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INVESTIGATING BARRIERS TO BUILDING INFORMATION MODELING
ADOPTION FOR SUSTAINABLE CONSTRUCTION IN TÜRKİYE

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ABSTRACT

INVESTIGATING BARRIERS TO BUILDING INFORMATION MODELING ADOPTION FOR SUSTAINABLE CONSTRUCTION IN TÜRKİYE

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As global environmental concerns intensify, the construction sector, one of the largest contributors to energy consumption and greenhouse gas emissions, has come under growing pressure to adopt sustainable practices. Sustainable buildings offer a significant opportunity to reduce the environmental impact of construction, and Building Information Modeling (BIM) has emerged as a promising digital tool to support this transition. By enabling data-driven decision-making and lifecycle analysis, BIM facilitates the design, construction, and operation of energy-efficient, eco-friendly buildings. However, despite its recognized benefits, the adoption of BIM in sustainable building projects remains limited in some regions, including Türkiye. This study investigates the key barriers to BIM implementation in sustainable construction within Türkiye's Architecture, Engineering, and Construction (AEC) industry. Eighteen barriers were identified through an extensive literature review, and a structured survey was developed to assess their significance. A pilot study preceded full-scale data collection to ensure the clarity and validity of the survey. Responses were analyzed using the Mean Score Method and Exploratory Factor Analysis (EFA) to classify and evaluate the impact of the barriers.

The findings indicate that financial constraints, particularly high training costs, licensing fees, and the cost of BIM experts, are the most critical barriers. In contrast, process-related and technological challenges, such as software complexity or copyright issues, were perceived as less significant. EFA grouped the barriers into six categories: Financial, Usability and Collaboration, Software, Market and Governmental, Knowledge, and Organizational and Regulatory. Each category reveals distinct challenges that hinder the integration of BIM in sustainable projects.

The study highlights the multifaceted nature of BIM adoption barriers in Türkiye and offers insights into the most pressing obstacles that need to be addressed to foster more widespread and effective use of BIM in sustainable building projects. The results can inform industry stakeholders and policymakers aiming to develop targeted interventions, improve awareness, and support BIM-based sustainable construction.

Keywords: Building Information Modeling (BIM), green buildings, sustainability, Exploratory Factor Analysis

ÖZ

**TÜRKİYE'DE SÜRDÜRÜLEBİLİR YAPILARDA YAPI BİLGİ
MODELLEMESİ UYGULAMASININ ÖNÜNDEKİ ENGELLERİN
İNCELENMESİ**

AKSOY, IRMAK

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Küresel çevresel kaygıların giderek artmasıyla birlikte, enerji tüketimi ve sera gazı emisyonlarının en büyük kaynaklarından biri olan inşaat sektörü, sürdürülebilir uygulamaları benimseme konusunda artan bir baskı altına girmiştir. Sürdürülebilir yapılar, inşaatın çevresel etkilerini azaltmak için önemli bir fırsat sunarken, Yapı Bilgi Modellemesi (YBM) bu dönüşümü destekleyen dijital bir araç olarak öne çıkmaktadır. YBM veri odaklı karar verme ve yaşam döngüsü analizi yoluyla enerji verimli ve çevre dostu yapıların tasarımını, inşasını ve işletmesini kolaylaştırmaktadır. Ancak, bilinen tüm faydalarına rağmen, YBM'nin sürdürülebilir yapı projelerinde kullanımı bazı bölgelerde, özellikle Türkiye'de sınırlı kalmaktadır.

Bu çalışma, Türkiye'deki Mimarlık, Mühendislik ve İnşaat sektöründe sürdürülebilir yapılarda YBM uygulamasının önündeki temel engelleri araştırmaktadır. Kapsamlı bir literatür taraması sonucunda on sekiz engel belirlenmiş ve bu engellerin önemini değerlendirmek üzere yapılandırılmış bir anket geliştirilmiştir. Anketin netliğini ve geçerliliğini sağlamak için tam ölçekli uygulamadan önce bir pilot çalışma gerçekleştirilmiştir. Elde edilen veriler Ortalama Skor Yöntemi ve Açıklayıcı Faktör Analizi (AFA) ile analiz edilerek engellerin sınıflandırılması ve etkilerinin değerlendirilmesi sağlanmıştır.

Bulgular, en kritik engellerin finansal nitelikte olduğunu ortaya koymuştur. Özellikle, yüksek eğitim maliyetleri, yazılım lisans ücretleri ve YBM uzmanlarının maliyeti öne çıkan engeller arasındadır. Buna karşılık, yazılım karmaşıklığı veya telif hakkı gibi süreç ve teknoloji temelli engeller daha az önemli olarak değerlendirilmiştir. AFA sonuçlarına göre, engeller altı kategori altında gruplandırılmıştır: Finansal, Kullanılabilirlik ve İş Birliği, Yazılım, Pazar ve Devlet, Bilgi, Kurumsal ve Mevzuat Engelleri. Her kategori, Türkiye’de sürdürülebilir projelerde YBM entegrasyonunu zorlaştıran farklı zorlukları ortaya koymaktadır.

Bu çalışma, Türkiye bağlamında YBM uygulamasının önündeki engellerin çok boyutlu yapısını gözler önüne sererken, sürdürülebilir yapı projelerinde YBM kullanımının yaygınlaştırılması için çözülmesi gereken temel sorunlara dair önemli bulgular sunmaktadır. Elde edilen sonuçlar, sektördeki paydaşlara ve politika yapıcılara, hedefe yönelik müdahaleler geliştirme, farkındalığı artırma ve YBM tabanlı sürdürülebilir inşaatı destekleme konusunda yol gösterici olabilir.

Anahtar Kelimeler: Yapı Bilgi Modellemesi (YBM), yeşil binalar, sürdürülebilirlik, Açıklayıcı Faktör Analizi

To my beloved mother ...

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SYMBOL/ACRONYM LIST

AEC	Architecture, Engineering, and Construction
AECO	Architecture, Engineering, and Construction, and Owner
AHP	Analytic Hierarchy Process
AMOS	Analysis of Moment Structures
ANP	Analytic Network Process
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
BIM	Building Information Modeling
CAD	Computer-Aided Design
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CI	Consistency Index
CR	Consistency Ratio
CNN	Convolutional Neural Network
CO ₂	Carbon dioxide
EFA	Exploratory Factor Analysis
eQUEST	Quick Energy Simulation Tool
GS	Green Star
GM	Green Mark
HEED	Home Energy Efficient Design
H&S	Health and Safety
HVAC	Heating, Ventilation, and Air Conditioning
IFC	International Finance Corporation
IPR	Intellectual Property Right
KMO	Kaiser-Meyer-Olkin
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, Electrical, and Plumbing Systems
SSP	Smart-Sustainable Practi

SPSS	Statistical Package for the Social Sciences
TRNSYS	Transient System Simulation Tool
UN	United Nations
PLS-SEM	Partial Least Squares Structural Equation Modeling
RII	Relative Importance Index
2D CAD	Two-dimensional Computer-aided Design



CHAPTER 1

INTRODUCTION

As technological advancements have made data more accessible, the extent of environmental degradation caused by human activities has become increasingly evident. The construction sector is widely recognized as one of the largest energy consumers worldwide [1]. Environmental concerns have increased in parallel with population growth and rapid urbanization. In addition, energy consumption in the building sector, particularly in residential buildings, plays a significant role in energy losses due to inefficient usage habits and outdated construction practices that have not benefited from recent technological advancements.

Over the past decade, global carbon emissions, climate change, and global warming have dominated international policy discussions, significantly affecting sectors worldwide. [2]. The construction industry is a notable contributor to greenhouse gas emissions, primarily due to its high energy consumption, extensive waste generation, and associated activities [3]. Buildings, in particular, significantly influence the environmental footprint of the construction sector [4], contributing to around 25% of CO₂ emissions and one-third of the global energy demand [5].

Buildings represent an important opportunity to address environmental problems by applying strategies that minimize energy consumption as well [6]. Today, the construction industry, which makes a significant contribution to global warming, climate change, and the exhaustion of energy worldwide, has been striving to develop a construction method that harmonizes with the natural environment and uses natural energy resources efficiently. This approach is commonly referred to as the “sustainable building” concept.

The idea of sustainable building has gained momentum among consumers, designers, and contractors, profoundly influencing project development. The focus has shifted toward environmentally friendly, energy- and water-efficient construction practices, promoting sustainability throughout a project's life cycle, from design and construction to operation and maintenance [7]. This growing interest has become a major driver for transformation within the construction sector [7, 8].

Green analysis involves various sustainability assessments, including carbon emissions, solar and daylight performance, natural ventilation, water efficiency, and acoustic performance [10]. These analyses require the integration of various data sources such as building geometry, orientation, materials, and mechanical, electrical, and plumbing (MEP) systems. [9]. Building Information Modeling (BIM) facilitates the digital management of such project data throughout a building's life cycle [10].

Building Information Modeling (BIM) is being increasingly utilized by construction companies to efficiently manage sustainable building projects at every stage, attracting significant attention. Unlike traditional methods, BIM allows easy access and collaboration among all stakeholders through interconnected models [9]. As sustainable buildings have more regulatory requirements and higher performance expectations than traditional ones, BIM plays a critical role in organizing and managing these complex demands [11, 12].

The advantages of sustainable buildings can be grouped into three categories: environmental, economic, and social. Environmentally, they reduce water and energy consumption, protect biodiversity, minimize pollution, and promote the reuse and recycling of materials [13]. Economically, they offer lower operational costs, increased property value, and improved occupant efficiency. Socially, sustainable buildings enhance occupant comfort and well-being, contributing to a higher quality of life.

BIM contributes significantly to sustainable building by integrating advanced environmental strategies and improving information flow. During the design phase, BIM enables energy performance analyses and offers feedback for optimizing building performance throughout its life cycle. BIM can be used through the lifecycle of the

sustainable building projects but the design phase is the most frequently employed stage in project development. Additionally, it streamlines data sharing among stakeholders, reduces construction costs, and accelerates project delivery through a collaborative online platform. Although BIM has been widely adopted in several countries, its potential for achieving sustainability in construction remains underutilized in others. In Türkiye, this gap is particularly evident. This research aims to investigate the barriers to adopting BIM in sustainable building projects within the Turkish construction industry.

This thesis is structured as follows: Chapter 2 provides an overview of sustainable buildings, including definitions, key principles, materials, rating systems, and their benefits. Chapter 3 explores BIM in depth, discussing its technical features and its applications in sustainable construction. Chapter 4 presents a literature review focused on barriers to BIM implementation in sustainable projects. Chapter 5 explains the research methodology, including survey design, data collection, and analysis techniques. Chapter 6 presents the results of the study, while Chapter 7 provides a discussion of the findings. Chapter 8 concludes the thesis, highlighting key findings and suggesting directions for future research.

CHAPTER 2

SUSTAINABLE BUILDINGS

The concept of ecological architecture emerged during the 1960s. The energy crisis of the 1970s accelerated the development of renewable energy sources, such as solar, geothermal, and wind energy, and spurred innovations in energy-efficient building designs [14]. By the 1980s, the idea of "sustainable development" had gained momentum, prompting many developed countries to adopt energy-conserving building systems at scale [14, 15]. In 1990, the United Kingdom introduced the world's first sustainable building standard, which was followed by the establishment of the U.S. Green Building Council in 1993 [15].

BREEAM (Building Research Establishment Environmental Assessment Method), developed in the 1990s by the Building Research Establishment (BRE), is recognized as the first global sustainable building rating tool [16]. Later in that decade, the U.S. Green Building Council launched the Leadership in Energy and Environmental Design (LEED) system to provide a standardized framework for assessing sustainable building practices. Although LEED originated in the U.S., it has since become a globally recognized certification system [16].

Since the 1990s, various organizations and countries have developed their sustainable building programs. Regardless of the specific system used, the concept of sustainable buildings has become a universal principle. It has transformed into a fundamental aspect of the construction industry and continues to be a major focus in both academic and professional spheres, as efforts to tackle global energy and environmental issues intensify [16].

Nevertheless, the historical evolution of sustainable building rating tools, including those created in subsequent years, has not been thoroughly documented by the

originating entities or within the available literature. This gap in documentation poses a risk of losing essential knowledge [17]. Specifically, there is a significant lack of records outlining the contributions of individuals who played key roles in the development and advancement of these rating systems [17].

Without a comprehensive understanding of their historical context, it is challenging to grasp the original intentions and goals behind their creation. For instance, what led to these tools being primarily designed for evaluating theoretical design and construction performance instead of actual operational results? What criteria were used to select environmental impacts, and how were the relative importance and weighting of each impact determined? Weighting is a vital aspect of all building assessment systems, as it considerably affects the final evaluation score of a building. However, existing literature offers limited insights into how the weighting schemes of prominent holistic rating systems, such as BREEAM and LEED, were established [18].

Since the early 1990s, there has been a growing focus on environmentally conscious practices in Türkiye, indicating an increasing variety of sustainable architectural approaches. In particular, following the Habitat II – the United Nations Conference on Human Settlements held in Istanbul in 1996, interest in sustainable buildings and the initiation of tangible projects in Türkiye has notably surged [19]. Examples of sustainable architectural projects in Türkiye include:

- Kayseri 80th Year Atatürk Indoor Artificial Turf Sports Hall (2000)
- İstanbul Allianz Tower (2014)
- Eskişehir Çimsa Dining Hall Building (2015)
- Afyon Çimsa Administrative Building (2017)
- Bursa Integrated Health Campus Project (2020)
- Sabiha Gökçen Airport Terminal Building (2019)

2.1 Definition of Sustainable Buildings

The construction sector has substantial environmental, social, and economic impacts. These effects are most evident in buildings, the core products of this industry, throughout their entire life cycle [20]. Growing awareness of construction-related issues, such as noise, dust, traffic congestion, water pollution, and waste generation, has driven the emergence of the concept of “sustainable buildings” [21].

Definitions of sustainable buildings vary across the literature. Kibert [22] defines sustainable buildings as “...healthy facilities built and operated in an ecologically friendly way and utilizing resource-efficient principles...”. Sur [23] describes a green building as a sustainable structure evaluated from the site selection stage through the building’s full life cycle. Such structures are designed to respond to local climatic and contextual conditions, utilize renewable energy, and rely on natural, non-toxic materials [23].

A sustainable building is one that, due to its construction and operational characteristics, improves the quality of life for occupants and the surrounding community, potentially even extending the building’s lifespan. Achieving this requires high efficiency, including reducing energy and water consumption, minimizing resource use, and preventing environmental degradation. The fundamental distinction between sustainable and traditional buildings lies in their environmental, social, and economic performance [20]. Sustainable buildings aim to:

- “Minimize energy demand”
- “Optimize energy efficiency”
- “Utilize renewable energy sources”

Other essential considerations during pre-construction include selecting appropriate sites and sustainable materials that significantly differ from conventional construction processes. Today, sustainability has become a central feature of policy agendas worldwide, particularly in the built environment. The construction industry contributes significantly to environmental degradation through the production, transportation,

assembly, use, maintenance, and demolition of buildings. According to the Global Status Report for Buildings and Construction [1], buildings account for 36% of global final energy use and 39% of energy-related CO₂ emissions, largely due to the production of materials such as steel, cement, and glass. Erten [24] mentioned that sustainable buildings can reduce:

- Energy use by 24-50%
- CO₂ emissions by 33-39%
- Water consumption by 30-50%
- Solid waste by up to 70%
- Operating costs by approximately 13%

Through careful design, innovative technologies, and responsible material selection, sustainable buildings reduce their ecological footprint while enhancing occupant health and offering long-term economic benefits [1, 22].

2.2 Sustainable Building Materials and Technologies

Sustainable buildings often incorporate innovative materials and technologies that differ significantly from traditional construction approaches. Conventional materials such as wood, brick, concrete, steel, glass, and aluminum each have distinct environmental and energy-related properties. For example:

- **Wood** is renewable, recyclable, and environmentally safe, especially for low-rise buildings [25].
- **Concrete** offers advantages such as thermal mass, helping to maintain indoor temperatures by retaining heat or coolness longer than other materials [25].
- **Masonry** promotes natural indoor environments, reducing the need for additional coatings or finishing materials. Its wide availability also makes it a cost-effective choice in many regions [25].

However, concrete has a complex sustainability profile. While useful for thermal performance, it contributes to carbon emissions. Cement, the key ingredient in

concrete, releases about one pound of CO₂ for every pound produced, due to chemical reactions during the hardening process [25].

From a recycling and reuse perspective:

- **Steel** is highly sustainable, especially when used with bolted (not welded) connections, which allow for easy disassembly and reuse.
- **Aluminum** is lightweight, corrosion-resistant, and requires low maintenance, making it effective in green designs.

Increasingly, high-performance, low-weight composite materials are also used in green buildings to minimize environmental impacts [26]. The use of renewable and local resources is prioritized over non-renewable alternatives.

A comprehensive sustainability assessment must consider the entire life cycle of construction materials, from extraction to disposal. Ideal sustainable materials have [27]:

- Low embodied energy
- High energy efficiency
- Minimal waste generation
- Low toxicity
- Water-saving properties
- Low cost

Tables 2.1 to 2.3 summarize the primary composite, natural, and earth-based materials used in sustainable construction. To further reduce environmental impact, green construction also integrates technologies that support temperature regulation, lighting control, and efficient ventilation systems. These technologies enhance indoor environmental quality while preserving natural resources [28].

Table 2.1 Summary of Composite Materials Used in Sustainable Buildings

N	Green Materials	References
Composite Materials		
1	Fly ash	[29]
2	Ferrock	[30, 31]
3	Recycled steel	[31]
4	Hempcrete	[30]
5	Recycled plastic	[30]
6	Ashcrete	[30]
7	Timbercrete	[30]
8	Insulated concrete forms	[32]
9	Earthbags	[32]
10	Polyurethane	[32]
11	Cellulose	[32]
12	Polystyrene and isocyanurate	[32]
13	Fibre cement	[32]
14	Fibreglass	[32]
15	Steel	[32, 33]
16	Non-VOC paints	[32, 34]
17	Insulated concrete forms	[32]
18	Structural insulated panels	[32]
19	Grass crete	[30]

During the design phase, several critical environmental analyses play a pivotal role in guiding sustainable decision-making. These include assessments of energy performance, carbon emissions, solar radiation and daylighting, natural ventilation, water usage, and acoustics [36].

Table 2.2 Summary of Natural Materials Used in Sustainable Buildings

N	Green Materials	References
Natural Materials		
1	Recycled wood	[30-32]
2	Mycelium	[30, 31]
3	Stray bales	[30-32, 34]
4	Bamboo	[30-32, 34]
5	Wood timber	[30, 32,35]
6	Wool (Natural fibre)	[31, 32]
7	Cork	[31, 32, 34]

Table 2.3 Summary of Earth Materials Used in Sustainable Buildings

N	Green Materials	References
	Earth Materials	
1	Stone	[32]
2	Bricks and tile	[35]
3	Limestone	[32, 35]
4	Natural clay and mud	[30, 32]

2.3 Sustainable Building Rating Systems

Typically, certification systems for green construction measures are based on the assessment of essential characteristics like energy efficiency, water savings, material sustainability, indoor environmental quality, reduction of waste, and the efficiency of building operations and maintenance [37]. Various rating systems have been created internationally, with different originators and qualifications. One of them is Leadership in Energy and Environmental Design (LEED), which was originally one of the first and most popular systems for rating sustainable buildings, followed by Building Research Establishment Environmental Assessment Method (BREEAM), Comprehensive Assessment System for Built Environment Efficiency (CASBEE), and others.

LEED, developed by the U.S. Green Building Council (USGBC), is the most widely adopted green building certification framework in the United States [38]. According to the U.S. Office of the Federal Environmental Executive, “sustainable building” refers to the practice of enhancing the efficiency with which buildings and sites use energy, water, and materials, while minimizing adverse effects on human health and the environment [38]. In 1995, USGBC formed a partnership with scientist Rob Watson of the Natural Resources Defense Council, which began the LEED development process [39]. The initial version of LEED was completed and officially released by the USGBC, with cooperation from the Federal Energy Management Program, in August 1998 [39].

Although the United Kingdom's BREEAM, introduced in 1990, was the world's first sustainability assessment method for buildings, the USGBC recognized the need for a certification system tailored specifically to the American construction industry [39]. LEED emerged to meet this need, offering a flexible, consensus-based framework for measuring building performance across multiple environmental categories.

Another significant system is the CASBEE, established in Japan in 2001. CASBEE was developed by a collaborative research committee consisting of representatives from industry, government, and academia [40]. As part of this collaborative initiative, the first assessment tool—CASBEE for New Construction was released in 2003 [40]. Since then, the CASBEE suite has expanded to include tools for houses, existing buildings, renovations, temporary structures, heat island mitigation, schools, urban development, and even entire cities. CASBEE evaluates sustainability based on two principal dimensions: Q (Quality) and L (Load), and each principal category is further divided into three subcategories:

- **Q (Built Environment Quality)** assesses improvements to occupant comfort and amenity within a hypothetical enclosed private space [40].
 - **Q1:** Indoor Environment
 - **Q2:** Quality of Services
 - **Q3:** Outdoor Environment

- **L (Built Environment Load)** measures the negative environmental impacts extending from the private domain to the surrounding public space [40].
 - **L1:** Energy
 - **L2:** Resources and Materials
 - **L3:** Off-site Environment

Table 2.4 provides a comparative overview of the five most common sustainable building rating systems. The LEED system offers specialized rating tools tailored to various project types, including new buildings and major renovations, core and shell developments, schools, retail spaces, data centers, warehouses, distribution centers, hospitality, and healthcare facilities [41].

Table 2.4 Overview of Sustainable Building Rating Systems

Rating System	Initiator	Country	References
LEED	US Green Building Council	US	[41]
BREEAM	Building Research Establishment (BRE)	UK	[42]
CASBEE	Japan Sustainable Building Consortium	Japan	[43]
GS	Green Building Council Australia	Australia	[44]
GM	Building and Construction Authority	Singapore	[45]

The *Green Star (GS)* rating tools are designed for a variety of applications within the built environment. *Green Star-Communities* focuses on community planning and development, while *Green Star-Design & As Built* evaluates building design and construction. *Green Star-Interiors* is tailored to the design and construction of interior fit-outs, and *Green Star-Performance* assesses the ongoing operations and maintenance of existing buildings [44]. Similarly, the Green Mark (GM) rating tools, developed in Singapore, are applied to a wide range of project types [45]. These include new non-residential buildings, super low-energy buildings, new residential buildings, and transit stations. The Green Mark is also used to assess existing non-residential and residential buildings, landed houses, schools, healthcare facilities, laboratories, and infrastructure projects. In addition, it is applied to district-level developments both domestically and overseas and supports sustainable construction practices in new and existing projects [45].

2.4 Benefits of Sustainable Buildings

Sustainable building designs offer various social advantages by enhancing quality of life, health, and overall well-being. Sustainable buildings that perform well not only provide great value for individuals but also have a positive impact on society. These buildings typically offer improved indoor air quality, greater occupant comfort, and enhanced cost-effectiveness. Furthermore, they are more likely to attract buyers who

prioritize health and wellness. In contrast, traditional buildings often incorporate construction materials that contain harmful chemicals, which have been linked to health problems such as childhood asthma, respiratory issues in adults, and frequent headaches [28]. For these reasons, sustainable buildings are recognized as having significant social value. In summary, the primary social advantages of green buildings include:

- Enhanced occupant health and comfort [46],
- Improved indoor air quality and overall environmental quality [47],
- Reduced demand on local utility systems [48],

In the long term, the economic benefits of sustainable buildings outweigh the initial investment required for their design and construction. Green buildings reduce utility and maintenance costs throughout their lifecycle, making them an attractive option for property owners. Certain sustainable design strategies also align with value engineering principles by ensuring that building systems are appropriately sized for efficiency [28]. Key techniques include the use of technologies and materials that minimize dependence on fossil fuels and reduce construction waste. In summary, the economic advantages of green buildings include:

- Lower operating costs [49],
- Optimized life-cycle economic performance [28, 50],
- Enhanced occupant productivity [28],

On the other hand, from an environmental perspective, sustainable buildings help mitigate negative impacts on ecosystems and contribute to both human and ecological health. These structures utilize energy, land, and water more efficiently than conventional buildings and generate significantly less waste and pollution. Green buildings often incorporate recycled, non-toxic materials and emphasize environmental conservation. Environmental protection is a core tenet of sustainability in the construction industry [28]. In summary, the environmental advantages of green buildings include:

- Reduced waste generation [28, 51],
- Protection of biodiversity and ecosystems [28, 52],
- Improved air and water quality [28, 53],

To maximize the benefits of sustainable buildings, it is essential to adopt consistent planning, implementation, and maintenance practices across the building lifecycle. Sustainability measures should be aligned with local and international building codes and standards, addressing both short- and long-term environmental impacts. Policymakers must enact supportive regulations and offer incentives to encourage sustainable construction. Likewise, stakeholders such as investors, insurers, developers, and property buyers must be informed and proactive in promoting sustainability in the built environment.

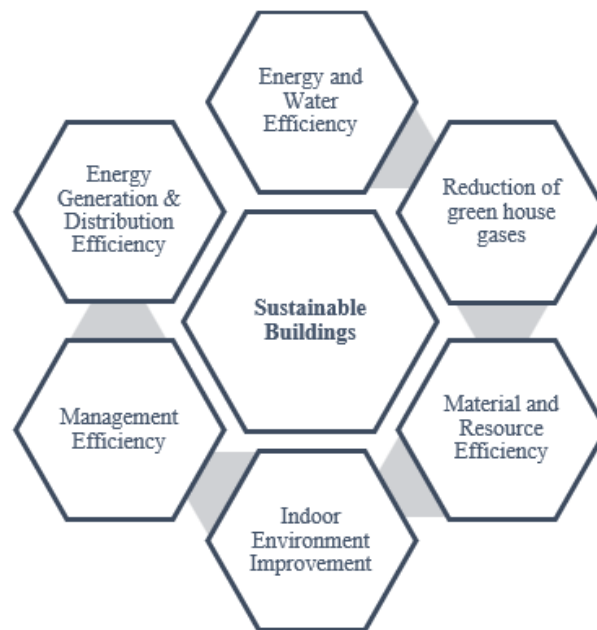


Figure 2.1 Benefits of Sustainable Buildings

CHAPTER 3

BUILDING INFORMATION MODELING

3.1 Definition of Building Information Modeling

The concept of Building Information Modeling (BIM) dates back to the 1970s, and the term “building model” was first introduced in academic literature in the mid-1980s [43]. In 1992, the term “building data model” was proposed to describe a digital representation of a building an early conceptualization of modern BIM [44]. BIM is defined as “a digital presentation of the physical and functional characteristics of a facility,” enabling the creation, use, and exchange of building information in digital form [44]. As the demand for smarter, more efficient construction increases, the Architecture, Engineering, and Construction (AEC) industry continues to shift away from traditional practices. BIM supports this transformation by offering a platform for the digital creation and management of comprehensive building information.

BIM is a process that facilitates the creation and management of digital data representing the physical and operational aspects of a building. These virtual models contain editable, interoperable information, enabling construction professionals to make better-informed decisions throughout a project’s life cycle. BIM is now widely applied in the design, planning, construction, and maintenance of various infrastructures, including roads, bridges, tunnels, energy facilities, and water distribution systems.

One of the key advantages of BIM is the ability to visualize the final structure through a detailed digital model before physical construction begins [54, 55]. This capability improves coordination, minimizes design errors, and enhances decision-making across disciplines. BIM also reduces material waste and rework, contributing to timely and

cost-effective project delivery [56]. Because of its multidisciplinary nature, BIM is interpreted and applied differently across professional domains:

- **Designers** see BIM as an evolution beyond traditional 2D CAD (Computer-Aided Design), offering greater efficiency in model creation and coordination.
- **Project managers and contractors** use BIM for effective project information management, data extraction, and scheduling.

While these perspectives share some similarities, full integration of BIM into all disciplines remains an ongoing challenge. Many studies have focused primarily on comparing BIM to older modeling methods like 2D CAD, often underestimating BIM's broader value as a centralized data management platform [57].

3.2 Technical Properties of Building Information Modeling

Building Information Modeling (BIM) includes several advanced features that enhance the efficiency, accuracy, and coordination of construction projects. One of the most valuable technical functions of BIM is clash detection, which identifies conflicts and inconsistencies between different design elements when multiple disciplines, such as architectural, structural, and MEP (mechanical, electrical, and plumbing), collaborate on a project. This allows project managers to detect and resolve spatial and technical issues during the design phase, avoiding costly delays and rework during construction [7-8].

Another key capability is energy analysis. BIM can simulate a building's energy performance and suggest design modifications, such as orientation adjustments or material substitutions, to optimize energy efficiency and sustainability [2, 4, 7-8]. Cost and time estimation are also major strengths of BIM. Accurate cost and schedule projections assist project teams in budgeting, resource planning, and time management throughout the entire project life cycle. These estimations enhance transparency and support well-informed decision-making for all stakeholders [4, 8-9]. BIM further facilitates interdisciplinary collaboration through the use of integrated, centralized digital models. Professionals from different fields can work simultaneously within the

same digital environment, ensuring consistency and improving coordination across teams. This integrated approach enhances communication, reduces errors, and promotes shared understanding of project goals and constraints [58].

Among BIM's many technical features, the ability to enhance collaboration and communication stands out as especially critical. By allowing all parties to access, modify, and share project data within a unified platform, BIM fosters a collaborative culture throughout the design, construction, and operation phases, ultimately leading to more efficient, high-quality project outcomes [61].

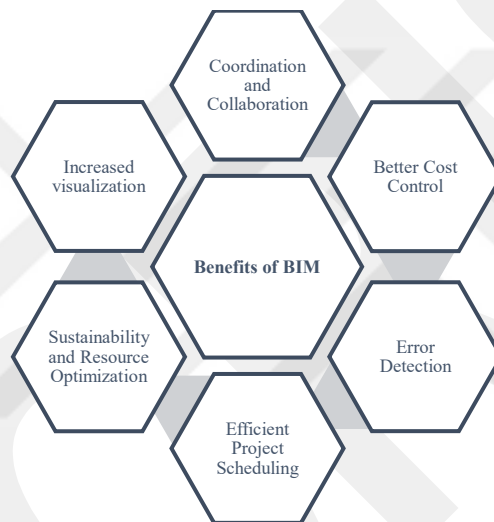


Figure 3.1 Benefits of Building Information Modeling

3.3 BIM for Sustainable Buildings

BIM also enables the execution of *green analyses*, which are among its most significant capabilities for promoting sustainable building design [10-16]. Energy performance, carbon emissions, natural ventilation, solar radiation and lighting, water usage, acoustic performance, and thermal comfort are some of the analyses that are essential for achieving sustainability goals in construction and particularly critical during the design phase of green buildings [64]. Energy performance analyses evaluate the entire building to assess energy-saving strategies, explore the feasibility of renewable energy sources, and detect potential inefficiencies. *Carbon emission*

analyses assist in minimizing emissions during the design phase by identifying high emission components and suggesting alternatives [36]. *Natural ventilation system analyses* estimate ventilation capacity and examine various strategies to improve indoor air quality. *Solar radiation and lighting analyses* focus on optimizing daylight availability, assessing exterior exposure, and performing detailed lighting simulations [36]. *Water usage analyses* help estimate consumption and propose efficient distribution methods. *Acoustic analyses* evaluate and enhance both auditory and spatial aspects of the building, while *thermal comfort analyses* aim to optimize indoor comfort through environmental simulations and sensor integration for real-time monitoring [36]. There are several types of BIM software available, with the twelve most popular ones and their features listed in Table 3.1 [36]. While green analyses such as energy performance, solar radiation and lighting, carbon emissions, water usage, natural ventilation, and acoustic performance are crucial, particularly in the design phase, no single BIM platform currently offers comprehensive support for all of these analyses. From a user perspective, stakeholders such as architects, designers, engineers, consultants, utility companies, government agencies, and building owners utilize BIM software; however, the interfaces of these tools are not uniformly suited to all user types.

The primary benefit of sustainable buildings becomes evident when high-performing structures address the needs of various stakeholders, such as owners, users, and consumers, despite common challenges like time constraints and construction costs. This, in turn, fosters increased collaboration among stakeholders [11, 18-26]. Given the complexity of managing multiple teams and delivering several buildings simultaneously, providing effective, sustainable building solutions can be difficult. In this context, BIM serves as a valuable online platform that enables all participants to collaborate throughout the building lifecycle. BIM supports the resolution of real-world problems by leveraging environmental data and efficient information-sharing methods, particularly during the design phase. For instance, receiving feedback during the design process is especially valuable for designers, as it allows them to improve their designs based on simulations, most notably, energy consumption analysis, which is a critical factor in sustainable building design. These energy-related feedback loops provide insights into expected energy usage, projected CO₂ emissions, and other

performance metrics [6-7,14,35]. The smart data generated through BIM can model a building's overall energy consumption, simulate its performance, and visually represent its energy dynamics [6].

Feedback produced by Building Information Modeling (BIM) allows designers to evaluate their work at various stages of a building's lifecycle, examine environmental effects, minimize waste, improve performance metrics, and ultimately enhance the design's overall worth. A prominent instance showcasing effective BIM utilization is the Shanghai Tower, which stands as China's tallest structure and illustrates the capabilities of BIM in extensive construction projects [72]. By implementing an innovative data management strategy rooted in BIM technology, this project achieved considerable gains in efficiency. Specifically, the use of BIM led to a substantial reduction in material waste, achieving a waste rate of just 4%, considerably lower than the national average of 10% in China [72].

Coordination and integration of building subsystems is a substantial problem for BIM implementation during construction, largely due to excessive waste of building materials. However, BIM can overcome this challenge through improved coordination that will result in a reduction of construction waste and, subsequently, a reduction in total construction costs [10, 18, 24, 29-31].

Table 3.1 BIM Software Types Sustainable Buildings

Name	Green Analyses	Users	Use
Autodesk Green Building Studio	Energy Performance, Carbon Emission, Solar Radiation and Lighting, Natural Ventilation System, Water Usage	Architects, Designers	Design, Operation, and Maintenance
Integrated Environmental Solutions Virtual Environment	Energy Performance, Carbon Emission, Solar Radiation and Lighting, Natural Ventilation System, Water Usage	Architects, Designers, Engineers, Owner	Design
EnergyPlus	Energy Performance, Carbon Emission, Solar, and Daylighting	Architects, Engineers	Design
HEED	Energy Performance, Carbon Emissions	Architects, Designers, Consultants, Owner	Design
Design Builder Simulation	Energy Performance, Carbon Emission, Solar Radiation, Lighting, Natural Ventilation System	Architects, Engineers, Consultants	Design
eQUEST	Energy Performance, Solar Radiation and Lighting, Natural Ventilation System	Architects, Engineers, Consultants	Design, Construction, Operation, and Maintenance
DOE2	Energy Performance, Solar Radiation and Lighting, Natural Ventilation System	Architects, Engineers, Consultants, Utility Company, and Government	Design
ODEON Room Acoustics Software	Acoustics	Architects, Engineers	Design
TRNSYS	Energy Performance, Solar Radiation and Lighting, Natural Ventilation System	Architects, Engineers	Design

Additionally, the implication of Building Information Modeling (BIM) in sustainable construction projects equally results in better scheduling and project management. BIM supports the stakeholders in effectively controlling the construction schedule, resulting in high-quality results throughout the project life cycle [11, 15, 33].



CHAPTER 4

LITERATURE REVIEW

Building Information Modeling (BIM) has attracted considerable attention in the construction industry due to its potential to enhance efficiency, collaboration, and sustainability. However, despite these advantages, several barriers continue to impede its widespread adoption. Numerous studies have investigated these obstacles, both in the context of general BIM implementation and specifically regarding its application to sustainable buildings. This chapter summarizes key findings from the literature by examining common barriers to BIM implementation and those specific to sustainable buildings.

4.1 Barriers to BIM Implementation

While BIM offers substantial benefits, its implementation remains a challenge in many countries due to various technical, financial, and organizational factors. Abubakar et al. [67] investigated BIM adoption barriers in Nigeria through semi-structured questionnaires and informal interviews. Their findings revealed several key challenges: absence of client-driven initiatives, high integration and education costs, lack of standardized implementation guidelines, legal and contractual uncertainties, and resistance to change from traditional construction practices. The study emphasized the need for strategic policy decisions to align Nigeria's construction industry with global standards.

Zahrizan et al. [57] explored BIM barriers in Malaysia using qualitative analysis. They found that the most frequent barrier was difficulty adapting to BIM software due to high implementation costs and unclear policies. Additionally, a shortage of skilled professionals was noted as a major hindrance to effective BIM use.

Olugboyega and Windapo [70] examined BIM adoption challenges in South Africa using Confirmatory Factor Analysis. Key barriers included a lack of demand caused by the absence of mandatory BIM regulations, high costs of implementation and training, insufficient process guidance, and a shortage of trained personnel. Technological issues such as software incompatibility and poor communication among stakeholders further impeded BIM uptake.

Cemesova et al. [74] analyzed BIM's integration into passive building design using case studies from Germany and the UK. Their findings indicated that current BIM tools cannot support detailed environmental simulations necessary for passive design strategies. Interoperability limitations, data specificity issues in early design phases, and workflow discontinuities were cited as key obstacles.

Durdyev et al. [75] studied barriers in the Cambodian construction industry through survey-based research. They identified high costs associated with training, licensing, and recruitment of BIM specialists as the primary barrier. Additional challenges included a shortage of skilled professionals, the absence of standardized protocols, and interoperability limitations across platforms.

Azhar [76] examined BIM use in the U.S., focusing on projects such as the Aquarium Hilton Garden Inn in Atlanta. While the study highlighted BIM's ability to detect design clashes and deliver cost savings, it also identified challenges such as incomplete documentation and poor consultant coordination.

Pezeshki and Ivari [78] conducted a literature review of BIM methodologies and found recurring barriers such as insufficient understanding of BIM concepts and high training and implementation costs.

Migilinskas et al. [79] compared historical and recent reconstruction projects in Lithuania. Their research revealed persistent issues, including a shortage of BIM experts and a lack of institutional support for training and implementation.

Ilter and Ergen [80] reviewed BIM applications in refurbishment and maintenance, identifying cultural resistance, unclear pricing structures, and interoperability issues as prominent challenges, especially in long-term projects.

4.2 Barriers to BIM Implementation for Sustainable Buildings

Adopting Building Information Modeling (BIM) for sustainable buildings faces several challenges that hinder its effective implementation across the construction industry. This section reviews key studies that have identified and analyzed the general barriers to BIM adoption in the context of sustainable building practices.

Alsehrawy et al. [2] focused on finding out more about common BIM barriers inhibiting its application in sustainable buildings and exploring the main causes of the continued disconnect between sustainability and BIM in the construction industry. One of the major obstacles to the integration of BIM and sustainability is that BIM and sustainability are equally recent phenomena within the industry. This lack contributes to issues such as insufficient design information, a shortage of qualified professionals, and the absence of standardized practices. These issues are further complicated by the unique characteristics of sustainable buildings compared to traditional ones, making the application of BIM more complex. One important difference between sustainable design and traditional design is that sustainable building requires architects to consider a number of sustainability analyses in the pre-design phase. There are a number of analyses that are needed, but no one BIM software can do them all. As a result, several software tools are required, thereby imposing financial overheads on the enterprises, as they need to pay expensive license fees for the different software products.

Veselka [4] surveyed four important certification systems (BREEAM, LEED, DGNB, and SBToolCZ) to investigate the integration of BIM with LCA (Life Cycle Assessment) in the certification of sustainable buildings. This approach was applied to a case study of a Siemens office building in Zug, Switzerland. In their study, several major obstacles to the integration included unintegrated classification systems, heterogeneity of material databases, manual personnel workload for data processing, and missing or incompatible information within BIM models.

Zhang [7] used the approach of Structural Equation Modeling (SEM) to determine 22 constraints influencing BIM adoption in sustainable buildings in China. The data used in this study were obtained from an online survey conducted among respondents from multiple cities in China (e.g., Beijing, Shanghai, Guangzhou, Shenzhen, Qingdao, Zhengzhou, Jinan, Tianjin, and Taiyuan). The findings identified key barriers such as the lack of implementation standards, limited understanding of BIM processes, and a shortage of interdisciplinary experts. The study concludes that public participation plays a vital role in BIM adoption and emphasizes the need for enhanced education and standardized guidelines to support its effective integration.

Ma et al. [8] conducted research in China using a case study of a student activity center project at a Chinese university, aiming to develop a BIM application system that supports the sustainable development of buildings throughout their entire lifecycle. The study employed a systematic literature review to analyze various case studies and identify the barriers to BIM implementation in sustainable building projects. The most commonly reported barriers include a lack of coordination and cooperation among stakeholders, the absence of adequate standards for BIM applications in sustainable buildings, limited industry experience and expertise, insufficient governmental mandates for the use of green technologies, and a lack of trust between project participants. The latter is particularly significant, as BIM enables access to and modification of geometric data, raising concerns about data control and collaboration.

Mohanta and Das [9] also carried out research in the sustainable building domain of the eastern part of India, based on mixed methods, which involved a literature survey, web surveys, and expert interviews. The Mann-Whitney U test and Kruskal-Wallis H test were used to analyze the data to determine major barriers to the BIM adoption. The research pointed to several major challenges, such as poor ICT facilities, a lack of competent and skillful professionals, and a lack of communication among partners. Although the potential of BIM is widely acknowledged, the findings suggest that its use remains largely limited to visualization purposes, thereby constraining its ability to enhance collaboration across project teams.

Biçer et al. [62], the general state of sustainable buildings in Türkiye and globally was examined, with a particular focus on Green Building-certified structures in Kayseri and the use of Building Information Modeling (BIM) in sustainable building evaluation. The required data was collected through an online questionnaire survey in Kayseri, Türkiye. The results highlighted a number of challenges; i.e. sustainable building approach is not established; the use of BIM is still uncertain; knowledge on BIM is limited; BIM is seen as a cost; the role of BIM in sustainable buildings is not clear; and additional costs of BIM are a big concern.

The objective of Rathnasiri and Jayasena [63] was to develop a framework for integrating Green BIM technology into existing buildings. The research focused on selected case studies in Sri Lanka, with conclusions drawn based on the country's specific contextual factors. This study addresses a research gap by examining the application of BIM in existing buildings—an area that has received limited attention. A qualitative methodology was employed to conduct a multiple case study analysis. The research identified the complexity of BIM software tools as the primary challenge hindering their effective use in the context of existing structures.

Shan et al. [65] examined the factors influencing the use of BIM for sustainable buildings among small contractors in Singapore and compared these findings with those of large contractors. The study identified 30 small contractors and conducted a questionnaire survey, which was analyzed using non-parametric statistical tests. The findings revealed that small contractors encounter greater barriers to the adoption of BIM when compared to larger firms. The primary challenge identified is the considerable cost associated with implementation, which represents a significant hurdle for smaller businesses. Additional barriers include a shortage of BIM experts specialized in sustainable buildings and the passive approach of clients in selecting sustainable design and construction solutions.

Ghaffarianhoseini et al. [66] found that the adoption of BIM for sustainable buildings is not fully realized within the sector, with both the benefits and barriers not being fully understood by industry stakeholders. In their study, barriers were categorized into five main areas: management, financial, environmental, legal, and technical risks, based on

a comprehensive literature review. The analysis highlights that cybersecurity, legal challenges, and a lack of demand from both clients and the government are among the key challenges that have been identified. The research also showed that BIM awareness and application are strongly correlated with the size of Architecture, Engineering, and Construction (AEC) firms. The small companies, in particular, experience more challenges as a result of limited involvement in BIM projects.

Gürkün et al. [69] investigated and evaluated the advantages of using BIM in sustainable building projects across different project stages. The study aimed to identify which stages provide the most benefits regarding specific project constraints and to assess the disadvantages of using BIM in sustainable building applications. The research methodology included a literature review followed by a pilot analysis and a survey. The Kruskal-Wallis test was performed to determine the participant profiles that had a significantly different perception, identified by the Mann-Whitney U test, among the levels of understanding of participants. It was observed that the challenges of BIM adoption in sustainable buildings are mainly the result of sustainable materials, current standards, and the lack of cash in qualified experts.

Tian et al. [71] conducted a study using selected case studies from the past five years in the UK and China to explore the barriers to BIM adoption for sustainable buildings. The methodology employed for analyzing the identified barriers involved Python based term frequency analysis. The analysis shows a diversity in the understanding of BIM for sustainable building, yet there is a lack of data model management processes and guidelines. The lack of standards and of BIM professionals in the industry was also emphasized by the study. The findings suggest that for sustainable buildings to be effectively promoted, they must adhere to complex energy and environmental standards.

Kineber et al. [81] conducted a questionnaire survey to examine the use of BIM for sustainable buildings in the Nigerian construction industry. The findings were interpreted through Exploratory Factor Analysis (EFA) to classify the challenges and were analyzed with Partial Least Squares Structural Equation Modeling (PLS-SEM) to determine the most significant barriers to BIM adoption. One of the main barriers presented is interoperability between different BIM software, which hinders

integration. Furthermore, the unique nature of the data managed by BIM systems can lead to security concerns, particularly when faced with interoperability challenges.

Anton and Diaz [82] emphasized various criteria that should be considered in sustainable building projects, including environmental, social, and economic factors. Their study pinpointed significant barriers to the adoption of Building Information Modeling (BIM), such as insufficient research and development efforts, challenges related to interoperability among diverse software platforms, a lack of established standards and guidelines, and complications in customizing BIM applications for the specific contexts of different organizations.

Ilhan and Yaman [83] discussed the integration challenges between BIM and sustainable buildings. While BIM has become central to the building project process, facilitating tasks such as performance analysis, cost and time planning, creating construction documents, and design visualization, their study emphasized that the construction industry is increasingly adopting sustainable practices. BIM is considered a highly qualified tool for this purpose. In their research, several case studies were analyzed, revealing that the most common challenges include insufficient funding, particularly when owners are reluctant to adopt new technologies. The high integration costs and the lack of mandatory government funding further exacerbate these barriers. Additionally, a significant challenge is the difficulty of incorporating green materials into BIM databases, as sustainable materials differ substantially from traditional ones, particularly in terms of selection.

Wen et al [84] researched to examine how BIM technology adds value at various stages of constructing a sustainable building, utilizing a Convolutional Neural Network (CNN) approach. The CNN method was applied to assess the effectiveness of BIM in sustainable construction projects. Before this, a survey using questionnaires was carried out in Shenzhen, China, to collect pertinent data. The research revealed that although BIM technology has proven effective in the design phase, its implementation during construction has not been as successful. Furthermore, the perceived social value of BIM within the industry is still limited, as clients and owners are reluctant to embrace new technologies.

Almutiri [85] aimed to assess the level of knowledge and implementation of Building Information Modeling (BIM) and sustainable building practices within the building industry in the Kingdom of Bahrain. A semi-structured questionnaire was administered to both professionals and academics in the industry. The main reasons for not implementing BIM in sustainable building projects included a lack of client demand, the absence of government regulations making BIM mandatory, high implementation costs, and insufficient expertise and knowledge of the BIM benefits among employees.

Doan et al. [86] investigated the barriers to BIM usage for sustainable buildings in the New Zealand construction industry through a semi-structured questionnaire survey. Using the Mean Score Method, the study identified the lack of specific regulations as the most significant barrier. This absence of regulations has led both the government and clients to perceive a low demand for sustainable buildings. Other common barriers include high implementation costs, lack of expertise, and insufficient knowledge about BIM's benefits.

Raouf and Al-Ghamdi [87] explored how BIM can support the development of sustainable buildings through an extensive literature review that incorporated findings from countries such as Singapore, South Korea, Turkey, Vietnam, and China. This review highlighted several significant barriers to implementation, including challenges associated with incorporating sustainability elements like energy modeling, efficiency measures, and daylight utilization into BIM systems. Additional issues identified were elevated costs for implementation, a lack of skilled professionals in the field, and insufficient collaboration among various stakeholders.

Chan et al. [88] focused on identifying barriers to the adoption of Smart-Sustainable Practices (SSP) while evaluating their potential effects on the construction sector. The study employed quantitative methods, including questionnaire surveys and data analysis through descriptive and inferential statistics. Additionally, fuzzy synthetic evaluation was employed to develop predictive models. The study identified several challenges, including resistance to change from traditional technologies, limited demand from clients and the government, insufficient knowledge of BIM and sustainability processes, and inadequate procurement policies and contractual agreements.

CHAPTER 5

RESEARCH METHODOLOGY

This study adopts an exploratory research design to examine the relevance of previously identified barriers to BIM implementation in sustainable projects within the context of Türkiye. A quantitative research methodology is employed using survey data, which is analyzed through Exploratory Factor Analysis (EFA) with the aid of IBM SPSS (Statistical Package for the Social Sciences). The primary objective is to identify and analyze the barriers affecting BIM adoption in sustainable building projects. The methodology is structured into four main stages: (1) questionnaire design, (2) data collection, (3) data analysis, and (4) interpretation of results. The research framework is presented in Figure 5.1.

5.1 Questionnaire Design

The questionnaire was developed in three sequential steps: (1) literature review, (2) development of survey questions, and (3) pilot study.

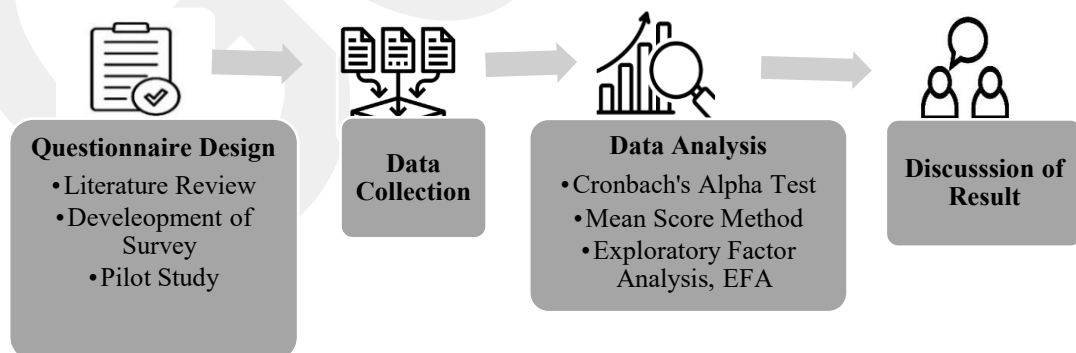


Figure 5.1 Research Framework

5.1.1 Literature Review

The first phase involved a comprehensive literature review aimed at identifying the most common barriers to BIM implementation in sustainable building projects. Academic databases such as Scopus, ScienceDirect, and Web of Science were utilized to access relevant studies published between 1992 and the present. Through the analysis of 35 selected articles which are related about the BIM usage for the sustainable building projects, a total of 18 distinct barriers were identified in these articles, as summarized in Table 5.1.

Table 5.1 Barriers to BIM implementation in Sustainable Building Project in Türkiye

Barrier	Description	References
B1	Lack of qualified BIM operators	[2], [7], [8], [11], [57], [62], [65], [66], [67], [68], [69], [70], [71], [73], [75], [79], [81], [83], [85], [86], [87], [88], [89]
B2	Resistance of professionals to new technologies	[2], [75]
B3	Lack of knowledge about BIM implementation in sustainable buildings	[2], [7], [11], [68], [84], [86], [87], [88], [90]
B4	Lack of sufficient experts in BIM and sustainable buildings	[2], [7], [8], [11], [57], [62], [65], [66], [67], [68], [69], [70], [71], [73], [75], [79], [81], [83], [85], [86], [87], [88], [89]
B5	Lack of BIM implementation guidelines and standards in sustainable buildings	[2], [7], [9], [57], [68], [69], [70], [71], [75], [76], [80], [81], [86], [87], [88], [89], [90], [91], [92]
B6	Copyright problems about data	[8], [11], [66], [75], [81], [87]
B7	Difficult to use in complex projects	[2], [68], [78], [90]
B8	Lack of coordination among project stakeholders	[11], [57], [65], [66], [67], [68], [69], [70], [71], [74], [80], [82], [93]
B9	Lack of market demand	[7], [66], [68], [70], [84], [85], [86], [87], [88], [89]
B10	Lack of government support	[2], [7], [11], [57], [65], [66], [67], [68], [80], [84], [87]
B11	Lack of demonstration projects to recommend BIM implementation in sustainable buildings	[7], [62], [78], [87], [90]

Table 5.1 (continued)

B12	Interoperability problems in Building Information Modeling (BIM)	[2], [4], [7], [68], [75], [76], [78], [80], [82], [83], [87], [90], [91], [92]
B13	No specific BIM type (eQUEST, Autodesk Green Building Studio, etc.) that conducts all sustainable analysis	[2], [7], [8], [62], [68], [69], [76], [78], [83], [87], [88], [90]
B14	Unreliable estimation for the energy performance analysis of sustainable buildings	[2], [7], [68]
B15	The complexity of the interface of the BIM software	[2], [7], [63], [68]
B16	High training costs	[7], [9], [67], [68], [70], [75], [80], [81]
B17	High licensing costs	[62], [65], [66], [67], [68], [70], [75], [80], [83], [85], [86], [87], [88], [89], [91]
B18	High cost of BIM experts	[7], [66], [67], [68], [70], [75], [78], [80], [81]

5.1.2 Development of Survey Questions

Following the literature review, the survey questions were developed based on the identified barriers. Previous survey studies were also analyzed to refine the questionnaire's structure. The finalized survey consisted of two main sections:

- Demographic Information: Collecting participant background data.
- Barrier Importance Assessment: Measuring the perceived importance of each identified barrier.

A five-point Likert scale was used, ranging from 1 (Not at all important) to 5 (Extremely important), as shown in Table 5.1. The questionnaire was created using Google Forms.

Table 5.2 5-point Likert Scale for Barriers

Score	1	2	3	4	5
Level of Significance	Not all Important	Slightly Important	Moderately Important	Very Important	Extremely Important

5.1.3 Pilot Study

A pilot study was conducted with seven industry professionals and academics experienced in BIM and sustainable buildings. The pilot study lasted one month, allowing for the refinement of the questionnaire based on participant feedback. In total, seven responses were collected and assessed to enhance the survey before its final distribution. The finalized version of the questionnaire is presented in Appendix A. Several modifications were made following the pilot study:

- The survey title and introductory explanation were adjusted to explicitly refer to Türkiye.
- A termination mechanism was introduced: if a participant selected "I do not agree" in the approval section, the survey would immediately conclude, redirecting the user to a "Thank you" page.

Revisions in Part A (Demographic Information)

- In Part A, Question 2, the option "Energy Systems Engineer" was added as a profession choice.
- In Part A, Questions 5, 7, 8, and 9, grammatical errors were corrected.
- Part A, Question 7 was revised to accommodate academic participants who may not have direct experience in the construction sector. A parenthetical note was added:
 - *(If you are working in academia, how many years have you been actively engaged in this profession?)*
- Part A, Question 9 was modified to explicitly ask:
 - *In how many projects have you used Building Information Modeling (BIM)?*

Revisions in Part B (Barrier Assessment)

- The term "operators" in the first barrier was replaced with "users" to prevent misunderstanding.
- For "*B9- Lack of support for BIM from the corporate environment*" was replaced with "*B9- Lack of market demand*".
- "*B10- Lack of government support*" was added.
- For B13, the phrase "green analyses" was refined to "sustainable analyses", and examples of BIM software, such as eQUEST and Autodesk Green Building Studio, were included in parentheses for clarity.
- General spelling and grammatical errors were reviewed and corrected.

5.2 Data Collection

Following the pilot study, the finalized questionnaire survey was distributed via email through a link to an online platform. The target group consisted of professionals from both the public and private sectors who had prior experience with BIM services and sustainable building projects in Türkiye. Data collection commenced on February 12, 2024, and concluded on April 24, 2024. A total of 82 responses were received; however, only 79 were included in the analysis, as three participants did not complete the survey.

5.3 Data Analysis

For this research, the data analysis process incorporated several key statistical techniques to ensure the reliability and validity of the findings. These included Cronbach's Alpha Test for reliability assessment, the Mean Score Method for ranking the significance of barriers, and Exploratory Factor Analysis (EFA) for identifying underlying factor structures.

5.3.1 Cronbach's Alpha Test

The reliability of the survey items was measured using Cronbach's Alpha to check internal consistency. This coefficient varies from 0 to 1, and values close to 1 indicate higher internal consistency between the items, as they are measuring the same underlying construct. In the current study, SPSS 25 was used to compute this metric.

$$\alpha = \frac{N * \bar{c}}{\bar{v} + (N + 1) * \bar{c}} \quad (1)$$

Where;

α : Cronbach's Alpha

N : Number of items

\bar{c} : Average covariance between item pairs

\bar{v} : Average variance of each item

5.3.2 Mean Score Method

The Mean Score Analysis was used to prioritize the barriers, and the relative importance of the barriers was highlighted using a mean value for each item. The Mean Score Method measures the mean of the scores of the responses from a group. This approach is commonly used in multiple regression analyses involving grouped data, as it facilitates the examination of relationships among variables [94].

The use of mean scores in data analysis offers several methodological advantages that enhance the robustness and interpretability of research findings. First, averaging individual scores helps mitigate the impact of random measurement errors, resulting in more stable and reliable estimates [95]. This process increases the consistency of measurements across different samples or study contexts. Furthermore, aggregating data through group means simplifies complex datasets, making it easier to identify underlying patterns and relationships [80]. The mean scores also facilitate comparisons by allowing us to compare directly from one group, condition, or period to another. In

addition, they are useful for dealing with missing data; sensitivity analysis, the mean score can provide information about whether findings are consistent under different levels of assumption about missing data [95].

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (2)$$

Where;

\bar{X} : Mean Score

X_i : Individual Scores

n : Total number of individuals

5.3.3 Exploratory Factor Analysis (EFA)

Exploratory Factor Analysis (EFA) is a statistical method utilized to uncover significant constraints by grouping interrelated variables into underlying factors [7]. This approach effectively demonstrates the connections between correlated variables, aiding in the identification of representative constraints. Once these variables have been identified through EFA, the subsequent step is to ascertain the key constraints, which are crucial for maintaining both the integrity and validity of the analysis [95]. EFA was performed using the Statistical Package for the Social Sciences (SPSS), which offers a broad mode to explore and confirm relations among observed variables [96]. Initially, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were applied to establish the dataset's suitability for factor analysis. Next, a Rotated Component Matrix was produced to help interpret the underlying factor structure.

CHAPTER 6

RESULTS

This chapter presents the results of the questionnaire survey, which was designed to identify the significance of the barriers to Building Information Modeling (BIM) implementation in sustainable building projects in Türkiye. It includes demographic characteristics of respondents, significance of the barriers, and the results of the Exploratory Factor Analysis (EFA).

6.1 Demographic Characteristics of Respondents

Figure 6.1 shows that 59.49% of the participants held a B.Sc. degree, 29.11% held an M.Sc., and 11.39% held a Ph.D. As seen in Figure 6.2, most respondents were civil engineers (64.56%), followed by architects (21.52%), energy systems engineers (11.39%), and both industrial and mechanical engineers (1.27% each).

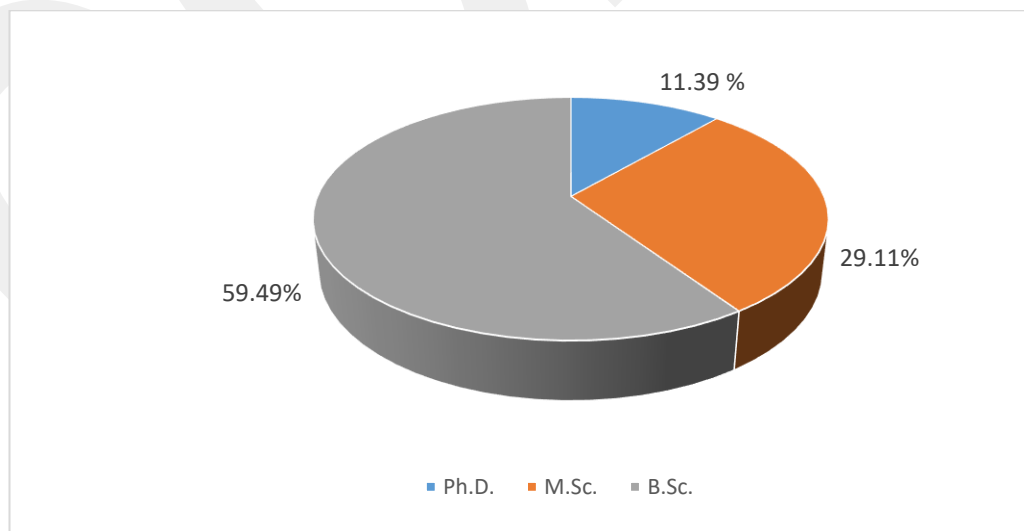


Figure 6.1 Respondents by Education Level

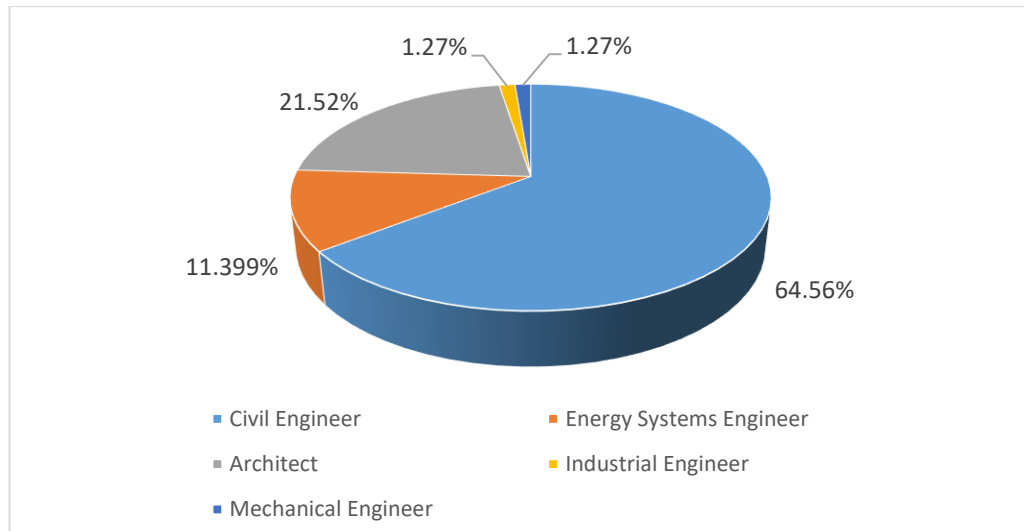


Figure 6.2 Respondents by Profession

In terms of employment type, Figure 6.3 reveals that 83.54% of respondents worked in private companies, while 16.46% were employed by public institutions. Job roles were varied, as shown in Figure 6.4: 21.52% were designers, 16.46% project managers, 12.66% academics, and 12.66% tendering engineers. Other roles included owners (8.86%), site engineers (8.86%), energy system engineers (6.33%), BIM design engineers (5.06%), civil engineers (3.80%), and others (1.27%), such as H&S managers and environmental engineers. As Figure 6.5 illustrates, 39.24% of participants had 6–15 years of experience, 34.18% had 16–25 years, 17.72% had 1–5 years, and 8.86% had over 25 years in the construction industry.

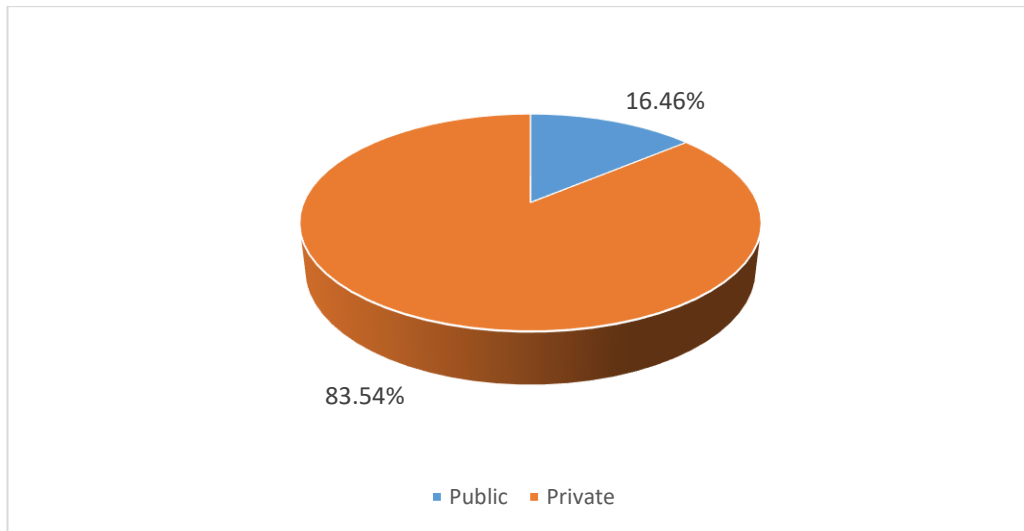


Figure 6.3 Respondents by Organization Type

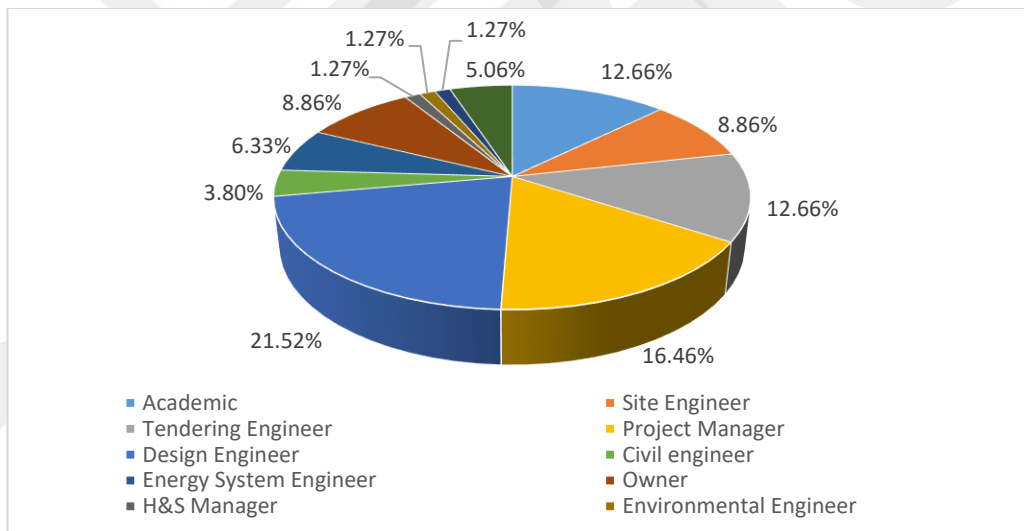


Figure 6.4 Respondents by Job Description

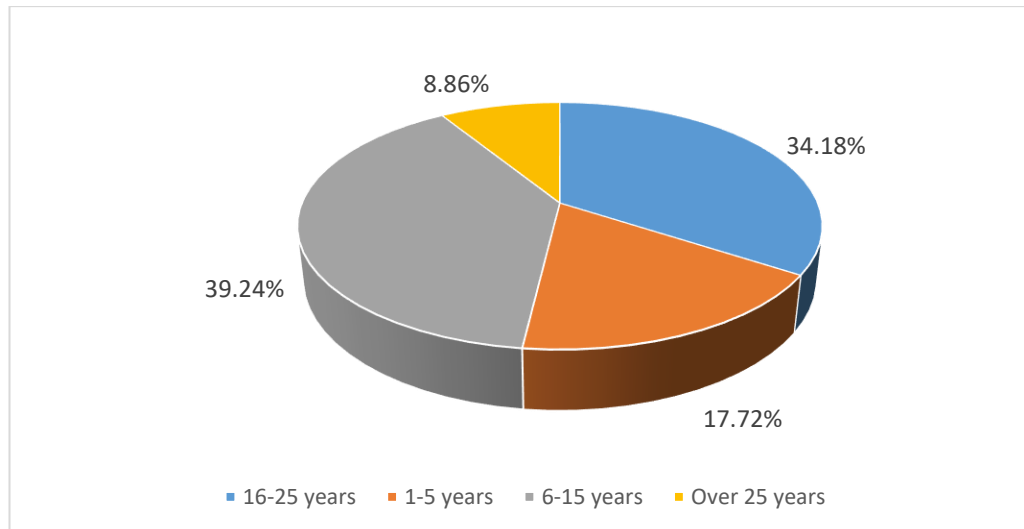


Figure 6.5 Respondents by Years of Experience in the Construction Industry

Organizational information was collected through two separate questions, which are illustrated in Figures 6.6 and 6.7. The first question focused on the age of the organization. According to the responses:

- 30.38% of firms have been in business for 10–20 years
- 24.05% for 5–10 years
- 18.99% for 20–30 years
- 15.19% for over 30 years
- 11.39% for 0–5 years

The second question addressed the size of the organization. The survey results indicate that:

- 29.11% of respondents work for organizations with fewer than 100 employees
- 26.58% for organizations with 100–250 employees
- 22.78% for organizations with 250–500 employees
- 21.52% for organizations with more than 500 employees

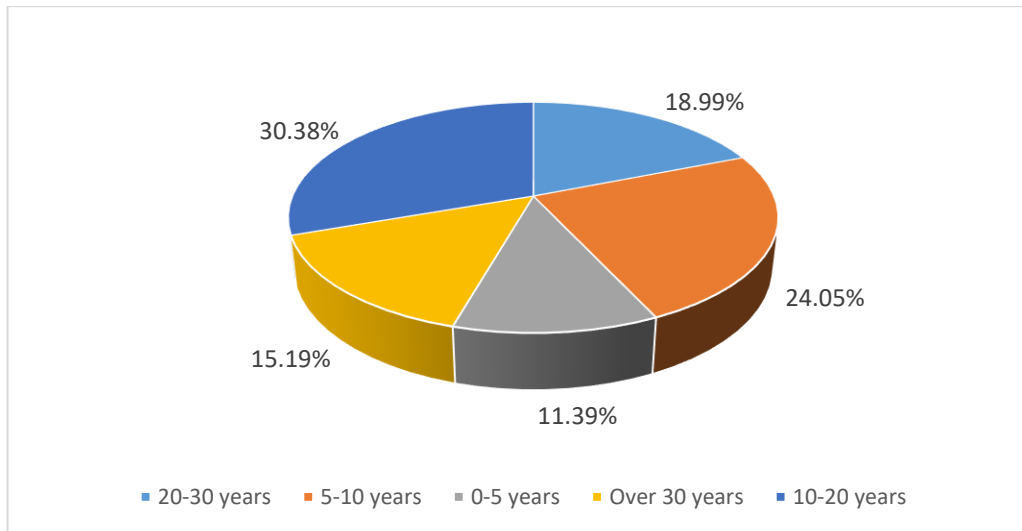


Figure 6.6 Respondents by Age of Their Organization

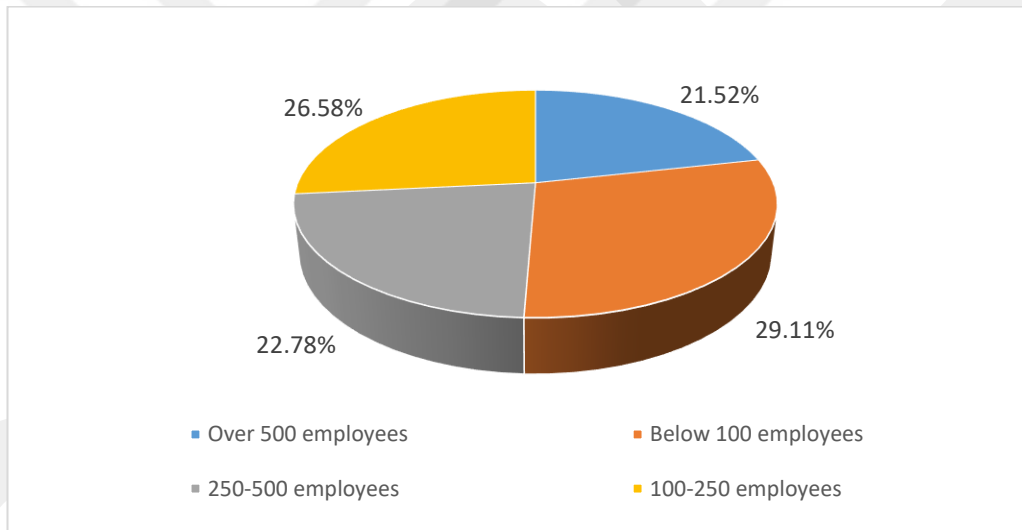


Figure 6.7 Respondents by Size of Their Organization

Experience with sustainable projects and BIM usage was detailed as follows:

- 30.38% of respondents participated in 1–5 sustainable projects;
- 29.11% in 6–10;
- 21.52% in more than 15;
- 18.99% in 11–15 projects (Figure 6.8).

Regarding BIM usage:

- 48.10% used BIM in 1–5 projects;

- 31.65% in 6–10;
- 12.66% in 11–15;
- 7.59% in more than 15 projects (Figure 6.9).

When asked about the number of sustainable building projects completed using BIM:

- 82.28% reported using BIM in 1–5 projects;
- 11.39% in 6–10;
- 3.80% in 11–15;
- 2.53% had no such experience (Figure 6.10).

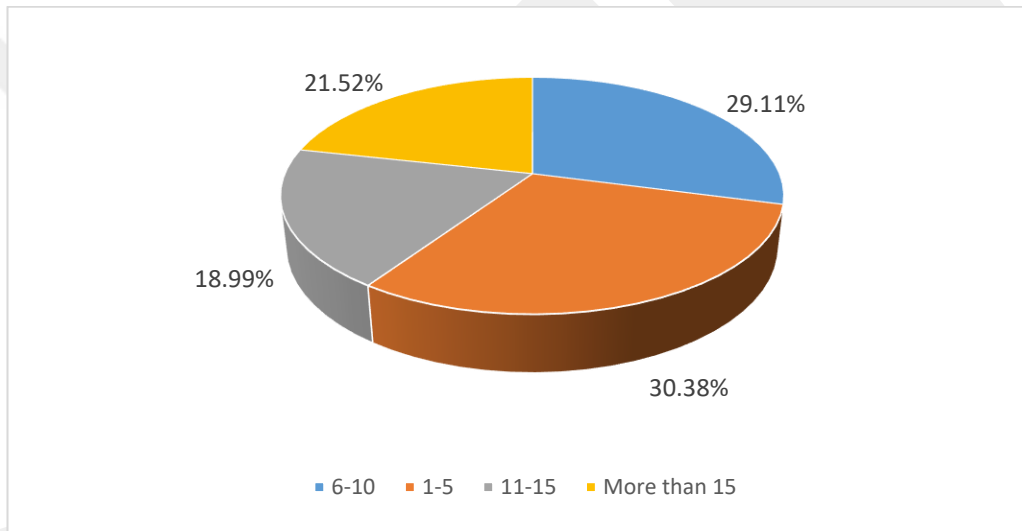


Figure 6.8 Respondents by Number of Sustainable Projects Involved

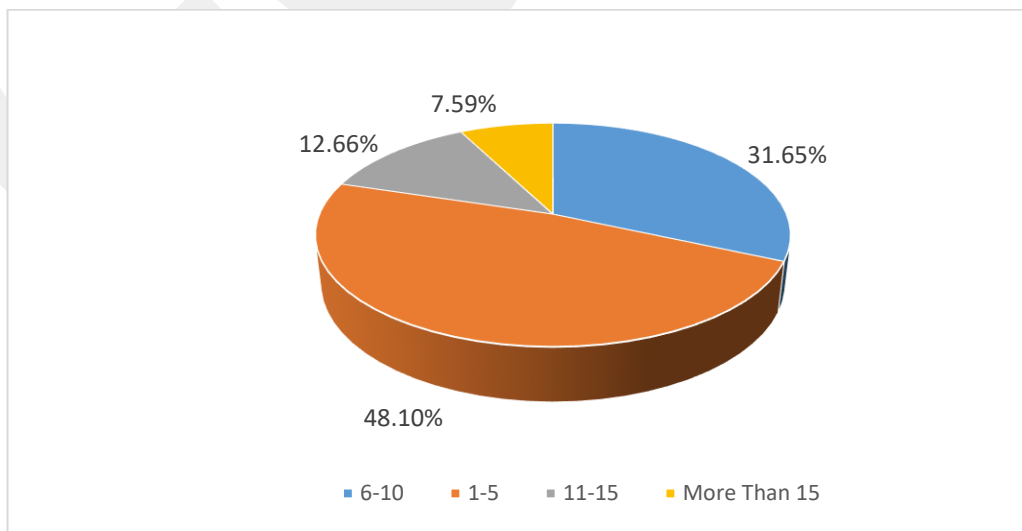


Figure 6.9 Respondents by Number of BIM Projects Involved

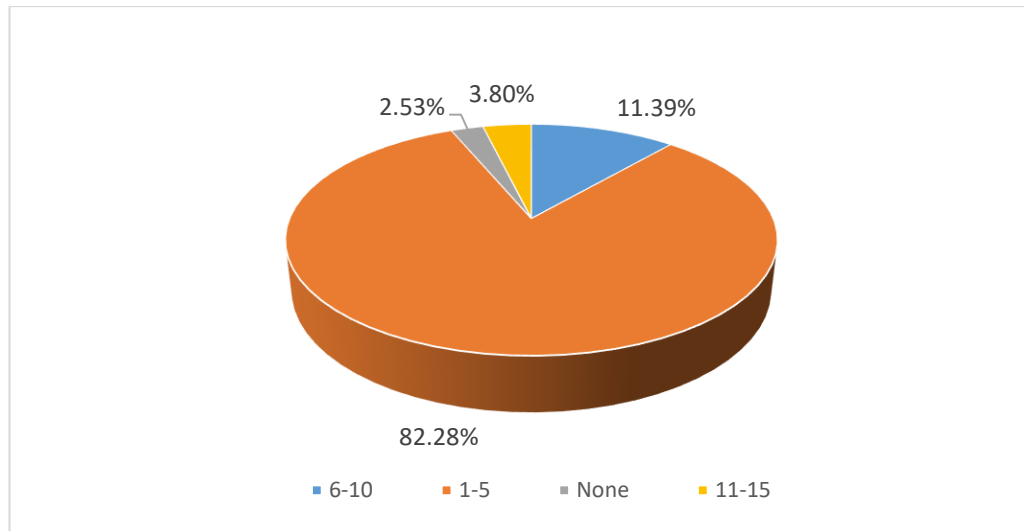


Figure 6.10 Respondents by Use of BIM in Sustainable Building Projects

6.2 Significance of the Barriers

The ranking of barriers to Building Information Modeling (BIM) implementation, as presented in Table 6.1, reveals a strong consensus among participants from both public and private sectors regarding the primary obstacles faced in sustainable building projects in Türkiye. The top three barriers “*B17- High licensing costs*”, “*B18- High cost of BIM experts*”, and “*B16- High training costs*” were consistently ranked as the most significant, regardless of sector. This uniformity underscores the dominant impact of financial constraints on BIM adoption across the construction industry. “*B17- High licensing costs*” emerged as the most critical barrier overall, with a mean score of 4.58, and ranked first in both public and private sectors. Its high rating reflects the universal challenge of accessing costly proprietary BIM software, particularly in resource-constrained organizations.

“*B18- High cost of BIM experts*” followed closely, with a mean score of 4.48 overall and placed second in the private sector, but third in the public sector. This discrepancy may be attributed to the private sector's more direct exposure to hiring and retaining specialized personnel, who command premium wages due to limited supply. “*B16- High training costs*” ranked third overall and was rated second by public respondents. This suggests that public institutions may experience greater difficulty allocating funds for ongoing staff development compared to their private counterparts. While public

and private respondents closely agreed on the severity of financial issues, their relative emphasis on specific cost components reflects differing operational constraints.

Beyond financial barriers, knowledge-related barriers such as “*B4- Lack of sufficient experts in BIM and sustainable buildings*” and “*B3- Lack of knowledge about BIM implementation in sustainable buildings*” also ranked highly, 4th and 5th respectively in the overall list. However, a notable divergence was observed in their sectoral rankings: while B3 was ranked 12th by public sector participants, it held the 5th position in the private sector. This disparity may indicate that private firms are more acutely aware of skill gaps, likely due to their greater involvement in BIM-integrated projects and client-driven performance expectations.

Organizational and regulatory barriers, including “*B2- Resistance of professionals to new technologies*”, were rated much lower overall, with B2 ranked 13th. Interestingly, both sectors ranked this barrier similarly, suggesting that while institutional resistance exists, it is not perceived as a primary challenge compared to financial and technical issues.

Software-related barriers such as “*B14- Unreliable estimation for the energy performance analysis of sustainable buildings*”, “*B12- Interoperability problems in Building Information Modeling (BIM),*” and “*B13- No specific BIM type (eQUEST, Autodesk Green Building Studio etc.) that conducts all sustainable analysis*” were ranked 11th, 12th, and 15th overall, respectively. Public sector participants ranked B14 higher (7th), indicating a greater concern about BIM’s limitations in performing environmental analyses critical for compliance or policy reporting. In contrast, private firms may have adapted to these limitations through workarounds or third-party integrations.

“*B6- Copyright problems about data*” and “*B7- Difficult to use in complex projects*” were consistently ranked among the lowest across all groups, reflecting a shared perception that legal and process-related barriers are less critical at present. In summary, the analysis of Table 6.1 highlights that financial and knowledge-related issues are perceived as the most urgent obstacles to BIM implementation in sustainable

buildings in Türkiye. While public and private sector participants generally agree on the overall barrier landscape, nuanced differences in their rankings underscore varying operational realities and priorities.

As illustrated in Figure 6.3, 86.08% of the participants are employed in the private sector. The results of the Mean Score Analysis for the private sector are identical to those of the overall analysis. Similarly, Table 6.1 demonstrates that the relative importance ratings of the barriers in the private sector are exactly the same as those observed in the overall results.

Table 6.1 Ranking of Identified Barriers

ID	Overall			Public			Private		
	Mean	Std. Dev.	Rank	Mean	Std. Dev.	Rank	Mean	Std. Dev.	Rank
B17	4.58228	0.81031	1	4.45455	0.82020	1	4.60294	0.81295	1
B18	4.48101	0.73136	2	4.27273	0.90453	3	4.51471	0.70165	2
B16	4.39241	0.89754	3	4.36364	1.02691	2	4.39706	0.88334	3
B4	3.98734	0.60962	4	3.63636	0.50452	4	4.04412	0.60923	4
B3	3.82278	0.71180	5	3.27273	0.64667	12	3.91176	0.68535	5
B5	3.82278	0.72959	6	3.45455	0.68755	9	3.88235	0.72337	6
B9	3.82278	0.97085	7	3.63636	1.12006	5	3.85294	0.95049	7
B1	3.68354	0.67071	8	3.63636	0.67420	6	3.69118	0.67487	8
B11	3.58228	0.82598	9	3.45455	0.82020	10	3.60294	0.83111	9
B10	3.50633	0.94562	10	3.54545	1.03573	8	3.50000	0.93840	10
B14	3.45570	0.85930	11	3.63636	0.92442	7	3.42647	0.85197	11
B12	3.07595	0.87372	12	3.27273	0.78625	14	3.04412	0.88830	12
B2	3.00000	1.15470	13	2.90909	1.13618	16	3.01471	1.16533	13
B8	2.96203	0.93976	14	3.45455	0.93420	11	2.88235	0.92283	14
B13	2.82278	0.97085	15	3.27273	0.90453	13	2.75000	0.96776	15
B15	2.70886	1.01466	16	3.00000	0.89443	15	2.66176	1.03102	16
B6	2.58228	0.84136	17	2.63636	0.80904	17	2.57353	0.85197	17
B7	2.29114	0.75366	18	2.45455	0.68755	18	2.26471	0.76525	18

6.3 Exploratory Factor Analysis Findings

Before conducting the Exploratory Factor Analysis (EFA), the Cronbach's Alpha Test was applied to assess the reliability of the data [97]. This test measures the internal consistency of the survey, i.e., how well the items (questions) intended to measure the same construct are correlated with one another. The reliability index of the data ranges

from 0 to 1 ($0 < \alpha < 1$) [97]. A value of Cronbach's Alpha above 0.5 indicates that the data is reliable and suitable for use in EFA [83]. As shown in Table 6.2, the Cronbach's Alpha value obtained from the survey conducted for this research is 0.610, demonstrating acceptable reliability.

Table 6.2 Cronbach's Alpha Test Results

Cronbach's Alpha	N of Items
0.610	18

Suitability for EFA was further confirmed through the Kaiser Meyer Olkin (KMO) Test and Bartlett's Test of Sphericity. The KMO test evaluates the adequacy of the correlation matrix by examining the proportion of common variance among variables. When sufficient common variance exists, factor analysis is deemed appropriate. If this condition is not met, variables with low shared variance are typically excluded before performing EFA [97]. A KMO less than 0.60 is considered unsatisfactory to continue the analysis. Table 6.3 shows that the KMO value of the current study was 0.643 (>0.60), which comes under from a moderate sample adequacy level.

Table 6.3 Results of the Kaiser-Mayer-Olkin and Bartlett's Test of Sphericity

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.643
Bartlett's Test of Sphericity	Approx. Chi-Square	339.126
	df	120
	Sig.	.000

KMO is frequently reported with Bartlett's Test of Sphericity, which measures whether the relationships between variables are significantly different from zero, indicating how strongly the variables are related to one another [97]. A statistically significant result ($p < 0.05$) indicates that the data are suitable for factor analysis [97]. As shown in Table 6.3, Bartlett's Test yielded a p-value below 0.05, confirming that the data are appropriate for conducting factor analysis.

After passing the KMO and Bartlett's Test, Exploratory Factor Analysis (EFA) was conducted. The Rotated Component Matrix is a table that illustrates the factor structure, showing the factor loadings obtained from the EFA, as presented in Table 6.4. During EFA, variables (in this case, barriers) may load onto more than one factor. Rotation is applied to simplify these loadings, ensuring that each variable is associated with a single factor.

The numbers in each cell of Table 6.4 represent the factor loadings of the respective barriers on the relevant factors. If a variable exhibits a high loading on more than one factor, it is typically removed from the analysis. In this study, “B3- Lack of knowledge about BIM implementation in sustainable buildings” and “B6- Copyright problems about data” were excluded because their factor loadings were below the 0.5 threshold, indicating that they had no significant impact on the factor structure. As presented in Table 6.6, six distinct categories were extracted from the remaining 16 barriers. The study identified six key categories that hinder BIM implementation in sustainable building projects in Türkiye, namely:

1. *Financial Barriers*
2. *Usability & Collaboration Barriers*
3. *Software Barriers*
4. *Market & Governmental Barriers*
5. *Knowledge Barriers*
6. *Organizational & Regulatory Barriers*

Table 6.4 Rotated Component Matrix

Barriers	Component					
	1	2	3	4	5	6
Category 1: Financial Barriers						
B16- High training cost	0.921					
B17- High licensing cost	0.919					
B18- High cost of BIM experts	0.676					
Category 2: Usability & Collaboration Barriers						
B7-Difficulty of use in complex projects		0.646				
B8- Lack of coordination among project stakeholders		0.565				
B15- The complexity of the interface of the BIM software		0.772				
Category 3: Software Barriers						
B12- Interoperability problems in Building Information Modeling (BIM)			0.495			
B13- No specific BIM type (eQUEST, Autodesk Green Building Studio, etc.) that conducts all sustainable analysis			0.601			
B14- Unreliable estimation for the energy performance analysis of sustainable buildings			0.822			
Category 4: Market & Governmental Barriers						
B9- Lack of market demand				0.765		
B10- Lack of government support				0.816		
Category 5: Knowledge Barriers						
B1- Lack of qualified BIM users					0.516	
B4- Lack of sufficient experts in BIM and sustainable buildings					0.646	
B11- Lack of demonstration projects to recommend BIM implementation in sustainable buildings					0.767	
Category 6: Organizational & Regulatory Barriers						
B2- Resistance of professionals to new technologies						0.748
B5- Lack of BIM implementation guidelines and standards in sustainable buildings						0.606

The Rotation Sums of Squared Loadings (Table 6.5) appear in the output for factor analysis and indicate the amount of variance explained by each category after the rotation process. The 'Cumulative%' represents the cumulative percentage of the total variance explained by the categories.

Table 6.5 Rotation Sums of Squared Loadings

Rotation Sums of Squared Loadings			
Component	Total	% of Variance	Cumulative %
1	2.616	16.35	16.35
2	1.830	11.44	27.79
3	1.696	10.6	38.38
4	1.605	10.03	48.41
5	1.527	9.54	57.96
6	1.313	8.21	66.16

CHAPTER 7

DISCUSSION

This chapter discusses the findings of the research in light of the reviewed literature and the results presented in Chapter 6. The analysis focuses on interpreting the significance of the identified barriers, understanding the implications of the factor groupings, and comparing the results with existing research. Key takeaways from the Exploratory Factor Analysis (EFA) and the Mean Score Method are examined to contextualize the challenges of BIM implementation in sustainable building projects in Türkiye.

7.1 Financial Barriers

Category 1 encompasses three primary financial barriers: "*B16- High training costs*", "*B17- High licensing costs*" and "*B18- High costs of BIM experts*". The loading factors for these items were 0.921, 0.919, and 0.676, respectively, as shown in Table 6.6. This category accounted for the largest proportion of the total variance, explaining 16.35%, as detailed in Table 6.7.

Generally, the most significant obstacle identified in public and private sector responses is "*B17- High licensing cost*", with a Mean Score of 4.58228, 4.45455, and 4.60294, respectively. As indicated in the Rotated Component Matrix, this barrier also emerges as a critical issue within the financial category. The high licensing cost of BIM software is a global challenge within the AEC industry [9]. Governments can mitigate the financial burden on small and medium-sized enterprises (SMEs) by introducing targeted subsidies, tax rebates, or grants to lower the initial and recurring costs associated with BIM software licenses. Such measures would facilitate the adoption of BIM technologies and the integration of sustainable practices within smaller construction firms [98]. Furthermore, promoting the development adoption of

open-source or cost-effective BIM software could allow smaller firms to access essential tools without the substantial licensing fees linked to proprietary systems [99]. This would, in turn, support the implementation of sustainable practices while effectively managing costs. In the construction industry of Türkiye, the most significant concerns are the fluctuations in the Turkish Lira. As BIM software is licensed in foreign currencies, the substantial fluctuations of the Lira in comparison to the US Dollar or Euro reduce the purchasing power for licenses, particularly for small to medium-sized firms [100].

To eliminate the impact of this barrier, subscription models such as pay-per-use or tiered could be implemented by BIM software providers. These flexible pricing strategies would enhance affordability for SMEs, enabling firms to scale their use of BIM technologies according to project needs, thereby reducing the financial burden associated with the upfront purchase of full software licenses [98].

“B18- High cost of BIM experts” is identified as the second most significant barrier overall, as well as within the financial category, with a mean score of 4.48101. It ranks as the second most important barrier in the private sector (Mean Score = 4.51471) and the third most significant in the public sector (Mean Score = 4.27273). Several factors contribute to the high cost of BIM experts. Firstly, the most challenging part is that the experts need expertise in both BIM software and sustainable buildings [100]. Training in sustainability assessment systems, which have complex simulations and assessments, and the BIM database in general, are different from each other. Secondly, experts must participate in continuing education and training programs to keep themselves current in their fields. These ongoing training processes affect the high rates of experts. Lastly, sustainable buildings are generally more complex than traditional buildings, involving additional interaction between different stakeholders, which increases the time and effort required from experts. The solution to this is for both government and industry associations to work together to create structured systems for BIM training and certification. Such initiatives would help upskill the existing workforce and cultivate new professionals at lower costs, thereby enhancing the overall affordability and accessibility of BIM expertise across the construction sector [101].

“B16- High training cost” is identified as the third most significant barrier, not only within the financial category but also among all barriers based on the Mean Score Method, with a mean score of 4.39241. It ranks as the third most important barrier for participants employed in private companies (Mean Score = 4.39706) and the second most important for those in the public sector (Mean Score = 4.36364). The high cost of training presents a significant barrier to the effective application of Building Information Modeling (BIM) technology in sustainable building projects. Unpredictable expenses associated with technical training, along with a shortage of cross-disciplinary professionals, limit users’ access to comprehensive instruction and thereby reduce overall project efficiency [7]. Moreover, the significant financial burden of acquiring and maintaining BIM software further impedes its widespread adoption in sustainable construction practices [7]. For small contractors, high training costs represent a particularly substantial barrier to entry into the sustainable building sector [65]. These costs result from the new technologies, equipment, and power investment aimed at complying with the sustainable construction regulations.

In addition to the BIM software, additional types of analysis must be performed by the BIM software users, such as energy performance analysis, carbon footprint appraisals, and green material incorporation users to BIM databases. Such specific analyses assume specific knowledge of sustainability assessment systems, which are not part of the typical BIM training. Given that BIM is relatively new and a fast-evolving technology, it requires ongoing learning and adaptation, so companies need to invest in their institutions to back up continuous training [102]. Several tactical measures against the high training costs of sustainable construction buildings could be taken. Governments have a critical role in providing financial subsidies and incentives to alleviate the financial burden of small- and medium-sized contractors in obtaining sustainability-related training [65]. In addition, cooperation between the building industry and education will enable the development of tailored, low-cost training programs that meet industry needs. Encouraging contractors to participate in continuing professional development programs is also beneficial because such programs offer a means for enhancing skills on an ongoing basis, and that is affordable [65].

Since the use of BIM software for sustainable building projects is a new and emerging area in Türkiye, the necessary training becomes a challenge because it is expensive. The Small-Medium Enterprises (SMEs) and the Supply Chain Financial Assistance Programs can facilitate a massive reduction in the economic hardship of the SMEs to deploy their resources in training and software procurement [99]. These schemes may consist of special tax incentives, grants, or subsidies to stimulate the adoption of BIM technologies and training, for example, in construction [99]. Furthermore, developing industry-specific training programs which is cost-effective and encourage public and private collaborations among government authorities, educational institutions, and private sector companies can be reasonable for the Türkiye's construction industry, as the training is not only customized but also fits the application of the training initiatives to the industry's ongoing processes [99].

7.2 Usability & Collaboration Barriers

Usability and collaboration barriers are grouped under Category 2 and include the following items, as identified in the Rotated Component Matrix (Table 6.6): “*B7- Difficulty to use in complex projects*” (factor loading = 0.646), “*B8- Lack of coordination among project stakeholders*” (factor loading = 0.565), and “*B15- The complexity of the interface of the BIM software*” (factor loading = 0.772). This category accounts for the second highest proportion of total variance, explaining 11.44%, as shown in Table 6.7.

Among these, “*B7- Difficulty to use in complex projects*” was identified as the least significant barrier based on the Mean Score Method (2.29114). Nevertheless, it remains a key obstacle within the usability and collaboration category. Currently, there is no specialized BIM software capable of performing all necessary analyses simultaneously for complex projects, particularly those requiring comprehensive green building assessments [36]. This limitation results in frequent data exchange challenges both between different types of analyses and among various stakeholders, such as architects and structural engineers, ultimately affecting the effectiveness of BIM implementation [103]. Furthermore, the BIM database is not inherently designed for

sustainability assessments. Consequently, sustainable material selection and other green analyses often necessitate data exports to external tools.

Similarly, in Türkiye, the development of BIM templates is largely time-consuming, since a real national green building certification system of reference does not exist yet, making BIM adoption more complex for complex building projects [104]. In order to counter these barriers, it is necessary to promote open BIM standards like Industry Foundation Classes (IFC). These standards enable seamless data exchange across different disciplines and software platforms [44]. Their adoption facilitates improved collaboration, reduces data loss, and supports more efficient and integrated project delivery throughout the construction lifecycle [60]. To address the challenges related to integrating energy analysis tools, such as energy performance simulations, daylighting studies, and life cycle assessments, with Building Information Modeling (BIM), it is essential to develop dedicated plugins or interoperable workflows that effectively link BIM platforms with simulation tools (e.g., IES-VE, EnergyPlus) [76]. These innovations would greatly enhance data interoperability, reduce the data analytical process, and improve general sustainability decision-making accuracy and efficiency at both the design and construction stages [76].

“B15- The complexity of the interface of the BIM software” represents another significant barrier within the usability and collaboration category. It ranks as the third least important in this group based on the mean score of 2.70886. Complex software interfaces can impede project development, particularly for users who lack comprehensive training in BIM. A user-friendly interface, by contrast, promotes faster adoption and reduces the likelihood of errors during the design and collaboration phases [76].

As discussed under *“B7- Difficulty to use in complex projects”*, the foundational design of most BIM software is not inherently geared toward sustainability. Integrating sustainability features or incorporating external sustainable design tools often increases the software’s complexity. While this may enhance consistency in analysis, it can also complicate the user interface. In Türkiye, the complexity of BIM interfaces may be further exacerbated by a lack of integration with local standards and codes.

This highlights the need for more accessible, regionally compatible BIM tools that support adjustable features aligned with national practices, regulations, and language preferences.

Moreover, “*B8- Lack of coordination among project stakeholders*” remains a critical concern in this category. As demonstrated in Table 3.1, not all BIM software is accessible or usable by every stakeholder group, leading to discrepancies in collaboration, particularly in sustainable building projects. Variations in stakeholders' BIM expertise, understanding, and roles further compound this issue. Despite its importance within the usability and collaboration category, this barrier holds the fourteenth position in overall significance, with a mean score of 2.96203.

Exchanging files between BIM software platforms can lead to inconsistencies that may affect stakeholders' understanding, thereby increasing time and effort. However, in Türkiye, BIM Execution Plans (BEPs) are not standardized, and most of the companies or firms have to create their own BEP, which may reduce the coordination between the related parties [105]. For instance, the Istanbul New Airport (IGA) project, a sustainable building complex, utilized BIM software, but the complexity of the software posed coordination challenges during the Architecture, Engineering, and Construction (AEC) process [106]. In Türkiye and many other countries, professionals working on projects operate within roles in place for BIM are either not clearly stated or overlapping. This fragmentation of organizations has long hindered the deployment of BIM for environmental design tool purposes, including energy modeling, sustainable material selection, and life cycle cost analysis [76]. To address these issues, an early-stage partnership is needed to tackle those problems. Decisions that may contribute to the energy efficiency and life-cycle of a building can easily be incorporated into the BIM model, therefore improving the overall sustainability and performance of the project [107]. It is also very important to use project delivery methods that foster cooperation, such as Integrated Project Delivery (IPD) or Design and Build. Traditional delivery methods have the effect of separating stakeholders, while IPD provides shared goals and the ability for real-time, model-based decision and making that enhances project collaboration and efficiency [76].

7.3 Software Barriers

Category 3, which pertains to software-related barriers, accounts for the third highest proportion of total variance, explaining 10.6% as shown in Table 6.7. This category includes three significant barriers: “*B12- Interoperability problems in Building Information Modeling (BIM)*”, “*B13- No specific BIM type (eQUEST, Autodesk Green Building Studio, etc.) that conducts all sustainable analysis*”, and “*B14- Unreliable estimation for the energy performance analysis of sustainable buildings*”. The factor loadings derived from the exploratory factor analysis (EFA) were 0.495, 0.601, and 0.822, as shown in Table 6.6. Referring to Table 6.2, “*B12- Interoperability problems in Building Information Modeling (BIM)*” ranks twelfth with a mean score of 3.07595, “*B13- No specific BIM type (eQUEST, Autodesk Green Building Studio, etc.) that conducts all sustainable analysis*” ranks fifteenth with a mean score of 2.82278, and “*B14- Unreliable estimation for the energy performance analysis of sustainable buildings*” ranks eleventh with a mean score of 3.45570, out of a total of 18 barriers. The interoperability of different software systems is a critical issue, particularly for sustainable building projects that require the integration of various systems, such as architectural design, energy modeling, green analysis, and structural analysis. During data export between these systems, inconsistencies in data standards, especially in Türkiye, can lead to the loss of important information [108]. Barrier *B12* is closely related to *B13*, as no single type of BIM software is capable of performing all necessary green analyses. As a result, experts must use multiple BIM software tools, which exacerbates the interoperability problem.

Unreliable energy performance analysis in BIM can arise from several factors. First, incorrect input data can lead to unreliable results, as certain parameters, such as the material properties of sustainable buildings, must be manually entered into the software [109]. Second, the lack of full integration between BIM tools for green analysis makes data transfer between systems difficult, further contributing to unreliable results. Climate data is crucial for sustainable building projects, particularly for analyses. For instance, in Türkiye, buildings can have different heating and cooling loads because of the Mediterranean climate, and should be taken into account during the design. Currently, the use of BIM for energy analysis is based on loads, airflows,

and heat transfer coefficients that are estimated and simulated values, which can be unreliable. Autodesk Ecotec overestimated illuminance levels in 98% of the observations and underestimated thermal loads in all field measurements, according to a case study of a LEED Gold-certified university building in the United States [110]. This problem results in both increased costs and time delays in project schedules.

To address these issues, utilizing open standards such as the Industry Foundation Classes (IFC) and Green Building XML (gbXML) can enhance compatibility between BIM and energy simulation software [60]. Since no single BIM tool can comprehensively address all aspects of sustainability analysis, it is essential to have a thorough understanding of the capabilities and limitations of various tools to select the most effective combination tailored to the specific requirements of the project [83].

7.4 Market & Governmental Barriers

Category 4, which pertains to market and governmental barriers, includes “*B9- Lack of market demand*”, with a factor loading of 0.765, and “*B10- Lack of government support*”, with a factor loading of 0.816, as shown in the Rotated Component Matrix in Table 6.6. This category accounts for the fourth-highest proportion of total variance, explaining 10.03% as presented in Table 6.7. Referring to Table 6.2, *B9* ranks seventh with a mean score of 3.82278, while *B10* ranks tenth with a mean score of 3.50633, making them the seventh and tenth most significant barriers overall.

In Türkiye, there is limited market demand for BIM in sustainable building projects, primarily because many firms do not fully understand BIM's role in sustainable construction. Both BIM and sustainable building concepts are relatively new, which negatively impacts market demand for BIM in this sector [111]. Additionally, the transition from traditional methods to BIM is not widely embraced within the Turkish construction industry, as BIM software is not mandatory for projects. The lack of market demand for BIM in sustainable building projects has slowed the adoption of sustainable practices, consequently reducing Türkiye's competitiveness compared to other countries [111].

The slow adoption of sustainable building practices in Türkiye can be attributed to several factors. The most significant barriers to the widespread implementation of sustainability in the Turkish construction industry are economic constraints and government-related challenges [111]. Government support is crucial for the successful development and deployment of technological systems in both the industry and the education sector. To overcome these barriers, BIM could benefit from soliciting government support to aid its implementation. The government can encourage technological advancement by funding research, fostering the creation of resources and services, establishing state-led standard-setting consortia, creating national science parks, acquiring necessary goods, and regulating competition from the private sector [112].

Government policies and regulations vary across countries, and as such, the use of BIM for sustainable building projects is neither mandatory nor fully supported by the government in Türkiye [113]. Unlike countries such as the United Kingdom and Singapore, where mandatory BIM requirements for public procurement have been established, Türkiye lacks standardized protocols, contractual frameworks, and official guidelines to support BIM adoption in government-led projects [113]. This regulatory gap leads to inconsistent practices within the industry and acts as a significant deterrent to widespread BIM adoption.

One key recommendation to address these barriers is the establishment of national regulations mandating the use of BIM in public construction projects. This would set a precedent and generate momentum for broader industry adoption [114]. Another recommendation is to promote the development of affordable BIM software packages for small and medium-sized enterprises (SMEs) through collaborations between the government and software providers [99].

7.5 Knowledge Barriers

Category 5 pertains to knowledge-related barriers and accounts for the fifth highest proportion of the total variance, explaining 9.54%, as shown in Table 6.7. This category includes three key barriers: “B1- Lack of qualified BIM operators”, “B4-

Lack of sufficient experts in BIM and sustainable buildings”, and “*B11- Lack of demonstration projects to recommend BIM implementation in sustainable buildings*”. The factor loadings from the Exploratory Factor Analysis (EFA) for these barriers were 0.516, 0.646, and 0.767, respectively, as indicated in Table 6.6. According to Table 6.2, *B1* ranks eighth with a mean score of 3.68354, *B4* ranks fourth with a mean score of 3.98734, and *B11* ranks ninth with a mean score of 3.58228, out of 18 identified barriers. As discussed under the financial barriers, the high costs associated with licensing and training contribute to a shortage of qualified BIM users, particularly those specializing in sustainable buildings.

This lack of expertise can be the source of major project-related issues, such as timing delays or variances in quality. Inadequately trained professionals are potentially dangerous to project plans and deadlines. Additionally, new staff must be recruited or trained, which is time-consuming and expensive. “*B4- Lack of sufficient experts in BIM and sustainable buildings*” is the fourth most significant barrier to BIM adoption for sustainable buildings, both overall and within the knowledge barriers category. *B4* is a people-related barrier, and that highlights a critical challenge in the industry: the shortage of professionals with the expertise to effectively integrate BIM into sustainable construction projects. Many employees in construction firms lack the necessary skills to implement BIM seamlessly, leading to limited experimentation and adoption within organizations [115]. The major cause of this barrier is the lack of education that helps in BIM knowledge and introduces the necessary skills. Since BIM is a relatively new and still emerging technology in the construction sector, especially in Türkiye, the number of qualified experts remains low.

This has led to many works using traditional forms of working rather than working with BIM. In light of this challenge, governments and industry associations are urged to invest in focused educational programs. These initiatives can include BIM-specific sustainability training and certification programs, training workshops, and closer cooperation between the academic and construction sectors [111]. These can assist to close the knowledge gap and accelerate the transition to sustainable and digital construction [111]. Stakeholders and construction firms likely face challenges in identifying benefits from BIM for sustainable buildings because of the gap between

academic research and practical demonstration [116]. As discussed earlier, BIM systems are not created for sustainability, and tasks related to building energy modeling and material selections are usually performed in other systems and later added to BIM contexts. This fragmented workflow slows down project development and creates uncertainty, particularly in the absence of real-world examples demonstrating comprehensive integration. In Türkiye, the lack of demonstration projects showcasing the effective use of BIM applications in sustainable building design limits the widespread adoption of BIM in the industry [111]. To overcome this barrier, the Turkish government should also initiate and sponsor some pilot projects that footage BIM and sustainable construction principles that combine BIM and sustainable construction practices [111]. These initiatives would generate valuable insights into the practical benefits and performance outcomes of BIM-based sustainable projects, thereby fostering greater trust, knowledge, and acceptance among industry stakeholders.

7.6 Organizational & Regulatory Barriers

Category 6, which pertains to organizational and regulatory barriers, accounts for the sixth highest proportion of the total variance, explaining 8.21%, as shown in Table 6.7. This category includes two key barriers: “*B2- Resistance of professionals to new technologies*”, and “*B5- Lack of BIM implementation guidelines and standards in sustainable buildings*”. According to the Rotated Component Matrix in Table 6.6, the factor loadings for these barriers were 0.748 and 0.606, respectively. Based on the mean scores presented in Table 6.2, *B2* ranks as the thirteenth most significant barrier with a mean score of 3.00000, while *B5* is ranked sixth, with a mean score of 3.82278, among the 18 identified barriers.

Small and medium-sized enterprises (SMEs) often prefer traditional construction methods due to several persistent barriers, including high licensing costs, the lack of standardized guidelines, and the difficulty in recruiting or training qualified BIM professionals [65, 66]. These challenges significantly contribute to the resistance of professionals toward adopting innovative technologies such as BIM. In addition to that, in the absence of a structured framework, the reluctance increases due to the

demonstration of how BIM contributes to sustainable objectives. This lack of detailed information on BIM about sustainable design and construction is likely to prevent industry professionals from acting as advocates or adopters of BIM for sustainable initiatives.

To reduce resistance, demonstration projects and open case studies showing the benefits of BIM performance are advised. Such initiatives can serve as practical proof-of-concept examples, highlighting BIM's capacity to enhance energy performance, facilitate life cycle assessment, and ensure compliance with green building standards [76, 117] "*B5- Lack of BIM implementation guidelines and standards in sustainable buildings*" represents a significant process-based barrier to the effective use of BIM. BIM standards not only provide the project owner with the desired data format but also support project continuity, improve productivity, and contribute to the overall sustainability of BIM implementation [60]. Nevertheless, the lack of specialized BIM standards and rules for sustainable building projects pushes many companies and engineers to use the general rules of established BIM practices of other scopes by applying them or linearly transferring them, which is a serious problem. In addition, due to the rapid changes in BIM technologies and the frequent updates of BIM-related standards, there are some barriers that professionals must overcome to adapt [118]. However, it is difficult to maintain the alignment of the current BIM workflow and practice with new best practices, while new standards and guidelines are always being developed [101]. These challenges cumulatively discourage the efficient use of BIM for a sustainable built environment.

To address these issues, it is essential to accelerate the development and standardization of BIM sub-models to better meet diverse user requirements and ensure seamless information exchange throughout the architecture, engineering, and construction (AEC) project lifecycle [119].

CHAPTER 8

CONCLUSION

This study aimed to identify and analyze the key barriers to Building Information Modeling (BIM) implementation in sustainable buildings in Türkiye. Through an extensive literature review, 18 of the most significant barriers to BIM implementation for sustainable construction were identified. To validate these findings and gather professional insights, a structured survey was developed. Before its full deployment, a pilot study was conducted to ensure the clarity and effectiveness of the survey questions and format. For the methodology, the Mean Score Method and Exploratory Factor Analysis (EFA) were employed. EFA, conducted using SPSS software, proved particularly valuable for addressing complex, multi-criteria issues by simplifying decision-making processes.

The results of the Mean Score Method revealed that the three most significant barriers are: “*B17- High licensing costs*”, “*B18- High cost of BIM experts*”, and “*B16- High training costs*”. Notably, all three are financial. In contrast, the three least significant barriers identified were: “*B15- The complexity of the interface BIM software*” (a technology-related barrier), “*B6- Copyright problems about data*”, and “*B7- Difficulty to use in complex projects*” (both process-related barriers).

According to the results of the Rotated Component Matrix from the Exploratory Factor Analysis (EFA), two items “*B3- Lack of knowledge about BIM implementation in sustainable buildings*” and “*B6- Copyright problems about data*” were excluded from further analysis due to their low factor loadings, indicating an insufficient effect size. The Rotated Component Matrix grouped the remaining barriers into six distinct categories:

- **Category 1-Financial Barriers:** This group includes *B16* to *B18*, which pertain to cost-related challenges.
- **Category 2-Usability & Collaboration Barriers:** Comprising *B7*, *B8*, and *B15*, these barriers relate to difficulties in software use and inter-professional coordination.
- **Category 3-Software Barriers:** Includes *B12* to *B14*, focusing on technical limitations of BIM software.
- **Category 4-Market & Governmental Barriers:** Encompasses *B9* and *B10*, which reflect external influences such as market dynamics and regulatory frameworks.
- **Category 5-Knowledge Barriers:** Consists of *B1*, *B4*, and *B11*, related to the lack of expertise and awareness within the industry.

These categorizations provide a clearer understanding of the multifaceted nature of BIM adoption barriers in the context of sustainable building in Türkiye. The summary of the Rotation Sums of Squared Loadings from the Exploratory Factor Analysis (EFA) provided insights into the percentage of variance explained by each category. Ranked from highest to lowest variance contribution, the categories are as follows: Financial, Usability & Collaboration, Software, Market & Governmental, Knowledge, and Organizational & Regulatory.

Given that both BIM and its application in sustainable building design are relatively new concepts, particularly within the global AEC industry and especially in Türkiye, further research is essential. Future studies can play a critical role in identifying solutions to existing barriers and promoting the adoption of BIM in the sustainable construction sector. Within each category, the most influential barriers identified are:

- **Financial:** “*B16- High training costs*”
- **Usability & Collaboration:** “*B15- The complexity of the interface of the BIM software*”
- **Software:** “*B14- Unreliable estimation for the energy performance analysis of sustainable buildings*”
- **Market & Governmental:** “*B10- Lack of government support*”

- **Knowledge:** “B11- Lack of demonstration projects to recommend BIM implementation in sustainable buildings”
- **Organizational & Regulatory:** “B2- Resistance of professionals to new technologies”

These findings underscore the multifaceted challenges of BIM adoption in sustainable building practices and highlight key areas for targeted intervention and policy development.

8.1 Limitations of the Study

This study has several limitations that should be considered when interpreting the findings. Firstly, the results obtained from the Exploratory Factor Analysis (EFA) may vary with changes in environmental databases, as well as in response to the specific characteristics of different building projects. Each construction project has unique requirements and constraints, which can differ significantly not only from project to project but also experience of the participants.

Secondly, increasing the number of participants may influence the analysis. The sample size, while sufficient for EFA, may still limit the statistical power and robustness of the conclusions. A larger and more diverse sample could enhance the reliability and generalizability of the results. The results of the questionnaire survey indicated that the majority of participants are employed in private companies. Repeating the survey with a larger sample of participants from the public sector may influence the analysis and the overall findings. This is because each participant possesses varying levels of knowledge regarding both BIM and sustainable buildings, as well as the adoption of BIM for sustainable building projects. Moreover, each participant has worked or is currently working on different sustainable projects, each with unique characteristics that may impact the results of the questionnaire survey. The study relies on self-reported data collected through surveys, which may be subject to response bias. Although efforts were made to ensure the clarity and neutrality of the

survey instrument, participants' interpretations or subjective experiences may have influenced their responses.

Finally, future research could build on these findings by proposing and evaluating practical strategies for overcoming the identified challenges, possibly through longitudinal studies or comparative analyses across different project types. Moreover, the literature review reveals a lack of case studies or demonstrations regarding the use of BIM in sustainable buildings in Türkiye. Increasing the number of studies on the adoption of BIM in sustainable building projects could encourage broader implementation within the Turkish construction industry. Additionally, although there are several companies in Türkiye providing BIM consultancy services, they remain relatively unknown within the industry.

8.2 Directions for Future Studies

Future studies could delve deeper into the specific barriers within each of the identified categories to develop targeted, practical solutions for enhancing BIM implementation in sustainable construction. Additionally, interdisciplinary approaches—such as incorporating insights from psychology and organizational behavior—may provide valuable, multifaceted perspectives on the behavioral and institutional factors that influence BIM adoption.

Moreover, methodological advancements could further strengthen future research. For instance, incorporating multi-criteria decision-making techniques such as the *Analytical Hierarchy Process (AHP)* may offer a more structured and quantitative approach to ranking the importance of barriers. Combining qualitative insights with robust quantitative tools would enrich the analysis and support more effective decision-making in the management of green building projects, particularly during the construction phase. On the other hand, *Structural Equation Modeling (SEM)* provides a comprehensive and rigorous method for analyzing the relationships among multiple variables simultaneously. This analytical approach enables researchers to test and validate hypotheses regarding the interdependencies among technological, economic, and social factors that influence the adoption of BIM for sustainable building projects.

Furthermore, SEM facilitates a more accurate assessment of causal relationships, offering valuable insights into the complex dynamics underlying the adoption and development of this emerging technology.



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APPENDIX

A. Questionnaire Survey

ATILIM UNIVERSITY

DEPARTMENT OF CIVIL ENGINEERING

Investigating the Barriers to Building Information Modeling (BIM) Implementation in Sustainable Building Projects in Türkiye

The Purpose of the Questionnaire

This questionnaire survey is part of an ongoing graduate thesis study investigating the barriers to Building Information Modeling (BIM) implementation in sustainable building projects in Türkiye. Various challenges have been encountered due to the rise in the world population, consumption rates, and ecological changes. After the oil crisis that emerged in the 1970s, fossil energy resources were accepted as non-renewable and exhaustible. The use of fossil energy has led to global climate change, environmental pollution, and an increase in natural disasters. Other major environmental problems include deforestation, increased demand for natural resources, soil erosion, eutrophication, acidification, and the release of toxic substances. Because of these issues, there is a growing inclination towards alternative energy sources that consume less energy, reduce CO₂ emissions, and decrease dependence on fossil fuels, causing less harm to the environment. In this context, the concepts of "Sustainable Building" and "Green Building" have emerged to balance the natural and built environment. On the other hand, as a multifunctional method, Building Information Modeling (BIM) makes an essential contribution to the AEC (Architectural Engineering and Construction) industry and the construction of green buildings. BIM can be used in multiple areas, such as structural, architectural, MEP, landscaping, and energy analyses, among others. This study aims to gain insight into

the key barriers to implementing Building Information Modeling (BIM) in sustainable building projects in Türkiye. The questionnaire consists of demographic questions and technical questions. Completing the survey should take approximately 5-10 minutes.

Date:/...../.....

PART A. GENERAL INFORMATION ABOUT THE ORGANIZATION AND THE RESPONDENT

This section of the questionnaire comprises general questions related to the respondent's occupation, qualifications, industry, and experience they have for working in that industry.

(Please check the relevant box)

1- What is your education level?

- B.Sc. M.Sc. Ph.D.

2- What is your profession?

- Civil Engineer Architect Mechanical Engineer

- Electrical Engineer Industrial Engineer Energy Systems Engineer

- Other

3- What type of organization do you work for?

- Public Private

4- What type of organization do you work for?

- Owner Site Engineer Design Engineer
 Tendering Engineer Project Manager Academic

5- What is the age of the organization where you are currently employed?

- 0-5 years 5-10 years 10-20 years
 20-30 years Over 30 years

6- What is the age of the organization where you are currently employed?

- Below 100 employees 100-250 employees 250-500 employees
 Over 500 employees

7- How many years have you been actively involved in the construction industry? (If you are working in academia, how many years have you been actively engaged in this profession?)

- 1-5 years 6-15 years 16-25 years Over 25 years

8- How many sustainable building projects have you been involved in?

- None 1-5 6-10 11-15 More than 15

9- How many projects have you been involved in using Building Information Modeling (BIM)?

- None 1-5 6-10 11-15 More than 15

10- How many sustainable building projects have you been involved in using Building Information Modeling (BIM)?

- None 1-5 6-10 11-15 More than 15

PART B. BARRIERS

Please score the significance of the following barriers to Building Information Modeling (BIM) implementation in sustainable building projects with using the 5 point Likert scale (*1-Not at all important | 2-Slightly important | 3-Moderately important | 4-Very important | 5-Extremely important*).

No	Drivers	Score				
		1	2	3	4	5
B1	Lack of qualified BIM users	1	2	3	4	5
B2	Resistance of professionals to new technologies	1	2	3	4	5
B3	Lack of knowledge about BIM implementation in sustainable buildings	1	2	3	4	5
B4	Lack of sufficient experts in BIM and sustainable buildings	1	2	3	4	5
B5	Lack of BIM implementation guidelines and standards in sustainable buildings	1	2	3	4	5
B6	Copyright problems about data	1	2	3	4	5
B7	Difficulty of use in complex projects	1	2	3	4	5
B8	Lack of coordination among project stakeholders	1	2	3	4	5
B9	Lack of market demand	1	2	3	4	5
B10	Lack of government support	1	2	3	4	5
B11	Lack of demonstration projects to recommend BIM implementation in sustainable buildings	1	2	3	4	5
B12	Interoperability problems in Building Information Modeling (BIM)	1	2	3	4	5

B13	No specific BIM type (eQUEST, Autodesk Green Building Studio etc.) that conducts all sustainable analysis	1	2	3	4	5
B14	Unreliable estimation for the energy performance analysis of sustainable buildings	1	2	3	4	5
B15	The complexity of interface of the BIM software	1	2	3	4	5
B16	High training cost	1	2	3	4	5
B17	High licensing cost	1	2	3	4	5
B18	High cost of BIM experts	1	2	3	4	5

(Optional)

Would you like to contribute any additional barriers to the questionnaire, based on your knowledge and experience, that you believe are significant within this context?

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