INTEGRATION OF BIM AND MODULAR CONSTRUCTION: ADVANTAGES, BARRIERS, AND IMPLEMENTATION STRATEGIES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BURCU ATAKUL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

APRIL 2024

Approval of the thesis:

INTEGRATION OF BIM AND MODULAR CONSTRUCTION: ADVANTAGES, BARRIERS, AND IMPLEMENTATION STRATEGIES
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ABSTRACT

INTEGRATION OF BIM AND MODULAR CONSTRUCTION: ADVANTAGES, BARRIERS, AND IMPLEMENTATION STRATEGIES

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April 2024, 130 pages

Building Information Modeling (BIM) has gained widespread acceptance as a method for managing building information in a digital environment. BIM offers a range of opportunities for integrating recent technologies into the design and construction processes, leading to greater efficiency in these areas. By integrating BIM, the construction industry can unlock tremendous potential, particularly in modular construction (MC) with more industrialized processes than other construction methods. While the theoretical benefits of this approach are well established, modular construction companies face challenges in transitioning from conventional methods to BIM. This study aimed to enhance the use of BIM in modular construction by presenting the advantages, barriers, and stakeholders' responsibilities to overcome these barriers. To achieve this, the study conducted a systematic literature review and qualitative research incorporating expert interviews with Turkish modular construction industry practitioners. The resulting analysis identifies the key advantages of BIM-MC integration, and the critical barriers to effective implementation, and presents stakeholders' responsibilities to overcome these barriers.

Keywords: Modular Construction, Building Information Modeling, BIM, Prefabricated Construction, Off-site Construction

ÖZ

BIM VE MODÜLER YAPILARIN ENTEGRASYONU: AVANTAJLAR, ENGELLER VE UYGULAMA STRATEJİLERİ

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Nisan 2024, 130 sayfa

Yapı Bilgi Modellemesinin (YBM-BIM), bir binanın bilgilerini dijital bir ortamda yönetme yöntemi olarak geniş kabul görmüştür. BIM, yeni teknolojilerin tasarım ve inşaat süreçlerine entegre edilmesi için bir dizi fırsat sunarak, bu alanlarda daha büyük verimliliğe yol açmaktadır. İnşaat sektörü, BIM'i entegre ederek, özellikle diğer inşaat yöntemlerine göre daha endüstriyelleştirilmiş süreçlere sahip modüler inşaatta (Mİ-MC) önemli bir potansiyele sahip olabilir. Bu yaklaşımın teorik avantajları iyi bir şekilde belirlenmiş olsa da, modüler inşaat şirketleri geleneksel yöntemlerden BIM'e geçişte zorluklarla karşılaşmaktadır. Bu çalışma, BIM-MC entegrasyonunun avantajlarını, engellerini ve bu engelleri aşmaya yönelik olarak paydaşların sorumluluklarını sunarak BIM'in modular yapılarda kullanımını güçlendirmeyi amaçlamaktadır. Bunu başarmak için sistematik bir literatür taramasıyla beraber Türkiye'deki modüler inşaat sektörü uygulayıcılarıyla yapılan mülakatları içeren bir araştırma gerçekleştirilmiştir. Ortaya çıkan analiz, BIM-MC entegrasyonunun temel avantajlarını, etkili uygulamanın önündeki kritik engelleri belirlemekte ve bu engellerin üstesinden gelmek için paydaşların sorumluluklarını ortaya koymaktadır.

Anahtar Kelimeler Modüler Yapı, Yapı Bilgi Modellemesi, YBM, BIM, Prefabrik Yapı, Saha Dışı İnşaat

Dedicated to my beloved family and my love…

ACKNOWLEDGMENTS

I wish to express my deepest gratitude to my supervisor Dr. Aslı Akçamete Güngör for her guidance, advice, criticism, encouragement, and insight throughout the research.

I want to extend my gratitude to everyone who helped and contributed to the completion of my thesis. I want to thank to the examining committee members for their valuable time, effort, and expertise in reviewing this thesis. I also thank the Turkish modular construction industry practitioners who participated in the expert interviews and shared their experiences and insights. Furthermore, I am grateful to the Graduate School of Natural and Applied Sciences at Middle East Technical University for the provision of the necessary resources and facilities for the research.

I want to express my heartfelt gratitude to my dear family for their love, support, and encouragement. My brother, Hasan Atakul, has always guided me and enlightened my path with his wisdom. My mother, Yeter Atakul, has inspired me with her strength, determination, and hard work. Despite his health struggles, my father, İsmail Atakul, has always been my source of unwavering love and support.

I finally want to thank all my close friends in Ankara for their support. Most importantly, I want to express my warmest gratitude to my best friend and love, İbrahim Akkaya, for being there for me throughout this journey.

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AI	Artificial Intelligence
AR	Augmented Reality
BIM	Building Information Modeling
CDE	Common Data Environment
DfMA	Design for Manufacture and Assembly
ENR	Engineering News-Record
EPC	Engineering, Procurement, and Construction
IBS	Industrialised Building System
IoT	Internet of Things
MC	Modular Construction
OECD	Organisation for Economic Co-operation and Development
RFID	Radio-frequency Identification
VR	Virtual Reality
WoS	Web of Science
YÖK	Council of Higher Education

CHAPTER 1

INTRODUCTION

Compared to other industries, the construction industry has been traditionally slow in embracing new technologies. It has not experienced any significant disruptive changes, and it has not widely implemented process advancements. Thus, efficiency gains in this field have not been sufficient yet, according to the World Economic Forum's report (2016). The problem is compounded by a fragmented supply chain, short-term thinking, culture, and complex projects due to the involvement of many stakeholders in a unique project. Additionally, the level of uncertainty of a project adds further complications to the project because of the unpredictable environmental conditions (Oesterreich et al., 2016). Sawhney et al. (2020) claim that Construction 4.0 is a conceptual framework that integrates cutting-edge technologies and emerging trends in the construction industry. Inspired by the principles of Industry 4.0, this paradigm shift has the potential to revolutionize the design, construction, and operation of built environment assets. They also state that Construction 4.0 aims to optimize the construction process, improve project efficiency, and enhance the overall quality of the built environment and it is based on 3 pillar themes: cyber-physical systems, industrial production, and digital and computing technologies. Robotics and automation are utilized in cyber-physical systems to carry out dangerous or repetitive tasks, while drones are utilized for surveying and location. Industrial production methods such as prefabrication, 3D printing, and offsite manufacture are to reduce the challenges posed by on-site construction. Digital transformation relies on the digital ecosystem developed in the Construction 4.0 framework, such as Building Information Modelling (BIM), and Common Data Environment (CDE), IoT, AI, blockchain. In this regard, the study aims to enhance the transition of the construction industry to a new level and increase digitalization in construction by supporting digital ecosystem transformation via BIM and

industrial production as indicated in the pillar themes of Construction 4.0. To achieve this, the study specifically aims to define the advantages and barriers of BIM and modular construction (MC) integration and the overcome strategies of the critical barriers.

1.1 Modular Construction

Modular construction is one kind of prefabricated construction. However, the phrases prefabricated and modular construction are frequently used synonymously in the literature. Because the off-site manufacturing of prefabricated building components and units assembled on-site is commonly referred to as "modular construction" in the international literature (Iacovidou et al., 2021), in this study “modular construction” term was used mainly.

Modularization, pre-assembly, off-site fabrication, and prefabrication are among the modern-day techniques available to clients, developers, and project managers for achieving greater cost-effectiveness in construction. This statement is supported by Gibb's (1999) work, which highlights the broad spectrum of innovative contemporary techniques available to the construction industry. By employing these techniques, stakeholders can achieve significant benefits in terms of reduced costs, increased efficiency, and improved quality management. As indicated in Lawson’s Design in Modular Construction book (2014), Gibb and Pendlebury (2006) define modular construction as a volumetric unit that is prefabricated in a factory and subsequently transported to the site as the primary structural elements of the building. Modular construction processes are distinct from traditional construction techniques in that they involve a series of steps. These steps begin with the creation of digital drawings that capture the design of all the modules or sections that will comprise the building. The digital drawings, which are generally in 2D, are then transmitted to the machinery in the factory where the components are produced individually in a controlled factory environment. Once completed, the modules are packed and shipped to the construction site, where they are assembled on-site to form

the complete structure. Therefore, the modular construction method encompasses the complete building process, starting from the initial design phase of a structure to its off-site production, transportation, and on-site assembly.

There are various advantages of modular construction. The integration of modular construction and digitalization can significantly enhance efficiency and sustainability. By leveraging digital tools, the industry can achieve multi-dimensional value, encompassing positive environmental, economic, social, and technical impacts while promoting circularity within the sector (Iacovidou et al., 2021).

1.2 Building Information Modeling

Building Information Modeling (BIM) technology is a powerful digital tool that integrates crucial information about construction engineering projects. This includes detailed 3D geometric shape data and vital non-geometric information such as material composition, performance capabilities, pricing, weight, location, and progress tracking for building components (Xinyu et al., 2019). As Building Information Modeling is increasingly developed and used, business practices are changing and thus the construction industry is further industrializing its practices (Blampain et al., 2023). According to the systematic review result of Musarat et al. (2023), BIM has been seen as one of the key deliverables of construction projects, with construction parties relying on it to complete their projects more efficiently and much faster.

1.3 BIM-MC Integration

Integrating Building Information Modeling (BIM) and modular construction is gaining traction to enhance productivity and sustainability in the global construction industry. This integration allows for more efficient and accurate planning, design, and construction processes, reducing costs, improved quality, and enhanced safety.

Additionally, using BIM in conjunction with industrialized building construction techniques promotes using environmentally friendly materials and practices, contributing to more sustainable and environmentally responsible construction practices (Wu, 2021). Furthermore, by facilitating data integration between information-rich building models and business processes, BIM helps the construction sector to achieve informatization and efficient production, which advances the industrialization of off-site construction (Ji et al., 2019)

Although the integration provides several advantages in terms of efficiency and sustainability (Li et al., 2019; Wang, 2019; Gbadamosi et al., 2019; Zhang et al., 2016; Peng et al., 2021; Bonenberg et al., 2019), there are various challenges to implementation of it. Some of these challenges are resistance to change, high financial and technical demands of integration, owners' or executives' negative perceptions, software-related problems, and governmental barriers (Ghalenoei et al., 2022; Chen et al., 2018; Lu et al., 2010; Lee et al., 2020; Lopez et al., 2022; Yan et al., 2020; Xu et al., 2023; P. Wu et al., 2021). On the other hand, there are a considerable number of studies about how to overcome these challenges. For example, Fang et al. (2023) state that there is a need for the development of local software for BIM implementation in modular constructions, and policies by the government could be made mandatorily to promote adaptation. According to Yan et al. (2020), an information-based platform can increase collaboration to overcome information exchange problems. As a solution to human resource problems, an academic training suggestion is given by Wen (2021) to gain innovative professionals.

1.4 Aim and Objective

Upon careful analysis of previous research studies, it is evident that the integration of MC-BIM yields significant advantages and promises a great potential to upgrade the construction industry. Despite all the advantages and promises, a review of these previous studies related to BIM and modular construction integration shows that

limited studies have been conducted to identify the key advantages and critical barriers to BIM implementation in modular construction. Moreover, few studies have explored how these barriers can be overcome, particularly by incorporating stakeholder responsibility. Therefore, the study aims to bridge this knowledge gap by clarifying the key advantages of BIM-MC integration, identifying the critical barriers, and proposing strategies to overcome them by taking into consideration of stakeholder's responsibility. With the shed of the aim, the objectives of the study are to 1) clarify the advantages and barriers of BIM-MC integration by incorporating a systematic literature review, 2) analyze the results of interviews conducted with Turkish modular construction experts, 3) propose strategies to overcome barriers by disclosing the responsible stakeholders.

1.5 Organization of the Thesis

The thesis investigates the integration of modular construction with BIM by providing advantages and barriers of, and implementation strategies for this integration. This study is composed of five chapters, and their contents are explained below.

The first chapter is the Introduction, where the brief background information about modular construction, BIM, and their integrations; the aim and objectives of the study; and the organization of the thesis are explained. The second chapter is Literature Review. In this section literature review methodology is explained with the number of search results. First, a list of identified BIM-MC advantages and barriers are indicated here from the systematic literature review studies and country-specific studies about BIM-MC integration. Second, the literature gap is explained in this section. The third chapter is Methodology which starts with the research questions. The procedures for literature review and interviews in addition to company and interviewee selection criteria are explained in this chapter. Lastly, data analysis and interpretation methods are explained. The fourth chapter is Findings and Discussion, where all the outputs of the literature review and interview are presented.

The fifth chapter is Conclusion. In this chapter, firstly, a summary of the research findings is provided including the key advantages and critical BIM-MC barriers, and stakeholders' responsibilities. Secondly, the practical implementation of the study is explained. Lastly, the limitations of the study and future works are presented.

CHAPTER 2

LITERATURE REVIEW

In the Literature review section literature review methodology is explained with the number of search results. First, lists of advantages and barriers associated with BIM-MC integration were indicated, and then, systematic literature review studies and country-specific studies about BIM-MC integration were presented. Finally, the section concludes with an explanation of the literature gap that currently exists in this field.

The study's literature review was conducted with trustworthy search sources; Scopus, Web of Science, Google Scholar, and Türkiye Council of Higher Education (YÖK) National Thesis Center database. The first part of the search combined the results of Scopus, Web of Science, and Google Scholar, while the second part was conducted with the YÖK National Thesis Center. Modular Construction and BIM were the main keywords for the search. These keywords were searched in the documents' titles, abstracts, and keyword sections. These keywords were applied to the search in various forms to avoid missing any related documents in the databases. These forms include the synonyms of “modular construction” and “BIM” such as “off-site construction”, “prefabricated construction”, and “Building Information Modeling”. All results collected from these databases were combined and examined. They all provided a basis for the research.

As a reliable search source, Scopus was used as one of the literature review databases with its advanced search option. The publication year and document type criterion were selected as “all” to examine diverse types of documents. No criterion restricted the language. As Table 2.1 shows, the first search query was TITLE-ABS-KEY (“modular construction” AND BIM), and 127 results were yielded. The second

search query was TITLE-ABS-KEY (“prefabricated construction” AND BIM), and 155 results were found. The last one was TITLE-ABS-KEY (“off-site construction” AND BIM), and the result was 77. Then all the above searches repeated with “building information modeling” instead of BIM. The results were respectively 93, 73, and 62 for modular, prefabricated, and off-site construction.

Web of Science (WoS), one of the most reliable sources, was also used for the literature review of this study. Its advanced search option was selected, and the criterion was set as “all” to see all documents related to the study. As shown in Table 2.1, the first search query was (ALL= (“modular construction”)) AND ALL=(BIM) with 71 results from the core collection. The second search was completed with the (ALL= (“prefabricated construction”)) AND ALL=(BIM) and 72 results were found. Lastly, the search query was (ALL= (“off-site construction”)) AND ALL=(BIM), and the result was 70. Then all the above searches repeated with “building information modeling” instead of BIM. The results were respectively 27, 22, and 21 for modular, prefabricated, and off-site construction.

Table 2.1 Scopus and WoS search keywords with the search results

Searched Keywords	**SCOPUS**	**WoS**
“Modular construction” AND BIM	127	71
“Prefabricated construction” AND BIM	155	72
“Off-site construction” AND BIM	77	70
“Modular construction” AND “Building information modeling”	93	27
“Prefabricated construction” AND “Building information modeling”	73	22
“Off-site construction” AND “Building information modeling”	62	21
Total	**587**	**283**

As the second part of the literature review, studies in the databases of the (YÖK) National Thesis Center were used. In the platform, samples of master's and doctoral theses presented at universities in Türkiye are published. Because the study will focus on the Turkish construction sector, the national thesis database of the country was additionally selected for the literature review. The advanced search option of the

YÖK National Thesis Center was selected for this search. All criteria were selected as “all” such as years, and document types. Because the database has documents written in both English and Turkish, the search was completed in both languages. There were no results found in this database when the search was performed with the following three keyword combinations: “modular construction” AND BIM; “prefabricated construction” AND BIM; “off-site construction” AND BIM. When the same search was applied with “Building information modeling” rather than “BIM”, there were also no results found. Therefore, these keywords were searched one by one in the database to reach any related documents. As in Table 2.2, the searches of “modular construction”, “prefabricated construction”, “off-site construction”, and “Building Information Modeling” yielded the following results respectively; 13, 43, 1, 228. Although several studies focus on BIM applications in the construction sector of Türkiye, there is no search specifically for MC and BIM integration. The result shows that there is a need for future studies on the BIM application of modular companies in Türkiye.

Table 2.2 YÖK National Thesis Center search keywords and results

Searched Keywords	**YÖK National Thesis Center**
"Modular construction” AND “BIM”	0
“Prefabricated construction” AND “BIM”	0
“Off-site construction” AND “BIM”	0
“Modular construction” AND “Building information modeling”	0
“Prefabricated construction” AND “Building information modeling”	0
“Off-site construction” AND “Building information modeling”	0
“Modular construction”	13
“Prefabricated construction”	43
“Off-site construction”	1
“Building information modeling”	228

The total search results yielded from Scopus and Web of Science were 587 and 283 respectively. The results include duplicates and unrelated documents. The following steps were applied to access the highly related documents that form the basis of this research.

First, the duplicates were deleted from these results. Once the duplication was eliminated, the results decreased to 354 for Scopus and 194 for Web of Science. Since the two databases have overlapped too, the overall document number of all searches was 434. Second, the 434 documents' titles and abstracts were examined to select related documents and eliminate irrelevant ones with the study. Documents were selected if they included BIM-MC application studies, BIM-MC integration advantages studies, BIM-MC integration barriers studies, and BIM-MC integration-related literature review studies. There are a considerable number of studies about the subject of technological advancements, such as IoT, Blockchain, RFID, GIS-Digital Twin (DT), and their synthesis with BIM and MC. These were included if they were applied to BIM-based modular constructions. There are several studies focused on BIM-MC integration in partial phases of construction or specific subjects of construction, such as early design phases, quality control phases, or the supply chain management subject of construction. These kinds of documents were selected to give an idea about the specific application of BIM in MC. The studies related to lean construction or construction 4.0 together with BIM-MC integration were also selected because these studies mainly examine industrialization and digitalization in construction too. On the other hand, subjects that are focused solely on BIM or MC were eliminated to specifically focus on their integration. The retracted studies were also eliminated to be able to examine reliable studies. Lastly, the studies which are not in English were excluded. When all the above-mentioned selection and elimination strategies were applied, 172 documents remained from the source of Scopus and Web of Science. Third, in addition to Scopus and Web of Science, Science Direct and Google Scholar were also searched with the same keyword combinations applied to Scopus and Web of Science. Relevant studies were selected according to the same relevancy criteria and added to the previous result. Thus, the total number of relevant documents became 174.

To conclude, when the 11 local database documents are combined with the 174 relevant documents, there are 185 documents were examined as full text for the study. In Figure 2.1 below, a systematic review flow diagram is demonstrated. Inside

these documents, in addition to the studies about the advantages and barriers of MC-BIM integration, 16 literature review studies and 37 country-specific studies were explored. As a result, the literature review of this study was explained under 5 sections: Advantages of BIM-MC Integration, Barriers of BIM-MC Integration, Literature review studies of BIM-MC Integration, Country-Specific Studies of BIM-MC Integration, and Gap in the Literature.

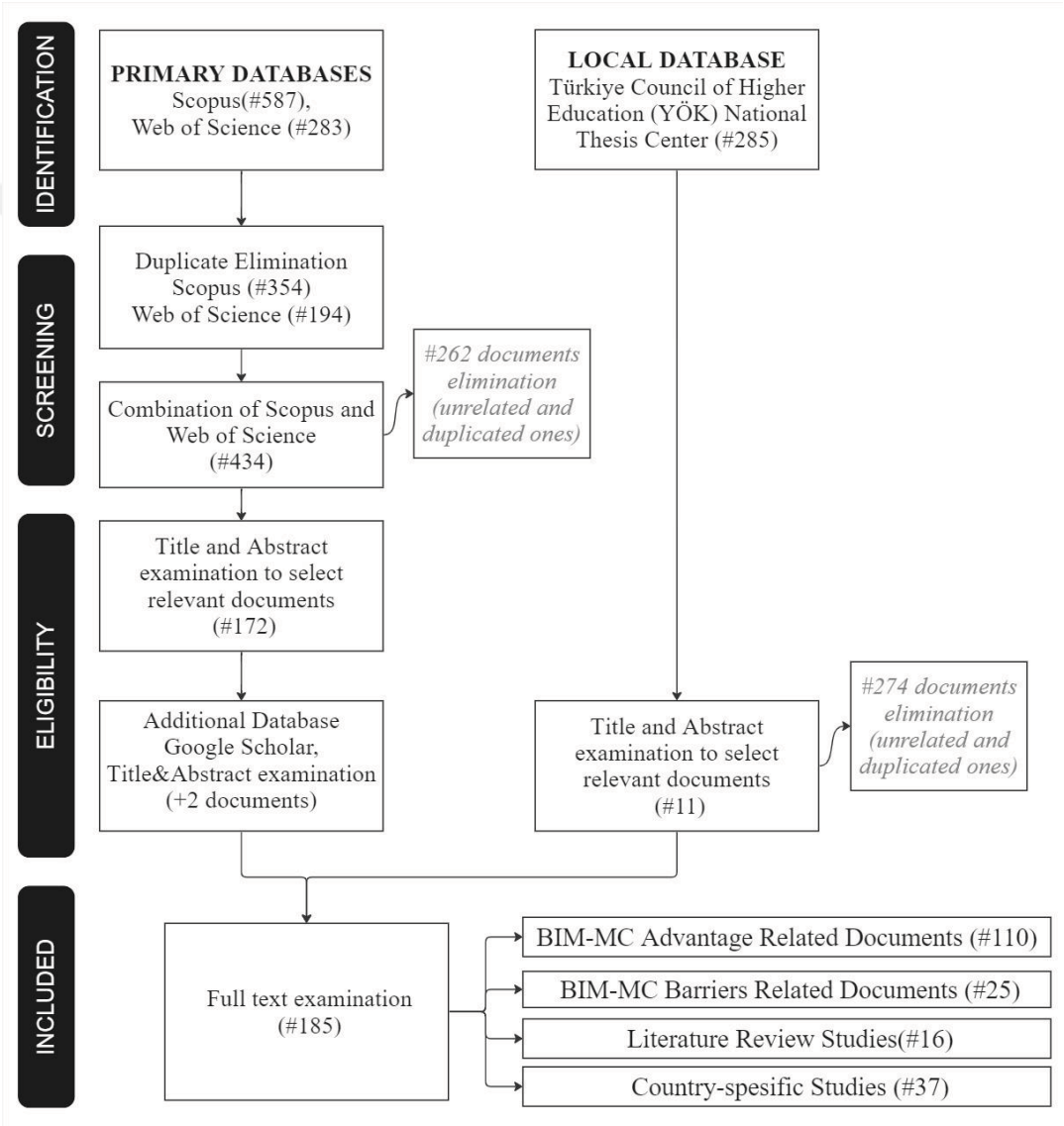


Figure 2.1 Systematic Review Flow Diagram

2.1 Advantages of BIM and Modular Construction Integration

In the literature, various studies provide the advantages of BIM-MC integration. In this section, these studies were presented by grouping the advantages under 20 categories as in Table 2.3 below. These categories are organized according to what extent integration is beneficial. According to the studies in the literature, BIM-MC integration provides advantages in the following categories: technology adaptation, concept integration, safety, structural stability, cost, robotic manufacture, visualization, progress monitoring, design, planning & scheduling, quality control, time, collaboration, optimization, management, efficiency & sustainability, automation, data management, supply chain management, and communication & coordination.

Table 2.3 Advantages of BIM and Modular Construction Integration[1]

1. TECHNOLOGY ADAPTATION	60, 94, 102
providing a data source for new technology adaptation for modular construction such as GIS&GPS, Blockchain, Digital Twin, Deep Learning, RFID,3D Scanning, IoT, Game simulation &Robotic, VR, AI, Big data	19, 23, 27, 33, 36, 41, 42, 57, 60, 66, 68, 72, 91, 108, 109, 110
2. CONCEPT INTEGRATION	
providing a data source for new concept integration for modular construction such as lean construction, construction 4.0, DfMA	8, 10, 16, 22, 58, 59, 61, 73, 74, 77, 92
3. SAFETY	1, 45
reducing safety risks and improving safety management	2, 78
improving crane management	17
detecting dangerous behaviors and potential workspace conflict	17, 32, 87
providing staff training and improving worker safety	17, 80
4. STRUCTURAL STABILITY	21, 29, 45, 99, 107
providing structural health monitoring	84
providing structural analysis	62
5. COST	83
providing effective cost management	93, 105
decreasing labor costs	1, 2
decreasing design/ redesign costs	11
decreasing construction costs	1, 12, 15, 31, 48, 71, 79, 81
decreasing installation costs	2
providing cost prediction, control, analysis, and assessment	15, 40 45, 106, 107
6. ROBOTIC MANUFACTURE	
providing information management and collaboration environment for robotic	4, 5, 19
7. VISUALIZATION	14, 40, 79, 88
improving simulation	14, 67, 83
changing the public perception of modular construction	37
providing control over interference and detecting clashes	14, 38, 47, 55, 97

Table 2.3 Advantages of BIM and Modular Construction Integration1 (cont'd)

8. PROGRESS MONITORING	
enhancing process monitoring and progress control	17, 36, 104
9. DESIGN	24, 38, 47, 54, 104
optimizing design	52
reducing design errors	43, 101
improving buildings' spatial relevance and artistic quality	81
reducing the drawing amount	97
avoiding 2D design problems	97
providing strong technical drawings	97
providing quick responses to design changes	100
allowing the creation of complex building geometries in 3D	25
enhancing the HVAC design	65
creating automatic design alternatives	11, 25, 28, 53, 70
providing walkthrough animations	38, 55
10. PLANNING & SCHEDULING	18, 38, 75, 76, 84
enabling automated planning & scheduling	50
enabling assembly sequencing planning	86
providing planning and scheduling simulations	39
11. QUALITY CONTROL	83
providing quality control of prefabricated components	53, 101
providing an automated compatibility check	64
improving tolerance control	44
providing effective rectification rate of project quality problems	49
12. TIME	
saving time by shortening the design and construction period	1, 2, 12, 15, 34, 49
allowing rapid construction in case of emergency(ex: Covid hospital)	46
13. COLLABORATION	7, 88, 98
providing effective construction information sharing	96
14. OPTIMIZATION	15, 14, 26, 48, 71, 89, 102, 104
providing carbon footprint and optimization	25
optimizing construction cost	51
optimizing production	54
15. MANAGEMENT	15, 53
improving system security	24
improving information management and integration	11, 12, 18, 53, 63, 71 81, 82, 96, 97, 98
improving risk management	20
providing systematic management	12
improving inventory management	30, 95, 96
providing effective decision-making	63
improving life cycle management	54, 56, 70
16. EFFICIENCY /SUSTAINABILITY	14, 26, 38, 43, 69, 85, 89, 101, 103
enables the reuse of modular structural components	33
providing less waste	1
17. AUTOMATION	104
decreasing human error	55
decreasing labor	2, 34
providing repetitive work and mass production	31,100
automating life cycle assessment	6, 35
providing automated draft and design	70

Table 2.3 Advantages of BIM and Modular Construction Integration1 (cont'd)

18. DATA	*104*
providing efficient data storage and processing	102
providing real-time data gathering and sharing	71
providing a transparent data structure	11
providing reliable information	63
19. SUPPLY CHAIN	
enhancing supply chain management	3, 13, 98
enhancing logistic-related decision-making	9, 18
predicting potential logistics risks and module delivery time	41
providing planning and control process of logistics operations	9
20. COMMUNICATION/ COORDINATION	
enhancing coordination and improving communication	38, 63, 81, 90, 100, 104

[1]**Note1:** 1: (Abanda et. al.,2017), 2: (Ahmadi et al., 2020), 3: (Ali et al., 2022), 4: (Anane et al., 2022), 5: (Anane et al., 2023), 6: (Ansah et al., 2021), 7: (Bakhshi et al., 2022), 8: (Barkokebas et al., 2021), 9: (Bataglin et al., 2017), 10: (Bataglin et al., 2020), 11: (Benjamin et al., 2022), 12: (Bi, 2021), 13: (Bian et al., 2017), 14: (Bonenberg et al., 2019), 15: (Borjeghaleh et al., 2016), 16: (Bortolini et al., 2019), 17: (Chatzimichailidou et al., 2022), 18: (Chen et al., 2018), 19: (Chong et al., 2019), 20: (Darko et al., 2020), 21: (Duan et al., 2023), 22: (Fang et al., 2023), 23: (Figueiredo et al., 2023), 24: (G. Wang, 2019), 25: (Gan, 2022), 26: (Gbadamosi et al., 2019), 27: (Gbadamosi et al., 2020), 28: (Ghannad et al., 2021), 29: (Guo et al., 2021), 30: (Hamdan et al., 2015), 31: (Han et al., 2020), 32: (Hou, 2023), 33: (Iacovidou et al., 2021), 34: (Jang et al., 2022), 35: (Ji et al.,2020), 36: (Katiyar et al., 2022), 37: (Kim et al., 2023), 38: (Korman et al., 2011), 39: (Lee et al., 2017), 40: (Lee et al., 2020), 41: (Lee et al., 2021), 42: (Li et al., 2021), 43: (Li et al., 2019), 44: (Li et al., 2020), 45: (Li et al., 2021), 46: (Li et al., 2022), 47: (Li, 2021), 48: (Liao, 2018), 49: (Li et al., 2022), 50: (Liu et al., 2014), 51: (Liu et al., 2017), 52: (Liu et al., 2019), 53: (Liu et al., 2021), 54: (Liu, 2021), 55: (Lu et al., 2010), 56: (Luo et al., 2018), 57: (Mao et al., 2018.), 58: (Marte et al., 2021), 59: (McDermott et al., 2023), 60: (Meng et al., 2022), 61: (Moghadam et al., 2012), 62: (Mohamed et al., 2016), 63: (Nawari, 2012), 64: (Noghabaei et al., 2022), 65: (Noveiri et al., 2020), 66: (O'grady et al., 2021), 67: (O'Neill et al., 2020), 68: (Panahi et al., 2023, 69: (Peng et al., 2021), 70: (Qi et al., 2014), 71: (Qi et al., 2018), 72: (Qi et al., 2018.), 73: (Razak et al., 2022), 74: (Robey et al., 2015.), 75: (Salama et al., 2016), 76: (Salama et al., 2017), 77: (Santana-Sosa et al., 2018), 78: (Shen et al., 2022), 79: (Shi et al. 2020), 80: (Shringi et al., 2023), 81: (Su et al., 2022), 82: (Tang et al., 2019), 83: (Tang, 2021), 84: (Valinejadshoubi et al., 2019), 85: (Vernikos et al., 2014), 86: (Wang et al., 2017) , 87: (Wang et al., 2018), 88: (Wang et al., 2020), 89: (Wang, 2019), 90: (Wang, 2021), 91: (Wang, 2023), 92: (Wasim et al., 2022), 93: (Wen et al., 2021), 94: (Wen, 2021), 95: (Wu, 2021), 96: (Xiao et al., 2022), 97: (Xinyu et al., 2019), 98: (Xuejian et al., 2019), 99: (Yang, 2020), 100: (Yoo et al., 2020), 101: (Yunlin et al., 2019.), 102: (Zeng et al., 2020), 103: (Zhang et al., 2016), 104: (Zhang et al., 2020), 105: (Zhang, 2021), 106: (Zhang, 2022), 107: (Zhang, 2023), 108: (Zhanglin et al., 2017), 109: (Zhao et al., 2019), 110: (Zhong et al., 2017)

The first advantage of integration is that BIM provides a basis for the adaptation of new technologies to MC. Because of collecting various kinds of building information, BIM serves as the main data source for the application of building digital twins (Figueiredo et al., 2023). Similarly, there are various emerging technologies being adapted to construction based on BIM such as Blockchain, IoT,

and RFID. Moreover, concepts such as Construction 4.0, lean construction, and DfMA are also integrated into modular construction with the basis of BIM. When BIM and lean are integrated with modular construction productivity is improved (McDermott et al., 2023; Santana-Sosa et al., 2018; Moghadam et al., 2012).

Safety and structural stability are the further categories of BIM-MC integration advantages. The integration is advantageous in terms of safety because it improves safety management (Ahmadi et al., 2020) and provides a detection system for dangerous behaviors and conflicts in construction sites (Chatzimichailidou et al., 2022). Moreover, with the help of visualization, it can provide realistic staff training to ensure workers' safety (Shringi et al., 2023). In addition to safety, integration is advantageous in terms of structural stability by providing structural health monitoring (Valinejadshoubi et al., 2019) and structural analysis (Mohamed et al., 2016). The other advantage category is related to cost. The integration provides effective cost management, decreasing design and construction costs, and facilitates a basis for cost-related analysis (Tang, 2021). As an addition to the cost category, according to Anane et al., (2023), integration paves the way for robotic manufacturing thanks to information management.

In the literature, the visualization advantages of BIM-MC are studied considerably. Thanks to the visualization that BIM enables, improved simulation, design, and construction can be possible as well as control over interferences and detection of clashes (Shi et al., 2020; Lee et al., 2020; Bonenberg et al., 2019). Visualization facilitates another category of advantages which is progress monitoring. When BIM is integrated into modular construction, the production phases can be monitored and the progress can be controlled (H. Li et al., 2020; Chatzimichailidou et al., 2022; Katiyar et al., 2022). BIM-MC integration advantages in terms of design are one of the most studied subjects resembling visualization. The advantages in the category vary from providing design optimization, creating design alternatives, avoiding 2D design problems and even increasing the aesthetic quality of design (Liu et al., 2019; Gan, 2022; Su et al., 2022).

BIM brings several advantages for MC in terms of planning and scheduling. It enables automated planning and scheduling processes while simulating them. (H. Liu et al., 2014; J. Lee et al., 2017). The integration saves time by shortening the design and construction period (Jang et al., 2022). Especially in case of an emergency, according to T. Li et al. (2022), it gives a chance for rapid construction. The collaboration and management aspects of integration are also studied in literature as advantages. As a collaboration advantage, the integration provides effective construction information-sharing (Xiao et al., 2022). Besides collaboration advantages, BIM-MC integration enhances communication and coordination. As a result of these advantages, BIM-MC integration improves information management (Xiao et al., 2022) as in the case of most kinds of management in construction such as risk management (Darko et al., 2020), inventory management (Wu, 2021), and life cycle management (Liu et al., 2021). Data management is also one of the well-studied advantages in literature. Specifically, some of the data management advantages are efficient data storage and processing (Zeng et al., 2020), real-time data gathering (Qi et al., 2018), transparency, and reliability (Benjamin et al., 2022).

The remaining categories of BIM-MC integration advantages are optimization, automation, efficiency & sustainability. Optimization is a category that includes carbon footprint optimization, construction cost optimization, and production optimization (Gan, 2022; H. Liu et al., 2017; Liu et al., 2021). With the help of BIM, automation is developed for modular construction (Zhang et al., 2020). Thanks to automation, human error, and necessary labor can be decreased, while design and production process efficiency can be increased. In the efficiency and sustainability category, reusing modular structural components (Iacovidou et al., 2021), and decreasing waste (Abanda et al., 2017) are studied advantages in the literature.

To conclude, there are a considerable number of studies in the literature that prove BIM-MC integration is advantageous in various aspects. According to these studies, when BIM is implemented in modular construction, efficiency increases with the help of automation, optimization, and digitalization by new technology and concept integrations. The quality of construction advances thanks to developed design and

visualization, increased structural stability, quality control, and progress monitoring process. Furthermore, while time and cost wasted on design and construction are reduced, management quality increases.

2.2 Barriers to Implementing BIM in Modular Construction

Although BIM-MC integration has a great number of advantages, integration faces a considerable number of barriers. These barriers were grouped into 20 categories, as shown in Table 2.4 below. These categories are public perception, resistance to change, owner and executive perception, organizational barriers, cost-related barriers, lack of knowledge and experience, human resource-related barriers, lack of standardization, software-related barriers, lack of academic research, geography and market condition-related barriers, collaboration-related barriers, design-related barriers, governmental barriers, time-related barriers, management-related barriers, communication and coordination-related barriers, supply chain-related barriers, structural barriers, and 3D BIM model barriers.

Table 2.4 Barriers to Implementing BIM in Modular Construction[2]

1. PUBLIC PERCEPTION	
public perception of modular houses is not aesthetic and non-customizable	5
2. RESISTANCE TO CHANGE	2, 3
3. OWNER/EXECUTIVE PERCEPTION	3, 17, 19
4. ORGANIZATIONAL BARRIERS	
inappropriate team and organizational configuration	3, 10
5. COST-RELATED BARRIERS	3, 7, 9, 10, 21
high capital cost	4,15, 22
high construction cost	15
high transportation cost	4, 6, 8, 15, 18
BIM tool cost	17
increased design costs	3,17
6. LACK OF KNOWLEDGE& EXPERIENCE	10, 17
Unclear BIM benefits	3, 17, 22
need high-level experience	1
lack of knowhow data from previous experiences, lack of BIM-based workflow	3, 15, 17, 22
lack of training	3
need high-level technical knowledge	1
7. HUMAN RESOURCE-RELATED BARRIERS	3, 10
lack of expertise	7, 15, 24
need trained labor	1

Table 2.4 Barriers to Implementing BIM in Modular Construction[2] (cont'd)

8. LACK OF STANDARDIZATION	14
lack of a standard format for data	16, 19
lack of standard BIM programs	16
lack of MC-BIM standard specification	19
lack of contractual standards	16, 19
need international standard practice	1
need national standard practice	1, 24
lack of standards	8, 16, 19
lack of building codes and standard	15, 24
9. SOFTWARE-RELATED BARRIERS	9
BIM software and domestic standards conflict, and the lack of local tool	16, 24, 25
storage limitations	23
insufficient library	11
low maturity of software	11, 16, 19
interaction between BIM software	25
10. LACK OF ACADEMIC RESEARCH	
lack of sufficient academic research	16, 19
11. GEOGRAPHY and MARKET CONDITION-RELATED BARRIERS	
lack of market demand	3
isolated geographic location	6
12. COLLABORATION-RELATED BARRIERS	
need a multi-disciplinary collaboration from all stakeholders	6, 9, 10, 25
required for early commitment	4
negative attitude towards data sharing	22
lack of advanced subcontractors	1
13. DESIGN-RELATED BARRIERS	9
need a more precise and complicated design	1, 4
increase the design workload	4
14. GOVERNMENTAL BARRIERS	
design restrictions and permitting	12
lack of laws and policies	8, 19
lack of incentives	19
15. TIME-RELATED BARRIERS	
need more early design period and time-consuming process of application	1
16. MANAGEMENT-RELATED BARRIERS	
lack of information management	13, 23, 25
17. COMMUNICATION / COORDINATION-RELATED BARRIERS	9, 15, 21, 23
lack of communication	2
extensive coordination need	4
18. SUPPLY CHAIN-RELATED BARRIERS	9
poor supply chain integration	15
uncertainty of demand and supply	20
19. STRUCTURAL BARRIERS	
complexity of connection	15
20. 3D BIM MODEL-RELATED BARRIERS	
ownership and control of the model	10

[2]**Note2:** 1: (Ahmadi et al., 2020), 2: (Chen et al., 2018), 3: (Ghalenoei et al., 2022), 4: (Hwang et al., 2018), 5: (Kim et al., 2023), 6: (Kordestani et al., 2022), 7: (Lee et al., 2020), 8: (Li et al., 2021), 9: (Lopez et al., 2022), 10: (Lu et al., 2010), 11: (Mahmoud et al., 2022), 12: (Messaoudi et al., 2021),

13: (Shi et al., 2020), 14: (Su et al., 2022), 15: (Sun et al., 2020), 16: (Tan et al., 2019), 17: (Wu et al., 2021), 18: (Xia et al., 2022), 19: (Xu et al., 2023), 20: (Xuejian et al., 2019), 21: (Yan et al., 2020), 22: (Yao et al., 2020), 23: (Zeng et al., 2020), 24: (Zhang et al., 2016), 25: (Zhang, 2023)

Barriers related to cost, standardization, collaboration, and software are some of the most studied categories together with a lack of knowledge and experience. One of the cost-related barriers is the high capital cost of adopting the BIM (Building Information Modeling) process (Sun et al., 2020). Furthermore, BIM tool costs and increased design expenses with BIM cause obstacles to implementing BIM in modular construction (Wu et al., 2021; Ghalenoei et al., 2022). BIM implementation requires developed standardization, which causes difficulties in integrating BIM with modular construction. All specifications, from the standard format for data to contractual standards and building codes, need to be satisfied for effective BIM implementation (Xu et al. 2023, Sun et al., 2020). Collaboration-related barriers include early commitment requirements between stakeholders (Hwang et al., 2018), negative attitudes toward data sharing (Yao et al., 2020), and a lack of advanced subcontractors (Ahmadi et al., 2020). In addition to collaboration, software-related barriers have adverse effects on BIM-MC implementation, such as storage limitations (Zeng et al., 2020), and insufficient library (Mahmoud et al., 2022). Furthermore, the conflict between BIM software and domestic standards and the lack of local tools are significant standardization barriers that require local studies for improved integration (Zhang, 2023; Tan et al., 2019).

The successful adaptation of BIM is influenced by the government's stance on the matter. Insufficient legislation, policies, and incentives are among the key hindrances associated with government involvement (Xu et al., 2023). Besides the government, the attitudes of owners and executives towards BIM-MC integration also have a crucial impact on implementation (Wu et al., 2021). Negative perceptions of decision-makers can act as a barrier, yet a positive approach from executives alone is not enough. Inappropriate team and organizational structures can also create obstacles, as highlighted in the organizational barrier category (Lu et al., 2010).

Generally, resistance to change can represent a significant challenge to the successful implementation of BIM-MC integration (Chen et al., 2018).

Several obstacles hinder the integration of modular construction with Building Information Modelling (BIM-MC). Negative public perception towards modular houses is one such barrier. Kim et al. (2023) claim that modular homes are perceived as non-aesthetic and non-customizable, leading to insufficient demand. Additionally, the lack of market demand poses a significant challenge to the integration of BIM-MC (Ghalenoei et al., 2022). To advance modular construction, there must be sufficient demand in the market. The location of modular manufacturers is also critical, as extensive transportation processes are involved. Therefore, if the manufacturer is in an isolated location, it can be a barrier (Kordestani et al., 2022).

In the literature, various obstacles to the successful implementation of BIM and MC have been explored. Lack of skilled personnel with expertise in these areas (Chen et al., 2018), effective supply chain management needs (Lopez et al., 2022), modeling complex structural connections in 3D (Sun et al., 2020), and ambiguity around BIM model ownership (Lu et al., 2010) are some of the challenges that have been identified.

2.3 Literature Review Studies of BIM-MC Integration

When the related documents were examined, 16 of them were found as a literature review study, as shown in Table 2.5 below. They are focused on BIM-MC integration and digitalization of offsite constructions and new technology adaptation. These studies provide information about the country-based study amount, year-based number of studies, and existing gaps in the literature related to the subject of BIM-MC integration.

Table 2.5 Literature Review Studies on BIM-MC Integration

METHODS	STUDIES
Bibliometric literature review	Qiuyu (2021)
Holistic literature review	Zhang et al. (2021); Anaç et al. (2023)
Systematic literature review	Mehdipoor et al. (2023); Musarat et al. (2023); Wang et al. (2020); Akbarieh et al. (2020); Nguyen et al. (2022); Cheng et al. (2023)
Review and future directions	Yin et al. (2019); Tong (2021); Jin et al. (2019); Blampain et al. (2023); Hussein et al. (2021); Jang et al. (2021); Olawumi et al. (2022)

China is the nation that has worked in the subject of prefabricated construction the most followed by the USA, Australia, UK, Canada, Poland, Malaysia, Brazil, and India according to Anaç et al.'s most influential country analysis (2023). Qiuyu (2021) claimed that prefabricated structures and BIM integration have seen explosive growth after 2016. Since 2005, BIM for prefabricated construction research has increased significantly, however, the largest number of publications on the subject was created after 2015 (S. Zhang et al., 2021).

Most of the studies emphasized the importance of BIM according to their findings. For example, 27 of 211 offsite digital technology-related articles, reviewed by Cheng et al., focused on BIM. Although it is a relatively old technology that goes back to the 2000s, BIM still attracts attention, and it is important for the off-site construction industry. Moreover, many recent technological advancements were developed based on BIM technology (Cheng et al., 2023). Building Information Modeling (BIM) systems are becoming more and more popular in prefabricated buildings, following the lead of technological improvements (Anaç et al., 2023). In modular construction, one of the most often used digital tools and technologies is building information modeling (Olawumi et al., 2022).

Even though the relationship between BIM and off-site construction has been discussed among researchers, gaps have been found in the literature regarding the

integration and there is not enough research on the integration of these applications (Mehdipoor & Iordanova, 2023). One of the identified research gaps by Zhang et al. (2021) is how to improve BIM-MC integration through improving modular construction technology.

As a result, according to the literature review studies, the existing condition of BIM-MC integration is that the subject has been tremendously increasing, especially since 2015. Even though there are various studies, there is still a need for more to achieve effective integration. As Qiuyu (2021) predicts that the relevant domestic literature in this field will continue to increase in the future, local integration strategies especially need to be developed.

2.4 Country-Specific Studies of BIM-MC Integration

In the literature, there are studies focused on BIM-MC integration, that resemble the scope of this study. However, they have some differences in several aspects. These studies are examined in the "Country-Specific BIM-MC Integration Studies" section of the literature review chapter. Therefore, the aim is to discuss the originality of the study by showing the highly related studies and by presenting their differences. While there are studies that clearly state the challenges of the BIM-MC integration and adaptation strategies in a general manner, there is a need for country-specific studies to offer solutions and strategies. Table 2.6 below lists 37 country-specific integrations of BIM and MC documents. As shown in the table, although there are country-specific studies applied to BIM-MC integration in countries such as China, New Zealand, Canada, Malaysia, UK, there is no research addressing the integration of BIM and MC Türkiye. Therefore, there is a need for a formal study that shows MC-BIM integration challenges, advantages, and strategies in the Turkish construction sector.

Table 2.6 Country-specific integration of BIM and MC studies

COUNTRY	STUDIES
China	Xu et al. (2023); Fang et al. (2023); Wen (2021); Wu et al. (2021); J. Liu & Zou (2021); W. Chen et al. (2021); Peng & Li (2021); H. Zhang (2021); X. Zhang (2021); Z. Liu (2021); Y. Wang (2021); Li et al. (2021); Zeng & Wang (2020); T. Zhang & Man (2020); Z. Zhang & Tang (2020); Yan et al. (2020); Yao et al. (2020); Bonenberg et al. (2019); Ji et al. (2019); Qi et al. (2018); Luo & Chen (2018); Zhanglin et al. (2017); J. Zhang et al. (2016)
New Zealand	Kordestani et al. (2022); Ghalenoei et al. (2022)
UK	Meng et al. (2022); Iacovidou et al. (2021); Marte Gómez et al. (2021); Vernikos et al. (2014)
Quebec, Canada	Mahmoud et al. (2022)
South Korea	Lee et al. (2020)
Hong Kong	Chen et al. (2018)
Italy	Alfieri et al. (2020)
US	Messaoudi & Nawari (2021)
Malaysia	Razak et al. (2022)
Australia	Lopez et al. (2022)
Singapore	Hwang et al. (2018)

A considerable amount of integration studies has been done for China, especially in recent years. There were 23 documents found focused on this country in the related documents. The studies mostly focus on BIM-MC challenges applied to China so that the overcome strategies can be derived according to these obstacles. For example, Xu et. al. (2023) studied barriers to BIM-MC integration in China from the stakeholder's perspective. The study starts with 28 initial barriers collected through a literature review and 7 from stakeholders. When their interaction was examined 5 critical barriers were identified with associated stakeholders. These barriers are lack of MC-BIM policies, lack of enthusiasm towards BIM investment by company owners, lack of MC-BIM standard specification, low maturity for MC-BIM software, and lack of sufficient academic research (Xu et al., 2023). As another

example, Tan et al. (2019) identified that there are 20 barriers under 5 categories for BIM implementation from the literature. According to the questionnaire survey result, 12 key barriers were identified for China's prefabricated construction sector. These key barriers were discussed through expert interviews. According to the discussion the lack of research on BIM implementation, the lack of BIM standards, and the lack of local tools are the most critical barriers in China compared to cost-related barriers (Tan et al., 2019). Wu et al. (2021) also identified 23 critical worldwide barriers to BIM implementation and grouped them into 5 main categories. According to the result of the questionnaire analysis, 5 of the critical barriers were selected for the BIM implementation for industrialized buildings; lack of support from senior management, lack of experience in adopting BIM, high cost of BIM software, lack of benefits brought by BIM and lack of talent with relevant skills and knowledge (Wu et al., 2021). When these studies are taken into consideration, critical barriers applied to China studied in different years and strategies to overcome these barriers can be provided according to the findings of the studies.

There are studies on BIM-MC integration conducted for New Zealand’s modular construction. Kordestani Ghalenoei et al. (2022) identified barriers to BIM and offsite construction separately for New Zealand. Although most of the challenges are common, transportation challenges have the most significance in literature for offsite construction in New Zealand because of the geographical location of the country. At the same time, interoperability and collaboration are challenging for BIM implementation in this country. To be able to overcome challenges 8 integration strategies were identified (Kordestani Ghalenoei et al., 2022). While the country's geographical condition can affect the integration as in the example of New Zealand, for Quebec, Canada technological barriers are critical according to Mahmoud et al. (2022) who identified 30 BIM implementation barriers for the country. He stated that there is a need for the improvement of current software libraries and software tools.

To conclude, there are several BIM-MC integration studies as shown in the table conducted for various countries. The countries are mostly developed countries except for China and Malaysia. Türkiye is differentiated from these countries in

terms of its development condition, geographic location, construction sector, and culture. Therefore, the study of BIM-MC integration conducted for Türkiye can fill the gap in the literature and can provide a basis for resembling countries.

2.5 Gap in the Literature

It is acknowledged that there is a knowledge gap in the application of technological advances in modular construction and Building Information Modeling (BIM) is one of the most important of these developments. Although the BIM-MC integration advantages have been proven in the literature with a considerable number of academic research, there are also various kinds of obstacles to integration. To be able to benefit from these advantages of BIM-MC integration, the barriers behind the integration should be well-defined. The barriers vary from country to country according to the countries' development levels, geographic locations, governmental approaches, and market conditions. Thus, the implementation strategies also show differences across the countries. Therefore, there is a need for local studies on BIM-MC integration barriers and, accordingly, BIM implementation strategy studies to overcome these barriers. This study was conducted to meet this need for Türkiye because it is one of the most important countries in the global construction sector. It ranked second with 40 companies in the "List of the World's Top 250 International Contractors" published annually by Engineering News-Record (ENR's top 250 international contractors of 2022). For a country with such a high construction volume, a local study on BIM-MC integration is an important gap that needs to be bridged. Lastly, the study is one of the unique studies that combined BIM-MC integration subjects for developing countries. There are a number of studies on the subject for developed countries, however, there is a knowledge gap for developing countries.

To conclude, this study specifically fills the gaps in the literature:

- Provide a list of BIM-MC integration barriers from around the world,

- Define the key advantages and critical barriers to Turkish construction companies’ BIM-MC integration,
- Provide strategies for Turkish construction companies’ BIM-MC integration to overcome the barriers that they encountered from the point of view of stakeholders' responsibility,
- Provide BIM-MC integration study for developing countries like Türkiye.

CHAPTER 3

METHODOLOGY

The methodology chapter provides detailed information about the phases and procedures of the research. The below-listed steps were followed for the study.

1. The literature review was conducted to collect documents related to state-of-the-art BIM-MC integration. It was conducted systematically to identify the advantages, barriers, and current implementation strategies of BIM for modular buildings.

2. The listed advantages and barriers collected from the literature were organized and listed under common categories.

3. The closed and open-ended interview questions were prepared by using these organized lists. Closed-ended questions in the interview were prepared to find out the BIM use levels of these companies in different modular construction phases, the applicability rates of both the advantages and the barriers of the BIM-MC integration for Turkish modular construction, and stakeholders' responsibility rates for the integration. Open-ended questions in the interview were prepared to find out what the key advantages and critical barriers to BIM-MC integration are, which strategies can be implemented to overcome these barriers, and what are the stakeholders' responsibilities for enhancing the integration.

4. Permission was taken from the METU Ethics Committee to conduct the interviews. (The protocol number of the permission is 0016-ODTUİAEK-2024)

5. The one-to-one interviews were conducted with experts from selected modular construction companies.

6. Data collected from the interviews was presented and analyzed in the findings section.

7. Findings are interpreted and compared with existing literature in the discussion section.

8. The key advantages of BIM-MC integration in Türkiye and the critical barriers to integration are summarized, together with strategies to overcome these barriers regarding stakeholders' responsibilities.

Figure 3.1 given below shows the flow chart of the methodology used in the study. It outlines the step-by-step approach of the research by visually representing the research process.

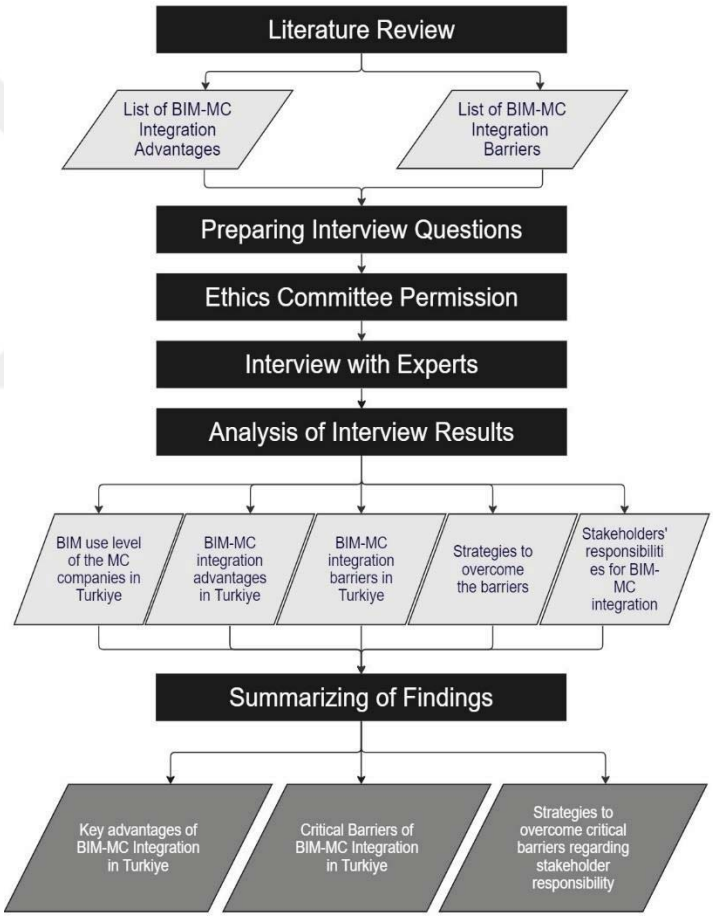


Figure 3.1 Research Flow.

3.1 Research Questions

This research aims to find the answers to the following four research questions.

- What are the advantages and barriers of BIM and modular construction integration?
- What are the key advantages of BIM-MC integration for Türkiye?
- What are the critical barriers behind the BIM-MC integration in Türkiye?
- Which stakeholders are responsible for the integration and what are their responsibilities to overcome these barriers?

To find the answers to the 1st question, a literature review was conducted, after that, the advantages and barriers were organized and listed. For the 2nd question, firstly, the listed advantages from the literature review were presented to the Turkish modular construction experts and they were asked to rate these advantages from 1 to 5 according to their applicability to the Turkish modular construction sector. Secondly, in the interview, open-ended questions were asked to the experts about the biggest advantages. The answers were analyzed and combined; thus, the frequently mentioned key advantages of BIM-MC integration for Türkiye were found. For the 3rd question, firstly, the listed barriers from the literature review were presented to the Turkish modular construction experts and they were asked to rate these barriers from 1 to 5 according to their applicability to the Turkish modular construction sector. Secondly, in the interview, open-ended questions were asked to the experts about the most critical barriers. The answers were analyzed and combined; thus, the frequently mentioned critical barriers to BIM-MC integration for Türkiye were found. The 4th and the last question were answered only by using the data obtained from experts. The first reason is that there were limited studies in the literature that examined integration from the stakeholder's perspective. Second, the answers can vary from country to country.

3.2 Research Approach

This section first explains literature review procedures. Secondly, the methodology for data collection and analysis is presented. Lastly, the methodology for the interview is described with the selection criteria of the companies and the interviewees in this section. The aim is to provide a clear and concise description of the research approach used in this study.

3.2.1 Methodology for the Literature Review

Throughout the research process, multiple iterations of the literature review were conducted to establish a comprehensive background and address specific research inquiries. Primary sources utilized for the study included Scopus, Web of Science, Google Scholar, and databases of the Türkiye Council of Higher Education (YÖK) National Thesis Center. The first phase of the literature review involved searches conducted on Scopus, Web of Science, and Google Scholar to locate international studies about the subject matter. In the second phase, a search was carried out on the National Thesis Center to pinpoint studies specifically related to Turkish construction companies. This approach was implemented to ensure that international studies were identified before exploring national studies. Thus, a literature review was conducted with a general-to-specific approach.

The main keywords for the first part of the search were various forms of “modular construction” and “building information modeling”, used in the literature including “prefabricated construction”, “offsite construction” and “BIM”. These keywords were searched without any publication year, or document type restriction so that diverse kinds of documents could be examined. For the second part of the search conducted on the national database, the same keywords were used but in the form of both English and Turkish. This is because some of the documents in the database were written only in Turkish.

The documents found in the first part of the literature review were brought together and duplicates were eliminated. After the first elimination, titles and abstracts of remaining documents were examined and studies unrelated to BIM-MC integration were eliminated. The remaining studies were examined as full text and both the advantages and barriers list of the integration created from these studies.

3.2.2 Methodology for the Data Collection and Analyses

In conducting the research, various data collection methods were carefully evaluated, and it was determined that a one-to-one expert interview approach was one of the most effective methods for two reasons. Firstly, there are a limited number of people who have a deep understanding of both the Turkish modular construction sector and BIM, allowing for accurate and detailed responses to inquiries. Secondly, open-ended questions would provide a more nuanced understanding of how companies in this sector are integrating BIM into their operations, what challenges they are facing, and how they are overcoming them. Only multiple-choice answers can limit the research by avoiding comprehensive and intricate insights into the factors that affect BIM-MC integration. As a result, the main goal is to gain a profound understanding of the unique experiences and perspectives of people who are directly involved in the field, and one-to-one expert interviews were selected to be helpful for the goal.

In this study, for analyzing and interpreting the data 5-point Likert scale analysis method was used together with the qualitative analysis method by interviewing experts. According to James et al. (2011), the Likert scale was developed by Rensis Likert (1931), who described and then developed this technique for the assessment of attitudes. Similarly, in this study, a 5-point Likert scale analysis was selected to assess the agreement of the interviewees. The participants were requested to evaluate their level of agreement about the validity of the advantages and barriers associated with the integration of BIM-MC outlined in international literature for Türkiye. 1 is for strongly disagree and 5 for strongly agree and 3 is for neutral. In addition to 5-point Likert scale questions, open-ended questions were analyzed qualitatively. The

most rated advantages and barriers, together with the ones that are frequently discussed during interviews, were defined as key benefits and critical barriers.

3.2.3 Methodology for the Interviews

For the study, a structured interview format was used to take advantage of its benefits, such as improved reliability, validity, and usefulness as a training tool (Segal et al., 2006). In the interview, participants were presented with various findings from previous literature and asked questions related to them. The questions were asked in the same order and format for all participants. Before the interview, all participants were given a "Research Voluntary Participation Form" (Appendix A) that provided details about the study's goals, the number of questions, the question format, how the answers would be used, and the researcher's contact information. Those who agreed to participate in the interview were asked to sign this form.

The interview includes 3 parts (Appendix B). In the first part general information about the interviewee was asked such as their major, education level, and experience in construction. In the second part general information about the company was asked. The years of service in the construction sector and the scale of the company information gathered in this part. Lastly, in the third part, BIM-MC integration-related questions were asked to the interviewee. In total, there were 10 questions. 6 of them were open-ended questions that sought to find information about the experience of the interviewee and the know-how of the company. The remaining questions are asked to measure the companies' BIM usage level, the agreement of the interviewees about the information gathered from the literature review, and stakeholders' responsibility for the BIM-MC integration.

METU Human Research Ethics Committee granted permission for the interview with permission protocol number 0016-ODTUİAEK-2024 (Appendix C). After obtaining the required permissions, the interviews took place in the experts' offices and were conducted in person. To facilitate the discussion, hard copies of the

interview questions were provided, and the experts were requested to provide their input by filling in the blanks. In the meantime, the interviewer carefully noted the important points of the conversation.

3.2.4 Methodology for the Modular Construction Company Selection

For the research, the prior company selection criterion is that companies need to be modular construction companies based in Türkiye. Additionally, they need to have a vision of implementing BIM into their process. There are various companies with a huge production volume, however, not all of them may be willing to switch their systems to BIM. Therefore, companies making at least an attempt to try BIM were selected for the study.

As a secondary criterion, the companies are expected to have been in the modular construction sector for a long term to have experienced a variety of projects. One of the other secondary selection criteria is being a large enterprise. Small and medium-sized enterprises (SMEs) employ fewer than 250 individuals. Large enterprises employ 250 or more individuals (OECD, 2023). Therefore, large enterprises were selected as the secondary criteria for the study. The last secondary criterion is that companies are expected to serve both nationally and internationally. They need to complete a considerable number of projects from various countries to apply the criteria.

As a result, 3 modular construction companies were selected for the study which all apply the prior selection criteria and at least two of the secondary criteria. With all the prior and secondary criteria, it is aimed to select experienced and advanced modular construction companies that can try to digitalize their processes and adapt their operations to BIM. The number of people interviewed from these companies is selected based on the companies' compliance with the criteria. Notably, the company that demonstrated higher conformity to the criteria was subject to a larger number of interviews.

3.2.5 Methodology for the Interviewee Selection

The study aims to gather valuable data that will shed light on the effective strategies for BIM integration in the Turkish modular construction sector. To achieve this aim, individuals with significant experience in the selected modular construction company were targeted. In particular, at least one senior manager from each company was invited for the interview because they were able to provide general information about the company's BIM vision. Additionally, individuals who have specialized in the field of construction through education or professional development were also sought after. Specifically, the study required participants who had completed at least a bachelor's degree in the construction disciplines. The selection process was aimed at ensuring that the participants were well-qualified in the modular construction industry both professionally and intellectually and possessed the necessary expertise to provide valuable insights for the study.

CHAPTER 4

FINDINGS AND DISCUSSION

The fourth chapter of the study is dedicated to presenting the Findings and Discussion. This section compiles all the findings from the literature review and interviews conducted. The findings section comprises data presented and analyzed through tables and graphics. The data was collected from interviews' rating questions, open-ended questions, and literature reviews. They were analyzed with descriptive analysis methods to visualize the relations. Furthermore, the discussion section delves into the interview questions. It involves the explanation and interpretation of the interview findings in comparison with the literature sources.

4.1 Findings

The findings of the study were presented under seven headings: Interviewee Profiles, Company Profiles, Advantages of BIM-MC Integration, Barriers of BIM-MC Integration, Key Advantages of BIM-MC Integration, Critical Barriers of BIM-MC Integration, and Stakeholders Responsibilities for BIM-MC Integration.

4.1.1 Interviewee Profiles

The demographic information gathered from interviewees was presented in this section. Table 4.1 shows the detailed background information of respondents. In total, there are 15 participants in the interview. As indicated in Figure 4.1, seven of them, 46,67 percent of the total participants, are architects; the other seven of them, 46,67 percent, are civil engineers; and one of them is a mechanical engineer, which is 6,67 percent. They all have at least a bachelor's degree and more than half of the participants have a master's degree. Their positions in the companies vary from

design to business development. Two of the participants are in director positions, while three of them are in managerial positions. Thus, five of the participants are in executive positions in their companies. Additionally, there is a BIM specialist among the participants. Only one of the selected three companies has a BIM-related department and human resources inside the organization.

Table 4.1 Interviewee Profile

	Major	Level of Education	Position	Experience in MC
1	Architect	Bachelor's	Design Director	20+
2	Civil Engineer	Bachelor's	Deputy Proposal Manager	1-5
3	Civil Engineer	Master	Deputy Manager Planning & Cost Control	10-15
4	Civil Engineer	Master	Planning & Cost Control Engineer	1-5
5	Architect	Master	Proposal Engineer	1-5
6	Architect	Bachelor's	BIM Specialist	1-5
7	Architect	Bachelor's	Architect	1-5
8	Architect	Master	Modular Construction Director	1-5
9	Architect	Master	Design Coordination Lead	1-5
10	Civil Engineer	Bachelor's	Business Development Engineer	1-5
11	Mechanical Engineer	Master	Engineering Manager	10-15
12	Civil Engineer	Bachelor's	Design (Static) Engineer	10-15
13	Civil Engineer	Master	Design Engineer	1-5
14	Civil Engineer	Bachelor's	Senior Production Engineer	1-5
15	Architect	Master	Design Lead	5-10

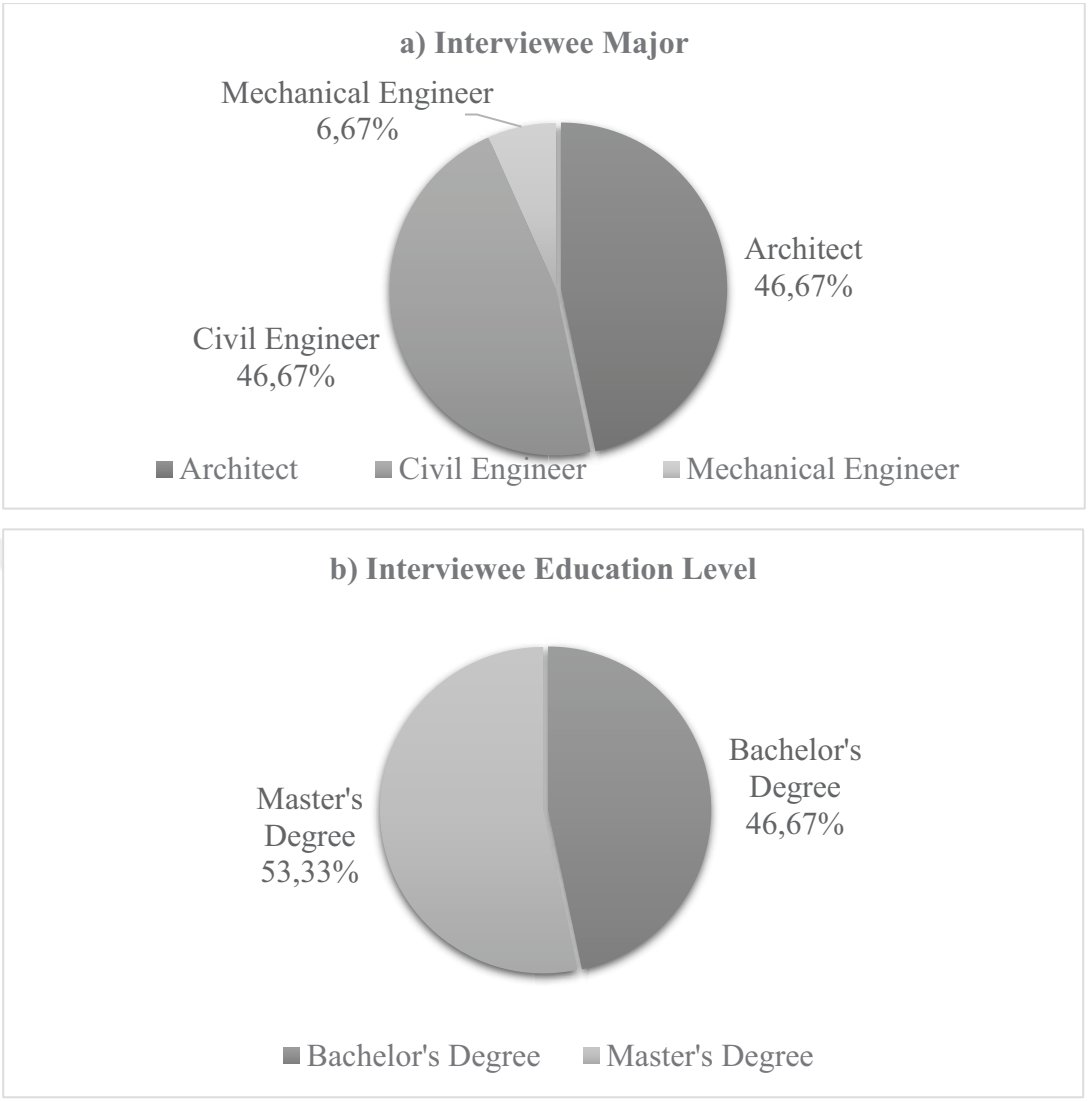


Figure 4.1 Interviewee Background: a) Interviewee Major, b) Interviewee Education Level

The experiences of the participants are also rated during the interview. As demonstrated in Figure 4.2, they were asked to indicate their experiences in three different categories: experience in construction, experience in specifically modular construction, and experience in BIM. They all have at least 1–5 years of modular construction experience; moreover, one-third of the participants have more than 5 years of experience in the specifically modular construction sector, as shown in

Table 4.2. Although it is less than the other experiences, all participants have experience in BIM. Since BIM is a relatively new technology, experience in this field does not exceed 20 years. Yet, as indicated in Table 4.3, four of the participants have over 5 years of BIM experience. Lastly, as shown in Table 4.4 below, it has been observed that 60% of the participants have more than 5 years of experience in the construction sector.

Table 4.2 Interviewee Experience in Modular Construction

	Frequency	Percent
1-5 YEAR	**10**	**66,7**
5-10 YEAR	**1**	**6,7**
10-15 YEAR	**3**	**20,0**
20+ YEAR	**1**	**6,7**

Table 4.3 Interviewee Experience in BIM

	Frequency	Percent
1-5 YEAR	**11**	**73,3**
5-10 YEAR	**3**	**20,0**
10-15 YEAR	**1**	**6,7**

Table 4.4 Interviewee Experience in Construction

	Frequency	Percent
1-5 YEAR	**6**	**40**
5-10 YEAR	**1**	**6,7**
10-15 YEAR	**3**	**20**
15-20 YEAR	**4**	**26,7**
20+ YEAR	**1**	**6,7**

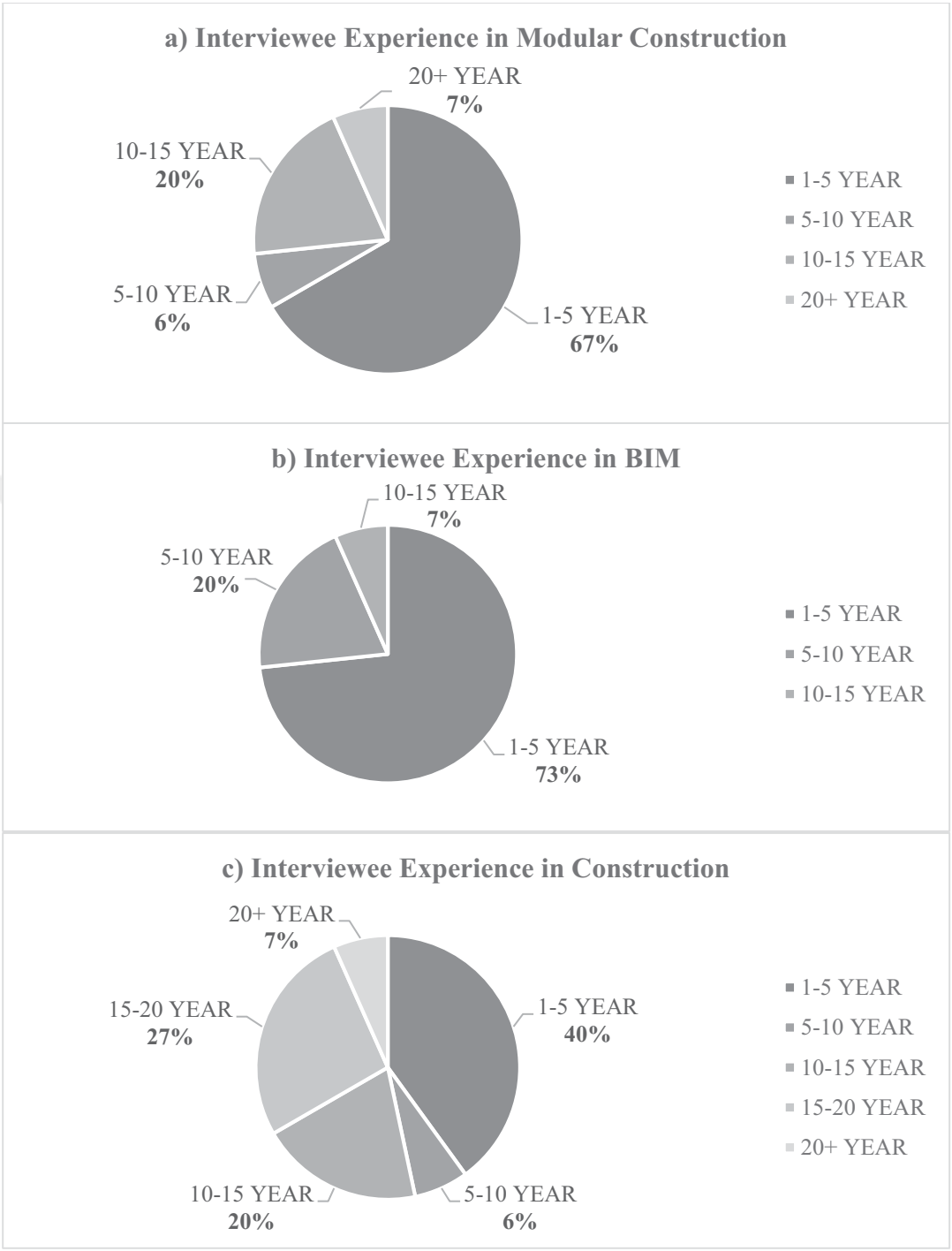


Figure 4.2 Interviewee Experiences: a) Interviewee Experience in Modular Construction b) Interviewee Experience in BIM c) Interviewee Experience in Construction

4.1.2 Company Profiles

The profiles of the selected companies are introduced in this section. Table 4.5 below shows details of these three companies renamed anonymously as Company A, B, and C. As a prior criterion of the study, all three companies have at least more than 30 years of experience in the modular construction sector, and they all have attempted to implement BIM in their processes.

Table 4.5 Company Profile

	Experience in MC	**The no of projects in a portfolio**	**The no of countries exported to**	**The no of personnel**	**The no of interviewees**
Company A	30+ years	500+	60+	500+	7
Company B	30+ years	500+	40+	250-500	5
Company C	30+ years	50-100	30+	100-250	3

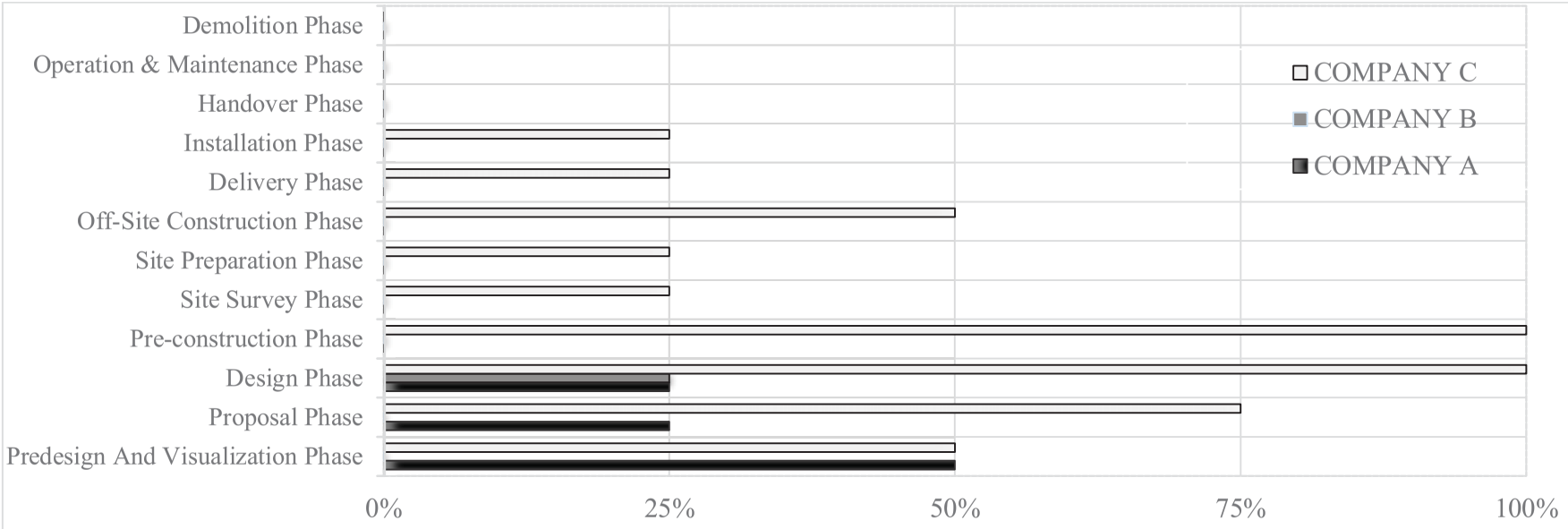
Company A specializes in modular construction projects that involve off-site prefabrication of building modules in factories, followed by on-site assembly. Its services include in-house engineering, procurement, manufacturing, logistics, on-site assembly, infrastructure, and superstructure works. It boasts a turnkey approach to completing prefabricated modular steel structures. It has more than 500 projects in its portfolio with over 40 years of experience in the field. The company also has international recognition in prefabricated modular steel constructions, providing export and international contracting services in more than 60 countries. According to Engineering News-Record, the company is recognized as one of the top 250 contracting companies in the world (ENR, 2022). Considering the ENR record, the number of countries exported to, and the number of personnel, the company is relatively bigger than the remaining two selected companies. Thus, seven of the fifteen interviewees were selected from this company.

Company B specializes in the production of modular prefabricated buildings, light steel permanent constructions, living containers, and steel frame buildings. The

company has the required knowledge and infrastructure to offer turnkey services that span from preliminary projects to final applications. With a portfolio of over 500 projects, the majority of which are large-scale international EPC (engineering, procurement, and construction) projects, Company B is a highly experienced provider of prefabricated buildings, having served clients in more than 40 countries worldwide. Considering the size of its workforce, which exceeds 200 employees, and the number of countries it exports to, Company B is in the middle of the remaining two selected companies. Therefore, five of the fifteen interviewees have been selected from this company.

Company C is one of the pioneering companies in Türkiye that specialize in "off-site construction" or "modular construction." The company has established its position in the industry with its steel construction systems and modular steel products, as well as its acquired knowledge and experience in real estate projects. With over 50 years of experience in construction, the company has completed more than 50 projects, and more than 50 percent of these projects are exported to over 30 countries. The total number of personnel working for the company is between 100 and 200. Although the company is not considered a large enterprise according to the OECD report definition, it was selected due to its high satisfaction ratings of other company selection criteria and extensive use of BIM. As a result, three out of the fifteen interviewees were selected from this company for the study.

Throughout the interviews, participants were requested to share insights about their utilization of BIM within their companies. To thoroughly assess the level of BIM implementation, it was categorized according to distinct phases of the modular construction from preliminary design to the demolition phase. Figure 4.3 below illustrates the BIM usage levels across various construction phases for each of the three modular construction companies.



	Predesign And Visualization Phase	Proposal Phase	Design Phase	Pre-construction Phase	Site Survey Phase	Site Preparation Phase	Off-Site Construction Phase	Delivery Phase	Installation Phase	Handover Phase	Operation & Maintenance Phase	Demolition Phase
COMPANY C	50	75	100	100	25	25	50	25	25	0	0	0
COMPANY B	0	0	25	0	0	0	0	0	0	0	0	0
COMPANY A	50	25	25	0	0	0	0	0	0	0	0	0

Figure 4.3 BIM Usage Levels of Companies

According to the data presented in Figure 4.3, it appears that Company A and Company C have effectively utilized BIM in 50% of the predesign and visualization phase, but Company B has not used it at all. Additionally, in the proposal phase, Company A and C have a usage rate of 25% and 75% respectively, whereas Company B does not use BIM at this phase either. All three companies use BIM during the design phase, but Company C appears to make the most use of it (100%), while Company A and Company B utilize it at a rate of 25%. During the construction phases, there is a significant decrease in the use of BIM by all three companies. Following the completion of the design phases, Company A and Company B do not use BIM, while Company C continues to use it at a rate of 100% in the pre-construction phase. The company continues its BIM usage by approximately 25% until the installation phase ends. None of the companies used BIM in the last three phases, namely the Handover Phase, Operation & Maintenance Phase, and Demolition Phase. In conclusion, Company C appears to be the only company that uses BIM for most of the project life cycle phases, with an average percentage of 40, which is significantly higher than Company A and Company B, whose total BIM usage rates are 8% and 2% respectively.

4.1.3 Advantages of BIM-MC Integration for Türkiye

The advantages of BIM-MC integration were collected through related studies in the literature review process. In the literature review section, these advantages were categorized into twenty groups according to their common subjects. Some of these categories are design, cost, visualization, and time-related advantages. Interviews were conducted through these organized lists and interviewees interpreted the categorization of the advantages. By taking into consideration the interviewees' suggestions, the table organization was updated and compacted. As a result, the advantages were recategorized into eight main groups for this study. They are (1) technology and concept integration-related advantages, (2) safety and stability-related advantages, (3) cost-related advantages, (4) design & visualization-related

advantages, (5) planning & scheduling-related advantages, (6) quality control-related advantages, (7) management-related advantages, and (8) efficiency & sustainability-related advantages. The participants rated the advantages. They were asked whether they agreed that these advantages were valid for the Turkish modular construction industry. They indicated their agreement on a scale of 1 to 5, with 5 indicating strong agreement and 1 indicating strong disagreement. The results of the ratings were explained under the following headings, in eight advantage categories.

4.1.3.1 Technology and Concept Integration Advantages

The first advantage category is technology and concept integration which includes two sub-advantages, and they were coded as indicated in Table 4.6 below. In the category, the advantage of BIM-MC integration is that BIM can be used as a data source for recent technology or new concept adaptation for modular construction. Participants mostly agree on these two advantages' applicability for Türkiye as indicated in Figure 4.4. Both advantages were rated strongly by over 50 percent of respondents. When the agreed rates are also taken into consideration, these advantages reach the approval of more than 80 percent of participants. Almost none of the participants disagree with these two advantages' applicability for Türkiye.

Table 4.6 Technology and Concept Integration Advantages

TA1: Recent technology adaptation: IoT, Blockchain, VR, AI, Big data
TA2: New concept adaptation: lean construction, construction 40, DfMA

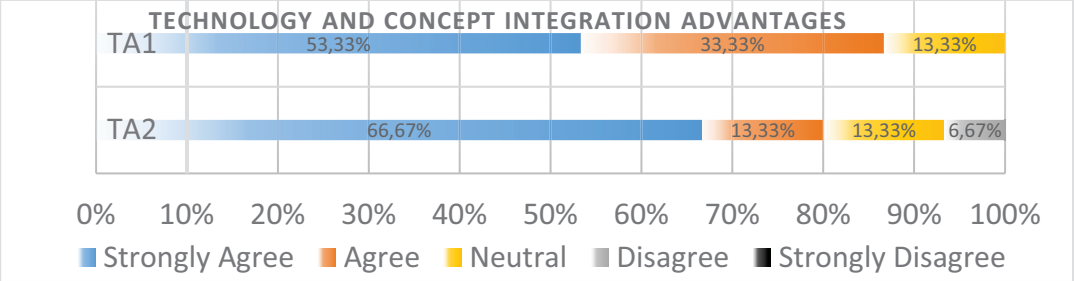


Figure 4.4 Technology and Concept Integration Advantages

4.1.3.2 Safety and Stability-Related Advantages

The second advantage category is safety and stability which includes six sub-advantages, and they were coded as indicated in Table 4.7 below. The category includes both the health and safety and structural stability advantages of modular constructions when they are constructed with the integration of BIM technology. As shown in Figure 4.5, the advantage of detecting dangerous behaviors in construction sites and potential workspace conflicts is the most strongly agreed advantage compared to others with 66.67 % percent of participants. On the other hand, some participants do not agree with the validity of the advantage in this category for Türkiye, especially for the advantages of crane management and structural stability improvement.

Table 4.7 Safety and Stability-Related Advantages

SA1:Detecting dangerous behaviors in construction sites and potential workspace conflicts
SA2: Providing structural analysis
SA3: Reducing safety risks and improving safety management
SA4: Providing staff training and improving worker safety
SA5: Improving structural stability
SA6: Improving crane management

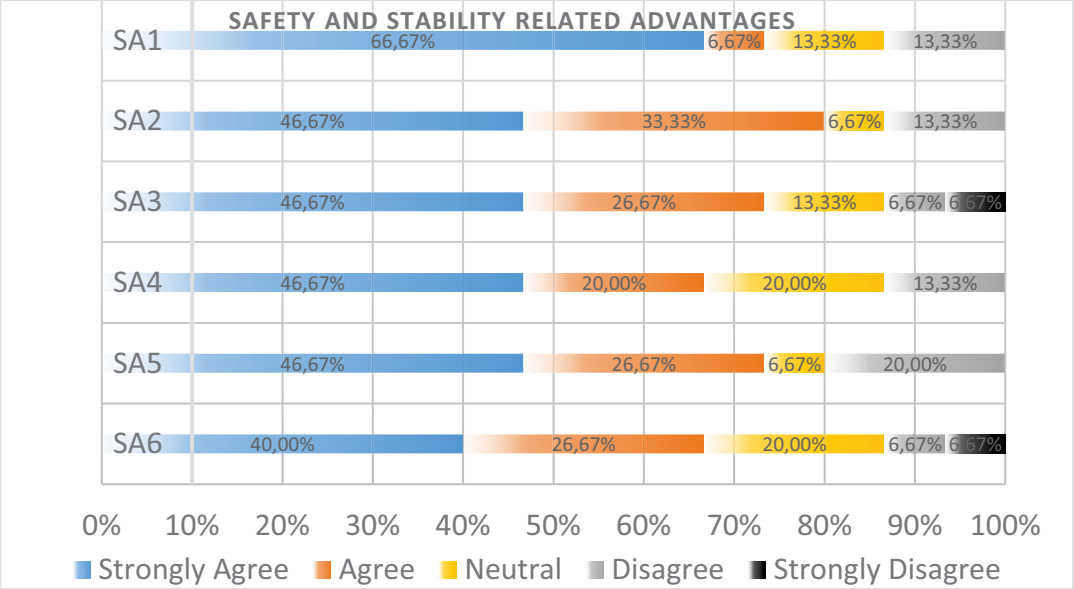


Figure 4.5 Safety and Stability-Related Advantages.

4.1.3.3 Cost-Related Advantages

This category boasts seven distinct sub-advantages, all of which are intricately tied to cost, as indicated in Table 4.8 below. Amongst these advantages, as shown in Figure 4.6, effective cost management reigns supreme, as strongly agreed by the majority of participants with an impressive percentage, which is 86.7%. The effective cost management advantage is followed by the advantages of a decrease in design and redesign costs. The sub-advantage of reducing installation costs appears to be the least favored advantage in this category with only 26.7% strong agreement and the existence of strong disagreements. Still, more than 70% of participants agreed with the applicability of the advantages.

Table 4.8 Cost-Related Advantages

CA1: Providing effective cost management
CA2: Decreasing design/ redesign costs
CA3: Providing financial improvements
CA4: Providing cost prediction
CA5: Decreasing labor costs
CA6: Decreasing construction costs
CA7: Decreasing installation costs

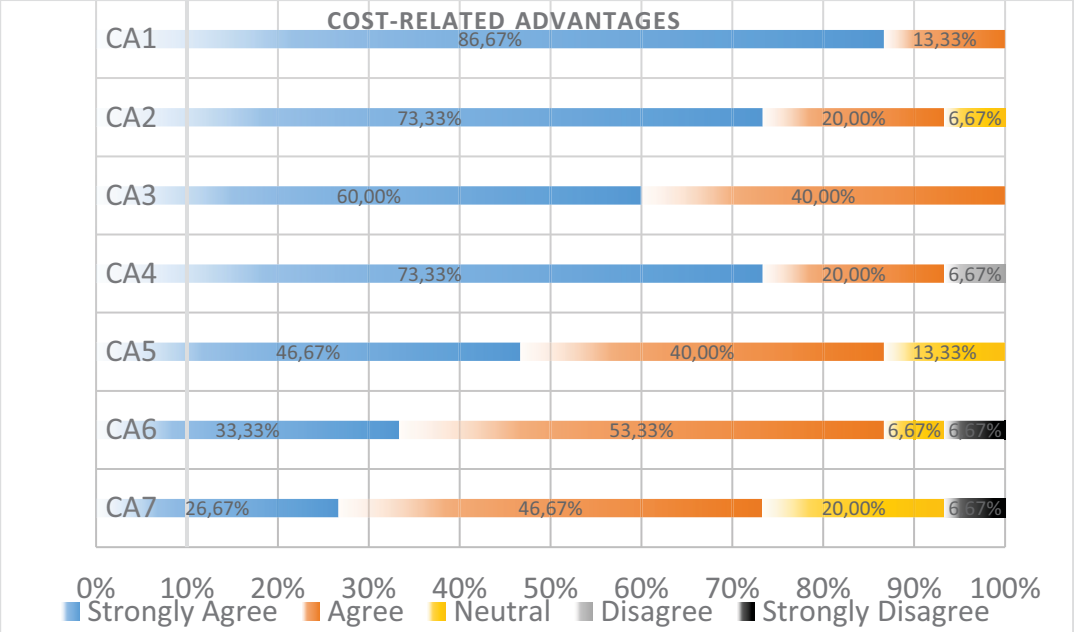


Figure 4.6 Cost-Related Advantages

4.1.3.4 Design & Visualization-Related Advantages

The fourth advantage category is design & visualization. The category includes fifteen sub-advantages as indicated in Table 4.9, which is one of the highest numbers among the other categories. Figure 4.7 shows that most of the participants strongly agreed that the design and visualization-related advantages apply to Turkish modular construction sectors. Especially the first three advantages; providing walkthrough animations, reducing design errors, and providing quick responses to design changes advantages were approved by 100% of the participants. Moreover, improving simulation, providing control over interference, and detecting clashes are the applicable advantages according to most of the participants, while reducing the drawing amount is one of the least agreed advantages in the category with 60% of participants.

Table 4.9 Design & Visualization-Related Advantages

DA1: Providing walkthrough animations
DA2: Reducing design errors
DA3: Providing quick responses to design changes
DA4: Improving simulation
DA5: Providing control over interference and detecting clashes
DA6: Optimizing design
DA7: Providing strong technical drawings
DA8: Allowing the creation of complex building geometries in 3D
DA9: Avoiding 2D design problems
DA10: Enhancing the HVAC design
DA11: Enhancing visualization in design and construction
DA12: Creating automatic design alternatives and diverse design options
DA13: Improving buildings' spatial relevance and artistic quality
DA14: Changing the public perception of modular construction
DA15: Reducing the drawing amount

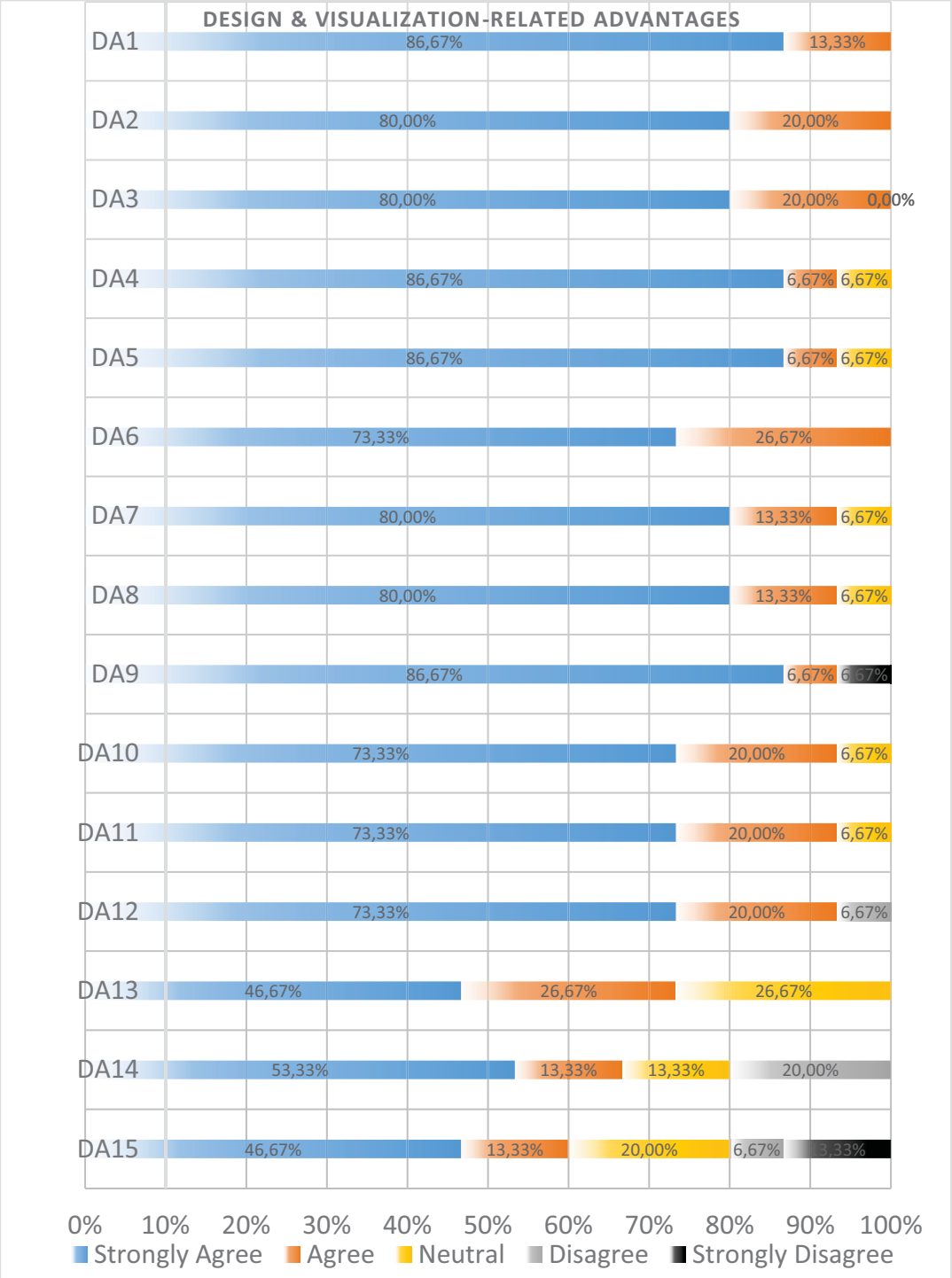


Figure 4.7 Design & Visualization-Related Advantages.

4.1.3.5 Planning & Scheduling-Related Advantages

The fifth advantage category is planning & scheduling, which has five sub-advantages indicated in Table 4.10. According to Figure 4.8, providing planning and scheduling simulations and enabling assembly sequencing planning advantages of BIM-MC integration are seen as slightly more applicable advantages for Turkish modular construction compared to time-related advantages such as saving by shortened design and construction period. Although the advantage of giving a chance to rapid construction in case of emergency has been rated as agreed by approximately 90 % of participants, it has been rated as strongly disagreed by 6.67% of participants.

Table 4.10 Planning & Scheduling-Related Advantages

PA1: Providing planning and scheduling simulations
PA2: Enabling assembly sequencing planning
PA3: Enabling automated planning & scheduling
PA4: Saving time by shortening the design and construction period
PA5: Giving a chance to rapid construction in case of emergency

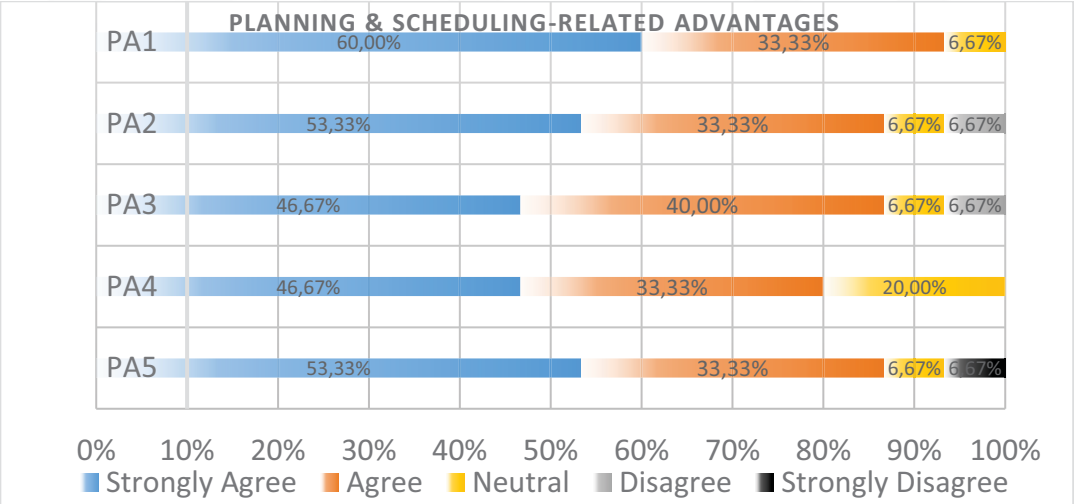


Figure 4.8 Planning & Scheduling-Related Advantages.

4.1.3.6 Quality Control-Related Advantages

The sixth advantage category is quality control, which has 6 sub-advantages as indicated in Table 4.11. Figure 4.9 illustrates that the advantage of enhancing process monitoring and progress control is highly rated by participants for Turkish modular construction with a 100% agreement. Similarly, providing an effective rectification rate of project quality problems and providing structural health monitoring advantages are also rated as agreed by almost 90% of the total participants. On the other hand, the least agreed advantages are providing quality control of prefabricated components and improving tolerance control in the quality control category.

Table 4.11 Quality Control-Related Advantages

QA1: Enhancing process monitoring and progress control
QA2: Providing effective rectification rate of project quality problems
QA3: Providing structural health monitoring
QA4: Providing an automated compatibility check
QA5: Providing quality control of prefabricated components
QA6: Improving tolerance control

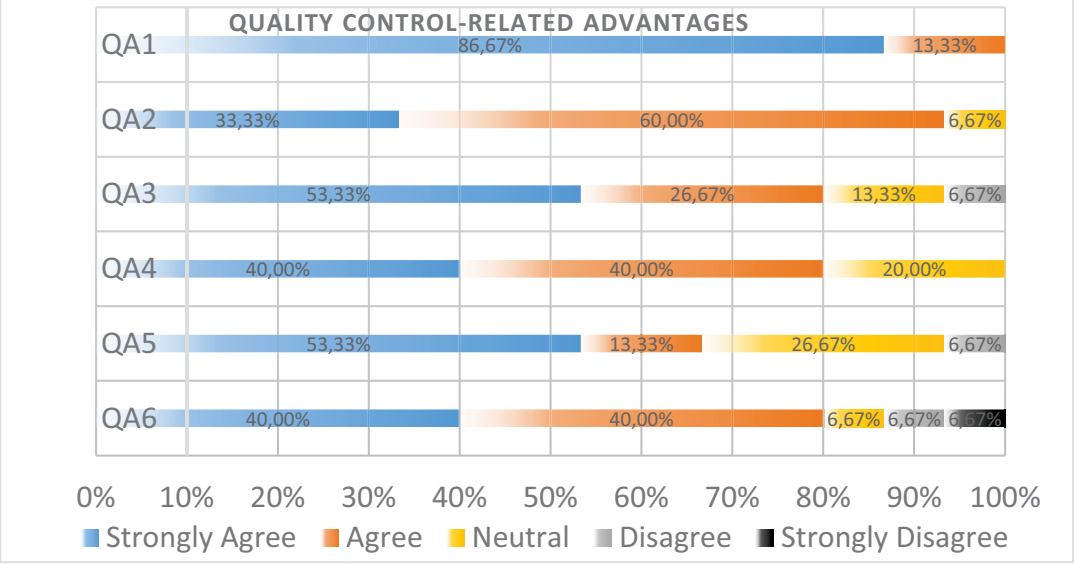


Figure 4.9 Quality Control-Related Advantages.

4.1.3.7 Management-Related Advantages

The seventh advantage category is the most mentioned group in the literature, with 19 sub-advantages shown in Table 4.12 below. The category includes various advantages that BIM-MC integration brings to construction management. Figure 4.10 shows that information management-related advantages in this category are the highest-ranked advantages, which include the advantages of providing transparent data structure, effective construction information sharing, improving information management and integration, and providing reliable information. All participants agreed on these advantages' applicability without any exceptions. Not only the information management-related advantages but also life cycle management and risk management-related advantages are highly rated in the category with the agreement of more than 90% of participants. Similarly, communication, coordination, and collaboration-related advantages of BIM-MC integration included in the category were rated with more than 90% agreement. Only one of the advantages, improving system security, in the category has been rated as strongly disagreed by 13.33% of the participants.

Table 4.12 Management-Related Advantages

MA1: Providing transparent data structure
MA2: Providing effective construction information sharing
MA3: Improving information management and integration
MA4: Providing reliable information
MA5: Providing systematic management
MA6: Improving inventory management
MA7: Improving life cycle management
MA8: Enhancing coordination
MA9: Improving communication
MA10: Providing efficient data storage and processing
MA11: Providing real-time data gathering and sharing
MA12: Enhancing collaboration
MA13: Enhancing supply chain management
MA14: Providing planning and control process of logistics operations
MA15: Improving risk management
MA16: Providing effective decision-making

Table 4.12 Management-Related Advantages (cont'd)

MA17: Enhancing logistic-related decision-making
MA18: Enabling to prediction of potential logistics risks and accurate module delivery time
MA19: Improving system security

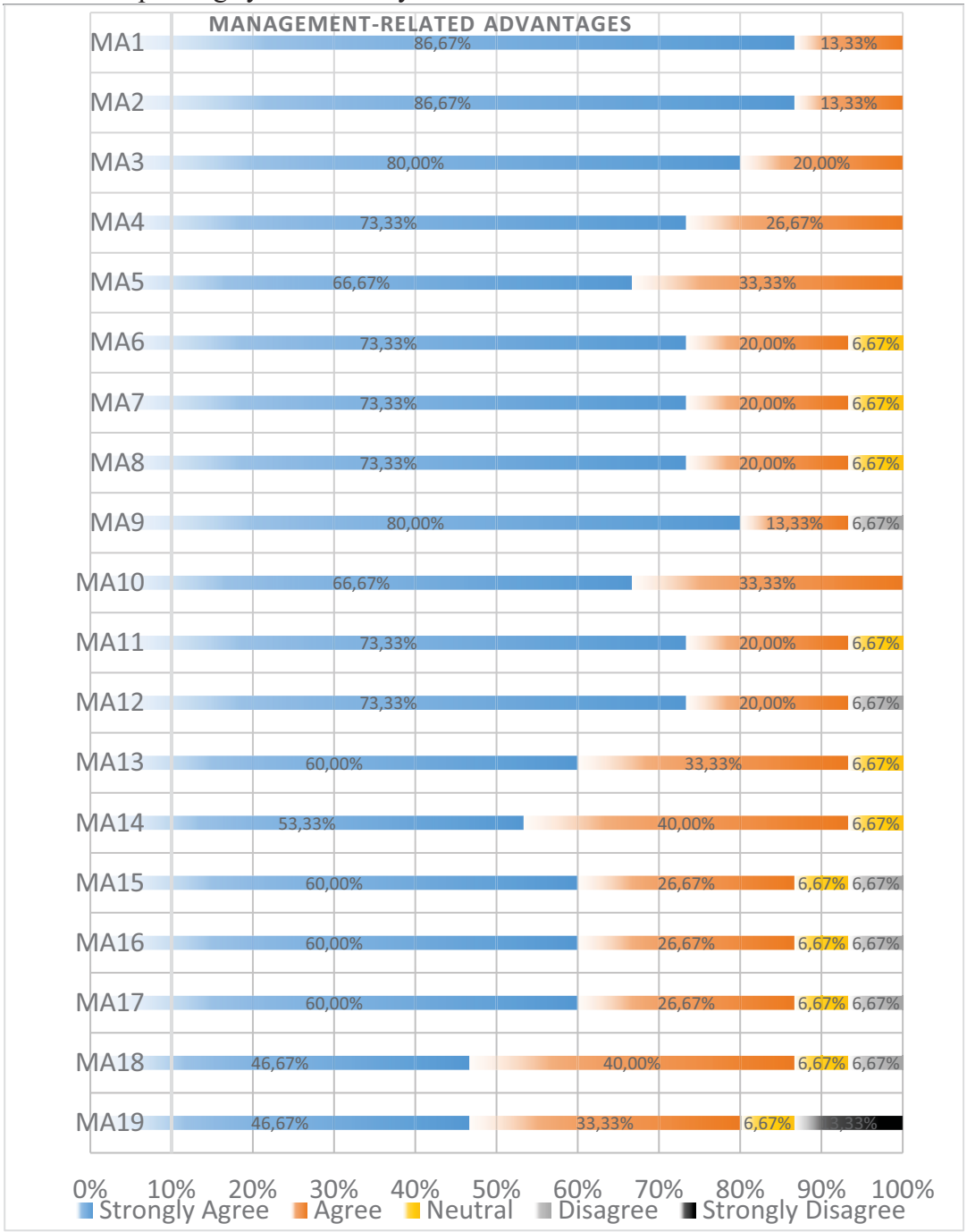


Figure 4.10 Management-Related Advantages.

4.1.3.8 Efficiency & Sustainability-Related Advantages

The last category of advantages is efficiency and sustainability. As shown in Table 4.13, this is one of the categories that includes the most sub-advantages with fourteen sub-advantages. According to Figure 4.11, the category is also one of the highest-ranked ones compared to the other seven categories. Although BIM-MC integration has many advantages, as evidenced by the 74 advantages offered in these eight categories, the advantage of providing repetitive work and mass production is ranked as the most applicable advantage for Turkish modular construction with a 93.33% strongly agreement and 6.67% agreement rate. Besides the mass production advantage, increasing efficiency in the construction and automation-related advantages included in this category are also highly ranked. All the participants agreed upon these advantages' applicability and most of them agreed strongly. Decreasing labor advantage, on the other hand, is the least favored advantage in this category with approximately 70% agreement and a 6.67% disagreement rate.

Table 4.13 Efficiency & Sustainability-Related Advantages

EA1: Providing repetitive work and mass production
EA2: Increasing efficiency in the construction
EA3: Automating life cycle assessment
EA4: Decreasing human error
EA5: Optimization of sustainable design
EA6: Improving optimization
EA7: Increasing sustainability in the construction
EA8: Providing automated draft and design
EA9: Paving the way for robotic manufacturing
EA10: Providing less waste
EA11: Optimizing construction cost
EA12: Enabling the reuse of modular structural components
EA13: Providing carbon footprint and optimization
EA14: Decreasing labor

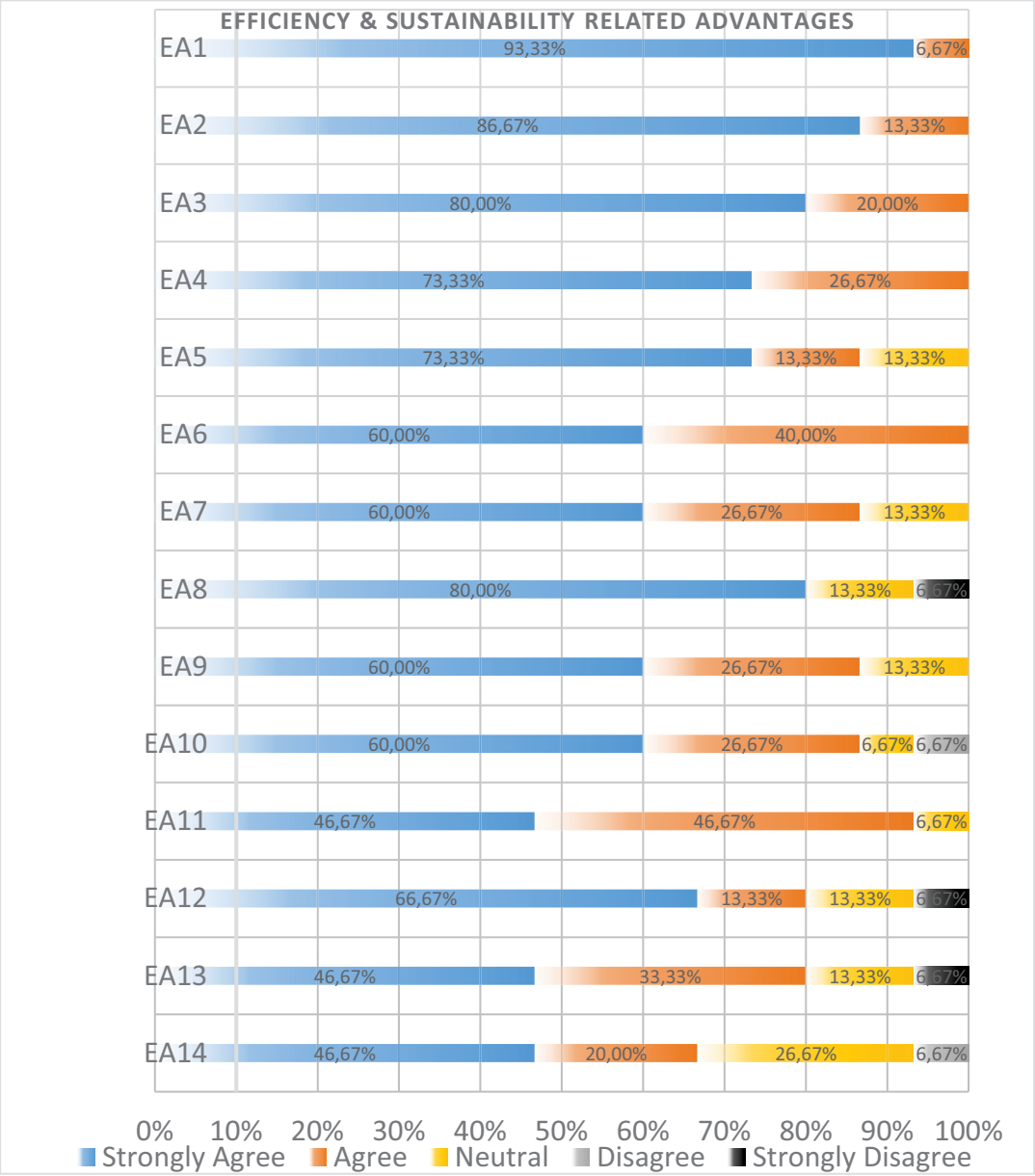


Figure 4.11 Efficiency & Sustainability-Related Advantages.

To conclude, when the eight category rates are compared with each other in a box plot, as can be seen in Figure 4.12, the participants mostly agree upon the advantage categories with the high mean values. Their rates for the first three categories are very close to each other. These high mean value categories are design & visualization-related advantages, management-related advantages, and efficiency &

sustainability-related advantages. The least rated categories, on the other hand, are safety and stability-related advantages, quality control-related advantages, and planning & scheduling-related advantages respectively. Cost-related advantages together with technology and concept integration advantages are in the middle of the eight categories according to participants' rates.

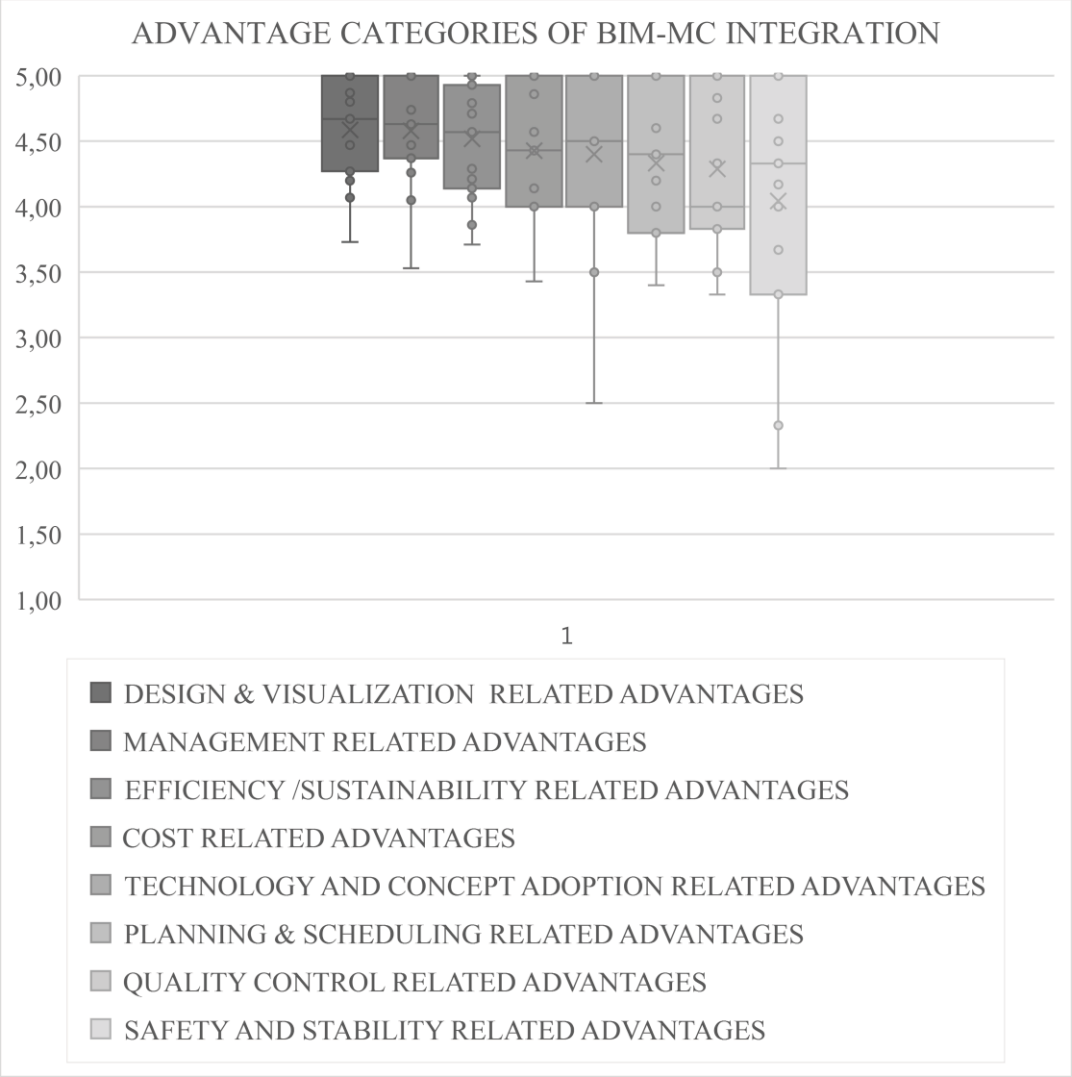


Figure 4.12 Advantage categories of BIM-MC Integration

4.1.4 Barriers to BIM-MC Integration for Türkiye

The barriers behind the implementation of BIM in modular construction were gathered from studies in the literature. In the literature review section, these barriers are divided into twenty categories according to their common themes. These categories vary from software-related barriers to governmental barriers. Interviews were conducted based on the organized barrier list, and the interviewees interpreted the categorization of the list. Considering the suggestions of the interviewees, the organization of the list was updated and compressed into eight main categories. The first category is behavioral barriers indicate human perception-related barriers such as resistance to change and owners' or executives' negative approaches to BIM-MC integration. The second category is organizational barriers present managerial and coordination-related barriers such as inappropriate team and organizational configurations or lack of information management. The remaining six categories indicate design-related barriers; software-related barriers; governmental and standardization-related barriers; external environment-related barriers; knowledge& experience-related barriers; and cost-related barriers. The categories are explained in the sections below. The barriers to the BIM-MC integration gathered from studies in the literature were listed and presented to the interviewees. They were asked whether they agreed that these barriers were valid for the Turkish modular construction industry. They were asked to rate the criticality of the barriers on a scale of 1 to 5 for Türkiye. To analyze the barriers, Box Pilots were used to present the distribution and statistical summaries of the rates from the interview.

4.1.4.1 Behavioral Barriers

The behavioral barriers category refers to barriers relating to human perception, including reluctance to change and unfavorable attitudes toward BIM-MC integration held by owners, executives' employees, or the public. Interviewees' rating results in this category are shown in Figure 4.13 with a box plot. According to

interviewees, resistance to change in the culture of Türkiye is an important barrier to new technological advancements as in the case of BIM-MC integration. The box plot also indicates that owners' and executives' negative attitudes towards the integration are barriers applicable to Türkiye with mean values of 4.13 and 4.07 respectively. For the first three barriers, interviewees mostly agreed on, which means their rating results are very close to each other. However, their rate differs on the least rated barrier which is the negative public perception of modular buildings in terms of aesthetics and customizability. It can be concluded that resistance to change is a critical barrier, and the public perception barrier is not as critical as the barrier of resistance to change for Turkish people.

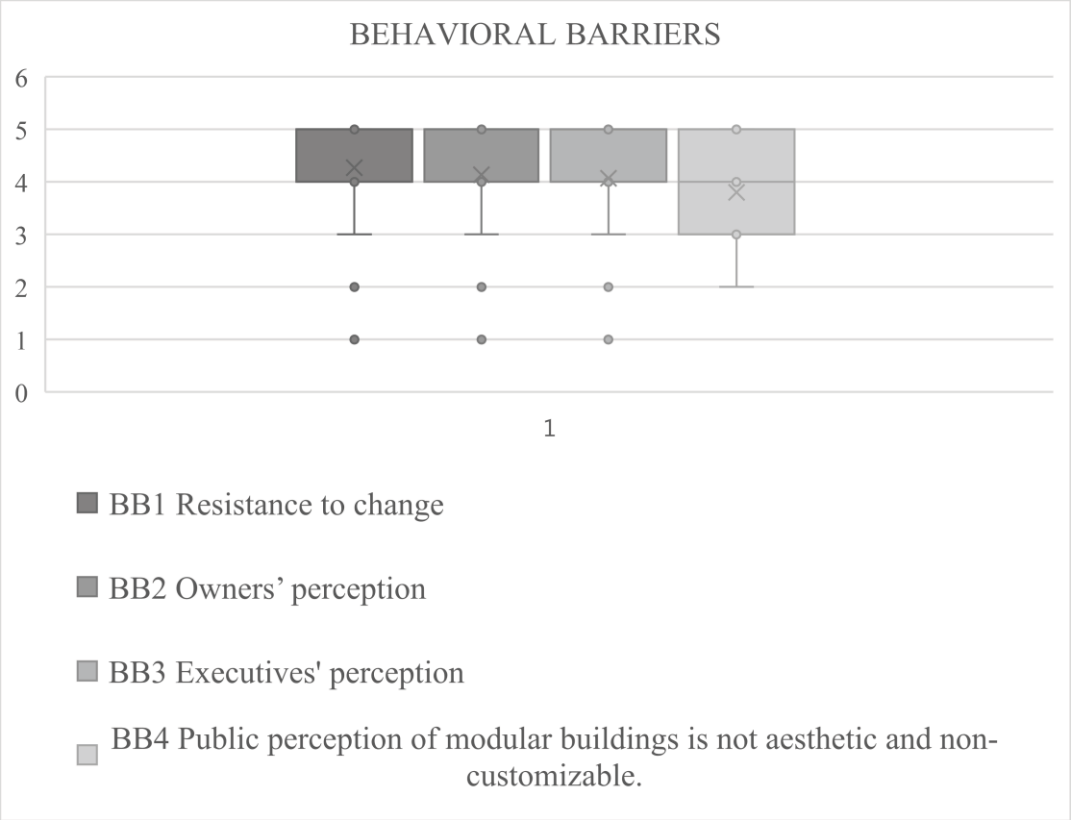


Figure 4.13 Behavioral barriers to BIM-MC integration.

4.1.4.2 Organizational Barriers

The organizational barriers category is the category with the highest number of barriers, with eleven barriers. Subcontractor-related barriers, management-related barriers, stakeholder-related barriers, and supply chain-related barriers are all included in this category. The interviewee's responses about the applicability of these barriers to the Turkish modular construction sector are demonstrated in Figure 4.14 with a box plot. According to interviewees, non-BIM-user subcontractors are the most critical barrier in this category. It is ranked with a mean value of 4.27 and most of the interviewees agreed upon the high rank as can be shown in the box plot. Uncertainty of demand and supply and inappropriate team and organizational configurations are critical barriers with a mean value over 4 in this category. Lack of information management system in the organization is another barrier in this category which is ranked in the sixth order. Most of the participants' rates for the barrier are close to each other by varying between 3 and 4. Stakeholder-related barriers appear in significant numbers in this category. Five of the eleven barriers in the category are related to stakeholders such as negative attitudes toward data sharing among stakeholders, the need for early commitment, and lack of communication, collaboration, and coordination between them. According to the participants, the most critical stakeholder-related barrier is the need for early commitment and the least one is the lack of coordination between them. Lastly, poor supply chain integration is not seen as a critical barrier for Türkiye by the participants.

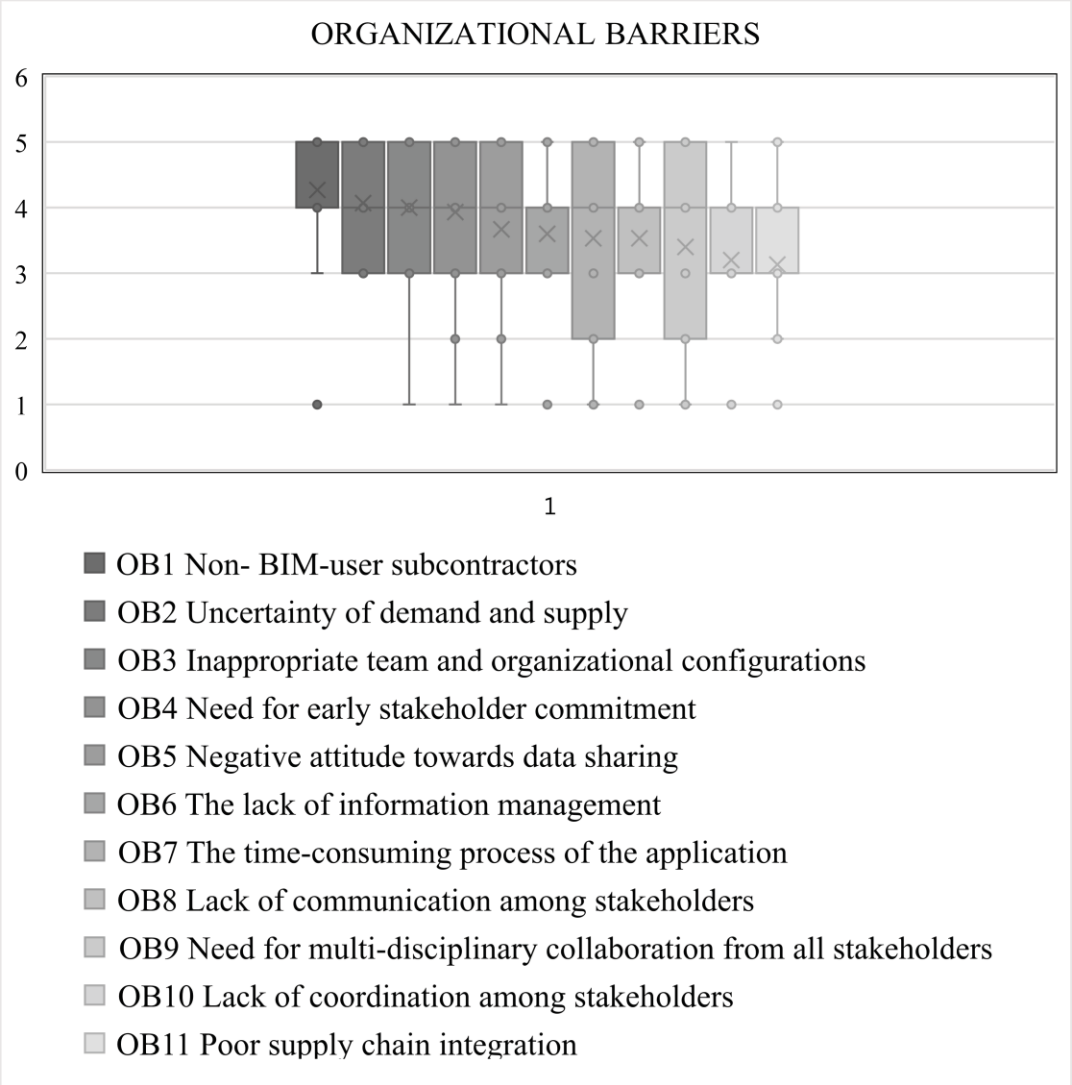


Figure 4.14 Organizational Barriers to BIM-MC Integration

4.1.4.3 Design-Related Barriers

The design-related barriers category refers to 4 barriers: increasing the design workload, the need for a more precise and complicated design, the need for an early design period, and the complexity of connection, as indicated in Figure 4.15. Regarding the interviewee responses, the most applicable barrier in this category is increasing design workload while the least rated barrier is the complexity of connection. Thus, for the Turkish modular construction sector complex connections

are not seen as a critical obstacle for BIM implementation. However, the need for a more precise and complicated design of modular construction by using BIM is one of the critical barriers in this category. The need for an early design period because of BIM is almost seen as critical as the need for a more precise and complicated design. These two barriers were rated closely by participants.

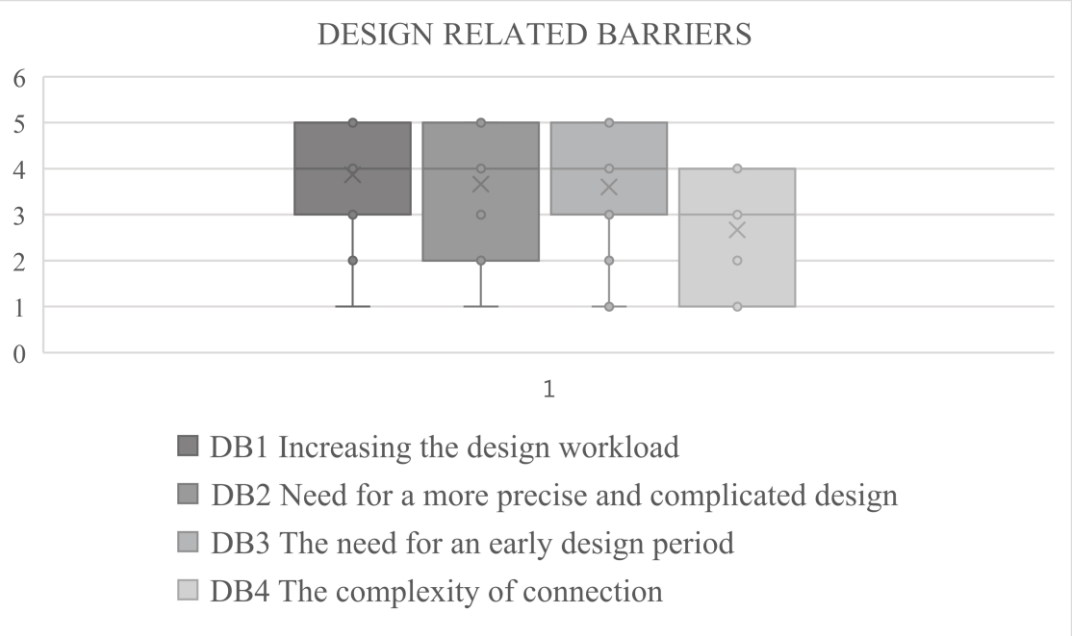


Figure 4.15 Design-Related Barriers to BIM-MC Integration

4.1.4.4 Software-Related Barriers

The software-related barriers category refers to 6 barriers. As shown in Figure 4.16 below, the barriers are a lack of local tools, the conflict between BIM software and domestic standards, insufficient maturity of software data, lack of interaction between different BIM software, and insufficient library and software storage limitations. Regarding the interviewee responses, the most applicable barriers in this category are related to the lack of national BIM tools and the conflict of existing tools with national standards for Türkiye. The least rated barrier, however, is the software storage limitation which is rated with the lowest mean value of 2.53. Thus, the interviewees mostly do not believe that the software limitation is a barrier to

BIM-MC integration. They mostly state the need for local studies on software-related obstacles.

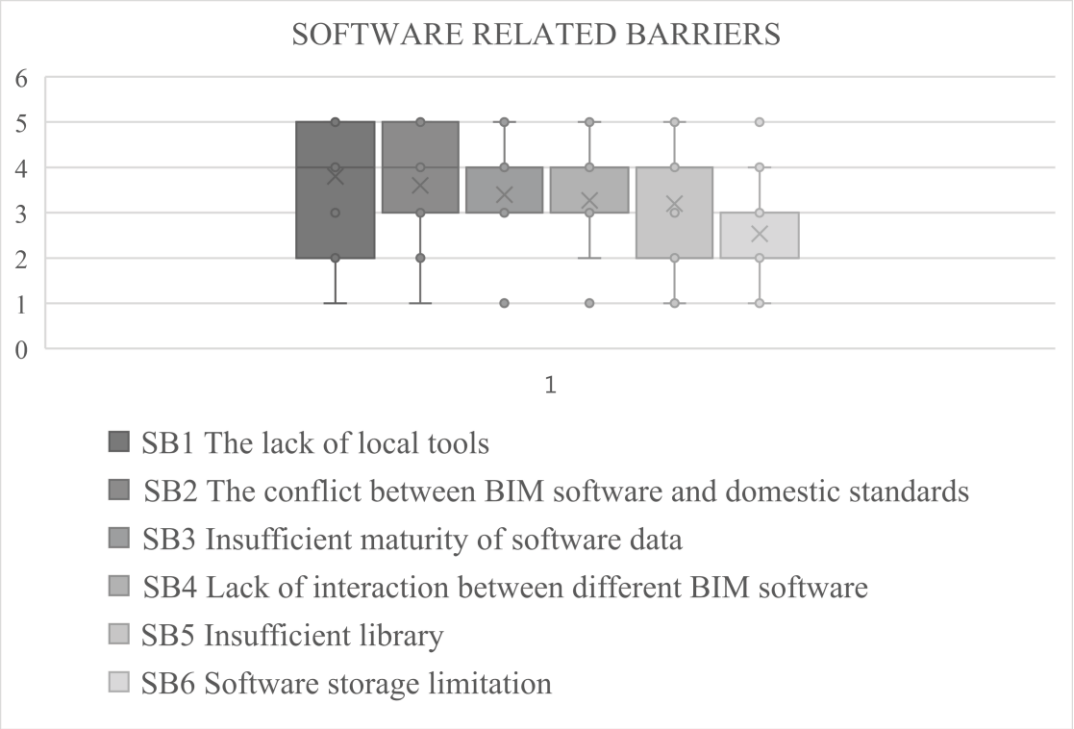


Figure 4.16 Software-Related Barriers to BIM-MC Integration

4.1.4.5 Governmental & Standardization-Related Barriers

The governmental & standardization-related barriers category refers to 10 barriers. The category is the second most barrier-containing category. According to Figure 4.17, the lack of incentive-oriented policies is seen as the most critical barrier with a mean value of 4.47, and the lack of standards, laws, and policies following this barrier. The lack of national data is seen as a critical barrier for the Turkish modular construction sector, on the contrary, the lack of international barriers is not seen as a critical barrier. Governmental design restrictions and permitting and ownership and control of the model are one of the least rated barriers with a mean value of 3.47 for each. Lastly, interviewees mostly agreed that ownership and control over the BIM

model are not as critical barriers as the remaining barriers in the category for Turkish modular construction companies. As a result, this category contains the highest-ranked barriers for Türkiye compared to other categories, and the participants' rates in these obstacles are quite close to each other.

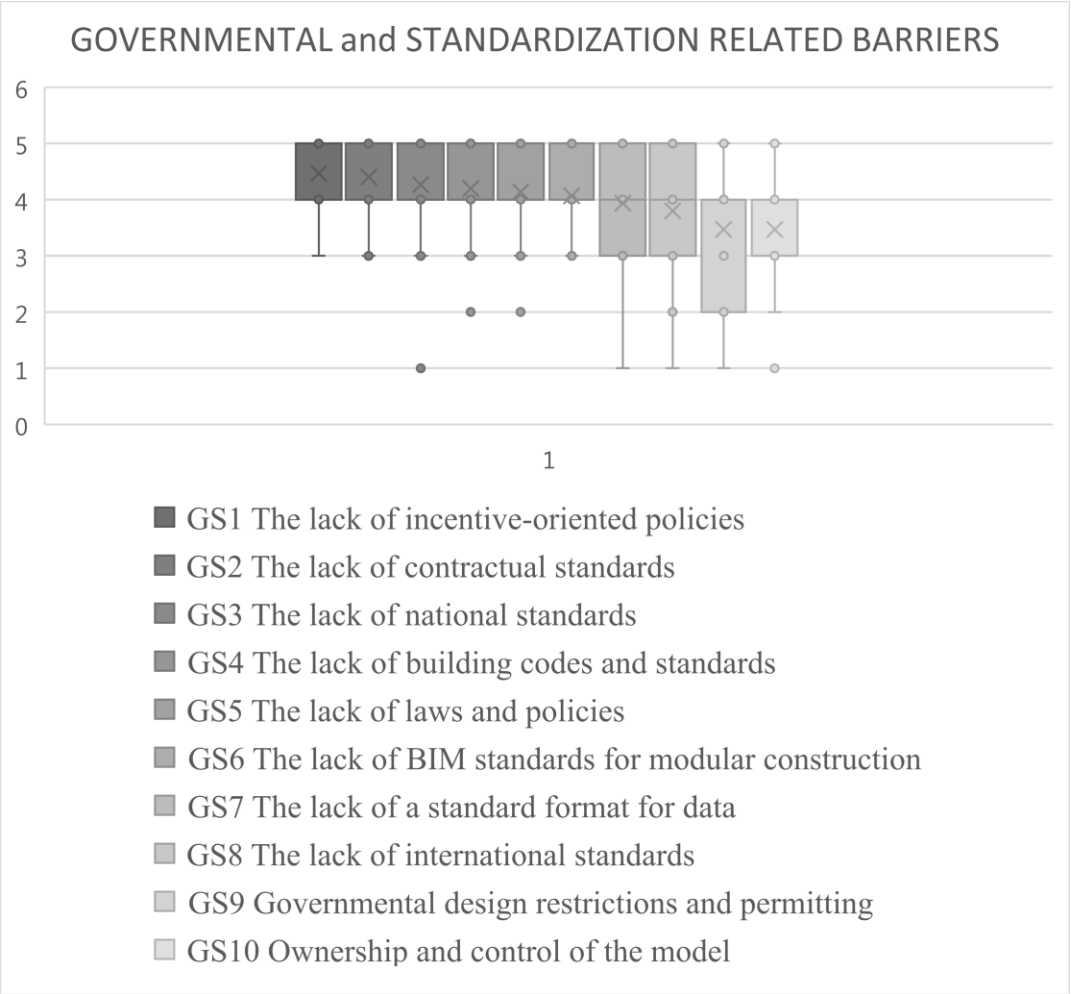


Figure 4.17 Governmental & Standardization-Related Barriers to BIM-MC Integration

4.1.4.6 External Environment-Related Barriers

The external environment-related barriers category refers to 3 barriers lack of market demand, the lack of related academic research, and geographic location as shown in Figure 4.18. The category is the least barrier-containing. In this category, the lack of market demand is seen as the most critical barrier with a mean value of 4.20, whereas geographic location does not create any barrier to BIM integration of Turkish modular construction. The geographic location is the most rejected barrier of all categories with a mean value of 1.87 and with high consistency among the respondents. The barrier of the lack of academic research was rated average by participants. While some participants believe that there is sufficient research on the subject, others state there should be more studies by academia to improve the BIM-MC integration.

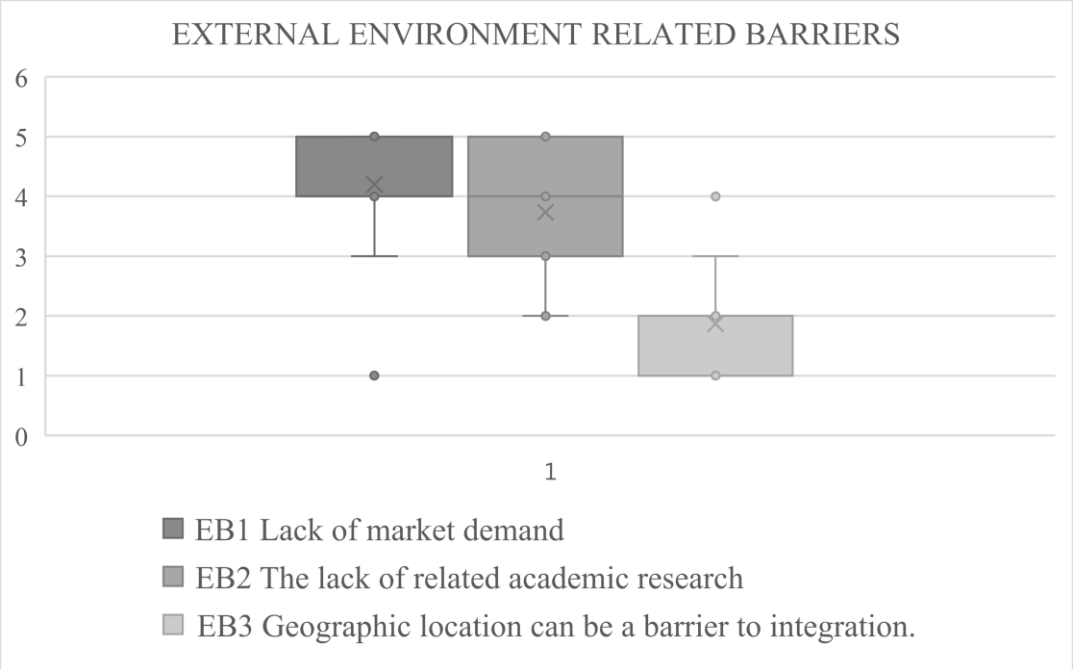


Figure 4.18 External Environment-Related Barriers to BIM-MC Integration

4.1.4.7 Knowledge & Experience-Related Barriers

The external environment-related barriers category contains 7 barriers that are related to the need for highly qualified and experienced human resources as indicated in Figure 4.19. In the category of the trained labor need, lack of know-how data about BIM-MC integration and the need for high technical knowledge are the most critical barriers while unclear BIM benefits are seen as least critical. It can be concluded that most of the interviewees believe that the benefits of BIM are so clear that they do not constitute a crucial barrier to BIM-MC integration.

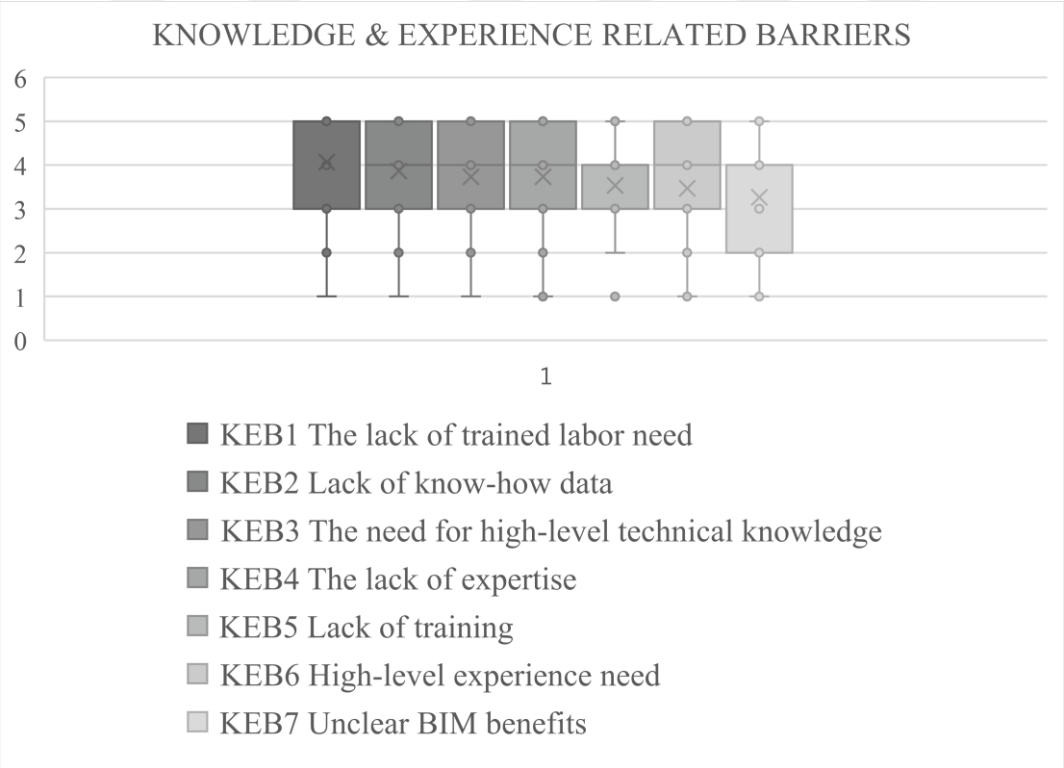


Figure 4.19 Knowledge& Experience-Related Barriers to BIM-MC Integration

4.1.4.8 Cost-Related Barriers

The last category is category cost-related barriers which contains 8 barriers as illustrated in Figure 4.20. In literature, mostly BIM-related costs are studied as a barrier to BIM-MC integration. Similarly, the interviewees rated BIM adaptation cost and BIM tool cost as the most critical cost barriers. On the other hand, transportation costs are not scaled as one of the critical barriers for Türkiye mostly because of its geographic location. BIM tool cost is also an important barrier for Türkiye according to the participants. The reason for the barrier is mainly because of the exchange rate difference and not having a local BIM tool in Türkiye.

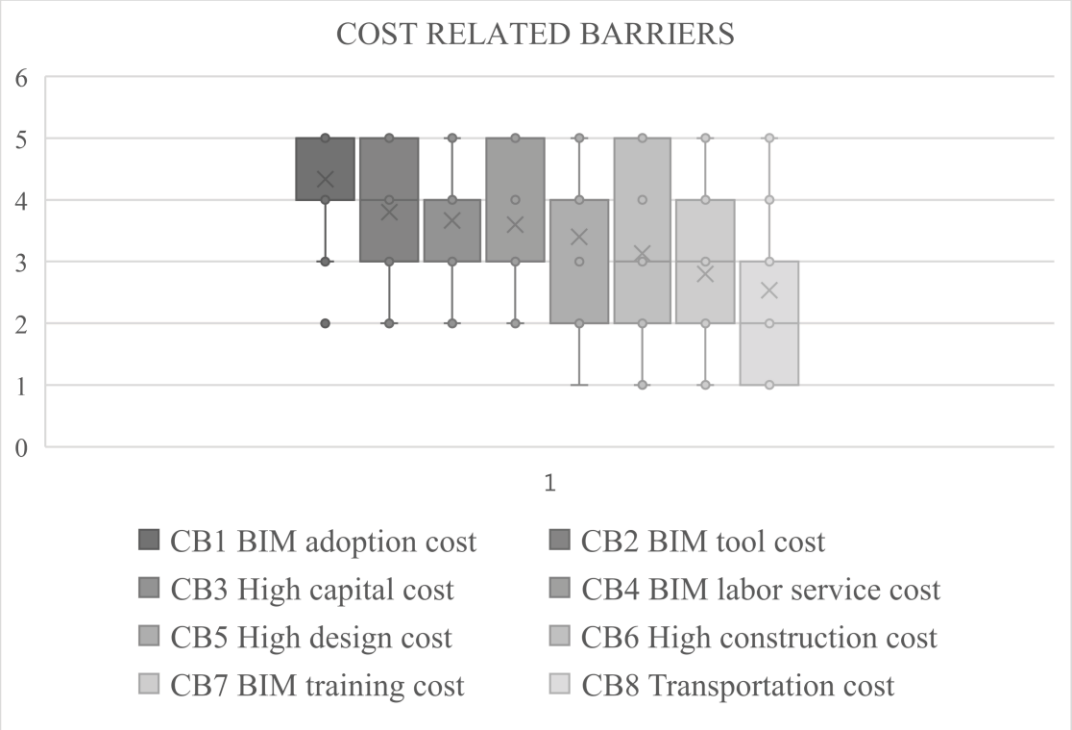


Figure 4.20 Cost-Related Barriers to BIM-MC Integration

When all eight categories are compared with each other, the behavioral barrier category is ranked as the most significant category for Turkish modular construction. As can be seen in the box plot below in Figure 4.21, the more participants agreed upon the categories, the mean value is getting higher. This means their rates for specific barrier categories are usually closer to each other and when they are high.

The behavioral barriers are followed by governmental and standardization-related barriers which also over a mean value of four. These two categories include more critical barriers compared to other groups when their mean value averages are taken into consideration. Organizational and knowledge & experience-related barriers were also identified as critical by the participants, although their mean values were lower than 4. Design and cost-related barriers are considered less critical categories with mean values around 3.5. Furthermore, Software-related barriers and external environment-related barriers are seen as the least critical categories. The software-related barriers are ranked with less consistency compared to the external environment-related barriers category.

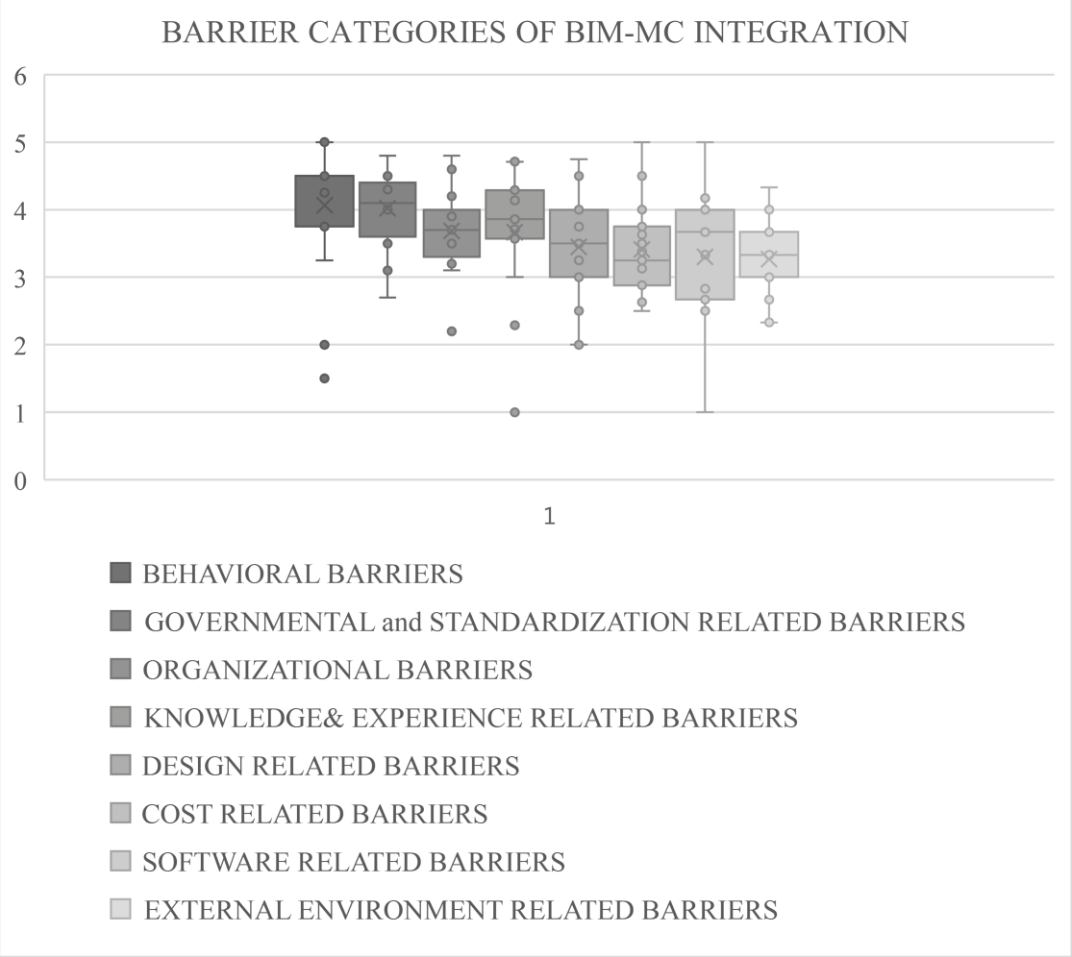


Figure 4.21 Barrier Categories of BIM-MC Integration

4.1.5 Key Advantages of BIM-MC Integration

The advantages of BIM-MC integration are a broadly studied subject in the literature as explored clearly during the literature review process. As one of the objectives of the study is to make clear the key advantages of the integration for Türkiye, 3 questions were asked during the interview about the advantages.

The first question is to determine key advantages by scaling the advantages listed in the literature review according to their applicability for Türkiye. The 74 advantages in 8 categories were gathered from literature scaled by the experts as shown in the Findings section under the heading of 4.1.3 Advantages of BIM-MC Integration for Türkiye. The bar chart in Figure 4.22 below presents the mean values of all the rated advantages applied for Türkiye. According to the chart, participants mainly agree that all the 74 advantages in the 8 categories apply to the Turkish modular construction sector as they all rated over the mean value of 4 except 3 of them. One of these 3 least-rated advantages is DA15-Reducing the drawing amount with a mean value of 3.73 in the design and visualization category. The advantages of reducing the amount of drawing are followed by CA7- Decreasing installation costs and SA6-Improving crane management with the mean value of 3,87 for each. Despite these 3, all the other 71 advantages are rated over the mean value of four.

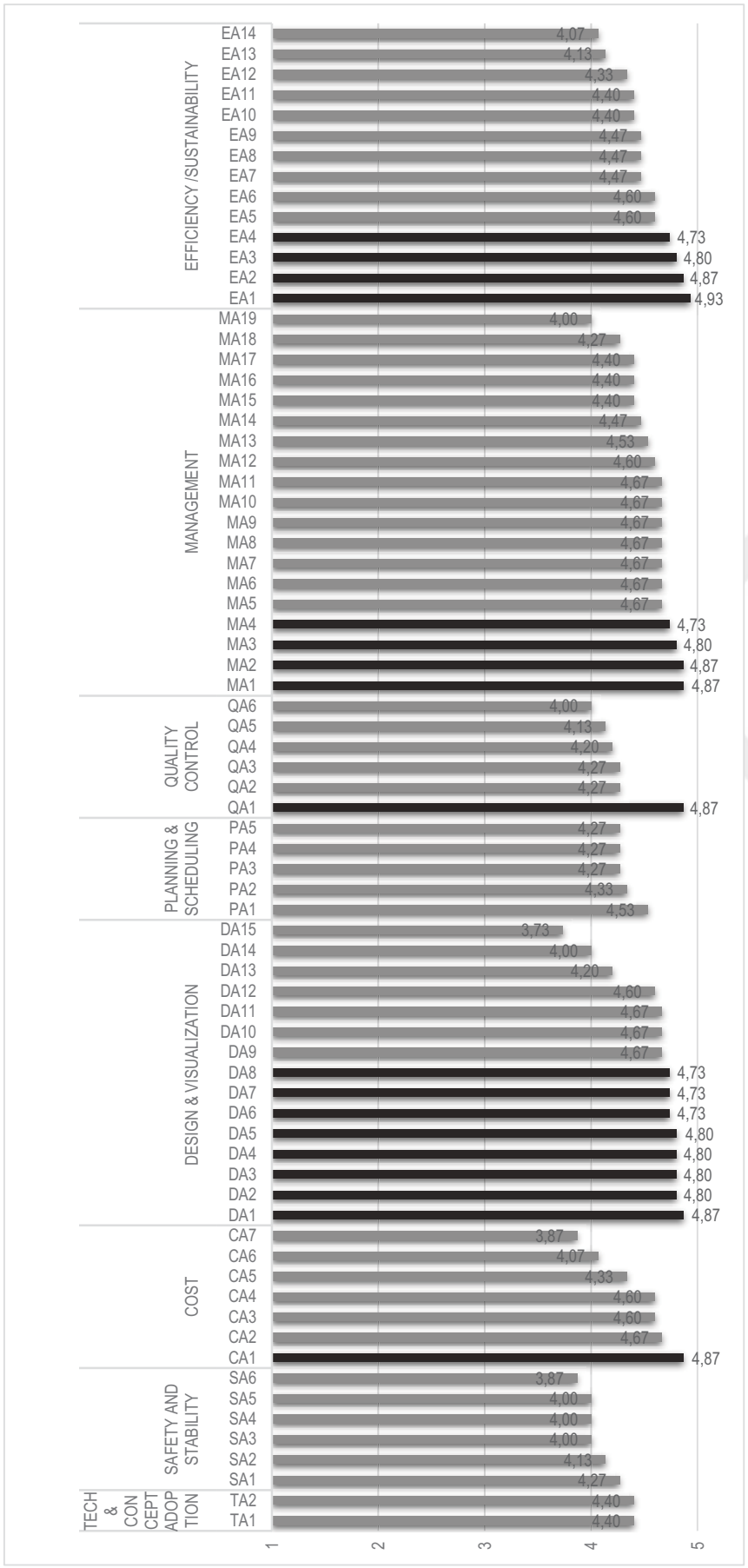


Figure 4.22 Advantage rates of BIM-MC Integration for Turkiye

As a result of the first question, 18 advantages were selected which are shown in black bars in Figure 4.21 above. These key advantages were selected by choosing the most rated 20% of total advantages. This accounts for 15 out of a total of 74 advantages. Additionally, the 16th, 17th, and 18th-ranked advantages, which are equivalent to the mean value of the 15th advantage, were also included in the selection process. Therefore, 18 advantages were selected as key in the first phase. These are listed in Table 4.14 below, starting with the highest mean value.

Table 4.14 1st Selection of BIM-MC Integration Advantages

No	1st Selection of BIM-MC Integration Advantages
1	EA1 Providing repetitive work and mass production
2	CA1: Providing effective cost management
3	DA1: Providing walkthrough animations
4	QA1: Enhancing process monitoring and progress control
5	MA1: Providing transparent data structure
6	MA2: Providing effective construction information sharing
7	EA2: Decreasing human error
8	DA2: Reducing design errors
9	DA3: Providing quick responses to design changes
10	DA4: Improving simulation
11	DA5: Providing control over interference and clash detection
12	MA3: Improving information management and integration
13	EA3: Automating life cycle assessment
14	DA6: Optimizing design
15	DA7: Providing strong technical drawings
16	DA8: Allowing the creation of complex building geometries in 3D
17	MA4: Providing reliable information
18	EA4: Increasing efficiency in the construction

The second question aimed to determine whether there were additional advantages that were not included among the 74 advantages. As indicated in Table 4.15, eight experts answered this question as there is no additional advantage. However, two

experts argued that BIM-MC integration would bring a systematic approach as an additional advantage. It is stated that BIM enhances efficiency by systematizing the whole sector of modular construction. Another expert's opinion is that BIM-MC integration is a means for advancement in building technology and progress in professionals' capacity. According to the experts, the more professional intelligence the fewer conflicts and fewer losses can be achieved thanks to this integration. Similarly, one of the other experts states that integration increases the worker's motivation and design vision to create more distinctive designs. Thus, increasing the qualification of professionals can be stated as a second additional advantage.

Table 4.15 Additional advantages suggested by experts.

No of expert	Additional BIM-MC Integration Advantages
3 experts	developing a culture of systematic approach
2 experts	increasing the qualification of professionals
1 expert	ending the nonregulated sub-contractor system
1 expert	providing competitive advantages
8 experts	no additional advantage

In the third question, the participants were asked what the biggest advantage of BIM-MC integration could be for Turkish modular construction. The answers are shown in Table 4.16 below. The first interviewee's answer is developing a culture of systematic approach. According to the interviewee, the biggest deficiency in Türkiye is to think and act systematically. Therefore, the systematic approach that BIM brings is the biggest advantage, especially for Türkiye. The interviewee gives an example of the success of the UK in terms of BIM integration which mainly takes its source from their systematic approach. The second interviewee claims that truly complex structures have started to be built with modular methods, therefore the biggest advantage of BIM is its 3D complex model creation ability. In contrast to 2D drawings, the 3D model provides the prediction for conflicts in electrical and mechanical installations, increases fabrication, and minimizes uncontrolled work to

be done in the field. According to the third expert, the biggest advantage is reducing design errors by increasing automation as indicated in the list of advantages gathered from the literature. Similarly, the fourth and fifth experts believe the biggest advantage is enhancing design and reducing design workload by allowing rapid drawing changes in 3D models. The sixth expert believes mass production support is the biggest advantage of BIM in modular construction, while the seventh one believes in developing a culture of systematic and transparent construction processes likewise one of the previous answers. The eight expert's unique analysis of the biggest BIM-MC advantage is to end the non-regulated sub-contracting system in Türkiye, non-educated construction workers, non-qualified contractors, and unsafe working conditions. Both the ninth and tenth experts' answers are to provide effective cost management for such a country where financial predictability is very low. The eleventh expert's answer is creating a technological ecosystem is the biggest advantage because there is a data management need in Türkiye. The expert also states that the integration provides a competitive advantage for Turkish companies in the international market. Similarly, the twelfth expert believes providing competitive advantages for international projects is the biggest advantage especially projects conducted for developed countries in which BIM use is mandatory. The thirteenth experts' opinion on the question is giving a change of control for all processes of construction and production. The fourteenth one claims cost-effectiveness is the biggest advantage thanks to knowing material quantity, decreasing waste, technology integration, and independence from human and human error. The last participant's answer is systematic and organized processes of construction. As a result, 3 of the above-mentioned advantages are additional advantages that are not included in the literature review result. They are developing a systematic approach, ending the nonregulated sub-contractor system, and providing competitive advantages.

Table 4.16 The biggest BIM-MC advantage according to the experts

Experts	The biggest BIM-MC advantage according to the experts
1st expert	developing a culture of systematic approach
2nd expert	3D complex model creation ability
3rd expert	reducing design errors by increasing automation
4th expert	rapid drawing changes in 3D models
5th expert	quick responses to design changes
6th expert	mass production support
7th expert	developing a culture of systematic and transparent construction processes
8th expert	Ending the non-regulated sub-contracting system in Türkiye
9th expert	effective cost management
10th expert	providing effective cost management
11th expert	creating a technological ecosystem
12th expert	providing competitive advantages for national and international projects
13th expert	change of control for all processes of construction and production
14th expert	cost-effectiveness
15th expert	systematic and organized processes of construction

When all the answers to the three questions were synthesized, the 23 most mentioned key advantages were defined for the Turkish modular construction sector. In the 3 questions, 15 experts provide their answers about the key advantages, and these advantages are listed by frequency of mention in these answers. 19 of the 23 advantages are from already defined advantages in the literature, while 4 of them are additional advantages that are valid for only Türkiye. The 23 key advantages are listed in Table 4.17 below. Coded ones are from literature, remainings are additional advantages.

Table 4.17 Key Advantages of BIM-MC Integration for Türkiye

No		Key Advantages of BIM-MC Integration for Türkiye	Frequency
1	AC1	Providing effective cost management	4
2		Developing a culture of systematic approach	4
3	AD3	Providing quick responses to design changes	3
4	AE1	Providing repetitive work and mass production	2
5	AQ1	Enhancing process monitoring and progress control	2
6	AD2	Reducing design errors	2
7	AD8	Allowing the creation of complex building geometries in 3D	2
8		Providing competitive advantages nationally and internationally	2
9		Ending the non-regulated sub-contracting system in Türkiye	2
10	AD1	Providing walkthrough animations	1
11	AM1	Providing a transparent data structure	1
12	AM2	Providing effective construction information sharing	1
13	AE2	Decreasing human error	1
14	AD4	Improving simulation	1
15	AD5	Providing control over interference and clash detection	1
16	AM3	Improving information management and integration	1
17	AE3	Automating life cycle assessment	1
18	AD6	Optimizing design	1
19	AD7	Providing strong technical drawings	1
20	AM4	Providing reliable information	1
21	AE4	Increasing efficiency in the construction	1
22		Increasing the qualification of professionals	1
23	TA1	Creating a technological ecosystem / Technology integration	1

4.1.6 Critical Barriers to BIM-MC Integration for Türkiye

The barriers to BIM-MC integration have been extensively studied and explored for various countries as indicated in the literature review chapter. One of the objectives of the study is to identify the critical barriers to BIM implementation in the Turkish modular construction sector. To achieve this goal, three questions were asked during the interviews about the barriers to BIM-MC integration.

The first question was about scaling 53 barriers gathered from literature according to their applicability to Türkiye. The 53 barriers in 8 categories scaled by the expert as shown in the Findings section under the heading of 4.1.4 Barriers to BIM-MC Integration for Türkiye. The bar chart below, shown in Figure 4.23, demonstrates the mean value distributions of each barrier with the categories that they belong to. Based on the chart, interviewees agreed that the total 53 barriers are mostly valid for the Turkish modular construction sector except for the geographic location barrier whose value is 1.83. Interviewees believed that geographic location is not a barrier for Türkiye. The other four barriers rated below the mean value of 3 are the complexity of connection, software storage limitation, transportation cost, and BIM training cost. They are not seen as critical barriers affecting the BIM-MC integration. Whereas, according to the respondents, the lack of incentive-oriented policies is the most critical barrier which is rated at 4.47. Resistance to change, non-BIM-user subcontractors, the lack of standards, lack of market demand, and high BIM adaptation costs are among the most rated barriers by the experts.

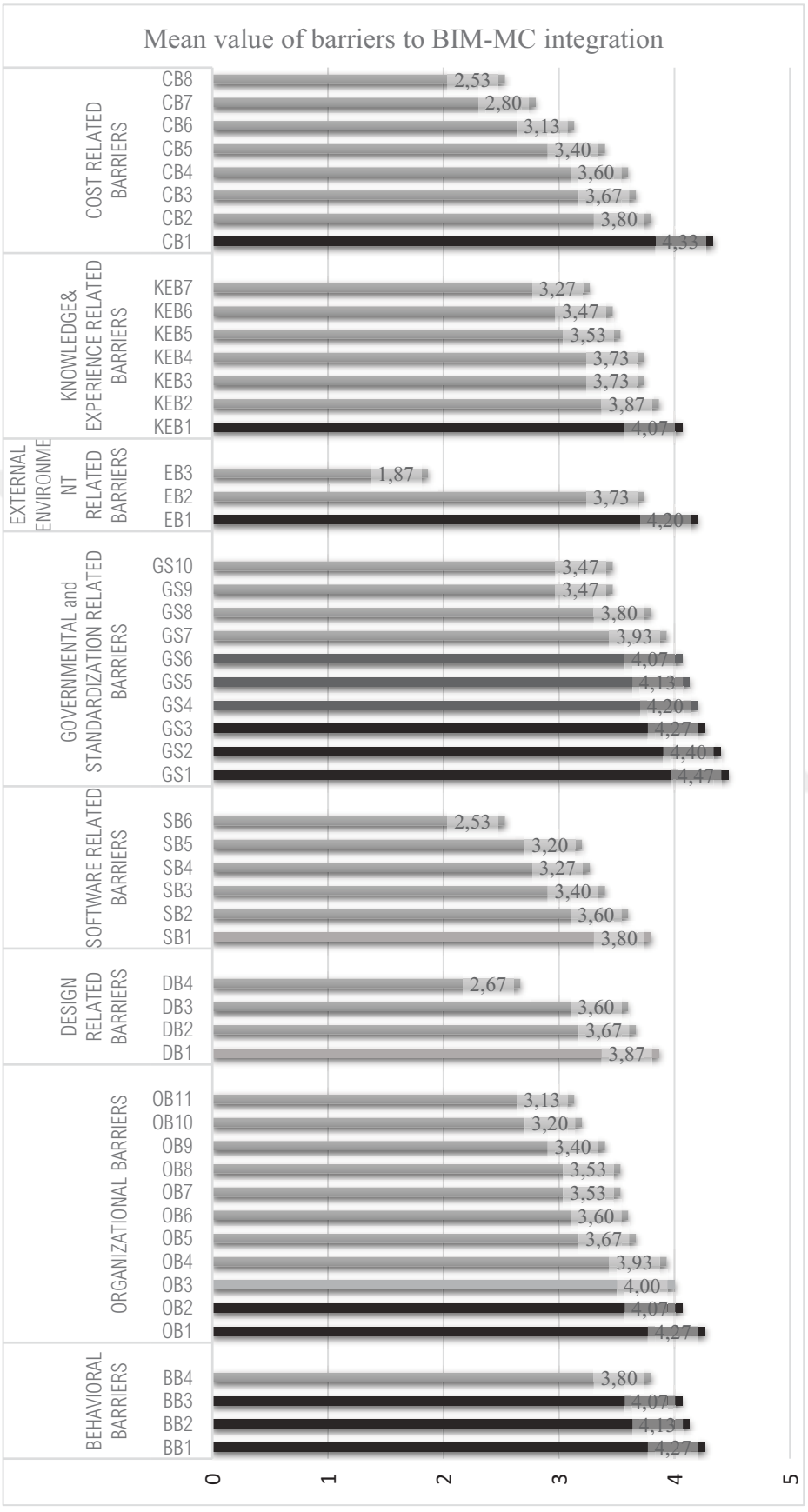


Figure 4.23 Mean value of barriers to BIM-MC integration

As a result of the first question, 14 critical barriers were selected which are shown in black bars in Figure 4.23 above. These barriers were selected by choosing the most rated 20% of total barriers. This accounts for 11 out of a total of 53 barriers. Additionally, the 12th, 13th, and 14th-ranked barriers, which are equivalent to the mean value of the 11th barrier, were also included in the selection process. Therefore, 14 barriers were selected as key in the first phase. These barriers are listed in Table 4.18 below, starting with the highest mean value.

Table 4.18 1st Selection of BIM-MC Integration Barriers

No	1st Selection of BIM-MC Integration Barriers
1	GS1: The lack of incentive-oriented policies
2	GS2: The lack of contractual standards
3	CB1: BIM adoption cost
4	BB1: Resistance to change
5	OB1: Non-BIM-user subcontractors
6	GS3: The lack of national standards
7	GS4: The lack of building codes and standards
8	EB1: Lack of market demand
9	BB2: Owners' perception
10	GS5: The lack of laws and policies
11	BB3: Executives' perception
12	OB2: Uncertainty of demand and supply
13	GS6: The lack of BIM standards for modular construction
14	KEB1: The lack of trained labor

The second question asked in the interview was about the barriers that the company of the experts encounters when trying to adopt BIM, whether they are overcome or not. The answers to the encountered barriers by the experts from the companies are listed in Table 4.19 below.

Table 4.19 Barriers encountered by the companies.

Companies	**Barriers encountered by the companies**
Company A	Resistance to change
	Software limitations for MC companies especially for the production process
	Lack of qualified human resources
	Lack of market and owner demand
	Executives' perception
	BIM software and training costs
	Time and effort needed for the BIM implementation process
	Unclear BIM benefits for company workers.
Company B	The time needed to implement BIM
	Current human resources are not qualified for BIM
	The high initial cost of BIM implementation
	Unclear BIM benefits for executives
	Resistance to change
	Non-BIM-user sub-contractors
	High BIM tool cost
Company C	Need for transparent information sharing
	Active collaboration between disciplines and parties
	Need for the time to be invested in design
	Lack of market demand
	Resistance to change
	Lack of incentive-oriented policies

Experts from Company A answered the questions as resistance to change, software limitation for modular companies especially for the production process, lack of qualified human resources, lack of market and owner demand, executives' perception, BIM software and training costs, time and effort needed for BIM implementation process and unclear BIM benefits for company workers. The company had a previous attempt to adapt BIM, and its second attempt is still ongoing. One of the biggest barriers to this company is resistance to change. The company director explains this barrier; "*People have habits, and to change these habits, everyone must believe that they will benefit from this change. In the BIM implementation process, the BIM users in the company are separated into 2 groups; those who enter the data into the system and those who use the data. The first group that enters the data into the system receives less benefit and spends more time and effort compared to the traditional method. Therefore, it is difficult to convince the first group. On the other hand, the other group gets more benefits by spending less time. General efficiency is mentioned; this efficiency is valid for the company; however, the situation differs in its sub-components. This was one of the biggest challenges that we encountered*." According to the director, the strategy to overcome the barrier was to educate its employees and explain to them the advantages of BIM. It is stated that people cannot be forced to change from top to bottom, and therefore the company selected the path of trying to explain the benefits of this application to people through training. To speed up the persuasion process of people, it was preferred that the training be given by an external consultant company specialized in BIM. Although this training was beneficial for the company at first, the high motivation of the employees decreased over time due to the integration flow taking time and being interrupted from time to time. The director also explains the software limitation that they encounter: "*Software infrastructures are not inclusive for the manufacturing process in the modular construction sector. Current BIM tools offer AEC packages, but when manufacturing is involved, it needs to be taken one step further and production design needs to be added to these packages. Therefore, the inadequacy of software tools created an obstacle in the integration process of our*

company. Since this disrupted the integration process, the necessary BIM benefit could not be achieved. Therefore, problems with the information flow at the point, where construction and manufacturing meet in the software environment, constitute an obstacle to the modular construction sector." The director also stated that their search and research continue for a smooth flow of implementation to overcome software limitation problems.

According to the experts from Company B, the encountered barriers are the time needed to implement BIM, current human resources not qualified for BIM, the high initial cost of BIM implementation, unclear BIM benefits for executives, resistance to change, non-BIM-user sub-contractors, and high BIM tool cost. According to the managers of the company, the barriers explained; *"Speed is very important for us as a modular construction company. Time is one of the most important competitive advantages compared to other means of construction. When we try to adapt to BIM, we need to create a whole new library and we need to work on the hard process while none of our current employees are qualified in BIM. On the other hand, the current traditional system is well established and readily works fast compared to the creation of a whole new system. Furthermore, from the point of workers' view, they couldn't spare time to develop their BIM qualification because of their busy work schedule*."

Company C experts believe that the need for transparent information sharing and active collaboration between disciplines and parties as well as the need for the time to be invested in design works before beginning the construction process are the barriers that the company encounters. To overcome these barriers, the company did not select to work with a consultant company to take training about BIM. Instead, they work with an architectural office that provides BIM services. The director of the company states that "*Working with an architectural design office that provides BIM service is the effective strategy to implement BIM for modular construction companies. I believe all architectural offices should advance their BIM system and provide it as an architectural service because they are not only responsible for designing function or appearance, but they should also design the whole system. BIM*

and modular construction require distinct professions, and two of them are broad subjects. Therefore, advancing in both would not be as successful as separating them". According to the director's opinion, thanks to getting a BIM service from an architectural office, they could increase their BIM use level in a very short time. Additionally, lack of market demand and lack of incentive-oriented policies are the barriers that the company experts state.

When comparing these 3 different companies, the barrier of time and effort needed for the BIM implementation process are valid for all 3 companies. While 2 of them are trying to overcome the barrier via training or searching for other strategies like taking consultancy, company C works with an architectural office that provides total BIM service. Therefore, Company A and Company B experience resistance to change barriers, on the contrary, Company C is not facing such a problem similar to the barrier of lack of qualified human resources. Both companies A and B are challenged with high BIM implementation costs and High BIM tool costs similarly Company C is facing the lack of incentive-oriented policies barrier because of the high implementation cost of BIM. Company A and Company C indicated the lack of market and owner demand is also a barrier to providing BIM implementation.

The third question asked during the interview is to choose 3 of the most critical barriers to BIM-MC integration for Türkiye. The answers to the questions are listed according to their frequency in Table 4.20 below. It can be observed that resistance to change and high BIM adaptation costs are the most mentioned critical barriers. The barrier of the lack of demand by the market and project owner is the third most mentioned barrier. The lack of national BIM standards is also a frequently mentioned barrier similar to not having a sufficient contractual standard in Türkiye. According to two of the experts, the current bidding and subcontracting system in Türkiye is problematic, and the situation causes a critical barrier. There are also critical barriers related to the lack of national and local BIM-related sources. For example, the lack of domestic tools leads to the use of imported BIM tools, which are quite expensive for a country like Türkiye. Similarly, the language restriction of Turkish people is also causing a critical barrier because of not having local tools or insufficiency of

BIM-related documents in Turkish. Consequently, a lack of BIM knowledge is mentioned as a critical barrier. Another critical barrier is the time constraints of modular constructions. The BIM implementation process needs considerable time and effort according to the experts. Thus, time constraints and increased design workload of workers with BIM cause barriers to implementation.

Table 4.20 The most critical barriers selected by experts.

Frequency	Barriers
7	Resistance to change
7	High BIM adaptation cost
6	Lack of demand by market and project owner
5	Lack of qualified human resource
4	Lack of governmental rule and regulation
3	Lack of BIM national standard
2	Current bidding and subcontracting system
2	BIM tool cost
2	Executives' perception
2	Lack of BIM knowledge, and confusion about BIM tools and BIM.
1	Not having a systematic approach in Türkiye
1	Lack of software integration
1	Time constraints of modular construction
1	Unrealistic expectations of Turkish companies from their employees, which is to implement BIM while maintaining existing workloads with traditional methods.
1	Language restriction of Turkish people to use BIM tools and to advance their knowledge via sources from other languages

When all the answers to the three questions are synthesized, 25 critical barriers are defined for the Turkish modular construction sector in below Table 4.22. In the 3 questions, 15 experts provided their answers about the scaling existing barriers from literature, the most critical 3 barriers, and the barriers that they encountered while trying to implement BIM. Their answers to all 3 questions were combined and listed according to the frequency of mention in these answers. Consequently, resistance to change, BIM adoption cost, lack of market demand, and lack of trained labor /qualified human resources are placed at the top of the critical barriers list. While 21 of the critical barriers are studied in the literature as indicated in the list in the literature section, 4 of them are additional barriers that are just valid for the Turkish modular construction sector. The additional barriers are current bidding and subcontracting systems, not having a systematic approach in Türkiye, and language restrictions of Turkish people to use BIM tools or BIM documents in a foreign language. Lastly, unrealistic expectations of Turkish companies from their employees cause a barrier, which is to implement BIM while maintaining existing workloads with traditional methods.

Table 4.21 Critical Barriers to BIM-MC Integration for Türkiye

No		Critical Barriers to BIM-MC Integration for Türkiye	Frequency
1	BB1	Resistance to change	11
2	CB1	BIM adoption cost	9
3	EB1	Lack of market demand	9
4	KEB1	The lack of trained labor /qualified human resource	8
5	GS5	The lack of laws and policies/rules and regulation	5
6	GS3	The lack of national standards	4
7	BB3	Executives' perception /	4
8	CB2	BIM tool cost	4
9	OB7	Time constraints of MC / The time needed to implement BIM	4
10	GS1	The lack of incentive-oriented policies	2
11	OB1	Non-BIM-user subcontractors	2
12	KEB7	Unclear BIM benefits for executives and company workers	2
13		Current bidding and subcontracting system in Turkiye	2
14	KEB3	Lack of BIM knowledge/confusion about BIM tools and BIM	2
15	SB3	Lack of software integration/ Software limitations for MC especially for the production process	2
16	GS2	The lack of contractual standards	1
17	GS4	The lack of building codes and standards	1
18	BB2	Owners' perception	1
19	OB2	Uncertainty of demand and supply	1
20	GS6	The lack of BIM standards for modular construction	1
21		Not having a systematic approach in Türkiye	1
22		Unrealistic expectations of Turkish companies from their employees, which is to implement BIM while maintaining existing workloads with traditional methods	1
23		Language restriction of Turkish people to use BIM tools and to advance their knowledge via sources from other languages	1
24	OB5	Need for transparent information sharing	1
25	OB9	Lack of active collaboration between disciplines and parties	1

4.1.7 Stakeholders' Responsibilities for BIM-MC Integration

One of the objectives of the study is to find the stakeholders responsible for BIM-MC integration and define what are the responsibilities of these stakeholders. The following steps were applied to meet the objective.

Firstly, the seven stakeholders mentioned in the literature were presented to interviewees and they were asked to scale the stakeholders' responsibilities. As shown in Figure 4.24 below, the results clearly show that the most responsible stakeholder is the government with almost a hundred percent agreement among the interviewees. The responsibilities of the design companies and the construction companies are the same and they are rated over the mean value of 4 and with high agreement of interviewees. Although the consensus among the interviewees is not high for these two stakeholders, the project owner and academics are scaled as responsible with a mean value close to 4. The responsibility of software companies in this regard was rated low compared to other stakeholders but it was still responsible with a mean value higher than 3. On the other hand, the end-users are rated with a 2.4 mean value which is the least one with very low consistency among the participants.



Figure 4.24 Stakeholders' Responsibility Rates for BIM-MC Integration

Secondly, to define strategies and actions that can be taken to increase the integration of BIM-MC by stakeholders, interviewees were asked to interpret stakeholders' responsibilities and suggest additional stakeholders, if any. It is aimed to help define strategies and actions that can be taken to increase the integration of BIM-MC.

According to almost all interviewees, the government should set strict rules and regulations and should strictly follow the application of these rules. BIM use should be mandatory, especially starting from public projects to private ones. Additionally, incentive-oriented policies should be strictly applied by the government. Building legislation and building codes should be defined clearly. Furthermore, one of the participants stated that the government should follow the new technologies and apply the advancements in its system to catch up with the development of a strong economy.

The second most responsible stakeholder is design companies. According to one of the interviewees, because design companies are the starting point of all processes, they are responsible for BIM implementation, and showing the implementation can apply to Türkiye. In other words, they are responsible for creating a positive perception of BIM-MC integration. According to the remaining respondents, they are not only responsible for designing the functions or appearance but also designing the whole system, not only designing the building but designing how it's going to be built and used. They can give priority to modular methods in their design and plan the lean concept integration for modular construction.

Construction companies share second place with design companies in terms of their responsibilities. Many of the answers are the same as design companies because most modular construction firms incorporate both design and construction processes.

Project owners are the following responsible stakeholders. They must be imposed BIM use in contracts according to almost all interviewees. One of the suggestions for project owners is to leave aside the goal of constructing the cheapest building, aiming to build a building with less waste, more benefits, a longer lifespan, and a high second-hand value.

The fifth responsible stakeholder is academia. According to responses, the academy should prepare BIM tools and methods. Without having any commercial pressure, they can create more effectively. Additionally, in terms of human resources, they have a huge responsibility. They should collaborate with the industry, contact professionals from the sector, and invite them for workshops, lectures, etc. Thus, the gap between academy and practice can be closed in time. Instead of remaining theoretical, it can make practical applications in cooperation with companies. Moreover, the academy and R&D departments of the company should work together. Lectures for students and training for professionals can be provided by them.

The next responsible stakeholder is software companies. According to the experts, they should provide tools specifically for production design, awareness should be raised about the benefits of integration as a marketing strategy. They need to increase communication between BIM tools. IFC is unwieldy, and there should be innovative solutions for this. There could also be a need for brand-new BIM software that is developed for modular construction which meets the special demand of it. Not only a matter of forcing companies to pay for the software but of helping them realize what they can achieve with the proper use of their software. They should be more involved in universities and commercial companies and should educate the young. Thus, they should not just think about money, they also should work to make BIM tools widespread.

The least responsible stakeholder was chosen as the end-user by the interviewees. Their only responsibility is to raise their awareness and demand the quality of structures that they use.

Lastly, the attendants were asked to ask additional stakeholders who are responsible for BIM-MC integration. One of the answers is Professional Chambers. They can increase the awareness of architects and engineers. Another answer is people who work in the modular construction sector. They increase their awareness about integration. The more they develop their knowledge, the more integration can be provided and enhanced. The last stakeholder suggested by the experts is non-

governmental organizations. They can contribute to increasing awareness about the BIM-MC integration when its efficiency and sustainability advantages are taken into consideration. Platforms, events, and training can be set up to enhance knowledge about the subject.

To conclude, with the seven stakeholders defined in the literature and three additional stakeholders suggested by participants, there are ten stakeholders in total. The government is the most accountable stakeholder, with a responsibility rate of 18%. Design and construction companies share equal responsibility, both with a rate of 15%. Project owners and academic institutions have similar levels of responsibility, with percentages of 14.75 and 14.50, respectively. Meanwhile, software companies and end users have the least responsibility, with rates of 13% and 9%, respectively. In addition to them, professional chambers, people who work in the modular construction sector, and non-governmental organizations were indicated as responsible for enhancing the BIM-MC integration in Türkiye.

4.2 Discussion

This section includes an explanation and interpretation of the interview findings by comparing them with literature sources. Starting from the key advantages, critical barriers to BIM-MC integration and the responsibilities of the stakeholders were discussed, respectively.

One of the objectives of the study was to find the advantages of BIM-MC integration and to select the key ones valid for Türkiye among these advantages. For this purpose, 23 key advantages were identified. One of the most studied advantages in the literature is the technology adaptation opportunity that BIM brings to the modular structure. Because it collects various kinds of building information, BIM serves as the main data source for the application of recent technologies or concepts such as blockchain, IoT, RFID, Construction 4.0, lean construction, and DfMA. However, according to the findings, there are more mentioned advantages than technology and

concept integration for Türkiye. According to the analysis result, the most rated key advantages are providing repetitive work and mass production and increasing efficiency in construction. One of the similarities between the literature and the study results is related to the advantages of design and management processes. In the literature, these two advantage categories are the most studied ones after the technology-related advantages. Similarly, according to the findings of the study, design-related advantages are the most rated ones, followed by management-related advantages. In addition to the defined advantages mentioned in the literature, four more advantages of BIM-MC integration were detected as a result of the study. These are developing a culture of a systematic approach, increasing the qualification of professionals, ending the nonregulated subcontractor system, and providing competitive advantages. As a result, the study propounds the current BIM-MC integration advantages and presents their applicability rates for the Turkish construction sector while detecting the additional advantages of the integration. While there have been numerous studies on the potential benefits of integrating BIM and MC, the actual advantages of BIM remain unclear. This lack of clarity presents a significant challenge to the advancement of integration (Ghalenoei et al., 2022). Thus, to overcome the barriers to BIM-MC integration, it is important to clearly define which benefits are applicable and identify new ones.

In the study, the second objective is to identify the critical barriers to BIM-MC integration, and 25 critical barriers are defined as a result of the analyses. The study identifies the first critical barrier as resistance to change. All the companies selected for the study had encountered this barrier, according to most experts. Generally, resistance to change can represent a significant challenge to the successful implementation of BIM-MC integration, as stated in the literature (Chen et al., 2018). Moreover, Wu et al. (2021) mention another behavioral barrier, which is the negative attitudes of owners and executives toward BIM-MC integration, and state that it has a crucial impact on implementation. Turkish experts also evaluate the perception barrier of executives as high and define it as critical. Barriers related to cost, collaboration, and software are some of the most studied categories in literature as

well, along with a lack of knowledge and experience. One of the cost-related barriers is the high capital cost of adaptations to BIM (Sun et al., 2020). The study finds that these barriers are highly applicable to Turkish modular construction companies as well. The Turkish experts rate the introduced following barriers as critical: BIM tool cost, lack of BIM knowledge, lack of software integration, and the BIM tool cost. Another critical barrier is related to the government which is highly mentioned in both literature and the study results. According to Xu et al. (2023), insufficient legislation, policies, and incentives are among the key hindrances associated with government involvement. These barriers were also rated as critical barriers by the experts who participated in the interview of the study. In addition to the defined barriers mentioned in the literature, the study finds additional barriers to BIM-MC integration. These barriers are current bidding and subcontracting systems, not having a systematic approach in Türkiye, language restrictions for Turkish people to use BIM tools or BIM documents in a foreign language, and unrealistic expectations of Turkish companies from their employees, which is to implement BIM while maintaining existing workloads with traditional methods. As a result, the study reveals the barriers to current BIM-MC integration, identifies additional barriers to integration, and provides validity rates for the Turkish construction industry.

As previously mentioned, numerous key advantages and critical barriers have been identified in the existing literature, primarily through studies conducted in developed countries, with a few exceptions. There is a lack of BIM-MC integration studies conducted in developing countries, making this study unique in that it was conducted in a developing country. However, a similar study was conducted for Malaysia, which falls into the developing country category. Muhammad et al. (2022) outline the main benefits, hindering factors, and enabling factors of Design for Manufacturing and Assembly (DfMA) and its integration with BIM. The findings of these two studies are somewhat comparable. In the Malaysian study, some of the factors hindering the implementation of DfMA are similar to the critical barriers identified in this study, including challenges such as awareness, acceptance, cost, contractual issues, integration, and standardization. Conversely, while Türkiye does

not face logistical issues, it is cited as a hindrance in Malaysia. Although these two studies share a focus on the same subject, there are notable differences between them. Unlike this study, the Malaysian sample was conducted based on the DfMA principle and solely relied on literature results. The Malaysian study did not offer additional barriers or benefits, and the methodologies used in the two studies differ, with the Malaysian example lacking expert opinions and a section on relevant stakeholders and their responsibilities.

As the third objective of the study, stakeholders' responsibility for the integration of BIM-MC in Türkiye was defined. Although there are several studies related to barriers to BIM-MC integration, few of them consider the stakeholders' responsibility for the integration. For instance, Xu et. al. (2023) studied barriers to BIM-MC integration in China from the stakeholder's perspective. The study starts with 28 initial barriers collected through a literature review and 7 stakeholders. When their interaction was examined 5 critical barriers were identified with associated stakeholders. The findings of the study, the seven stakeholders, and their responsibilities were in parallel with the study conducted by Xu et. al (2021). Both in the literature and the study, stakeholders' responsibilities were defined as similar. The government should set strict rules and regulations and should strictly follow the application of these rules. Design companies and construction companies because design companies are the starting point of all processes, thus, they are responsible for BIM implementation. Project owners are the following responsible stakeholders in demanding integration strictly. The academy should prepare BIM tools and methods and guide the integration. The remaining stakeholders mentioned in the literature are software companies and end-users are also similar. Different from the literature, some additional stakeholders are responsible for BIM-MC integration, according to the findings of the study; Professional Chambers, people who work in the modular construction sector, and non-governmental organizations.

CHAPTER 5

CONCLUSION

This chapter includes an overview presentation of the study together with the contribution of the study discussion. Lastly, the limitations of the study are explained with recommendations.

5.1 Study Overview

The construction sector has been slower than other sectors in adopting new technologies, which has prevented it from achieving the desired level of sustainability and efficiency. To address this issue, the concept of Construction 4.0 was proposed, inspired by the principles of Industry 4.0. This approach aims to overcome challenges such as uncertainty, fragmented management, short-term thinking, and complex projects in the field of construction. The three pillars of Construction 4.0 are industrialization (prefabrication), digital ecosystem (BIM), and new materials. These pillars aim to optimize the construction process, improve project efficiency, and enhance the overall quality of construction. This study aims to promote the industrialization and digitization of construction by fostering the transformation of the digital ecosystem through the study of BIM in modular construction.

Research has shown that integrating MC-BIM can significantly improve the construction industry. However, more research is needed to identify the main advantages and challenges of BIM implementation in modular construction, and how to overcome them. The study aims to address these gaps by exploring the benefits and barriers of BIM-MC integration, proposing strategies to tackle them, and identifying the key stakeholders involved. To achieve these goals, the study followed several steps. First, a systematic literature review was conducted to gather the latest

information on BIM-MC integration. This review identified the common advantages, barriers, and implementation strategies of BIM for modular buildings. Based on these findings, closed and open-ended interview questions were developed to explore BIM usage levels, applicability rates, and stakeholder responsibilities. The open-ended questions aimed to uncover the key advantages and critical barriers to BIM-MC integration, as well as the strategies and responsibilities needed to enhance the integration. One-to-one interviews were then conducted with experts from selected modular construction companies. The findings of the study include a summary of the key advantages, critical barriers, and strategies for BIM-MC integration in Türkiye, as well as the stakeholders' responsibilities in promoting this integration.

In the literature review section, the advantages were grouped into twenty categories based on their common subjects. These categories include design, cost, visualization, and time-related advantages. Using these organized lists, interviews were conducted, and the interviewees provided their interpretations of the categorized advantages. The table organization was then updated and condensed based on the interviewees' feedback. As a result, the advantages were reorganized into eight main groups for this study. These groups are technology and concept integration-related advantages, safety and stability-related advantages, cost-related advantages, design and visualization-related advantages, planning and scheduling-related advantages, quality control-related advantages, management-related advantages, and efficiency and sustainability-related advantages. The participants were asked to rate the validity of these advantages for the Turkish modular construction industry. The majority of the 15 participants agreed that all 74 advantages in the eight categories apply to the Turkish modular construction industry. When comparing the categories, design and visualization-related advantages were found to be the most applicable category for Turkish modular construction. The second most highly rated categories were management-related advantages, and efficiency and sustainability-related advantages, while the least rated categories were safety and stability-related advantages, quality control-related advantages, and planning and scheduling-related advantages, respectively. Cost-related advantages and technology and concept

integration advantages fell in the middle of the eight categories based on participants' ratings. To be able to define the key advantages of BIM-MC integration in Türkiye, the 18 most rated advantages from the literature, 4 additional advantages suggested by experts, and the biggest advantage opinions of the experts were synthesized. As a result, the 23 most mentioned key advantages were defined for the Turkish modular construction sector. 19 of them are already defined advantages in the literature, while 4 of them are additional advantages that are valid only for Türkiye.

The study aims to pinpoint the obstacles to BIM implementation in the modular construction sector in Türkiye. To attain this objective, the interviewees were asked three questions regarding the barriers to BIM-MC integration. The initial question focused on scaling 54 barriers obtained from literature and determining their relevance to Türkiye. The expert categorized these 54 barriers into eight categories, with the behavioral barrier category ranked as the most significant for the Turkish modular construction industry. Following the behavioral barriers, governmental and standardization-related barriers were ranked as the second highest in terms of significance. Participants also identified organizational and knowledge & experience-related barriers as critical. Additionally, design and cost-related barriers, software-related barriers, and external environment-related barriers were considered the least critical categories. The second question asked the experts about the obstacles their company faces when attempting to adopt BIM, while the third question required them to select three critical barriers to BIM-MC integration in Türkiye. Upon synthesizing the responses to the three questions, a total of 25 significant barriers have been identified for the modular construction sector in Türkiye. It is noteworthy that 21 of these barriers have been previously documented in the literature, as outlined in the literature section. The remaining 4 barriers are unique to the Turkish modular construction sector and have been identified through this study.

One of the last objectives of this study is to identify the stakeholders responsible for integrating BIM-MC and define their respective responsibilities. To achieve this, a series of steps were taken. Firstly, the seven stakeholders identified in the literature

were presented to interviewees, who were then asked to rank their responsibilities. Secondly, interviewees were asked to identify any additional stakeholders and their respective responsibilities. As a result, ten stakeholders were identified, including the original seven and three additional stakeholders suggested by participants. The government was found to be the most accountable stakeholder, with a responsibility rate of 18%. Design and construction companies shared equal responsibility, both with a rate of 15%. Project owners and academic institutions had similar levels of responsibility, with percentages of 14.75 and 14.50, respectively. Meanwhile, software companies and end users were found to have the least responsibility, with rates of 13% and 9%, respectively. In addition to these stakeholders, interviewees also identified professional chambers, individuals working in the modular construction sector, and non-governmental organizations as being responsible for enhancing BIM-MC integration in Türkiye.

5.2 Contribution of the Study

There are three main contributions of the study. The first one is the key advantages of BIM-MC integration for Türkiye. The second one is critical barriers to BIM-MC Integration for Türkiye. The last one is the stakeholders responsible for overcoming the barriers to BIM-MC Integration and their responsibilities.

Firstly, the study has identified 23 key advantages of integrating Building Information Modelling (BIM) and modular construction (MC) for Türkiye. They are respectively providing effective cost management, developing a culture of systematic approach, providing quick responses to design changes, providing repetitive work and mass production, enhancing process monitoring and progress control, reducing design errors, allowing the creation of complex building geometries in 3D, providing competitive advantages nationally and internationally, ending the non-regulated sub-contracting system in Türkiye, providing walkthrough animations, providing a transparent data structure, providing effective construction information sharing, decreasing human error, improving simulation, providing

control over interference and clash detection, improving information management and integration, automating life cycle assessment, optimizing design, providing strong technical drawings, providing reliable information, increasing efficiency in the construction, increasing the qualification of professionals, creating a technological ecosystem / technology integration.

Secondly, according to the study findings, 25 critical barriers to BIM-MC Integration for Türkiye were found. They are respectively resistance to change, BIM adoption cost, lack of market demand, the lack qualified human resource, the lack of laws and policies, the lack of national standards, executives' perception, BIM tool cost, time constraints of MC and the time needed to implement BIM, the lack of incentive-oriented policies, non-BIM-user subcontractors, unclear BIM benefits for executives and company workers, current bidding and subcontracting system in Türkiye, lack of BIM knowledge, lack of software integration and software limitations for MC especially for the production process, the lack of contractual standards, the lack of building codes and standards, owners' perception, uncertainty of demand and supply, the lack of BIM standards for modular construction, not having a systematic approach in Türkiye, unrealistic expectations of Turkish companies from their employees, which is to implement BIM while maintaining existing workloads with traditional methods, language restriction of turkish people to use BIM tools and to advance their knowledge via sources from other languages, need for transparent information sharing, lack of active collaboration between disciplines and parties.

Lastly, 10 stakeholders have been identified as responsible for overcoming the barriers to BIM-MC Integration. These stakeholders are the government, design companies, construction companies, project owners, academia, software companies, end-users, professional chambers, people who work in the modular construction sector, and non-governmental organizations. Each stakeholder has a specific responsibility to ensure that BIM-MC Integration is successful. The government is responsible for setting strict rules and regulations and ensuring that they are strictly followed. Design and construction companies are responsible for BIM implementation and demonstrating how the implementation can be applied in

Türkiye. Project owners must enforce the use of BIM in contracts. Academia should prepare BIM tools and methods. Software companies should provide tools specifically for production design, and awareness should be raised about the benefits of integration as a marketing strategy. End-users only need to raise their awareness and demand quality. Professional Chambers can increase the awareness of architects and engineers. People who work in the modular construction sector can increase their knowledge about integration. Non-governmental organizations can set up platforms, events, and training to enhance knowledge about the subject.

As a result, in addition to 23 key advantages, 25 critical barriers and 10 responsible stakeholders, one of the primary contributions of this research is its potential to impact not only Türkiye but also other developing nations or countries with comparable construction practices.

5.3 Practical Implementation of the Study

In light of the findings obtained above, the practical implementation of this study is on three main issues. First, this study aims to eliminate doubts about the advantages of BIM implementation thanks to the identified advantages. There is a general uncertainty in the industry about the advantages of using BIM in modular structures. This uncertainty is even more prevalent in the modular construction sector in Türkiye, which has just started to implement BIM. The study both compiled the BIM-MC integration advantages studied in the literature and revealed additional advantages valid only for Türkiye. Moreover, it was determined which of these advantages were of greater importance for Türkiye and the 23 advantages mentioned above were listed. Thus, it is aimed to eliminate the doubts of companies that want to implement BIM. It has been explained that the BIM application will not only provide improvements in design but also in all processes of construction, from production to administrative processes, integration of new technologies, occupational health and safety, and logistics processes.

Secondly, the study identified the barriers that may be encountered during the integration of BIM applications in modular structures. These barriers are intended to be a guide for companies that want to realize this integration in practice. If these companies can foresee the obstacles, they are likely to encounter during the integration process, they can take the necessary precautions and plan developments in these areas. This not only prevents the integration from being interrupted but also prevents the integration from being abandoned due to difficulties in the process. For the same purpose, the study also briefly included what obstacles Türkiye's three modular construction companies intending to implement BIM encountered in the process and what strategies they developed to overcome these barriers. One of the most important contributions of the research is that it reveals how resistance to change is a critical barrier. Companies try to increase awareness of their human resources about the benefits of the integration so that they can break this resistance. Similarly, the high initial investment cost and the fact that the market demand has not yet formed at a sufficient level have also been analyzed as important factors.

Finally, the study also revealed how to identify all stakeholders with responsibilities to strengthen BIM-MC integration, prioritize these stakeholders, and what their responsibilities are. For example, for Türkiye, it has been revealed that the biggest responsibility in this context falls on the state, and the biggest barrier is the lack of governmental rule and regulation and the lack of incentive-oriented policies. By revealing those responsible and their responsibilities, a resource has been created that not only companies but also relevant stakeholders can benefit from to improve this integration. As a result, with the combination of all three contributions, it was intended to provide the necessary sources for enhancing the BIM-MC to be used by both companies and other stakeholders such as academia, government, and software companies.

5.4 Limitations and Future Works

There were a few limitations to this study, including the fact that only three modular construction companies from Türkiye were interviewed as a focus group and the experts were limited to those from these companies. Additionally, a survey was not conducted, particularly for closed-ended interview questions, although the questions could be presented in a survey format to the experts. The study could benefit from a larger sample size of more informed participants to yield more efficient results. Lastly, having participants from different stakeholder groups would provide the opportunity to evaluate barriers and enablers from various perspectives.

As a recommendation for future studies, it would be beneficial to explore the correlations between BIM implementation barriers in Türkiye's modular construction sector using an interpretive structural modeling approach. This would allow for statistical analysis of the barriers to BIM-MC integration. Additionally, the roles and responsibilities of BIM-MC integration stakeholders could be studied from their perspective, with participants from various stakeholder groups providing valuable insights into barriers and enablers.

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APPENDICES

A. Research Voluntary Participation Form

VOLUNTARY PARTICIPATION FORM

(ARAŞTIRMAYA GÖNÜLLÜ KATILIM FORMU)

This research study is being conducted by Burcu Atakul, a graduate student in the Department of Civil Engineering at Middle East Technical University. This form is designed to inform you about the research conditions and your role as a participant.

(Bu araştırma, Orta Doğu Teknik Üniversitesi İnşaat Mühendisliği Bölümü yüksek lisans öğrencisi Burcu Atakul tarafından yürütülen bir çalışmadır. Bu form sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.)

Purpose of the Study

(Çalışmanın Amacı Nedir?)

The study aims to ensure and strengthen the integration of the "Building Information Modelling (BIM)" system, which allows modeling all building-related information in a digital environment, with modular/prefabricated construction companies in Türkiye. For this purpose, qualitative research will be conducted, including a systematic literature review and expert interviews with practitioners in the Turkish modular construction industry. The resulting analysis will identify the advantages of BIM-MC integration and the barriers to effective BIM implementation and will provide potential implementation strategies to overcome these barriers.

(Çalışma Türkiye'deki modüler/prefabrik inşaat firmalarının, yapıya ait tüm bilgilerin dijital ortamda modellenmesini sağlayan "Yapı Bilgi Modellemesi (YBM-BIM)" sistemi ile entegrasyonunu sağlamayı ve güçlendirmeyi amaçlamaktadır. Bu amaçla, çalışmada sistematik bir literatür taraması ve Türk modüler inşaat endüstrisi uygulayıcılarıyla yapılan uzman görüşmelerini içeren nitel bir araştırma gerçekleştirilecektir. Ortaya çıkacak olan analiz, BIM-MC entegrasyonunun avantajlarını ve BIM'in etkili bir şekilde uygulanmasının önündeki engelleri belirleyecek ve bu engelleri aşmak için potansiyel uygulama stratejilerini sunacaktır.)

Your Contribution

(Bize Nasıl Yardımcı Olmanızı İsteyeceğiz?)

If you agree to participate in the research, you are expected to answer a series of questions on a rating scale in the survey and briefly answer 6 open-ended questions. Participation in this study takes an average of 1 hour.

(Araştırmaya katılmayı kabul ederseniz, sizden beklenen, ankette yer alan bir dizi soruyu derecelendirme ölçeği üzerinde yanıtlamanız ve 6 adet açık uçlu soruyu kısaca cevaplandırmanızdır. Bu çalışmaya katılım ortalama olarak 1 saat sürmektedir.)

Data Usage

(Sizden Topladığımız Bilgileri Nasıl Kullanacağız?)

Your participation in the research should be completely voluntary. No identificatiın or institution-identifying information will be requested from you during the interview. Your answers will be kept completely confidential and will only be evaluated by the researchers. The information obtained from the participants will be evaluated in aggregate and used in scientific publications. The data you provide will not be matched with the identification information collected in the voluntary participation forms.

(Araştırmaya katılımınız tamamen gönüllülük temelinde olmalıdır. Mülakatta, sizden kimlik veya kurum belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamamıyla gizli tutulacak, sadece araştırmacılar tarafından değerlendirilecektir. Katılımcılardan elde edilecek bilgiler toplu halde değerlendirilecek ve bilimsel yayımlarda kullanılacaktır. Sağladığınız veriler gönüllü katılım formlarında toplanan kimlik bilgileri ile eşleştirilmeyecektir.)

What you need to know about your participation

(Katılımınızla ilgili bilmeniz gerekenler)

The study does not involve any risks beyond those that may be encountered in everyday life. It only contains questions about sectoral knowledge. If you feel uncomfortable with the questions or for any other reason during your participation, you are free to stop answering. In such a case, it will be sufficient to inform the person conducting the study that you wish to withdraw from the study. At the end of the study, your questions regarding the research will be answered. The study contributes to examining the current state of the subject in the literature.

(Çalışma günlük hayatta karşılaşılması muhtemel olağan risklerin ötesinde bir risk içermemektedir. Yalnızca sektörel bilgi soruları içermektedir. Katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakmakta serbestsiniz. Böyle bir durumda çalışmayı uygulayan kişiye, çalışmadan çıkmak istediğinizi söylemek yeterli

olacaktır. Çalışma sonunda, bu araştırmayla ilgili sorularınız cevaplanacaktır. Çalışma söz konusu araştırma konusunun literatürdeki güncel durumunu inceleme katkısı sunmaktadır.)

Contact Information

(Araştırmayla ilgili daha fazla bilgi almak isterseniz)

Thank you for participating in this study. For more information about the study, please contact Burcu Atakul, M.Sc., Graduate Student, Department of Civil Engineering, Middle East Technical University. Email: burcu.atakul@metu.edu.tr

(Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Araştırma hakkında daha fazla bilgi almak için Orta Doğu Teknik Üniversitesi İnşaat Mühendisliği Bölümü yüksek lisans öğrencisi Burcu Atakul ile (E-posta: burcu.atakul@metu.edu.tr) ile iletişim kurabilirsiniz.)

I have read the information above and I agree to participate in this study completely voluntarily.

(Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.)

Please return the completed and signed form to the interviewer.

(Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz)

Name Surname *(İsim Soyad)* Date *(Tarih)* Signature *(İmza)*

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B. Interview Questions

PART 1: GENERAL INFORMATION OF THE INTERVIEWEE

(BÖLÜM 1: GÖRÜŞÜLEN KİŞİ HAKKINDA GENEL BİLGİLER)

-What is your major? *(Bölümünüz nedir?)*

- Architect *(Mimar)*
- Civil Engineer *(İnşaat Mühendisi)*
- Mechanical Engineer *(Makine Mühendisi)*
- Electric/Electronic Engineer *(Elektrik/Elektronik Mühendisi)*
- Industrial Engineer *(Endüstri Mühendisi)*
- Computer/Software Engineer*(Bilgisayar/Yazılım Mühendisi)*
- Other: *(Diğer)*

- What is your highest level of education? *(Eğitim Durumunuz)*

- Associate degree *(Ön Lisans)*
- Bachelor's degree *(Lisans)*
- Master *(Yüksek Lisans)*
- PHD *(Doktora)*
- Other: *(Diğer)*

- What is your position in the company? *(Şirketteki pozisyonunuz nedir?)*

- How many years have you been working in this position? *(Kaç yıldır bu pozisyonda çalışıyorsunuz?)*
  - 1-5
  - 5-10
  - 10-15
  - 15-20
  - 20+
- How many years of experience do you have in the construction sector? *(İnşaat sektöründe kaç yıllık deneyiminiz var?)*
  - 1-5
  - 5-10
  - 10-15
  - 15-20
  - 20+
- How many years of experience do you have in the modular construction sector? *(Modüler inşaat sektöründe kaç yıllık deneyiminiz var?)*
  - 1-5
  - 5-10
  - 10-15
  - 15-20
  - 20+

- How many years of experience do you have in BIM? *(BIM konusunda kaç yıllık deneyiminiz var?)*
    - ☐ 1-5
    - ☐ 5-10
    - ☐ 10-15
    - ☐ 15-20
    - ☐ 20+

PART 2: GENERAL INFORMATION OF THE COMPANY

(BÖLÜM 2: ŞİRKET HAKKINDA GENEL BİLGİLER)

- Name of the company (optional)? *Şirketin adı (isteğe bağlı)*
- How many years has your company been in the modular construction business? *(Şirketiniz modüler inşaat sektöründe kaç yıldır faaliyet gösteriyor?)*
    - ☐ 1-5
    - ☐ 5-10
    - ☐ 10-15
    - ☐ 15-30
    - ☐ 30+
- How many projects does it have in its portfolio? *(Şirketin portföyünde kaç proje var?)*
    - ☐ 1-10
    - ☐ 10-50
    - ☐ 100-250
    - ☐ 250-500
    - ☐ 500+
- Number of personnel in this company? *(Şirkette kaç çalışan var?)*
    - ☐ 1-50
    - ☐ 50-100
    - ☐ 100-250
    - ☐ 250-500
    - ☐ 500+
- Number of labors in this company? *(Şirkette kaç işçi var?)*
    - ☐ 1-100
    - ☐ 100-500
    - ☐ 500-1000
    - ☐ 1000-2000
    - ☐ 2000+

PART 3: INTERVIEW QUESTIONS

(BÖLÜM 3: MÜLAKAT SORULARI)

1. Do you believe BIM is advantageous for Turkish modular construction? *(BIM'in Türkiye'deki modüler inşaat için avantajlı olduğunu düşünüyor musunuz?)*
2. In which construction phase does your company use BIM effectively? Please rate your answers below. *(Şirketiniz BIM'i hangi inşaat aşamasında etkili bir şekilde kullanıyor? Lütfen aşağıdaki tabloda oranlayarak cevaplayın.)*

	MC PHASES / BIM USE LEVEL *MODÜLER INŞAAT AŞAMALARI / BIM KULLANIM ORANI*	**0%**	**25%**	**50%**	**75%**	**100%**
1	Predesign And Visualization Phase *Ön Tasarım ve Görselleştirme Aşaması*					
2	Proposal Phase *Teklif Aşaması*					
3	Design Phase *Tasarım Aşaması*					
4	Preconstruction Phase *İnşaat Öncesi Aşaması*					
5	Site Survey Phase *Saha Araştırması Aşaması*					
6	Site Preparation Phase *Saha Hazırlık Aşaması*					
7	Off-Site Construction Phase *Saha Dışı İnşaat Aşaması*					
8	Delivery Phase *Teslimat Aşaması*					
9	Installation Phase *Kurulum Aşaması*					
10	Handover Phase *Devir Aşaması*					
11	Operation & Maintenance Phase *İşletme & Bakım Aşaması*					
12	Demolition Phase *Yıkım Aşaması*					

3. The advantages of BIM-MC integration from the literature are listed below. Do you agree that these advantages are valid for the Turkish modular construction sector? Kindly choose from 1 to 5. (1 is for strongly disagree and 5 for strongly agree.) *Literatürde BIM-Mİ entegrasyonunun avantajları aşağıda listelenmiştir. Bu avantajların Türkiye modüler inşaat sektörü için geçerli olduğunu düşünüyor musunuz? Lütfen 1 ile 5 arasında işaretleme yapınız. (1 hiç katılmamak, 5 şiddetle katılmak anlamına gelir.)*

ADVANTAGES *AVANTAJLAR*	**Subcategories** ***Alt Kategoriler***	**1**	**2**	**3**	**4**	**5**
TECHNOLOGY ADAPTATION *TEKNOLOJİ ADAPTASYONU*	BIM can be used as a data source for new technology adaptation for modular construction such as (IoT, Blockchain, VR, AI, Big data) *BIM modüler inşaatta yeni teknoloji adaptasyonu (IoT, Blockchain, VR, AI, Big data) için bir veri kaynağı olarak kullanılabilir.*					
CONCEPT INTEGRATION *KONSEPT ENTEGRASYONU*	BIM can be used as a data source for new concept adaptation for modular construction such as (lean construction, and construction 4.0, DfMA) *BIM, modüler inşaatta yeni konsept adaptasyonu (lean construction, inşaat 4.0, DfMA gibi) için bir veri kaynağı olarak kullanılabilir.*					
SAFETY *GÜVENLİK*	The integration reduced safety risks and improved safety management. *Entegrasyon, güvenlik risklerini azaltır ve güvenlik yönetimini geliştirir.*					
	The integration improved crane management. *Entegrasyon, vinç yönetimini geliştirir.*					
	The integration detects dangerous behaviors in construction sites and potential workspace conflicts. *Entegrasyon, şantiyelerdeki tehlikeli davranışları ve potansiyel çalışma alanı uyuşmazlıklarını tespit eder.*					
	The integration provides staff training and improves worker safety. *Entegrasyon, personel eğitimi sağlar ve işçi güvenliğini artırır.*					
STRUCTURAL STABILITY *YAPISAL SAĞLAMLIK*	The integration improves structural stability. *Entegrasyon, yapısal sağlamlığı artırır.*					
	The integration provides structural health monitoring. *Entegrasyon, yapısal sağlık takibi sağlar.*					
	The integration provides structural analysis. *Entegrasyon, yapısal analiz sağlar.*					
COST *MALİYET*	The integration provides effective cost management. *Entegrasyon, efektif maliyet yönetimi sağlar.*					
	The integration provides financial advantages. *Entegrasyon, finansal avantajlar sağlar.*					
	The integration decreases labor costs. *Entegrasyon, işçilik maliyetlerini düşürür.*					
	The integration decreases design/redesign costs. *Entegrasyon, tasarım/yeniden tasarım maliyetlerini düşürür.*					
	The integration decreases construction costs. *Entegrasyon, inşaat maliyetlerini düşürür.*					
	The integration decreases installation costs. *Entegrasyon, kurulum maliyetlerini düşürür.*					

	The integration provides cost prediction. *Entegrasyon, maliyet tahmini sağlar.*					
ROBOTIC MANUFACTURE *ROBOTİK ÜRETİM*	The integration paves the way for robotic manufacturing. *Entegrasyon, robotik üretim için zemin hazırlar.*					
VISUALIZATION *GÖRSELLEŞTİRME*	The integration improves simulation. *Entegrasyon simülasyonu geliştirir.*					
	The integration can change the public perception of modular construction. *Entegrasyon, toplumların modüler inşaat algısını değiştirebilir.*					
	The integration enhances visualization in design and construction. *Entegrasyon, tasarım ve inşaatta görselleştirmeyi geliştirir.*					
	The integration provides control over interference and detects clashes. *Entegrasyon, çakışmaların kontrolünü ve tespitini sağlar.*					
PROGRESS MONITORING *SÜREÇ TAKİBİ*	The integration enhances process monitoring and progress control. *Entegrasyon, süreç takibi ve ilerleme kontrolünü geliştirir.*					
DESIGN *TASARIM*	The integration optimizes design. *Entegrasyon tasarımı optimize eder.*					
	The integration reduces design errors. *Entegrasyon, tasarım hatalarını azaltır.*					
	The integration improves buildings' spatial relevance and artistic quality. *Entegrasyon, binaların mekansal uyumluluk düzeyini ve sanatsal kalitesini artırır.*					
	The integration reduces the drawing amount. *Entegrasyon, çizim miktarını azaltır.*					
	The integration avoids 2D design problems. *Entegrasyon, 2 boyutlu tasarım sorununu ortadan kaldırır.*					
	The integration provides strong technical drawings. *Entegrasyon, güçlü teknik çizimler sağlar.*					
	The integration provides quick responses to design changes. *Entegrasyon, tasarım değişikliklerine hızlı yanıtlar verir.*					
	The integration allows the creation of complex building geometries in 3D. *Entegrasyon, karmaşık bina geometrilerinin 3D olarak oluşturulmasına olanak tanır.*					
	The integration enhances the HVAC design. *Entegrasyon, Isıtma, Havalandırma ve İklimlendirme (HVAC) tasarımını geliştirir.*					

	The integration creates automatic design alternatives and diverse design options. *Entegrasyon, otomatik tasarım alternatifleri ve çeşitli tasarım seçenekleri oluşturur.*					
	The integration provides walkthrough animations. *Entegrasyon, gezinme animasyonları sağlar.*					
PLANNING & SCHEDULING *PLANLAMA & PROGRAMLAMA*	The integration enables automated planning & scheduling. *Entegrasyon, otomatik planlama ve programlama sağlar.*					
	The integration enables assembly sequencing planning. *Entegrasyon, montaj sırası planlamasını sağlar.*					
	The integration provides planning and scheduling simulations. *Entegrasyon, planlama ve programlama simülasyonları sağlar.*					
QUALITY CONTROL *KALİTE KONTROL*	The integration provides quality control of prefabricated components. *Entegrasyon, prefabrik elemanların kalite kontrolünü sağlar.*					
	The integration provides an automated compatibility check. *Entegrasyon, otomatik uyumluluk kontrolü sağlar.*					
	The integration improves tolerance control. *Entegrasyon, tolerans kontrolünü geliştirir.*					
	The integration provides effective rectification rate of project quality problems. *Entegrasyon, proje kalitesi sorunlarının etkili düzeltme oranını sağlar.*					
TIME *ZAMAN*	The integration saves time by shortened design and construction period. *Entegrasyon, kısalan tasarım ve inşaat süresi ile zamandan tasarruf sağlar.*					
	The integration gives a chance to rapid construction in case of emergency (ex: Covid hospital) *Entegrasyon, acil durumda (örneğin: Covid hastanesi) hızlı inşaata olanak tanır.*					
COLLOBORATION *İŞBİRLİĞİ*	The integration enhances collaboration. *Entegrasyon, işbirliğini artırır.*					
	The integration provides effective construction information sharing. *Entegrasyon, inşaat bilgilerinin etkin bir şekilde paylaşılmasını sağlar.*					
OPTIMIZATION *OPTİMİZASYON*	The integration improves optimization. *Entegrasyon optimizasyonu geliştirir.*					
	The integration provides carbon footprint and optimization *Entegrasyon, karbon ayak izi ve optimizasyon sağlar.*					
	The integration provides construction cost optimization *Entegrasyon inşaat maliyeti optimizasyonu sağlar.*					
	The integration enhances design optimization. *Entegrasyon tasarım optimizasyonunu geliştirir.*					

MANAGEMENT *YÖNETİM*	The integration improves system security *Entegrasyon sistem güvenliğini artırır.*					
	The integration improves information management and integration. *Entegrasyon, bilgi yönetimini ve entegrasyonunu geliştirir.*					
	The integration improves risk management. *Entegrasyon, risk yönetimini geliştirir.*					
	The integration provides systematic management. *Entegrasyon, sistematik yönetim sağlar.*					
	The integration improves inventory management *Entegrasyon, envanter yönetimini geliştirir.*					
	The integration provides effective decision-making. *Entegrasyon, etkili karar verme sağlar.*					
	The integration improves life cycle management *Entegrasyon, yaşam döngüsü yönetimini geliştirir.*					
	The integration enhances automated life cycle assessment. *Entegrasyon, otomatik yaşam döngüsü değerlendirmesini arttırır.*					
EFFICIENCY /SUSTAINABILITY *VERİMLİLİK / SÜRDÜRÜLEBİLİRLİK*	The integration increases efficiency in the construction *Entegrasyon, inşaatta verimliliği artırır.*					
	The integration increases sustainability in the construction *Entegrasyon, inşaatta sürdürülebilirliği artırır.*					
	The integration enables the reuse of modular structural components *Entegrasyon, modüler yapısal bileşenlerin yeniden kullanımına olanak tanır.*					
	The integration provides less waste. *Entegrasyon daha az atık sağlar.*					
AUTOMATION *OTOMASYON*	The integration decreases human error. *Entegrasyon, insan hatasını azaltır.*					
	The integration decreases labor *Entegrasyon işgücünü azaltır.*					
	The integration provides repetitive work and mass production *Entegrasyon, tekrarlayan işler ve seri üretim sağlar.*					
	The integration provides automated draft and design. *Entegrasyon, otomatik taslak ve tasarım sağlar.*					
DATA *VERİ*	The integration provides efficient data storage and processing. *Entegrasyon, verimli veri depolama ve işleme sağlar.*					
	The integration provides real time data gathering and sharing. *Entegrasyon, gerçek zamanlı veri toplama ve paylaşımını sağlar.*					

	The integration provides transparent data structure. *Entegrasyon, şeffaf veri yapısı sağlar.*					
	The integration provides reliable information. *Entegrasyon, güvenilir bilgi sağlar.*					
SUPPLY CHAIN *TEDARİK ZİNCİRİ*	The integration enhances supply chain management. *Entegrasyon, tedarik zinciri yönetimini geliştirir.*					
	The integration enhances logistic- related decision-making *Entegrasyon, lojistikle ilgili karar vermeyi geliştirir.*					
	The integration enables to predict potential logistics risks and accurate module delivery time. *Entegrasyon, potansiyel lojistik risklerini ve doğru modül teslim süresini tahmin etmeyi sağlar.*					
	The integration provides planning and control process of logistics operations. *Entegrasyon, lojistik operasyonlarının planlama ve kontrol sürecini sağlar.*					
COMMUNICATION/ COORDINATION *İLETİŞİM / KOORDİNASYON*	The integration enhances coordination. *Entegrasyon, koordinasyonu geliştirir.*					
	The integration improved communication. *Entegrasyon, iletişimi geliştirir.*					

4. Are there any other advantages of BIM-MC integration? *(BIM-Mİ entegrasyonunun başka avantajları var mı?)*

5. What could be the biggest advantage of BIM-MC integration for Turkish modular construction? *(BIM-Mİ entegrasyonunun Türk modüler inşaat için en büyük avantajı ne olabilir?)*

6. Below the barriers to BIM-MC integration from the literature are listed. Do you agree that these barriers are valid for the Turkish modular construction sector? Kindly choose from 1 to 5. (1 is for strongly disagree and 5 for strongly agree.) *(Aşağıda, literatürden BIM-Mİ entegrasyonunun önündeki engeller sıralanmıştır. Bu engellerin Türk modüler inşaat sektörü için geçerli olduğunu düşünüyor musunuz? Lütfen 1 ile 5 arasında bir değerlendirme yapınız. (1 hiç katılmıyorum, 5 şiddetle katılıyorum anlamına gelir.)*

BARRIERS ***ENGELLER***	**Subcategories** ***Alt Kategoriler***	**1**	**2**	**3**	**4**	**5**
PUBLIC PERCEPTION *KAMU ALGISI*	Public perception of modular buildings is not aesthetic and non-customizable. *Modüler binaların estetik olmadığı ve özelleştirilebilir olmadığına dair kamuoyu algısı.*					
RESISTANCE TO CHANGE *DEĞİŞİME KARŞI DİRENÇ*	Resistance to change is a barrier to integration. *Değişime karşı direnç, entegrasyonun önündeki bir engeldir.*					

OWNER/EXECUTIVE PERCEPTION *FİRMA SAHİBİ/FİRMA YÖNETİCİLERİNİN ALGISI*	Owners' perception is a barrier to integration. *Firma sahiplerinin algısı, entegrasyonun önündeki bir engeldir.*					
	Executives' perception is a barrier to integration. *Firma yöneticilerinin algısı, entegrasyonun önündeki bir engeldir.*					
ORGANIZATIONAL BARRIERS *ORGANİZASYONEL ENGELLER*	Inappropriate team and organizational configurations are a barrier to integration. *Entegrasyona uygun olmayan ekip ve organizasyonel yapılandırmalar, entegrasyonun önündeki bir engeldir.*					
COST RELATED BARRIERS *MALİYET İLE İLGİLİ ENGELLER*	High construction cost is a barrier to integration. *Yüksek inşaat maliyeti, entegrasyonun önündeki bir engeldir.*					
	Transportation cost is a barrier to integration. *Ulaşım maliyeti, entegrasyonun önündeki bir engeldir.*					
	High capital cost is a barrier to the integration. *Yüksek sermaye maliyeti, entegrasyonun önündeki bir engeldir.*					
	BIM adaptation cost is a barrier to integration. *BIM adaptasyon maliyeti, entegrasyonun önündeki bir engeldir.*					
	BIM training cost is a barrier to integration. *BIM eğitim maliyeti, entegrasyonun önündeki bir engeldir.*					
	BIM labor service cost is a barrier to integration. *BIM işgücü hizmeti maliyeti, entegrasyonun önündeki bir engeldir.*					
	BIM tool cost is a barrier to integration. *BIM aracı maliyeti, entegrasyonun önündeki bir engeldir.*					
	High design cost is a barrier to integration. *Yüksek tasarım maliyeti, entegrasyonun önündeki bir engeldir.*					
KNOWLEDGE& EXPERIENCE RELATED BARRIERS *BİLGİ VE DENEYİM İLE İLGİLİ ENGELLER*	High-level experience need is a barrier to integration. *Yüksek düzeyde deneyim ihtiyacı, entegrasyonun önündeki bir engeldir.*					
	Lack of know-how data is a barrier to integration. *Bilgi birikim eksikliği, entegrasyonun önündeki bir engeldir.*					
	Lack of training is a barrier to integration. *Eğitim eksikliği, entegrasyonun önündeki bir engeldir.*					
	Unclear BIM benefits are a barrier to integration. *BIM'in net olmayan faydaları, entegrasyonun önündeki bir engeldir.*					
	The need for high-level technical knowledge is a barrier to integration. *Yüksek düzeyde teknik bilgi ihtiyacı, entegrasyonun önündeki bir engeldir.*					
HUMAN RESOURCES-RELATED BARRIERS *İNSAN KAYNAKLARI İLE İLGİLİ BARİYERLER*	The lack of expertise is a barrier to the integration. *Uzman eksikliği, entegrasyonun önündeki bir engeldir.*					
	The lack of trained labor need is a barrier to integration. *Eğitimli işgücü eksikliği, entegrasyonun önündeki bir engeldir.*					
STANDARDIZATION RELATED BARRIERS *STANDARTİZASYON İLE İLGİLİ ENGELLER*	The lack of BIM standards for modular construction is a barrier to integration. *Modüler inşaat için BIM standartlarının eksikliği, entegrasyonun önündeki bir engeldir.*					
	The lack of a standard format for data is a barrier to integration. *Veri için standart format eksikliği, entegrasyonun önündeki bir engeldir.*					
	The lack of contractual standards is a barrier to integration. *Sözleşme standartlarının eksikliği, entegrasyonun önündeki bir engeldir.*					

	The lack of national standards is a barrier to integration. *Ulusal standartların eksikliği, entegrasyonun önündeki bir engeldir.*					
	The lack of international standards is a barrier to integration. *Uluslararası standartların eksikliği, entegrasyonun önündeki bir engeldir.*					
	The lack of building codes and standards is a barrier to integration. *Yapı kodları ve standartlarının eksikliği, entegrasyonun önündeki bir engeldir.*					
SOFTWARE RELATED BARRIERS *YAZILIMLA İLGİLİ ENGELLER*	The conflict between BIM software and domestic standards is a barrier to integration. *BIM yazılımı ile yerel standartlar arasındaki çatışma, entegrasyonun önündeki bir engeldir.*					
	The lack of local tools is a barrier to integration. *Yerel araçların eksikliği, entegrasyonun önündeki bir engeldir.*					
	Software storage limitation is a barrier to integration. *Yazılım depolama sınırlaması, entegrasyonun önündeki bir engeldir.*					
	Insufficient library is a barrier to integration. *Yetersiz kütüphane, entegrasyonun önündeki bir engeldir.*					
	Insufficient maturity of software data is a barrier to integration. *Yazılım verilerinin gelişmemişliği, entegrasyonun önündeki bir engeldir.*					
	Lack of interaction between different BIM software is a barrier to integration. *Farklı BIM yazılımları arasında etkileşim eksikliği, entegrasyonun önündeki bir engeldir.*					
ACADEMIC RESEARCH RELATED BARRIERS *AKADEMİK ARAŞTIRMAYLA İLGİLİ ENGELLER*	The lack of related academic research is a barrier to integration. *İlgili akademik araştırmaların eksikliği, entegrasyonun önündeki bir engeldir.*					
GEOGRAPHY and MARKET CONDITION-RELATED BARRIERS *COĞRAFYA VE PAZAR KOŞULLARIYLA İLGİLİ ENGELLER*	Geographic location can be a barrier to integration. *Coğrafi konum, entegrasyonun önünde bir engel olabilir.*					
	Lack of market demand is a barrier to integration. *Piyasa talebinin eksikliği, entegrasyonun önündeki bir engeldir.*					
COLLABORATION RELATED BARRIERS *İŞBİRLİĞİYLE İLGİLİ ENGELLER*	Need for multi-disciplinary collaboration from all stakeholders is a barrier to integration. *Tüm paydaşlardan çok disiplinli işbirliğine ihtiyaç duyulması, entegrasyon için bir engeldir.*					
	Need for early stakeholder commitment is a barrier to integration. *Erken aşamada paydaş taahhüdü ihtiyacı, entegrasyon için bir engeldir.*					
	Negative attitude towards data sharing is a barrier to integration. *Veri paylaşımına karşı olumsuz tutum, entegrasyon için bir engeldir.*					
	Non-BIM-user subcontractors are a barrier to integration. *BIM kullanmayan alt yükleniciler, entegrasyon için bir engeldir.*					

DESIGN RELATED BARRIERS *TASARIMLA İLGİLİ ENGELLER*	The need for a more precise and complicated design is a barrier to integration. *Daha kesin ve karmaşık bir tasarıma ihtiyaç duyulması, entegrasyon için bir engeldir.*					
	Increasing the design workload is a barrier to integration. *Tasarım iş yükünün artması, entegrasyon için bir engeldir.*					
GOVERNMENT RELATED BARRIERS *DEVLETLE İLGİLİ ENGELLER*	Governmental design restrictions and permitting is a barrier to integration. *Devlet tasarım kısıtlamaları ve izin süreci, entegrasyon için bir engeldir.*					
	The lack of laws and policies is a barrier to integration. *Yasaların ve politikaların eksikliği, entegrasyon için bir engeldir.*					
	The lack of incentive-oriented policies is a barrier to integration. *Teşvik odaklı politikaların eksikliği, entegrasyon için bir engeldir.*					
TIME RELATED BARRIERS *ZAMANLA İLGLİ ENGELLER*	The need for an early design period is a barrier to integration. *Erken tasarım dönemine ihtiyaç duyulması, entegrasyon için bir engeldir.*					
	The time-consuming process of the application is a barrier to integration. *Uygulamanın zaman alıcı süreci, entegrasyon için bir engeldir.*					
MANAGEMENT RELATED BARRIERS *YÖNETİM İLE İLGİLİ ENGELLER*	The lack of information management is a barrier to integration. *Bilgi yönetiminin eksikliği, entegrasyon için bir engeldir.*					
COMMUNUCATION AND COORDINATION RELATED BARRIERS *İLETİŞİM VE KOORDİNASYON İLE İLGİLİ ENGELLER*	Lack of coordination among stakeholders is a barrier to integration. *Paydaşlar arasında koordinasyon eksikliği, entegrasyon için bir engeldir.*					
	Lack of communication among stakeholders is a barrier to integration. *Paydaşlar arasında iletişim eksikliği, entegrasyon için bir engeldir.*					
SUPPLY CHAIN MANAGEMENT RELATED BARRIERS *TEDARİK ZİNCİRİ YÖNETİMİ İLE İLGİLİ ENGELLER*	Poor supply chain integration is a barrier to integration. *Zayıf tedarik zinciri entegrasyonu, entegrasyon için bir engeldir.*					
	Uncertainty of demand and supply is a barrier to integration. *Talep ve arzın belirsizliği, entegrasyon için bir engeldir.*					
STRUCTURAL BARRIERS *YAPISAL ENGELLER*	The complexity of connection is a barrier to integration. *Bağlantının karmaşıklığı, entegrasyon için bir engeldir.*					
3D BIM MODEL RELATED BARRIERS *3D BIM MODELİ İLE İLGİLİ ENGELLER*	Ownership and control of the model is a barrier to integration. *Modelin mülkiyeti ve kontrolü, entegrasyon için bir engeldir.*					

7. Which barriers did you/your company encounter when trying to adopt BIM? Did you overcome these barriers? Please write down your suggestions or overcome strategies for these barriers. *(BIM adaptasyon*

sürecinde siz veya şirketiniz hangi engellerle karşılaştı? Bu engelleri aşabildiniz mi? Lütfen önerilerinizi veya engelleri aşma stratejilerinizi yazınız.)

8. Please select 3 critical barriers for BIM-MC integration for Türkiye and provide your possible overcome strategies or suggestions for these 3 barriers.
   (Lütfen Türkiye için BIM-Mİ entegrasyonunun önündeki 3 kritik engeli seçiniz ve bu 3 engel için olası engelleri aşma stratejilerinizi veya önerilerinizi belirtiniz.)
9. Please rate the stakeholder's responsibility for providing solutions for BIM-MC integration in Türkiye. *(Lütfen Türkiye'de BIM-Mİ entegrasyonu için çözümler sağlama konusunda paydaşların sorumluluklarını derecelendiriniz.)*

STAKEHOLDERS *PAYDAŞLAR*	**Not Responsible** *Hiç Sormulu değil*	**Less Responsible** *Daha az sorumlu*	**Undecisive** *Kararsız*	**Responsible** *Sorumlu*	**The most Responsible** *En Sorumlu*
Government *Devlet*					
Academia *Akademik Kurumlar*					
Design Companies *Tasarım Şirketleri*					
Construction Companies *İnşaat Şirketleri*					
Project Owner *Proje Sahibi*					
End-User *Son Kullanıcı*					
Software Companies *Yazılım Şirketleri*					

10. What could be the actions that the below-listed stakeholders can take to increase the BIM-MC integration? *(Aşağıdaki paydaşların BIM-Mİ entegrasyonunu artırmak için alabilecekleri aksiyonlar nelerdir?)*
    Government:
    Devlet
    Academia:
    Akademik Kurumlar
    Design Companies:

Tasarım Şirketleri
Construction Companies:
İnşaat Şirketleri
Project Owner:
Proje Sahibi
End-User:
Son Kullanıcı
Software Companies:
Yazılım Şirketleri
Other:
Diğer

C. Human Research Ethics Committee Permission for Interview

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
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18 OCAK 2024

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Dr.Öğr.Üyesi Aslı AKÇAMETE GÜNGÖR

Danışmanlığını yürüttüğünüz Burcu Atakul'un ***"BIM VE MODÜLER YAPILARIN ENTEGRASYONU:AVANTAJLAR, ENGELLER VE UYGULAMA STRATEJİLERİ"*** başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek **0016-ODTUİAEK-2024** protokol numarası ile onaylanmıştır.

Bilgilerinize saygılarımla sunarım.

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