors, will be explained in this part. Stakeholder-related, technology-related, design-related, and handover-related factors were identified as four sub-categories. There are six stakeholder-related factors, five technology-related factors, six design process-related factors, and six handover process-related factors in the final list. The final list of CSFs with references is shown in Table 4.1.

Stakeholders-related factors are the fundamental part of the BIM-FM integration because they depend on people, technology, and process. If teams make an effort to engage people, processes, and technology in a cooperative environment that allows for effective information sharing, outstanding project outcomes can be achieved (Ashworth, 2020). Stakeholders-related factors are explained in order below.

- "*S1 - General commitment to BIM adoption for FM"* also contains the FM readiness to engage BIM, client demand/awareness of BIM adoption for FM, and change a preparation for employees and organization. The utilization of BIM by stakeholders in the building life cycle is crucial to the industry's success.
- *"S2 – BIM education and training for employees"* includes administrative and staff BIM training strategies and technical support for interoperability issues.
- *"S3 - Availability of capable/experienced personnel (both in FM and AEC)"* includes experience level of the firm, BIM competence of in-house team experience.
- *"S4 - Top leadership backing & motivation"* means that support and motivation shown by the managers to build a positive corporate culture, a broad understanding

of BIM's influence on FM, and a general sense of BIM as a process that is progressing.

- *"S5 – Stakeholders (architecture, construction, engineering, facility management) collaboration on the project"* means participants' readiness and eagerness to share information.
- *"S6 - Perceived ease of use"* tries to tell us that BIM software's user interface should be welcoming and customizable based on the user's background and role, which will increase user participation and interoperability.
- *"S7 - Government support and incentives for BIM in the FM industry"* covers support from the government in the form of laws being enforced and the presence of government initiatives to encourage the adoption of BIM in the sector.

Technology-related factors included factors affecting an organization's technological capabilities and competence. Technology-related factors are explained in order below.

- *"T1 - Design of well-executed 3D model and as-built data"* stands for executing well-designed information-rich BIM models which contain three-dimensional details. Besides 3D geometry, BIM can provide consolidated and standardized asset and area information to FM systems that can be utilized for maintenance and refurbishment (Akcamete *et al*., 2010).
- *"T2 - Hardware and software for BIM-FM are readily available"* encompasses the accessibility and availability of BIM hard and soft tools, the necessary hardware required for widespread BIM adoption, and software that encapsulates users' prerequisites for interoperability in BIM model environments.
- *"T3 - Databases for BIM are readily available"* encompasses the availability of required information and technological infrastructure existence of good content of libraries and layouts.

- *“T4 - Cybersecurity for stored data”* means security risks for the project data, restricting access to data in the model to relevant persons, and precautions against this situation.

- *“T5 - Cost of keeping system (continuous investment)”* stands for initial investment costs, including hardware and software costs and training fees, cost of development, annual license renewals for software, and continuous presence of financial resources because technology is constantly evolving and changing.

Factors that impact an organization’s capacity to implement BIM at the project level were included in the design process-related factors. Design process-related factors are explained in order below.

- *“D1 - BIM execution plan (BEP)”* includes a clear definition of what BIM-enabled FM entails, developing an FM/client-oriented employers information requirements to meet their needs, defining project BIM goals, clearly defining roles and responsibilities of stakeholders and project teams, BIM vision and objectives, integrated BIM meetings and LOD determination for the FM stage handover.

- *“D2 - BIM standards and guidelines”* means standardization of the BIM process and defining guidelines to deploy BIM technologies and workflows in accurately. The function of facility managers in the BIM process and their role in generating the employer’s information needs were the subject of BIM standards and guidelines (Ashworth *et al*., 2018).

- *“D3 - Early involvement of Facility Managers in the BIM process”* stands for early awareness of the operations and maintenance (O&M) phase, as well as the building and project stages of FM participation, including the participation of an FM person in the design process and other strategic choices. Clients and facility managers being actively involved early in the BIM process, according to Ashworth *et al.* (2016), is a significant success element in meeting BIM objectives.

- *“D4 - Project type/size/complexity*” means that every project has unique features. So those features affect the BIM-FM integration, such as types of project delivery system, the purpose of a building (e.g., office, hospital, factory, residential, physical size (floor area) of a project, total project construction cost, location of a site (e.g., overseas projects, domestic projects), number of utilities and assets, etc.

- *"D5 - Determining Information Delivery Plan (IDP) (space, asset, energy, management data requirements)"* encompasses determining space management data requirements, maintenance management data requirements, asset management data requirements (asset model geometry, asset classification system), energy and environmental sustainability data requirements which are crucial for FM operations and building lifecycle.
- *"D6 - QA/QC (quality assessment/quality control) plan for checking BIM deliverables"* means the existence of a QA strategy for managing the modeling and a comprehensive QC strategy for testing the final outputs for conformity with the quality criteria (Motamedi *et al*., 2018). QA and QC procedures for BIM models assure the model's accuracy throughout the project lifetime and that the information is suitable for ultimate usage during the operations and maintenance phase (Leygonie, 2020).

Factors impacting the quality, efficiency, and reliability of the information handed over to satisfy operational performance objectives are included in the handover process-related factors. Handover process-related factors are explained in order below.

- *"H1 - Well-executed interoperability plan for exchanging data between BIM tools and FM systems"* includes BIM modeling with open sources, such as IFC (for simple importation and exportation without losing any information), and providing an excellent interoperability plan for exchanging data with COBie spreadsheets to FM systems and other database tools.
- *"H2 - Using BIM to maximize potential cost savings (return on investment of built assets)"* reflects understanding the benefits of BIM for FM and understanding and using BIM for FM with the expected direct and indirect cost savings.
- *"H3 - Populating Cobie spreadsheet from the model"* is the step for exchanging data from the model to FM systems.

- *“H4 - Defining the mapping rules between shared parameters and Cobie parameters*” is essential for exporting the final COBie spreadsheet.
- “*H5 - Preparing a critical assets list*” is necessary for tracking essential assets and helping to capture critical asset information based on your operation information requirements.
- *“H6 - Tracking asset history*” is vital for building lifecycle FM cost. BIM helps to track assets. It is imperative to track resources for maintenance in FM systems.

Table 4.1. Final Critical Success Factors List of BIM-FM Integration with references.

Sub Categories	CSFs	CSFs for BIM enabled FM	References
stakeholders related	S1	General commitment to BIM adoption for FM	[7],[9],[12],[13],[14],[15]
	S2	BIM education and training for employees	[1],[2],[6],[7],[9],[10],[11],[12],[13],[14],[15]
	S3	Availability of capable/experienced personnel (both in FM and AEC)	[2],[3],[6],[8],[9],[11],[12],[14],[15]
	S4	Top leadership backing & motivation	[1],[2],[3],[5],[6],[8],[10],[11],[13],[14],[15]
	S5	Stakeholders(architecure,construction,engineering,facility management) collaboration on the project	[2],[3],[5],[7],[8],[9],[10],[12],[13],[14],[15]
	S6	Perceived ease of use	[2],[3],[11],[13],[7]
	S7	Government support and incentives for BIM in FM industry	[2],[8],[9],[10],[11],[12],[15]
technology related	T1	Design of well-executed 3D model and as-built data	[1],[3],[6],[7],[12],[15],[16]
	T2	Hardware and software for BIM-FM are readily available	[1],[2],[6],[9],[11],[12],[15]
	T3	Databases for BIM are readily available.	[2],[8],[9],[11],[12],[15]
	T4	Cybersecurity for stored data	[2],[19]
	T5	Cost of keeping system (continuous investment)	[1],[2],[3],[6],[8],[9],[11],[12],[15]
design process related	D1	BIM execution plan(BEP)	[1],[3],[5],[6],[7],[11],[12],[13],[14],[15],[16],[17],[18]
	D2	BIM standards and guidelines	[2],[6],[7],[10],[11],[12],[13],[15]
	D3	Early involvement of Facility Managers in the BIM process	[1],[3],[4],[14],[18]
	D4	Project type/size/complexity	[2],[3],[8],[12]
	D5	Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)	[1],[3],[6],[7],[16],[17],[18]
	D6	QA/QC(quality assessment/quality control) plan for checking BIM deliverables	[5],[6],[16],[17],[18]
handover process related	H1	Well-executed interoperability plan for exchanging data between BIM tools and FM systems	[2],[3],[5],[6],[7],[12],[14]
	H2	Using BIM to maximize potential cost savings (return on investment of built assets)	[2],[3],[9],[11],[14]
	H3	Populating COBIe spread sheet from the model	expert opinion
	H4	Defining the mapping rules between shared parameters and COBIe parameters	expert opinion
	H5	Preparing a critical assets list	expert opinion
	H6	Tracking asset history	expert opinion

[1]Badrinath&Hsieh(2019); [2]Won *et al.* (2013); [3]Sarkar *et al.* (2015); [4]Ashworth *et al.* (2016);[5]Pishdad-Bozorgi *et al.* (2018); [6]Giel&Issa(2016); [7]Ashworth *et al.* (2018); [8]Ozorhon&Karahan(2017); [9]Abubakar *et al.* (2014); [10]Liao and Teo(2017); [11]Amuda-Yusuf(2018); [12]Darwish *et al.* (2020); [13]Farahaneza *et al.* (2018); [14]Ashworth(2020); [15]Oluleye *et al* .(2021); [16]Leygonie(2020); [17]Motamedi *et al.* (2018); [18]Borhani&Dossick(2020); [19]Ghadiminia *et al.* (2021).

4.2. Demographic Structure of the Participants

Nine experts participated in the survey. The sample of the participants consists of people who have worked on BIM-FM international-national construction projects carried out by Turkish contractors. The aim is to observe how Turkish contractors interpret the success factors of BIM-FM processes. Experts with experience working on various construction projects took part in the online survey. Participants consist of 3 BIM Coordinators, 1 Project Manager, 1 Engineering & Design Director, 1 Academician, 1 BIM Architect, 1 Airport Senior Architect, and 1 BIM Engineer. The experts evaluated pairwise matrices between clusters and nodes. Then, the geometric mean of the nine participants' answers was then used to create the final data set. Demographic information of participants was expressed using pie chart figures below. Furthermore, Table 4.2 contains information about the country of employment of the participants, education level, job title, experience in the AEC-FM industry, experience in BIM-FM projects, types of projects they have worked on, and project budgets.

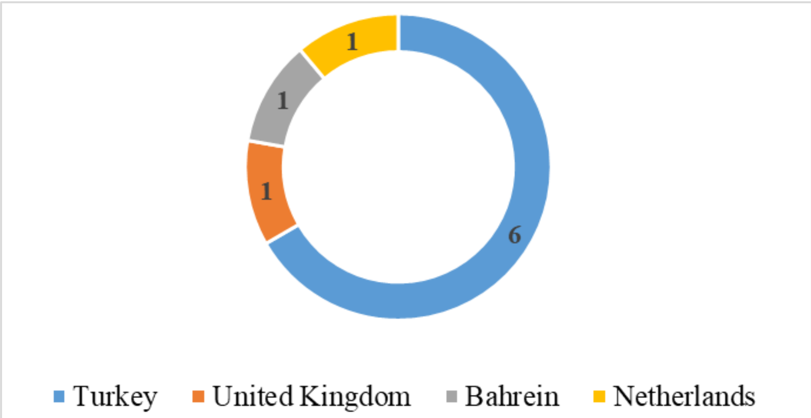

Figure 4.1. Country where participants work.

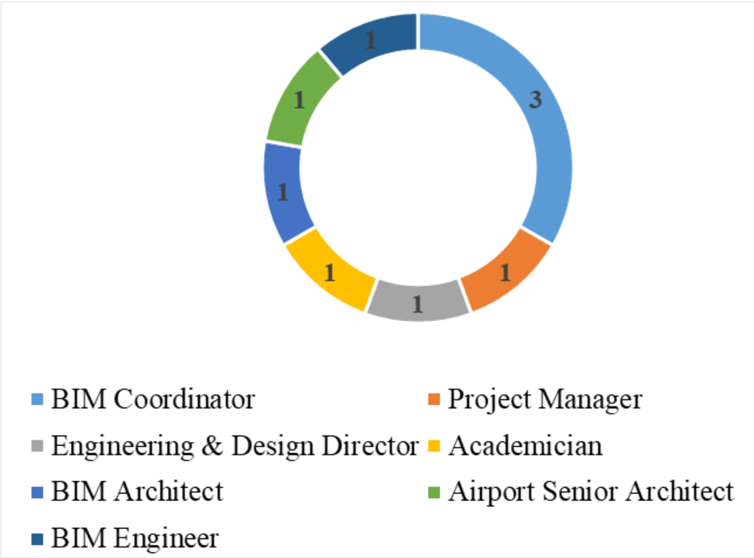

Figure 4.2. Job titles of the participants.

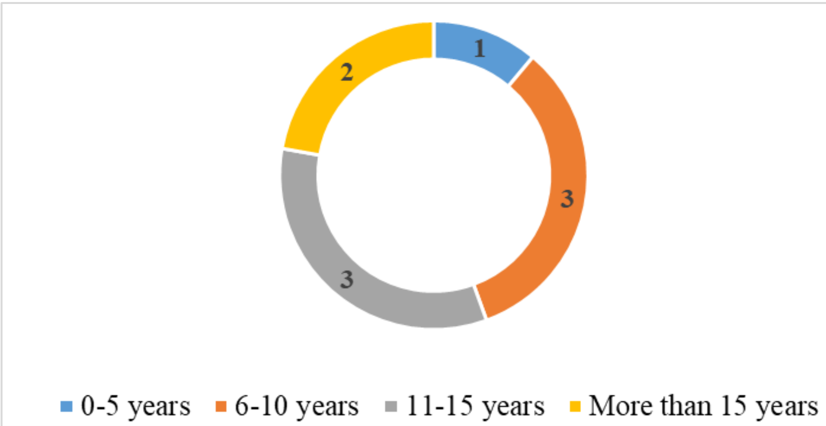

Figure 4.3. Participants’ experience in the industry.

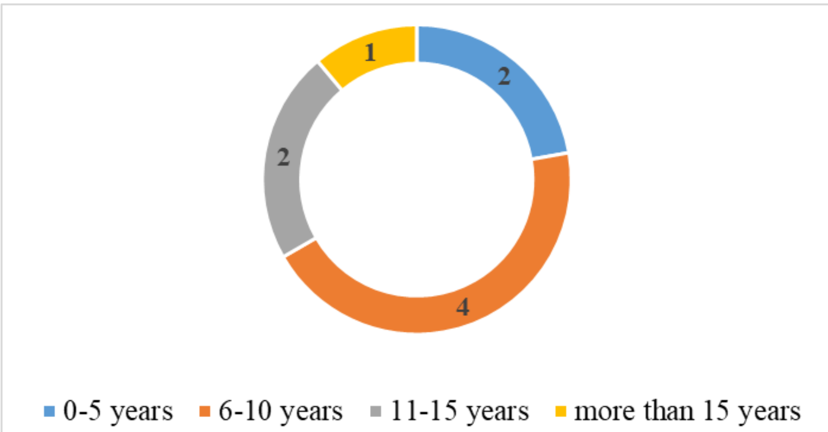

Figure 4.4. Expertise of participants in BIM project.

Table 4.2. Respondents' demographic structure and experience.

	Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**	**Expert 7**	**Expert 8**	**Expert 9**
Country of employment	Turkey	Turkey	Turkey	Turkey	United Kingdom	Netherlands	Bahrain	Turkey	Turkey
Level of education	Bachelor's Degree	Master's Degree	Doctorate	Doctorate	Master's Degree	Bachelor's Degree	Bachelor's Degree	Master's Degree	Bachelor's Degree
Current role	BIM Coordinator	Project Manager	Engineering & Design Director	Academician	BIM Architect	BIM Coordinator	Airport Senior Architect	BIM Coordinator	BIM Engineer
Experience in the AEC-FM	6-10 years	11-15 years	More than 15 years	More than 15 years	11-15 years	6-10 years	11-15 years	6-10 years	0-5 years
Experience on BIM projects	6-10 years	6-10 years	11-15 years	More than 15 years	6-10 years	6-10 years	11-15 years	0-5 years	0-5 years
Expertise	Airport, Industrial Facilities, Shopping Mall , Office Building, Residential Building.	Airport,Shopping Mall , Office Building, Residential Building.	Airport,Shopping Mall ,Office Building, Residential Building.	Airport,Tunnel, Bridge,Highway, Shopping Mall , Office Building, Residential Building, Healthcare Facilities.	Metro Projects, Shopping Mall, Office Building, Residential Building, Healthcare Facilities.	Metro Projects.	Airport.	Airport,Shopping Mall, Office Building, Residential Building.	Tunnel, Highway,Metro Projects, Industrial Facilities,Office Building.
Budgets of the projects with BIM-FM integration	(500 Million $ - 1 Billion $) (1-10 Billion $)	(100-500 Million $),(500 Million $ - 1 Billion $), (1-10 Billion $)	(100-500 Million $),(500 Million $ - 1 Billion $), (1-10 Billion $)	(Over than 20 Billion $)	(500 Million $ - 1 Billion $)	(500 Million $ - 1 Billion $)	(1-10 Billion $)	(10-20 Billion $)	(100-500 Million $),(500 Million $ - 1 Billion $), (1-10 Billion $)

4.3. Clusters and Nodes Priorities

After the final data set of all comparison matrices is entered into the program, it automatically calculates supermatrices. The effects of elements in a network on other elements are brought together in an unweighted supermatrix. It is the matrix in which the elements in a set and the priorities among these elements are expressed. For the software to generate an unweighted supermatrix, the data of the pairwise comparisons between the elements must be entered, taking into account the interactions of the elements in the network. After the unweighted supermatrix is created, the values in the columns of the unweighted supermatrix are normalized by dividing by the column totals. This matrix consists of column values whose sum is one and is called the weighted supermatrix. The importance weights are equalized at some point by exponentiation of the weighted supermatrix. The limit supermatrix is the new matrix that results. The values of the limit supermatrix show the total priority values of the network's components. Calculated priorities of nodes are included in Table 4.3.

Table 4.3. Priorities of elements.

CSFs No	**FACTORS DEFINITION (Clusters - Nodes)**	**PRIORITIES**
STAKEHOLDERS RELATED		**0.5269**
S1	General commitment to BIM adoption for FM	0.1546
S2	BIM education and training for employees	0.2434
S3	Availability of capable/experienced personnel (both in FM and AEC)	0.2060
S4	Top leadership backing & motivation	0.2308
S5	Stakeholders (architecture, construction, engineering, facility management) collaboration on the project	0.0403
S6	Perceived ease of use	0.0241
S7	Government support and incentives for BIM in FM industry	0.1008
TECHNOLOGY RELATED		**0.0216**
T1	Design of well-executed 3D model and as-built data	0.7894
T2	Hardware and software for BIM-FM are readily available	0.0360
T3	Databases for BIM are readily available.	0.1484
T4	Cybersecurity for stored data	0.0053
T5	Cost of keeping system (continuous investment)	0.0210

Table 4.3. Priorities of elements (cont.).

CSFs No	FACTORS DEFINITION (Clusters - Nodes)	PRIORITIES
DESIGN PROCESS RELATED		**0.2821**
D1	BIM execution plan (BEP)	0.2521
D2	BIM standards and guidelines	0.1435
D3	Early involvement of Facility Managers in the BIM process	0.3361
D4	Project type/size/complexity	0.1157
D5	Determining Information Delivery Plan (IDP) (space, asset, energy, management data requirements)	0.1287
D6	QA/QC (quality assessment/quality control) plan for checking BIM deliverables	0.0239
HANDOVER PROCESS RELATED		**0.1695**
H1	Well-executed interoperability plan for exchanging data between BIM tools and FM systems	0.1143
H2	Using BIM to maximize potential cost savings (return on investment of built assets)	0.5562
H3	Populating COBIe spread sheet from the model	0.1797
H4	Defining the mapping rules between shared parameters and COBIe parameters	0.0774
H5	Preparing a critical assets list	0.0409
H6	Tracking asset history	0.0316

4.4. Importance Weights

After determining the priorities, the next stage is to clarify the importance of weights. Çomu *et al*. (2016) stated that determining the importance weights of each success factor by multiplying the node priorities with the associated cluster priorities. Table 4.4 shows the importance weights of clusters with respect to successful BIM-FM integration.

Table 4.4. Importance Weights of Clusters with Respect to Successful BIM-FM Integration Goal.

RANK	CLUSTERS	IMPORTANCE WEIGHTS
1	STAKEHOLDERS RELATED FACTORS	0.5269
2	DESIGN PROCESS RELATED FACTORS	0.2821
3	HANDOVER PROCESS RELATED FACTORS	0.1695
4	TECHNOLOGY RELATED FACTORS	0.0216

Table 4.5 shows the importance weights of all nodes with respect to successful BIM-FM integration. For example, to calculate the importance weight of node S2, the associated cluster weights are multiplied by its priority, and the node's weight is found.

The cluster weight of "Stakeholder Related Factors" is "0.5269" as given in Table 4.4 above, and the priority value of S2 is "0.2434" in Table 4.3. When we multiply these two values, we get "0.1282". This is the importance weight of the "S2-BIM Education and Training for Employees" node, as seen in Table 4.5.

Table 4.5. Importance Weights of Nodes with Respect to Successful BIM-FM Integration Goal.

RANK	**CSF No**	**NODES**	**IMPORTANCE WEIGHTS**
1	S2	BIM education and training for employees	0.1282
2	S4	Top leadership backing & motivation	0.1216
3	S3	Availability of capable/experienced personnel (both in FM and AEC)	0.1085
4	D3	Early involvement of Facility Managers in the BIM process	0.0948
5	H2	Using BIM to maximize potential cost savings (return on investment of built assets)	0.0943
6	S1	General commitment to BIM adoption for FM	0.0815
7	D1	BIM execution plan (BEP)	0.0711
8	S7	Government support and incentives for BIM in FM industry	0.0531
9	D2	BIM standards and guidelines	0.0405
10	D5	Determining Information Delivery Plan (IDP) (space, asset, energy, management data requirements)	0.0363
11	D4	Project type/size/complexity	0.0327
12	H3	Populating COBIe spread sheet from the model	0.0305
13	S5	Stakeholders (architecture, construction, engineering, facility management) collaboration on the project	0.0212
14	H1	Well-executed interoperability plan for exchanging data between BIM tools and FM systems	0.0194
15	T1	Design of well-executed 3D model and as-built data	0.0170

Table 4.5. Importance Weights of Nodes with Respect to Successful BIM-FM Integration Goal (cont.).

RANK	CSF No	NODES	IMPORTANCE WEIGHTS
16	H4	Defining the mapping rules between shared parameters and COBIe parameters	0.0131
17	S6	Perceived ease of use	0.0127
18	H5	Preparing a critical assets list	0.0069
19	D6	QA/QC(quality assessment/quality control) plan for checking BIM deliverables	0.0067
20	H6	Tracking asset history	0.0054
21	T3	Databases for BIM are readily available.	0.0032
22	T2	Hardware and software for BIM-FM are readily available	0.0008
23	T5	Cost of keeping system (continuous investment)	0.0005
24	T4	Cybersecurity for stored data	0.0001

As can be seen, based on clusters, the Stakeholders Related Factor cluster was the first important cluster with 0.5269 weight of importance, while the design process related factor, handover process-related factor, and technology-related factor followed it with 0.2821, 0.1695, and 0.0216 values, respectively.

The top five nodes according to the survey results are as follows respectively; BIM education and training for employees (0.1282), Top leadership backing & motivation (0.1216), Availability of capable/experienced personnel (both in FM and AEC) (0.1085), Early involvement of Facility Managers in the BIM process (0.0948), Using BIM to maximize potential cost savings (return on investment of built assets) (0.0943).

4.5. Interviews

An interview was planned to examine the final CSF list and receive expert opinions from the sector. The interview's purpose is to get a better understanding of the current status of BIM-enabled FM applications in Turkey, gather expert feedback on the final list of CSFs, and assess BIM-FM practitioners' satisfaction with the benefits and barriers of BIM-FM. The outcomes of the interview questions are shared and presented with some graphics in this section. You can find the interview questions in Appendix E.

The interviews were conducted with three different experts apart from the people who participated in the survey, because it is important to evaluate the survey results and the final list with an objective eye. In this way, the validation of the survey findings will be provided in a more objective way. Experts were selected from people who have gained experience in Turkish contractor BIM-FM projects. Table 4.6 demonstrates the expert’s demographic profile.

Table 4.6. Demographic Structure of the Experts Interviewed.

	Level of Education	**Current Role**	**Experience in current role**	**Experience in BIM-FM**
Expert 1	Phd	Engineering& Design Director	6-10 years	11-15 years
Expert 2	Masters	BIM Manager	6-10 years	6-10 years
Expert 3	Bachelors	BIM Coordinator	6-10 years	0-5 years

First of all, the purpose of the study and previous survey were explained in detail to experts. The final list of BIM-FM critical success factors was shared. Then, semi-structured interview questions were asked to learn their views on the subject. Experts stated that they use BIM-based Bentley AECOsim, Autodesk Revit, Allplan, Autodesk BIM 360 and Navisworks, CAD-based - Autodesk AutoCAD, Bricsys BricsCAD, GIS-based - ESRI, and finally for FM works CMMS-based - IBM Maximo, IFS EAM for BIM-FM integration in their projects. It was stated that the use of CAD was kept to a minimum. They use FM programs for asset management, cleaning, assignment of work orders, finance and budgeting, inventory management, preventative maintenance, room & maintenance scheduling, and space management.

They were given the task of evaluating the BIM-FM benefits and barriers described in the literature and generated with the help of the focus group. On a 1-5 Likert scale, they were asked to rate their degree of satisfaction or dissatisfaction. The figures below (Figure 4.5, Figure 4.6) describe their responses to the statements.

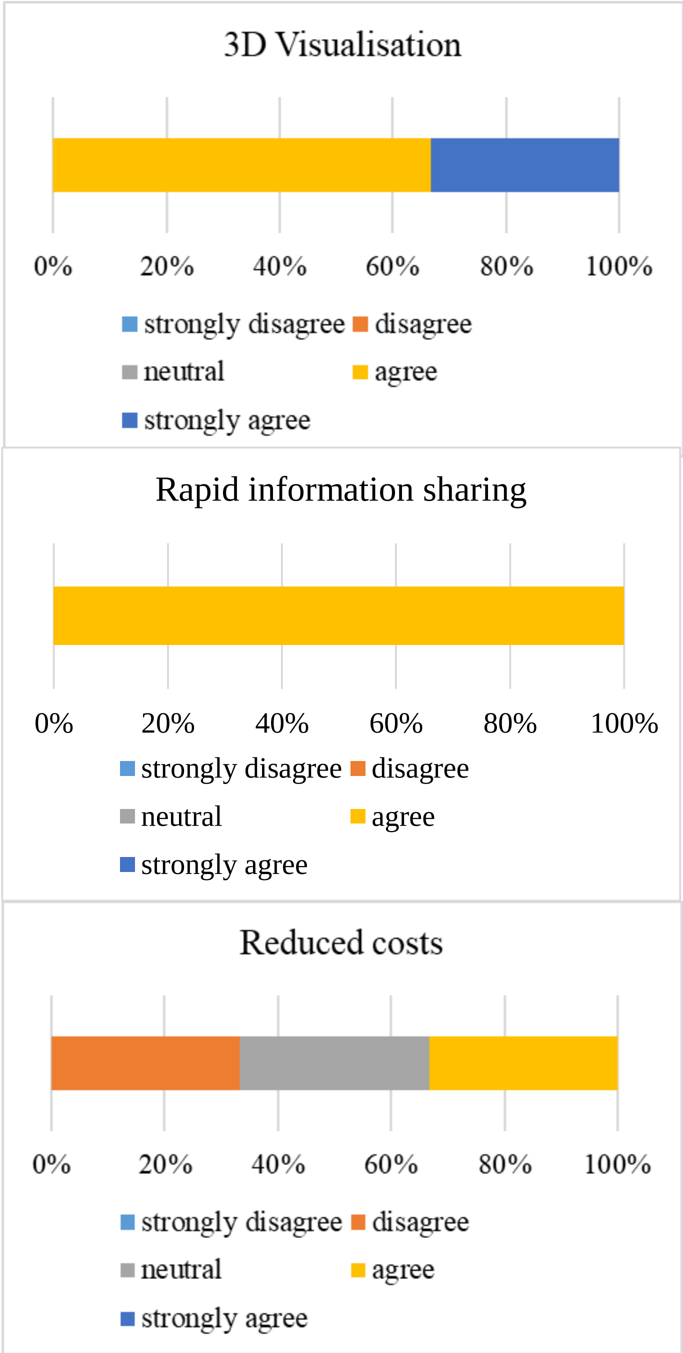

Figure 4.5. Responses to the benefits of BIM-FM Integration.

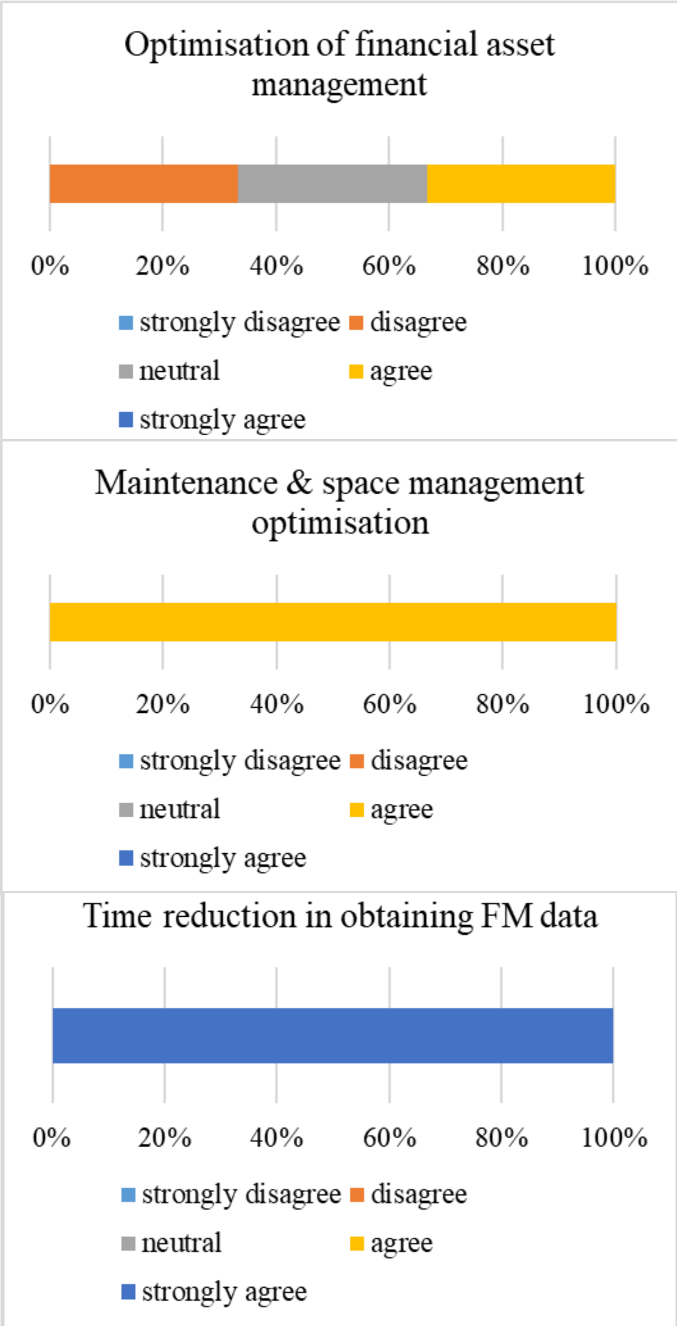

Figure 4.6. Responses to the benefits of BIM-FM Integration (cont.).

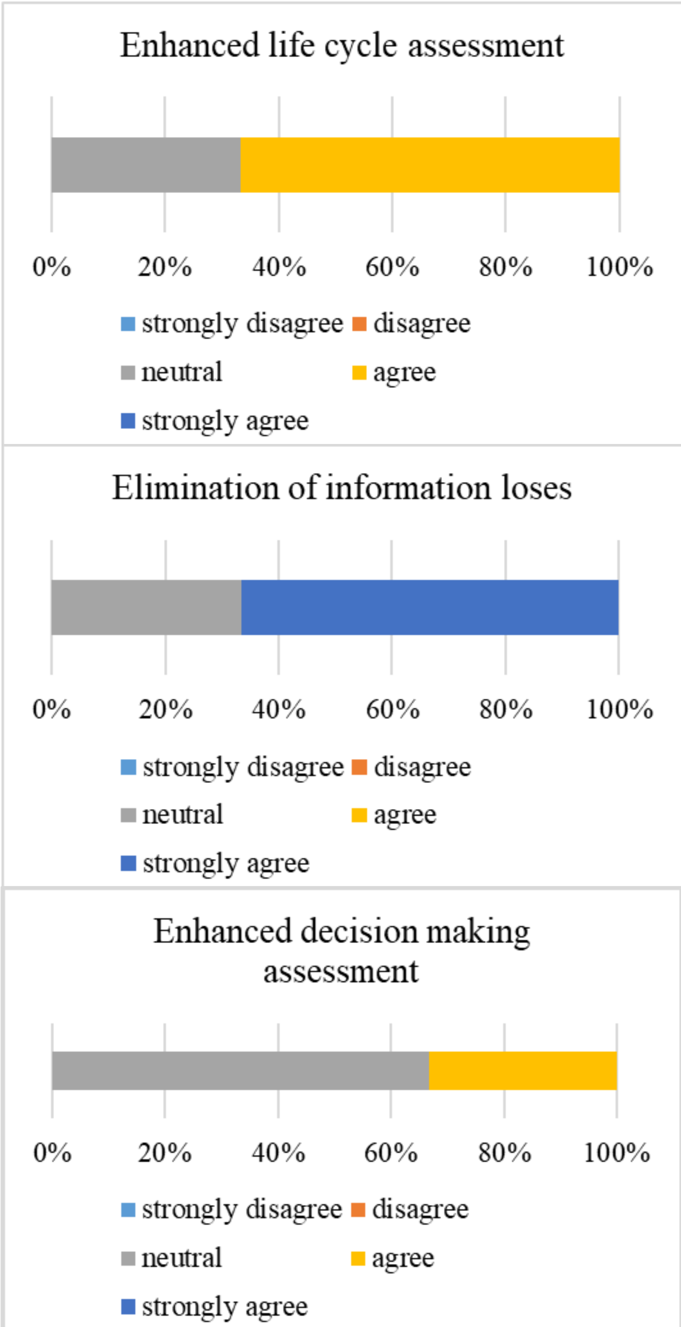

Figure 4.7. Responses to the benefits of BIM-FM Integration (cont.).

When the responses were pooled and geometrically averaged, it was shown that the most significant advantage of BIM-FM integration was “time reduction in obtaining FM data”. “Elimination of information losses, enhanced life cycle assessment, maintenance & space management optimization, rapid information sharing, and 3D visualization” were equally rated as the second significant benefits of BIM-FM integration. “Reduced costs, optimization of financial asset management, and enhanced decision-making assessment” were rated as neutral satisfied benefits of BIM-FM integration. These three benefits are also vague and immeasurable in the literature, as they are the benefits that occur with the processes occurring in the building life cycle. According to the results, “lack of FM consideration/collaboration in design and construction phases” was rated as the most significant barrier against BIM-FM integration. “Lack of technical knowledge and guidelines regarding BIM, interoperability issues between BIM-FM software, unclear roles, and responsibilities, and up-to-date model follow-up (room and furniture change arrangements)” were rated equally as the second significant barrier. Furthermore, it was stated that one additional barrier, which is an essential barrier, may be included as a remark. This is a “lack of clear client requirements and preparedness both organizational and infrastructure to utilize BIM-FM”.

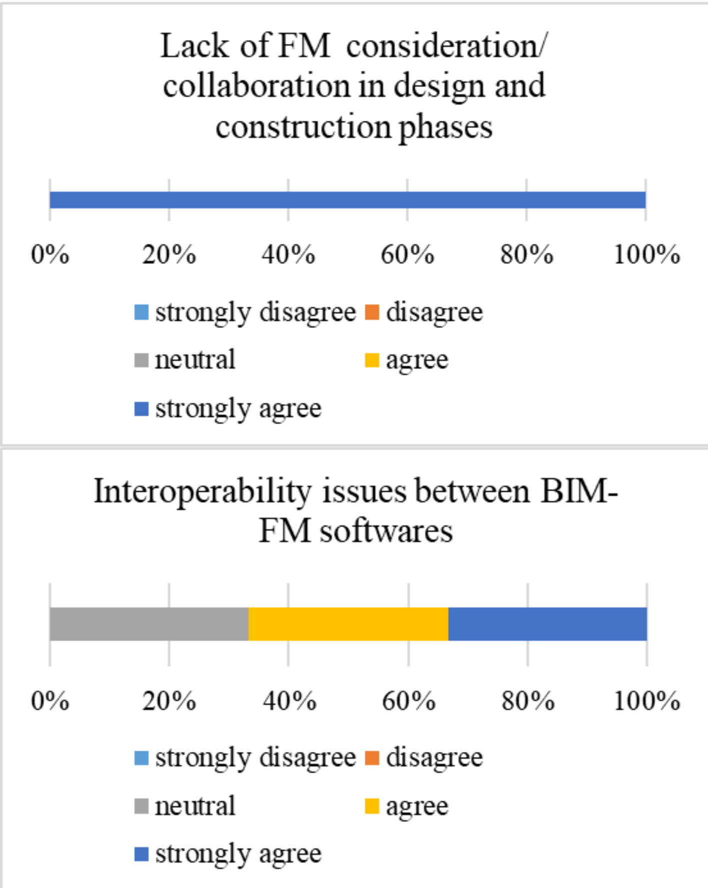

Figure 4.8. Responses to the barriers of BIM-FM Integration.

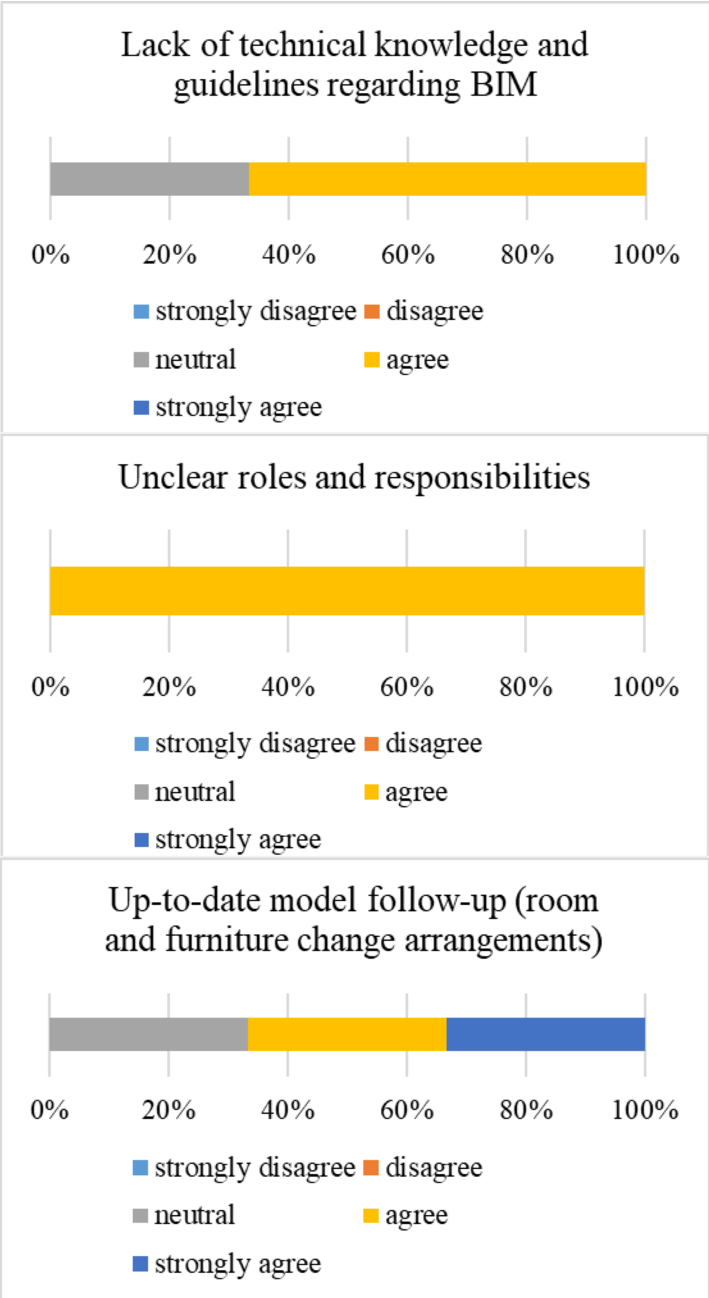

Figure 4.9. Responses to the barriers of BIM-FM Integration (cont.).

In the second part of the interview, they were asked to review the final CSF list for effective BIM-FM integration and share their perspectives on BIM-FM integration. According to the first expert, without clarity for use cases on the operations side, even the most excellent BIM Execution Plan or models are meaningless. Project BIM specifications are usually written by third parties specializing in design or construction. Any FM scope is either shallow or unrelated to the needs or circumstances. The FM team's (D3) early engagement is essential, but it may not be enough if operation specifics are not defined or clear. What could be lacking is a “FM System” or a procurement timeline to even discuss interoperability (H1- Well-executed interoperability plan for exchanging data between BIM tools and FM systems). To ensure success, the client/operator must be prepared and explicit about their objective through a high-level Organizational Information Requirements (OIR) document, as specified by ISO 19650. Only then “S1-General commitment to BIM adoption for FM” would be significant, prompting the search for suitable personnel (S3-Availability of capable/experienced personnel). Long-standing suppliers and products still regulate CMMS infrastructure, which has yet to catch up to current processes and is often unaware of FM demands or the opportunities associated with digital data. On the other hand, FM employees are unfamiliar with technological infrastructure and are only interested in completing their tasks. They are also oblivious of the possibilities of digital data. Client demand and understanding of the favourable effects it will have on operations are essential success factors for BIM-FM. Architects, engineers, and subcontractors who create BIM models for their own purposes are deprive of desire or expertise that is necessary for FM implementations.

According to the second expert, the technological process requires as much planning as design. This research study can be tailored to different types of projects because the type of project has a significant impact on the model. For example, models are being built in an infrastructure project at many different locations, and BIM monitoring is difficult to set up. The application in the field still does not adequately communicate with the design. This can lead to errors in the models. This communication must be strong; D1- BIM execution plan (BEP) is essential; otherwise, the optimal data becomes irrelevant, and the model becomes inefficient.

According to third expert, early engagement of the FM manager in a project is critical. The FM manager may then identify and highlight which handover data from the construction phase to the operation phase needs to be given. In addition, the FM manager and BIM manager can use the model and Cobie parameters as needed. Interoperability between BIM tools and the FM system is also vital since the model must be updated regularly. The system may then readily track associated information regarding FM and assets. Finally, one of the most important aspects of controlling and utilizing this system is employee education and knowledge. The final CSFs list describes real-world project obstacles in general.

5. DISCUSSION

BIM is a three-dimensional information exchange process that may help individuals involved in designing, constructing, and maintaining various architectural projects. Of all the building lifecycle phases, O&M is where the owner will spend the most time and money, so FM is a vital process (Sarkar *et al.*, 2015). Facility management is a field that deals briefly with O&M (Gao and Pishdad-Bozorgi, 2019). Operation and maintenance encompass six subgroups; maintenance and repair, energy management, emergency management, change/relocation management, security, and facility (Gao and Pishdad-Bozorgi, 2019). Facility managers frequently experience inefficiencies due to a misconception of building design intent, resulting in a disparity between anticipated and actual facility performance (Borhani and Dossick, 2020). Improving the efficiency of facility management solutions using BIM data is an emerging topic of interest. Facilities management integrated with BIM helps as a virtual guide in monitoring building space, operations, and assets. However, on a worldwide basis, BIM adoption in the FM sector has been gradual and inadequate; this might be due to a lack of knowledge about the critical success factors (CSFs) that can help it succeed (Oluleye *et al.*, 2021). To successfully use BIM in FM operations, FM teams must identify and understand the functional CSFs required lifecycle (Oluleye *et al., 2021*). Successful and efficient building lifecycle management requires optimizing building use from an FM perspective (Arayici *et al.*, 2012). Thanks to BIM models, the analysis allows facility managers to conduct a risk analysis for O&M activities, resulting in better coordination between stakeholders (Becerik-Gerber *et al.*, 2012).

Although there is plenty of research on critical success factors for BIM implementation in projects, there is scant academic research on CSFs that affect FMs' capacity to participate fully in the BIM process (Ashworth, 2020). There is a scarcity of consistent information on the CSFs and drivers needed to improve BIM deployment throughout the facilities lifecycle (Oluleye *et al., 2021*). Better knowledge of the critical success factors required for FM operations is essential (Oluleye *et al., 2021*). There are insufficient academic studies (Oluleye *et al.,* 2021; Pishdad-Bozorgi *et al.,* 2018; Sarkar *et al., 2015;* Ashworth *et al., 2018;* Ashworth, 2020) focus on CSFs of BIM-FM in the literature. In this study, construction projects carried out by Turkish contractors were chosen as the focal point to evaluate CSFs in BIM-FM integration. While the basic principles are essentially the same, there are a few key differences between this study and the others. The differences and theoretical contributions will be explained in this section.

In 2015, Sarkar *et al.* aimed to determine the key performance indicators (KPIs) that influence the use of BIM as a facility management resource in India. 41 KPIs were determined based on a primary data questionnaire survey conducted with BIM representatives in India from all types of projects. These 41 KPIs, which included both "leading" and "lagging" indications, were simplified to 15 KPIs using factor analysis. Finally, using the principal component analysis (PCA) method of factor analysis, 15 chosen indicators were grouped into five separate categories, and the categories were prioritized. "O&M process reengineering, technical features offered by BIM, involvement of client & consultants in the process" was found as the most important three groups among five, respectively. According to the study's findings, BIM is currently used more in the conceptual, design, and development phases of projects in India. However, almost three out of four respondents felt that using BIM for FM was beneficial. This demonstrates that BIM has much potential as a facility management tool (Sarkar *et al.*, 2015).

In 2018, Pishdad-Bozorgi *et al.* conducted a study on BIM-FM integration on an actual university building project study in the US and identified three CSFs as lessons from this case study. The lessons learned in this study contains the following: 1) absence of an FM manager and FM IT professional at the beginning of the project to determine data requirements with the preselected FM software and incorporate such requirements in BIM-FM guidelines, and communicate with the project group in the design stage; 2) create models in BIM authoring applications, rather than any other software that use IFC formats; 3) ensure quality control and assurance for BIM deliverables; 4) allocate enough investment in BIM 5) built a fully engaged team consist of AEC and FM staff; 6) give adequate time for adopting this new technology for your project. The first factor corresponds to two combined factors in this study, "Early involvement of FM in the BIM process and BIM standards and guidelines", rated as the fourth and ninth important factors, respectively. The scopes and contents of the CSFs may vary in the studies; simultaneously, the priorities vary according to the sample chosen, the country, and the type of project observed. BIM education and training for employees, which was considered the first important factor in this study, may not have been evaluated in that project because that study handled the BIM-FM process as a case study, and therefore, feedback was created about the design and handover processes.

In 2018, Ashworth *et al.* aimed to create and test an employer's information requirements (EIR) template and guidance report developed to address customer and FM demands in the BIM procedure and the critical success factors for facilities management employer's information requirements (EIR). A qualitative design approach was used, with a focus group from the British Institute for Facilities Management (BIFM), semi-structured interviews with the Glasgow Life Burrell Renaissance Project case study was conducted, and interviews with BIM/CAFM experts done. The research results lead to identifying CSFs during the interviews. Facility managers admit the potentially significant benefits of BIM ("FM Awareness of BIM") to the FM industry. They are familiar of industry BIM standards and guidelines, but not always in depth. However, there is uncertainty over the roles and responsibilities of experts and their adoption of all BIM standards and terminologies.

For example, in 2021, Oluleye *et al.* performed a study using a fuzzy synthetic evaluation to evaluate CSFs of BIM adoption in FM with data collected from 146 facility managers in the Nigerian metropolis of Lagos. 23 CSFs were chosen from literature and identified into six groups. "1) Adequate BIM knowledge within FM; 2) stakeholders' awareness and engagement to BIM process; 3) availability of BIM hardware and software; 4) FM leaders and staff commitment to integrating BIM; 5) BIM investment and organization readiness for change; 6) presence of BIM metric and model" were found to be top six groups respectively, which includes 23 factors. The factors were ranked within the groups, but their order within the total is unknown. "Adequate BIM knowledge within FM" was the most important group among the six groups. The first important factor was rated as "Motivation for BIM adoption in FM" in this category. In the category "stakeholders' awareness and engagement with the BIM process", the first important factor was rated as "Promoting BIM benefits among stakeholders". In the category of "availability of BIM hardware and software", the first important factor was rated as "Accessible BIM software vendor for FM". In the category of " FM leaders and staff commitment to integrating BIM", the first important factor was rated as " Leadership backing for BIM". "Top leadership backing and motivation and general commitment to BIM adoption", which are similar to the pre-mentioned important factors, are among the top 10 important factors in this study. However, the "Accessible BIM software vendor for FM" factor is a country-based problem.

In this study, critical success factors for the successful adoption of BIM-FM were investigated and listed with the help of the literature review and focus group contribution. Then, construction projects undertaken by Turkish contractors were chosen as the focus of the study to evaluate the final CSF list. The ANP method was chosen as the best option for this evaluation, and a survey was performed. After the survey results were examined with the help of Super Decisions software, an interview was conducted with industry representatives to evaluate BIM-FM benefits and barriers and the final CSFs list. There is a gap in the literature on BIM-FM CSFs. In addition to this, there has not been any study based on the Turkish AEC industry to evaluate CSFs for BIM-FM integration. Hence, the most significant contribution of this study to the literature is filling this gap in the Turkish construction industry. Another contribution of this study is that this study focuses on projects undertaken by Turkish contractors to evaluate CSFs of BIM-FM integration. Examining CSF priorities and factors importance weights is one of the study's primary goal. The use of the ANP technique in this study also contributes to the literature as a different MCDM method. ANP method provide a framework for decision-makers in the industry to study and evaluate the CSFs of BIM-FM integrated projects while taking interrelationships into account. This study allows them to understand the critical success factors and understand the steps necessary to ensure successful BIM-FM integration. Four subcategories (stakeholder-related, technology-related, design process-related, and handover process-related) were created from 24 CSFs. The first two important groups are stakeholders and design-related factors, respectively. The following are the top seven factors for successful BIM-FM integration: "BIM education and training for employees (0.1282)", "Top leadership backing & motivation (0.1216)", "Availability of capable/experienced personnel (both in FM and AEC) (0.1085)", "Early involvement of facility managers in the BIM process (0.0948)", "Using BIM to maximize potential cost savings (0.0943)", "General to BIM adoption for FM (0.0815)", "BIM execution plan (BEP) (0.0711)". While the most minor seven relevant factors are: "Preparing a critical assets list (0.0069)", "QA/QC plan for checking BIM deliverables (0.0067)", " Tracking asset history (0.0054)", "Databases for BIM are readily available (0.0032)”, “Hardware and software for BIM-FM are readily available (0.0008)”, “Cost of keeping system (continuous investment) (0.0005)”, “Cybersecurity for stored data (0.0001)”.

In 2013, Won *et al.* published research on the criteria for selecting BIM services; “the predicted economic benefit (return on investment) of adopting BIM services” was rated as the first CSF. This study also proved the importance of “cost savings” by evaluating it as the fifth important factor. If we want to compare similar factors in other studies, Giel and Issa (2016) conducted a study based on building owners’ BIM competency. The most important finding of that study is it emphasizes the importance of the top management buy-in and the quality control plan. Building owners, in other words, clients, care more about the QA/QC plan, which is reasonable from client perspective. In this study, as emphasized by Giel and Issa (2016), the importance of top management has been proven. In another study investigating the most cited CSFs in the literature on BIM in FM, “Senior leadership support” and “education and training” were found to be the first and second most cited factors (Farahaneza *et al.*, 2018). In this study, it was observed that these factors were evaluated as the first and second important factor, which is consistent with the literature.

In 2016, Özorhon and Karahan conducted a study to evaluate the CSFs of BIM implementation in Turkey. In that study, instead of FM integration, the BIM process was taken into account. According to the findings, the five most essential criteria were “availability of qualified staff, effective leadership, availability of information and technology, coordination among project parties, and training of employees”. Whereas in this study, BIM education and training for employees was rated as the first important factor, senior leadership support and motivation rated as the second important factor, and the availability of talented staff in FM and AEC as the third. From these two different studies on BIM in Turkey in different scopes, it has been revealed that BIM education and training, leadership support, and the presence of experienced personnel still maintain their importance in the Turkish construction industry.

The last part of the study aims to understand the expert opinions on the current situation of BIM-FM integration in Turkey. In the interview, according to the opinions of industry professionals, it was revealed that customer demand and awareness are very important. Client interest was pooled in this study under the heading “S1 - General commitment to BIM adoption for FM” and it is rated as sixth important factor. It has been observed that “Client demand and awareness to use BIM-FM” might be included as a distinct component in future studies rather than combining it with “General commitment to BIM adoption for FM”. It has been expressed by experts that FM and customers are unaware of the use of digital data and all opportunities. FM software vendors are also said to be unaware of FM demands or the possibilities connected with digital data. The clarity on the operational use of BIM data at the beginning is stated as very crucial for successful BIM-FM integration. All these comments confirm the importance of education and training, which was found to be the first factor in this study as well. It was stated that FM experts should also be involved in the creation of BIM specifications; only in this way an efficient FM scope can be created. The FM team’s early involvement in the process was considered very important, but the operation specifics must be defined or clear. These interpretations confirm the early involvement of facility managers, which emerged as the fourth important factor in the study. As Ashworth *et al.* (2018) asserted, facilities managers are in charge of asset management after the construction handover. As a result, early participation of FM in the process is critical to ensuring sustainability throughout the life cycle of a building. Furthermore, this participation might help speed up the industry’s adoption of BIM (Oluleye *et al.*, 2021). It was stated in the interviews that AEC experts who designed BIM models were far from FM applications, and therefore, efficient models could not be created. This interpretation, emphasizes the importance of experienced and equipped personnel, which is expressed by the third factor in the study. An interoperability plan between BIM and FM software is also said to be an essential cornerstone for seamless integration. Well-implemented interoperability plan for data exchange between BIM tools and FM systems was found to be the fourteenth important factor in this study. The reason why this is less important in the survey is because it is one of the last steps in the BIM-FM process. Finally, they mentioned that infrastructure and superstructure projects have quite different BIM models and that this study will yield more successful results if applied on a project basis. Moreover, finally, they confirmed that the final CSF list covers a wide range of project challenges and identifies the fundamental issues of BIM-FM integration in the Turkish construction industry.

Interviews were also used to interpret the benefits and barriers found in the literature under the term BIM-FM. According to the interviews, the essential benefit of BIM-FM integration was “the reduction in the time required to get FM data”. Second-tier benefits of BIM-FM integration were rated as: “improved life cycle evaluation”, “maintenance and space management optimization”, “quick information exchange”, and “3D visualization”. The most significant barrier to BIM-FM integration was found as “ lack of FM consideration/collaboration in design and construction phases.” The second most important barrier was determined as “lack of technical understanding and guidelines related to BIM”, “interoperability concerns with BIM-FM software”, “unclear roles and duties”, and “up-to-date model follow-up”. It was also indicated that one more barrier, which is a significant barrier, might be included as a remark. This is due to a “lack of defined customer needs and organizational and infrastructure readiness to use BIM-FM”.

This study has demonstrated the value of BIM training and awareness when survey and interview data are combined. The lack of understanding of data use capacity in FM is confirmed by both expert comments and survey findings. Furthermore, the interview revealed that client demand, which is mentioned under the factor “General commitment to BIM adoption for FM”, is particularly crucial. “BIM education and training” factor already influences the second, sixth and seventh CSFs, as seen from the interrelation matrix. These factors are “top leadership backing and motivation”, “general commitment to BIM adoption for FM” and “BIM Execution Plan”, respectively. According to the survey, the first factor affects fifty percent of the other first seven factors. This emphasizes the importance of BIM education and training, as well. Because informed and equipped individuals know how to use data efficiently, the presence of FM and AEC experienced employees is critical. The importance of involving the FM group early in the BIM process and how such early engagement helps the BEP was also discussed in the interviews.

Given the level of adoption of BIM-FM in developed countries, for example, they are familiar with BIM standards and guidelines in the UK construction industry (Ashworth *et al*., 2018). Ashworth *et al*. (2018) also highlight the need to train FM specialists rather than AEC specialists in the UK. According to this research conducted specifically for the Turkish construction industry, it has been revealed that education is much more important for both AEC and FM in Turkey than in developed countries, and the awareness of FM is low. With expert comments, H3, H4, H5, and H6 variables were added to the handover process-related factors and these new factors contributed to the literature. According to the survey results, these factors were not rated as important. Due to the participants' AEC background, they may have placed more emphasis on design-related and stakeholder-related factors in which they were actively involved than in the handover process. This also indicates that FM awareness is low on the AEC side. The technology cluster has the least importance weight in the clusters. They ignore the importance of technological infrastructure. Awareness of technological processes can be increased by giving training and seminars about technological processes. The technological factors that were rated the most important within the group were the T1-Design of a well-executed 3D model, and as-built data (0.7894) and T3-Databases for BIM are readily available (0.1484). These two factors are the factors that designers take part in, and the other three technological factors are the contractor's responsibility. These are: hardware and software for BIM-FM are readily available, cost of keeping system (continuous investment and cybersecurity for stored data. These could be seen as more important if viewed from the perspective of the contractor or the client. AEC experts think that the remaining three factors should already be provided for implementing BIM-FM, and they do not have enough experience with the problems that may arise from these factors. It is necessary to train FM practitioners and employees about how BIM performs; this is vital since training and education are one of the most successful ways of acquiring information for current technology adoption (Amuda-Yusuf, 2018). CSFs are critical in every type of management or technology implementation since they help firms focus their efforts on particular areas, identify problem areas, and take remedial action (Won *et al.*, 2013).

The limited sample size who participated in the survey is one of the study's limitations. The suggested method can be validated across a broader sample. Considering the adoption rate of BIM-FM and the limited number of construction projects using BIM-FM in Turkey, participants who specialize in infrastructure and superstructure projects were evaluated together in the survey. This study may be done with a larger sample in the future, as BIM-FM adoption is spreading rapidly worldwide. It is also possible to evaluate CSFs that are particular to superstructure and infrastructure projects or exclusive to a project type since BIM data vary according to the project-specific. The sequence of these CSFs may change depending on the nature of the company's business, resource constraints, and project type. Different results might be obtained depending on the project delivery technique used. The contract type for PPP delivery projects defines the contractor's responsibilities for operation and maintenance. This obligation may have an impact on the contractors' perception of the facilities management process. However, all construction project types and project delivery methods were evaluated together in this study. The Delphi panel method, rather than the geometric mean method, can be used to synthesize survey data. Delphi is a technique with a lengthier process since multiple panels will be organized, and participants must attend these panels regularly. The Delphi approach is an effective technique for reaching consensus. However, the Delphi approach was not chosen due to concerns about the level of participation as the participants work in different countries. Therefore, the geometric mean technique was preferred, and a separate session was planned for matrices with only consistency ratio problems.

6. CONCLUSION

The use of BIM data for economic gain in facility management operations is an increasingly popular research area. However, there are limited studies on identifying critical success factors of BIM-FM integration. Identifying CSFs will be helpful as a leading framework for assessing the success of this integration. For this reason, this study aims to determine the critical success factors for BIM-FM integration. Later, it is proposed to evaluate these factors with an ANP model by Super Decisions software.

This research aims to identify and categorize the CSFs of successful BIM-FM integration. The first CSFs list was prepared by choosing 19 research out of 80 published in the past nine years. An exhaustive literature study was conducted for this aim, and all conceivable CSFs in various building projects were seen and listed.

There were 57 factors in the first CSF list. It was discovered that several comparable factors overlapped. Later, the factors with similar meanings and overlaps were removed, reducing the number of factors to 31. The literature studies' factor grouping approaches were investigated in-depth, and the second-factor list was grouped into four subgroups: people-related, policy-related, technology-related, and process-related factors.

A focus group was formed subsequently. The focus group, which comprises two academics, one BIM Engineer, and one BIM Coordinator, agreed to update the group's name, merge related success criteria and add three new factors. As a result, 24 CSFs were grouped into four subcategories. The new subgroups' names were the stakeholders-related, technology-related, design process-related, and handover process-related factors. There are seven stakeholders related, five technology-related factors, six design process-related factors, and six handover process-related factors.

To prioritize success factors and determine their importance weights, the ANP model was chosen as the best way. The ANP model was extremely appropriate when considering the internal and external relationships among the factors. The interrelation matrix was then created with the aid of the focus group, revealing the interconnections between the factors.

For pairwise comparisons, the ANP model was created using Super Decisions software. Clusters and nodes make up the network model. Subgroups are represented by clusters, while nodes represent factors. The interrelation matrix was used to create the network model, and pairwise comparisons were produced automatically by the software.

Once pairwise comparisons were translated to an online environment, an online survey was established. They were presented to the survey focus group, soliciting their feedback. The participants were then chosen. The participants were people who worked on Turkish contractors' BIM-FM integrated projects. Nine surveys were completed by participants who worked on various projects. The answers were then entered into the Super Decisions. Priorities and importance weights for each program were computed automatically. Priorities of subgroups and factors and importance weights of all factors were presented.

Stakeholders-related factors, design-related factors, handover-related factors, and technology-related factors emerged as the most important groups for purpose, respectively. The following are found as the top 10 factors for a successful BIM-FM integration; S2-BIM education and training for employees, S4-Top leadership backing & motivation, S3-Availability of capable/experienced personnel (both in FM and AEC), D3-Early involvement of Facility Managers in the BIM process, H2-Using BIM to maximize potential cost savings (return on investment of built assets), S1-General commitment to BIM adoption for FM, D1-BIM execution plan (BEP), S7-Government support and incentives for BIM in the FM industry, D2-BIM standards and guidelines, D5-Determining Information Delivery Plan (IDP) (space, asset, energy, management data requirements).

As a final step, industry representatives were interviewed about their perspectives on BIM-FM integration and their thoughts on the advantages and barriers discussed in the literature and the final CSF list. Interview questions were created with the help of the literature, and the questions were evaluated with the focus group. Then, interviews were held with three sector representatives. During the interview, it was verified that the final CSF list accurately reflects the steps toward successful BIM-FM integration. It was stated that in the Turkish construction industry, understanding of BIM's FM capabilities are poor. It was shared that FM professionals should be included in developing BIM guidelines. It has been said that AEC professionals who create BIM models are unaware of FM processes, and therefore it is challenging to create well-executed models.

AEC contractors can use the final list of CSFs as a checklist to adopt BIM in their FM operations. The findings of the interviews provided an interpretation of the benefits and barriers identified in the literature in the Turkish construction industry. Several challenges to BIM-FM adoption in the Turkish construction sector were also highlighted in the interviews. Furthermore, determining how much they are influenced by the benefits and barriers indicated in the literature might serve as a reference for contractors implementing BIM-FM in the future. Tracking these success factors helps FM organizations strengthen their operations. The findings demonstrated the significance of BIM training, education, and managerial support. Given this, AEC and FM firms might hold frequent training and seminars for their employees. Manager training is also critical because they are undoubtedly vital for the success of BIM-FM integration. Because BIM-FM is a research field that is constantly evolving and may be integrated with various technologies, managers should be aware of their contribution to the BIM process and encourage employees to learn about the process and any challenges. The survey findings show the significance of facility managers' early engagement in the BIM process. Involving facility managers early in the design process helps establish BIM specifications for FM and provides a precise description of organizational information requirements. These are essential for success. According to the survey results, using BIM to maximize potential cost savings was also one of the essential factors. Being FM-aware while designing the BIM model and modeling all FM requirements for essential assets can eventually boost the ROI in the FM process. Increased ROI would encourage clients' or FM firms' interest in the contribution of BIM, leading to an increase in the usage of BIM in FM. The concrete contributions of the study to the stakeholders are summarized in a table below (Table 6.1).

Table 6.1. Contributions to the stakeholders.

Stakeholder	**Issue**	**Action Proposed**
AEC Contractors	BIM-FM adoption in a project	Use the final list of CSFs as a checklist to adopt BIM in their FM operations.
AEC&FM firms	Strengthen FM awareness	Hold frequent training and seminars for their employees.
FM firms/clients	Strengthen FM operations	Tracking these success factors helps FM organizations strengthen their operations.
Facility Manager	Precise description of FM needs	Facility managers early participation in the design process helps establish BIM specifications for FM and provides a precise description of organizational information requirements.
Leaders	Encouragement of employees	Managers are vital to the success of BIM-FM integration. Manager training is also critical, as BIM-FM is a field of research that is constantly evolving and can be integrated with various technologies.
Designers	Maximize potential cost savings	Being FM-aware while designing the BIM model and modeling all FM requirements for essential assets can eventually boost the ROI in the FM process.

To summarize, there is no research on the CSFs on BIM-FM integration specific to the Turkish market in the literature. As a result, this study makes a significant contribution by defining and analyzing success factors for BIM-FM integration in construction projects. It also attempts to fill a gap in the literature by using the ANP approach in this domain. This research provides a framework for achieving successful BIM-FM integration. The findings of the proposed model can assist FM and AEC stakeholders in reviewing their projects and in getting the necessary procedures to ensure project success.

For further studies, because each project type creates its parameters, this study may be conducted on different projects to produce diverse project-based outcomes. It can also be re-evaluated with different MCDM methods instead of an ANP-based model. Considering that the number of daily BIM-FM users is increasing steadily around the world, this study may be repeated with a larger sample in the future. Furthermore, this study included participants from the AEC sector. It may be repeated with FM practitioners, and differences can be assessed.

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APPENDIX A: LITERATURE REVIEW LIST FOR ALL CRITICAL SUCCESS FACTORS

Table A.1. Literature Review List for All Critical Success Factors.

No	CSFs for BIM enabled FM
1	Organisation of general commitment to BIM adoption for FM
2	Development of BIM adoption framework/BIM execution plan
3	Motivation for BIM adoption on FM
4	Personnel preparation for change
5	End-users participation
6	Availability and affordability of cloud-based technology
7	Adequate knowledge sharing on BIM
8	Involvement of in-house FM project teams
9	Development of good practice 3D model for BIM
10	Promoting BIM benefits among stakeholders
11	Support and incentive from government for BIM in FM industry
12	Availability of BIM databases
13	Organisation re-engineering for BIM
14	BIM research promotion (return on investment..etc)
15	Adequate BIM regulations and guidelines
16	Availability of BIM hardware and software
17	Capacity building for the adoption of modern technology
18	Staff education and training on BIM
19	Investment in BIM
20	Availability of competent staff
21	Accessible BIM software vendor for FM
22	Leadership backing for BIM
23	Collaboration of project stakeholders
24	Clear definition of what FM-enabled BIM constitutes of
25	Allocation of budget towards BIM data
26	LOD determination
27	Early involvement of Facility Managers in the BIM process
28	Clearly defining roles and responsibilities of stakeholders and project teams
29	Having a well-executed interoperability plan for exchanging data between BIM tools and facility management systems
30	Integrated BIM meetings
31	Determining Space management data requirements
32	Determining Maintenance management data requirements
33	Determining asset management data requirements
34	Reliability of collected as-built data

Table A.1. Literature Review List for All Critical Success Factors (cont.).

No	CSFs for BIM enabled FM
35	Using model-based deliverables to improve design, construction and operation of facilities
36	A seamless and practical process of collecting the FM-enabled BIM data throughout project development phases
37	Capacity building for the adoption of modern technology
38	Asset model geometry
39	Delivery methods that address BIM
40	Research and design strategies
41	Organizational job charts
42	Administrative BIM training strategies
43	Having a BIM coordinator or BIM facilitator
44	Willingness to share information among project participants
45	Technical supports for interoperability issues
46	Standardized work procedures for BIM
47	Interoperability plan selection
48	Cost of information gathering
49	Potentiality of direct&indirect cost savings in using BIM as FM tool
50	Client satisfaction level on BIM projects
51	Number of subcontractors/partners experienced with BIM projects
52	Facility management system data transfer
53	Research and design strategies
54	Information-sharing protocols
55	FM/Client agreement on BIM adoption for FM
56	Client interest in/request for BIM
57	Demand/awareness of client to use BIM as FM tool
58	Cybersecurity at the post-occupancy phase

APPENDIX B: CSFs FOR BIM ENABLED FM BEFORE FOCUS GROUP VALIDATION

Table B.1. Critical Success Factors for BIM enabled FM Before Focus Group Validation.

Sub Categories	**CSFs**	**CSFs for BIM enabled FM**	**References**
people related	C1	General commitment to BIM adoption for FM	[7],[9],[12],[13],[14],[15]
	C2	Change preparation for employees and organization	[1],[6],[7],[9],[10],[12],[13],[15],[14]
	C3	BIM education and training for employees	[2],[6],[7],[8],[9],[10],[11],[12],[13],[14],[15]
	C4	Availability of capable/experienced personnel (both in FM and AEC)	[2],[3],[6],[8],[9],[11],[12],[14],[15]
	C5	Top leadership backing	[1],[2],[3],[5],[6],[8],[10],[11],[13],[15]
	C7	Stakeholders (design, construction, engineering, facility management) collaboration on the project	[2],[3],[5],[7],[8],[9],[10],[12],[13],[14],[15]
	C8	Perceived ease of use	[11],[13],[7]
policy related	C9	Government support and incentives for BIM in FM industry	[2],[8],[9],[10],[11],[12],[15]
	C10	Investing in BIM	[1],[2],[3],[6],[8],[9],[11],[12],[15]
	C11	Motivation for BIM adoption on FM	[2],[14],[15]
technology related	C12	Design of well-executed 3D model for BIM	[1],[3],[6],[7],[12],[15]

Table B.1. Critical Success Factors for BIM enabled FM Before Focus Group Validation (cont.).

Sub Categories	**CSFs**	**CSFs for BIM enabled FM**	**References**
technology related	C13	Having a well-executed interoperability plan for exchanging data between BIM tools and FM systems	[2],[3],[5],[6],[7],[12],[14]
	C14	Hardware and software for BIM-FM are readily available	[1],[2],[6],[9],[11],[12],[15]
	C15	Reliability of collected as-built data	[3],[6],[17]
	C16	Cybersecurity at the post-occupancy phase	[2],[19]
	C17	Databases for BIM are readily available.	[2],[8],[9],[11],[12],[15]
process related	C18	Clear definition of what BIM-enabled FM constitutes of	[1],[3],[6],[7],[14]
	C19	Clearly defining roles and responsibilities of stakeholders and project teams	[1],[3],[6],[7],[11],[13]
	C20	BIM standards and guidelines that are adequate	[2],[6],[7],[10],[11],[12],[13],[15]
	C21	Existence of BIM adoption framework/BIM execution plan	[1],[6],[11],[12],[15]
	C22	Integrated BIM meetings	[1],[5],[6],[18]
	C23	LOD determination for the FM stage handover	[6],[7],[16],[17],[18]
	C24	Early involvement of Facility Managers in the BIM process	[1],[3],[4],[14],[18]
	C25	Determining space management data requirements	[1],[3],[6]

Table B.1. Critical Success Factors for BIM enabled FM Before Focus Group Validation (cont.).

process related	C26	Determining maintenance management data requirements	[3],[6]
	C27	Determining asset management data requirements (asset model geometry, asset classification system)	[3],[6],[7],[16],[17],[18]
	C28	Energy and environmental sustainability data requirements	[6]
	C29	QA/QC(quality assessment/quality control) plan for checking BIM deliverables	[6],[16],[17],[18]
	C30	Project type/size	[3],[8],[12]
	C31	Using BIM to maximize potential cost savings (return on investment of built assets)	[2],[3],[9],[14],[11][14]
[1]Badrinath and Hsieh(2019);[2]Won *et al.*(2013);[3]Sarkar *et al.*(2015);[4]Ashworth *et al.* (2016);[5]Pishdad-Bozorgi *et al.* (2018); [6]Giel and Issa(2016);[7]Ashworth *et al.*(2018); [8]Ozorhon and Karahan(2017);[9]Abubakar *et al.*(2014);[10]Liao and Teo(2017); [11]Amuda-Yusuf(2018);[12]Darwish *et al.*(2020); [13]Farahaneza *et al.*(2018);[14]Ashworth(2020);[15]Oluleye *et al.*(2021); [16]Leygonie(2020);[17]Motamedi *et al.*(2018);[18]Borhani and Dossick(2020); [19]Ghadiminia *et al.*(2021).			

APPENDIX C: WEB QUESTIONNAIRE SURVEY

Critical Success Factors for a Successful BIM-FM Integration ir

Bitte wählen Sie eine Sprache aus. / Veuillez s'il vous plaît choisir une langue. / Please choose a language. / Selezionare una lingua. / Lütfen bir dil seçin. / Por favor, seleccione un idioma. / Por favor escolha um idioma. / Kies een taal. / Välj ett språk. / Vennligst velg et språk. / Vælg sprog. / Valitse kieli. / الرجاء اختيار لغتك.

İngilizce

Sayfa 1

You are invited to participate in a research study on determining the Critical Success Factors of Building Information Modeling and Facility Management Integration and prioritizing these factors
As a part of this study, a survey is designed for authorities who have worked in BIM-FM Integrated Projects.

This study is being conducted by Bensu Namlı Özfurat under the supervision of Asst. Prof. Semra Çomu Yapıcı at Boğaziçi University Civil Engineering Department.
Your participation is greatly appreciated. We assure you that the personal information will be confidential and anonymous. The collected data will be utilized for scientific and academic purposes only. Please choose the most appropriate option that represents your opinion about pairwise comparisons of critical success factors.

The questionnaire takes approximately 20 minutes of your time. Thank you for your time and consideration!

Institution : Bogazici University
Name of the research: Critical Success Factors for a Successful BIM-FM Integration in Projects.
Name of Researcher: Bensu NAMLI ÖZFURAT
E-mail address: bensunamli@hotmail.com

Country of employment *

What is your highest level of education? *

- ◯ Bachelor's Degree
- ◯ Master's Degree
- ◯ Doctorate
- ◯ Other ____________

Which of the following best describes your current role? *

- ◯ BIM Coordinator
- ◯ BIM Manager
- ◯ BIM Engineer
- ◯ BIM Architect
- ◯ Mechanical Engineer
- ◯ Electrical Engineer
- ◯ Structural Engineer
- ◯ Information Manager
- ◯ Facility Manager
- ◯ Asset Manager
- ◯ Other ____________

How long have you been working in the AEC-FM(Architecture Engineering Construction-Facility Management) industry ? *

Lütfen seçiniz ...

How many years have you been working on BIM projects ? *

Lütfen seçiniz ...

What kind of mega projects have you worked on with BIM-FM integration? *

- ☐ Airport
- ☐ Off-shore Wind Turbine
- ☐ Tunnel
- ☐ Bridge
- ☐ Highway
- ☐ Metro Projects
- ☐ Industrial Facilities
- ☐ Shopping Mall
- ☐ Office Building
- ☐ Residential Building
- ☐ Healthcare Facilities
- ☐ Other

What is the size of the BIM-FM integrated project you are working on or you have worked? *

- [ ] 100-500 Million $
- [ ] 500 Million $ - 1 Billion $
- [ ] 1-10 Billion $
- [ ] 10-20 Billion $
- [ ] Over than 20 Billion $
- [ ] Other

Below you can see the CRITICAL SUCCES FACTOR(CSF) list of SUCCESSFULL BUILDING INFORMATION MODELING(BIM)-FACILITY MANAGEMENT(FM) INTEGRATION which divided into 4 subcategories.

CSFs for BIM ENABLED FM

STAKEHOLDERS RELATED FACTORS
S1 General commitment to BIM adoption for FM
S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)
S4 Top leadership backing & motivation
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project
S6 Perceived ease of use
S7 Government support and incentives for BIM in FM industry

TECHNOLOGY RELATED FACTORS
T1 Design of well-executed 3D model and as-built data
T2 Hardware and software for BIM-FM are readily available
T3 Databases for BIM are readily available.
T4 Cybersecurity for stored data
T5 Cost of keeping system (continuous investment)

DESIGN PROCESS RELATED FACTORS
D1 BIM execution plan(BEP)
D2 BIM standards and guidelines
D3 Early involvement of Facility Managers in the BIM process
D4 Project type/size/complexity
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)
D6 QA/QC(quality assessment/quality control) plan for checking BIM deliverables

HANDOVER PROCESS RELATED FACTORS
H1 Well-executed interoperability plan for exchanging data between BIM tools and FM systems
H2 Using BIM to maximize potential cost savings (return on investment of built assets)
H3 Populating COBie spread sheet from the model
H4 Defining the mapping rules between shared parameters and COBie parameters
H5 Preparing a critical assets list
H6 Tracking asset history

To mark the relative importance between the parameters, the relative importance in the following questionnaire is listed as follows :

9- Extremely important
7-Very strongly important
5-Strongly important
3-Moderately important
1-Equally important
2,4,6,8- Intermediate values between the two adjacent judgments

For Example:

A/B ------- (9) 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9 = If you choose 9 from left side it means that "A is extremeyl important than B with respect to the objective."
A/B ------- 9 8 7 6 5 4 3 2 (1) 2 3 4 5 6 7 8 9 = If you choose 1 it means that "A and B contribute equally to the objective."
A/B ------- 9 8 7 6 5 4 3 2 1 2 3 4 (5) 6 7 8 9 = If you choose 5 from right side it means that "B is strongly important than A with respect to the objective."

This questionnaire consists of 3 parts. In this first part, you will compare the sub-categories (clusters).

Pairwise comparison of CSFs(Critical Success Factors) subcategories(clusters) with respect to successfull BIM-FM Integration(goal). *

If you believe that the first subcategory is more important with respect to the successfull BIM-FM Integration, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
design process / handover process	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process / stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process / technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
handover process / stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
handover process / technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
stakeholder /technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of subcategories(clusters) with respect to the design process cluster. *

If you believe that the first subcategory affects the "design process" cluster more than the other subcategory , rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
design process / stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process / technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
stakeholder /technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of subcategories(clusters) with respect to the handover process cluster *

If you believe that the first subcategory affects the "handover process" cluster more than the other subcategory , rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
design process / handover process	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process / stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process /technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
handover process/ stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
handover process / technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
stakeholder /technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of subcategories(clusters) with respect to the stakeholders cluster *

If you believe that the first subcategory affects the "stakeholders" cluster more than the other subcategory , rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
design process / handover process	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process / stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
handover process/ stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of subcategories(clusters) with respect to technology cluster *

If you believe that the first subcategory affects the "technology" cluster more than the other subcategory , rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
design process / stakeholder	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
design process/ technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
stakeholder/technology	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

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In this second section , you will compare the nodes(factors) with respect to their clusters(subcategories).

Pairwise comparison of factors(nodes) with respect to design process(cluster) *

If you believe that the first node is more important with respect to design process cluster, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

D1 BIM execution plan(BEP)

D2 BIM standards and guidelines
D3 Early involvement of Facility Managers in the BIM process
D4 Project type/size/complexity
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)
D6 QA/QC(quality assessment/quality control) plan for checking BIM deliverables

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
D1/D2																	
D1/D3																	
D1/D4																	
D1/D5																	
D1/D6																	
D2/D3																	
D2/D4																	
D2/D5																	
D2/D6																	
D3/D4																	
D3/D5																	
D3/D6																	
D4/D5																	
D4/D6																	
D5/D6																	

Pairwise comparison of factors(nodes) with respect to handover process(cluster) *

If you believe that the first node is more important with respect to handover process cluster, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

H1 Well-executed interoperability plan for exchanging data between BIM tools and FM systems
H2 Using BIM to maximize potential cost savings (return on investment of built assets)
H3 Populating COBle spread sheet from the model
H4 Defining the mapping rules between shared parameters and COBle parameters
H5 Preparing a critical assets list
H6 Tracking asset history

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
H1/H2																	
H1/H3																	
H1/H4																	
H1/H5																	
H1/H6																	
H2/H3																	
H2/H4																	
H2/H5																	
H2/H6																	
H3/H4																	
H3/H5																	
H3/H6																	
H4/H5																	
H4/H6																	
H5/H6																	

Pairwise comparison of factors(nodes) with respect to the stakeholder(cluster) *

If you believe that the first node is more important with respect to stakeholder cluster, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

S1 General commitment to BIM adoption for FM
S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)
S4 Top leadership backing & motivation
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project
S6 Perceived ease of use
S7 Government support and incentives for BIM in FM industry

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S1/S2																	
S1/S3																	
S1/S4																	
S1/S5																	
S1/S6																	
S1/S7																	
S2/S3																	
S2/S4																	
S2/S5																	
S2/S6																	
S2/S7																	
S3/S4																	
S3/S5																	
S3/S6																	

S3/S7

S4/S5

S4/S6

S4/S7

S5/S6

S5/S7

S6/S7

Pairwise comparison of factors(nodes) with respect to technology(cluster). *

If you believe that the first node is more important with respect to the technology cluster, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective more and how strongly(1-9) more than another element.

T1 Design of well-executed 3D model and as-built data
T2 Hardware and software for BIM-FM are readily available
T3 Databases for BIM are readily available.
T4 Cybersecurity for stored data
T5 Cost of keeping system (continuous investment)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
T1/T2																	
T1/T3																	
T1/T4																	
T1/T5																	
T2/T3																	
T2/T4																	
T2/T5																	
T3/T4																	
T3/T5																	
T4/T5																	

In this final part, you will compare the inner and outer dependencies of nodes(factors) with respect to the affected node.

Pairwise comparison of factors(nodes) with respect to D1-BIM execution plan(BEP). *

If you believe that the first node is more important with respect to the node D1, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

D2 BIM standards and guidelines
D3 Early involvement of Facility Managers in the BIM process
D4 Project type/size/complexity
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
D2/D3																	
D2/D4																	
D2/D5																	
D3/D4																	
D3/D5																	
D4/D5																	
S2/S3																	

Pairwise comparison of factors(nodes) with respect to D3-Early involvement of Facility Managers in the BIM process *

If you believe that the first node is more important with respect to the node D3, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S1 General commitment to BIM adoption for FM
S4 Top leadership backing & motivation

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S1/S4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to D5 - Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements) *

If you believe that the first node is more important with respect to the node D5, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

D3 Early involvement of Facility Managers in the BIM process
D4 Project type/size/complexity
D6 QA/QC(quality assessment/quality control) plan for checking BIM deliverables

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
D3/D4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
D3/D6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
D4/D6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S3/S5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to D6 - QA/QC(quality assessment/quality control) plan for checking BIM deliverables. *

If you believe that the first node is more important with respect to the node D6, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

D4 Project type/size/complexity
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
D4/D5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to H1 - Well-executed interoperability plan for exchanging data between BIM tools and FM systems. *

If you believe that the first node is more important with respect to the node H1, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

H3 Populating COBle spread sheet from the model
H4 Defining the mapping rules between shared parameters and COBle parameters

D3 Early involvement of Facility Managers in the BIM process
D4 Project type/size/complexity
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project

T1 Design of well-executed 3D model and as-built data
T2 Hardware and software for BIM-FM are readily available

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
H3/H4																	
D3/D4																	
D3/D5																	
D4/D5																	
S2/S3																	
S2/S5																	
S3/S5																	
T1/T2																	

Pairwise comparison of factors(nodes) with respect to H2-Using BIM to maximize potential cost savings (return on investment of built assets). *

If you believe that the first node is more important with respect to the node H2, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

H3 Populating COBle spread sheet from the model
H4 Defining the mapping rules between shared parameters and COBle parameters
H5 Preparing a critical assets list
H6 Tracking asset history

D3 Early involvement of Facility Managers in the BIM process
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
H3/H4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H3/H5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H3/H6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H4/H5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H4/H6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H5/H6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
D3/D5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to H4 - Defining the mapping rules between shared parameters and COBle parameters. *

If you believe that the first node is more important with respect to the node H4, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

D2 BIM standards and guidelines
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)

S3 Availability of capable/experienced personnel (both in FM and AEC)
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project

H1 Well-executed interoperability plan for exchanging data between BIM and FM
H3 Populating COBle spreadsheet from the model

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
D2/D5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S3/S5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H1/H3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to H5 - Preparing a critical assets list *

If you believe that the first node is more important with respect to the node H5, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

H1 Well-executed interoperability plan for exchanging data between BIM tools and FM systems
H2 Using BIM to maximize potential cost savings (return on investment of built assets)

S3 Availability of capable/experienced personnel (both in FM and AEC)
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
H1/H2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S3/S5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to H6 - Tracking asset history *

If you believe that the first node is more important with respect to the node H6, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

H1 Well-executed interoperability plan for exchanging data between BIM tools and FM systems
H2 Using BIM to maximize potential cost savings (return on investment of built assets)
H5 Preparing a critical assets list

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
H1/H2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H1/H5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
H2/H5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to S1 - General commitment to BIM adoption for FM *

If you believe that the first node is more important with respect to the node S1, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S2 BIM education and training for employees
S4 Top leadership backing & motivation
S6 Perceived ease of use
S7 Government support and incentives for BIM in FM industry

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S2/S4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S4/S6	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S4/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S6/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to S2 - BIM education and training for employees *

If you believe that the first node is more important with respect to the node S2, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S3 Availability of capable/experienced personnel (both in FM and AEC)
S4 Top leadership backing & motivation
S7 Government support and incentives for BIM in FM industry

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S3/S4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S3/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S4/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to S4 - Top leadership backing & motivation *

If you believe that the first node is more important with respect to the node S4, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S2 BIM education and training for employees
S7 Government support and incentives for BIM in FM industry

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S2/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to S5 - Stakeholders(architecure,construction,engineering,facility management) collaboration on the project *

If you believe that the first node is more important with respect to the node S5, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S1 General commitment to BIM adoption for FM
S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S1/S2	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S1/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to T1- Design of well-executed 3D model and as-built data *

If you believe that the first node is more important with respect to the node T1, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

D1 BIM execution plan(BEP)
D4 Project type/size/complexity
D5 Determining Information Delivery Plan(IDP)(space,asset,energy,management data requirements)

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)
S5 Stakeholders(architecure,construction,engineering,facility management) collaboration on the project

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
D1/D4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
D1/D5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
D4/D5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S3/S5	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to T3 - Databases for BIM are readily available. *

If you believe that the first node is more important with respect to the node T3, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S2/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to T4 - Cybersecurity for stored data. *

If you believe that the first node is more important with respect to the node T4, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

S2 BIM education and training for employees
S3 Availability of capable/experienced personnel (both in FM and AEC)
S4 Top leadership backing & motivation

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
S2/S3	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S2/S4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S3/S4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pairwise comparison of factors(nodes) with respect to T5 - Cost of keeping system (continuous investment in BIM) *

If you believe that the first node is more important with respect to the node T5, rank from the left side other wise rank from the right side. Comparisons of elements according to which element(left/right) influences the objective node more and how strongly(1-9) more than another element.

T2 Hardware and software for BIM-FM are readily available
T4 Cybersecurity for stored data

S4 Top leadership backing & motivation
S7 Government support and incentives for BIM in FM industry

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
T2/T4	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
S4/S7	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Anketi başarıyla tamamladınız. Katılımınız için teşekkür ederiz.

Pencereyi kapatabilirsiniz.

APPENDIX D: PAIRWISE COMPARISON MATRICES

Table D.1. Pairwise Comparison Matrix 1.

DESIGN	D1	D2	D3	D4	D5	D6
D1	1	2	2	5	2	4
D2	1/2	1	2	4	2	2
D3	1/2	1/2	1	2	2	2
D4	1/5	1/4	1/2	1	2	1
D5	1/2	1/2	1/2	1/2	1	1
D6	1/4	1/2	1/2	1	1	1

Table D.2. Pairwise Comparison Matrix 2.

HANDOVER	H1	H2	H3	H4	H5	H6
H1	1	6	6	4	2	4
H2	1/6	1	1	3	2	3
H3	1/6	1	1	2	3	2
H4	1/4	1/3	1/2	1	2	3
H5	1/2	1/2	1/3	1/2	1	2
H6	1/4	1/3	1/2	1/3	1/2	1

Table D.3. Pairwise Comparison Matrix 3.

STAKEHOLDERS	S1	S2	S3	S4	S5	S6	S7
S1	1	5	3	3	3	4	5
S2	1/5	1	2	2	2	4	2
S3	1/3	1/2	1	3	2	4	2
S4	1/3	1/2	1/3	1	2	2	2
S5	1/3	1/2	1/2	1/2	1	1	2
S6	1/4	1/4	1/4	1/2	1	1	3
S7	1/5	1/2	1/2	1/2	1/2	1/3	1

Table D.4. Pairwise Comparison Matrix 4.

TECHNOLOGY	T1	T2	T3	T4	T5
T1	1	5	3	5	3
T2	1/5	1	4	2	1
T3	1/3	1/4	1	2	1
T4	1/5	1/2	1/2	1	2
T5	1/3	1	1	1/2	1

Table D.5. Pairwise Comparison Matrix 5.

D1	D2	D3	D4	D5
D2	1	3	4	2
D3	1/3	1	4	3
D4	1/4	1/4	1	1
D5	1/2	1/3	1	1

Table D.6. Pairwise Comparison Matrix 6.

D1	S2	S3
S2	1	2
S3	1/2	1

Table D.7. Pairwise Comparison Matrix 7.

D3	S1	S4
S1	1	2
S4	1/2	1

Table D.8. Pairwise Comparison Matrix 8.

D5	D3	D4	D6
D3	1	6	3
D4	1/6	1	1
D6	1/3	1	1

Table D.9. Pairwise Comparison Matrix 9.

D5	S2	S3	S5
S2	1	3	3
S3	1/3	1	1
S5	1/3	1	1

Table D.10. Pairwise Comparison Matrix 10.

D6	S2	S3
S2	1	2
S3	1/2	1

Table D.11. Pairwise Comparison Matrix 11.

D6	D4	D5
D4	1	2
D5	1/2	1

Table D.12. Pairwise Comparison Matrix 12.

H1	D3	D4	D5
D3	1	2	3
D4	1/2	1	1
D5	1/3	1	1

Table D.13. Pairwise Comparison Matrix 13.

H1	S2	S3	S5
S2	1	2	4
S3	1/2	1	4
S5	1/4	1/4	1

Table D.14. Pairwise Comparison Matrix 14.

H1	H3	H4
H3	1	5
H4	1/5	1

Table D.15. Pairwise Comparison Matrix 15.

H1	T1	T2
T1	1	2
T2	1/2	1

Table D.16. Pairwise Comparison Matrix 16.

H2	D3	D5
D3	1	3
D5	1/3	1

Table D.17. Pairwise Comparison Matrix 17.

H2	H3	H4	H5	H6
H3	1	5	2	3
H4	1/5	1	2	2
H5	1/2	1/2	1	1
H6	1/3	1/2	1	1

Table D.18. Pairwise Comparison Matrix 18.

H3	H1	H4
H1	1	3
H4	1/3	1

Table D.19. Pairwise Comparison Matrix 19.

H3	D4	D5
D4	1	2
D5	1/2	1

Table D.20. Pairwise Comparison Matrix 20.

H3	S3	S5
S3	1	6
S5	1/6	1

Table D.21. Pairwise Comparison Matrix 21.

H4	S3	S5
S3	1	3
S5	1/3	1

Table D.22. Pairwise Comparison Matrix 22.

H4	H1	H3
H1	1	2
H3	1/2	1

Table D.23. Pairwise Comparison Matrix 23.

H4	D2	D5
D2	1	4
D5	1/4	1

Table D.24. Pairwise Comparison Matrix 24.

H5	H1	H2
H1	1	4
H2	1/4	1

Table D.25. Pairwise Comparison Matrix 25.

H5	S3	S5
S3	1	2
S5	1/2	1

Table D.26. Pairwise Comparison Matrix 26

H6	H1	H2	H5
H1	1	4	3
H2	1/4	1	2
H5	1/3	1/2	1

Table D.27. Pairwise Comparison Matrix 27.

S1	S2	S4	S6	S7
S2	1	2	3	3
S4	1/2	1	3	2
S6	1/3	1/3	1	1
S7	1/3	1/2	1	1

Table D.28. Pairwise Comparison Matrix 28.

S2	S3	S4	S7
S3	1	2	5
S4	1/2	1	4
S7	1/5	1/4	1

Table D.29. Pairwise Comparison Matrix 29.

S4	S2	S7
S2	1	3
S7	1/3	1

Table D.30. Pairwise Comparison Matrix 30.

S5	S1	S2	S3
S1	1	3	2
S2	1/3	1	2
S3	1/2	1/2	1

Table D.31. Pairwise Comparison Matrix 31.

T1	D1	D4	D5
D1	1	4	3
D4	1/4	1	1
D5	1/3	1	1

Table D.32. Pairwise Comparison Matrix 32.

T1	S2	S3	S5
S2	1	2	2
S3	1/2	1	1
S5	1/2	1	1

Table D.33. Pairwise Comparison Matrix 33.

T3	S2	S3
S2	1	2
S3	1/2	1

Table D.34. Pairwise Comparison Matrix 34.

T4	S2	S3	S4
S2	1	2	1
S3	1/2	1	1
S4	1	1	1

Table D.35. Pairwise Comparison Matrix 35.

T5	S4	S7
S4	1	2
S7	1/2	1

Table D.36. Pairwise Comparison Matrix 36.

T5	T2	T4
T2	1	1
T4	1	1

Table D.40. Pairwise Comparison Matrix 40.

SUCCESSFUL BIM-FM	DESIGN P.	HANDOVER P.	STAKEHOLDERS	TECHNOLOGY
DESIGN P.	1	3	3	4
HANDOVER P.	1/3	1	5	5
STAKEHOLDERS	1/3	1/5	1	3
TECHNOLOGY	1/4	1/5	1/3	1

Table D.41. Pairwise Comparison Matrix 41.

DESIGN P.	DESIGN P.	STAKEHOLDERS	TECHNOLOGY
DESIGN P.	1	7	5
STAKEHOLDERS	1/7	1	2
TECHNOLOGY	1/5	1/2	1

Table D.42. Pairwise Comparison Matrix 42.

HANDOVER P.	DESIGN P.	HANDOVER P.	STAKEHOLDERS	TECHNOLOGY
DESIGN P.	1	2	4	3
HANDOVER P.	1/2	1	5	4
STAKEHOLDERS	1/4	1/5	1	3
TECHNOLOGY	1/3	1/4	1/3	1

Table D.43. Pairwise Comparison Matrix 43.

STAKEHOLDERS	DESIGN P.	HANDOVER P.	STAKEHOLDERS
DESIGN P.	1	3	3
HANDOVER P.	1/3	1	2
STAKEHOLDERS	1/3	1/2	1

Table D.44. Pairwise Comparison Matrix 44.

TECHNOLOGY	DESIGN P.	STAKEHOLDERS	TECHNOLOGY
DESIGN P.	1	4	3
STAKEHOLDERS	1/4	1	2
TECHNOLOGY	1/3	1/2	1

APPENDIX E: INTERVIEW QUESTIONS

You are invited to participate in a research study on determining the “Critical Success Factors of Building Information Modeling and Facility Management Integration and prioritizing these factors in construction projects”. This study is being conducted by Bensu Namlı Özfurat under the supervision of Asst. Prof. Semra Çomu Yapıcı at Boğaziçi University Civil Engineering Department. As a part of this study, a survey was designed for authorities who have worked in BIM-FM integrated projects. Then, an interview will be held as a second part of this study. The interview will take approximately 15 minutes of your time. Thank you for your time and consideration!

- Name Surname :

- What is the highest degree you obtained?
  - Bachelors
  - Masters
  - Phd

- What best describes your position?
  - Facilities Manager
  - Asset Manager
  - BIM Engineer
  - BIM Architect
  - BIM Coordinator
  - Electrical Engineer
  - Mechanical Engineer
  - BIM Manager
  - Other _____________

- How long have you been working for your current role?

0-5 years	6-10 years	11-15 years	>15 years

- How many years have you been dealing with the BIM-facility management field?

0-5 years	6-10 years	11-15 years	>15 years

<u>FIRST PART</u>

- Which programs or systems do you utilise for your facility management works?

(For Example = BIM (Building Information Modeling),CAD(Computer Aided Design),CAFM(Computer-Aided Facility Management) ,CIFM(Computer Integrated Facility Management) , CMMS(Computerized Maintenance Management System) , IWMS (Integrated Workplace Management Systems), GIS(Geographic Information Systems)

- For which activities do you utilise your FM programs or systems?
    - Asset Management
    - Cleaning
    - Contract Management
    - Disaster Management
    - Assignment of work orders
    - Environmental Management
    - Finance and Budgeting
    - Health & Safety
    - Inventory Management
    - Occupancy Management
    - Preventative Maintenance
    - Project Management
    - Room Scheduling
    - Maintenance Scheduling
    - Security
    - Space Management
    - Sustainability & Energy Management
    - Other

- Please rank the benefits of BIM-FM integration according to satisfaction level.

	1 very unsatisfied	2 unsatisfied	3 neutral	4 satisfied	5 very satisfied
3D Visualisation					
Rapid information sharing					
Reduced costs					
Optimisation of financial asset management					
Maintenance & space management optimisation					
Time reduction in obtaining FM data					
Elimination of information loses					
Enhanced life cycle assessment					
Enhanced decision making assessment					

OTHER………………

- Please rank the challenges of BIM-FM integration according to satisfaction level.

	1 very unsatisfied	2 unsatisfied	3 neutral	4 satisfied	5 very satisfied
Lack of FM consideration/ collaboration in design and construction phases					
Lack of technical knowledge and guidelines regarding BIM					
Interoperability issues between BIM-FM softwares					
Unclear roles and responsibilities					
Up-to-date model follow-up (room and furniture change arrangements)					

OTHER……………

SECOND PART

The final list of 24 Critical Success Factors (CSFs) that I have compiled based on literature review and expert opinions for successful BIM-FM Integration is presented below.

- What are your personal thoughts? Do you think this CSFs reflects the reality of the industry? What helps FMs best engage in the BIM process in construction projects?

List of Critical Success Factors (CSFs) that affect successful BIM-FM integration

Sub Categories	CSFs	CSFs for BIM enabled FM
stakeholders related	S1	General commitment to BIM adoption for FM
	S2	BIM education and training for employees
	S3	Availability of capable/experienced personnel (both in FM and AEC)
	S4	Top leadership backing & motivation
	S5	Stakeholders (architecture, construction, engineering, facility management) collaboration on the project
	S6	Perceived ease of use
	S7	Government support and incentives for BIM in FM industry
technology related	T1	Design of well-executed 3D model and as-built data
	T2	Hardware and software for BIM-FM are readily available
	T3	Databases for BIM are readily available.
	T4	Cybersecurity for stored data
	T5	Cost of keeping system (continuous investment)

design process related	D1	BIM execution plan (BEP)
	D2	BIM standards and guidelines
	D3	Early involvement of Facility Managers in the BIM process
	D4	Project type/size/complexity
	D5	Determining Information Delivery Plan (IDP) (space, asset ,energy, management data requirements)
	D6	QA/QC(quality assessment/quality control) plan for checking BIM deliverables
handover process related	H1	Well-executed interoperability plan for exchanging data between BIM tools and FM systems
	H2	Using BIM to maximize potential cost savings (return on investment of built assets)
	H3	Populating COBIe spread sheet from the model
	H4	Defining the mapping rules between shared parameters and COBIe parameters
	H5	Preparing a critical assets list
	H6	Tracking asset history

Your Opinion: