Turkish Journal of Civil Engineering, 2026, 77-103, Paper 832, ***Research Article***

Structural Equation Model for BIM Adoption in the Turkish Construction Industry

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ABSTRACT

The construction industry is criticized as lagging behind other sectors in terms of digitalization and technology adoption. Building Information Modelling (BIM) is widely acknowledged as a transformative tool that can drive significant progress in the construction industry amid ongoing technological developments. Despite widespread recognition of BIM's benefits for the construction industry, adoption rates in Türkiye remain below expectations. Therefore, this study aims to present a BIM adoption model tailored to the Turkish construction industry. The model was tested using the Structural Equation Modelling (SEM) method, incorporating insights from 150 industry professionals in Türkiye. According to the SEM analysis results, "Environmental Factors" have a significant impact on "Organizational Factors" and "Perceived Ease of Use" while "Behavioral Intention" mediates the relationship between "Perceived Usefulness" and "Actual BIM Usage". Developed model highlights key areas for BIM adoption improvement in Türkiye. Additionally, the model can serve as a tool for assessing BIM adoption performance and facilitating benchmarking between companies, thereby boosting overall industrial success through improved BIM adoption.

Keywords: Building Information Modelling (BIM), construction industry, digitalization, Structural Equation Modelling (SEM), technology adoption.

Note:
- This paper was received on February 17, 2025 and accepted for publication by the Editorial Board on October 13, 2025.
- Discussions on this paper will be accepted by May 31, 2026.

• https://doi.org/10.18400/tjce.1641335

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1. INTRODUCTION

Construction companies need to advance in the field of technology and innovation to survive in the long term and to maintain competitive advantages by virtue of the changing business conditions, customer demands and rapid technological developments. Therefore, technological and innovative approaches such as Information Technology (IT) are one of the most important factors in terms of increasing the competitiveness of construction companies as well as ensuring the continuity of industiral success. Although the construction industry is listed as one of the more technologically backward sectors [1], it seems possible to close this gap with new opportunities. Building Information Modelling (BIM) stands out as a key and rapidly growing technology that has the potential to help bridge this gap. Its potential lies in the ability to revolutionize and elevate performance through the reduction of inefficiencies, the enhancement of productivity, and the facilitation of collaboration among project stakeholders [2]. Embracing BIM enables the visualization of designs, swift generation of alternative design options, automated assessment of model reliability, report generation, and forecasting of building performance [3]. Moreover, the integration of BIM presents significant advantages in expediting and simplifying project delivery [4]. Herewith, BIM is a system that should be used not only by large companies dealing with complex projects, but also by all construction companies that want to produce quality work, grow their business and reinforce their long-term presence in the industry.

Countries recognizing the ability and benefits of BIM technology in enabling seamless integration and cooperation between project participants at different project stages, are making the BIM use obligatory, especially for public projects. While some countries such as the UK, Germany, Norway and Finland require BIM use in public projects, others such as the US, China, South Korea, Brazil and Singapore have established their own BIM standards [5], [6]. In Dubai, BIM use is manditory for the construction companies that will carry out the construction works of the buildings higher than 40 storeys, hospital and university projects. Similarly, the European Union has sent a directive to member states for the use of BIM in public projects [7]. Another striking feature of countries with high levels of BIM adoption is that in these countries, certain BIM policies and strategies have been outlined by the government, especially in public projects [8]. Approaches of governments around the world to make BIM use mandatory leads to the willingness of both private and the public intities in construction industry to adopt and implement BIM technology, especially in large-scale projects. Unlike the countries mentioned above, the lack of standardized frameworks for managing the transition to BIM has hindered widespread adoption in Türkiye [9]. However, a recent amendment to the Zoning Regulation for Planned Areas represents a significant milestone in the country's digital transformation efforts within the construction industry. According to the recent amendment to the Zoning Regulation for Planned Areas, for projects to be determined by the Ministry, the construction permit annexes shall be prepared in accordance with the principles to be set by the Ministry and in compliance with the relevant BIM standards as of January 1, 2027 [87]. This regulatory development is expected to act as a major catalyst for BIM adoption and should be considered when evaluating current and future implementation trends in the national context. While this step demonstrates progress, broader strategic planning and public sector coordination remain limited, particularly in terms of developing national BIM standards and ensuring industry-wide readiness for compulsory implementation.

While Turkish firms working internationally have begun gaining BIM experience in response to contractual demands, the proportion of Turkish construction companies with BIM experience remains low [10]. Despite a growing demand for BIM in domestic contracts, both industry professionals and academic studies frequently note that the BIM adoption in Türkiye is still in its early stages compared to other countries [10], [11], [12]. In the ranking of the world's 250 largest international contractors announced by Engineering News Record (ENR), Türkiye ranked second with 43 companies [13]. Considering the leading role of Turkish construction companies, it is becoming a necessity for construction companies to adopt BIM technologies. In this context, it is evident that Turkish construction companies should move towards the use of BIM to increase and maintain their global competitiveness.

The adoption of BIM technology is steadily increasing across the construction industries globally. However, Türkiye is still a late adopter, experiencing a slower rate of BIM adoption compared to other countries. While numerous studies have developed BIM adoption models for various countries, a specific model tailored to Türkiye has yet to be created. This gap exists because various individual, organizational and sectoral factors influence BIM adoption level among Turkish construction companies. In addition, the challenges and process each country faces in implementing and transitioning to BIM are unique. For this reason, research on country basis are in an effort to present a specific adoption model shaped by the prominent factors for that country. As the number of BIM applications and trained users grows, the positive perception of BIM among users is expected to increase. This shift in perception could lead to changes in the BIM adoption process. Over time, even existing adoption models for a particular country may need to be updated to reflect changes in the mechanisms of BIM acceptance, driven by evolving attitudes and experiences of BIM users [14]. Therefore, study aims to proposed an up-to-date and country specific adoption model in order to estimate the relationships between the factors affecting BIM adoption with a focus on Turkish construction industry.

The main objective of this study is to identify the factors influencing BIM adoption and to develop a BIM adoption model tailored to the Turkish construction industry. The scope of the study is outlined as follows:

1. Determination of salient factors impacting BIM adoption in Turkish construction industry (through literature review and expert evaluations),
2. Categorization of determined factors under Technology Acceptance Model (TAM) as a tentative BIM adoption model,
3. Performing Structural Equation Model (SEM) analysis to revel the final BIM adoption model tailored to Turkish construction industry.

From this perspective, the integration of internationally recognized constructs with local expert input to capture the unique dynamics of the Turkish construction industry constitutes the core novelty of the proposed model. The proposed model allows companies to evaluate their BIM adoption status, benchmark against peers, and identify strategies to enhance their BIM capabilities. A key contribution of this study is its potential to improve sectoral success by enhancing project management competencies, as companies can use the model to identify necessary actions to accelerate BIM adoption. Ultimately, the developed model will deepen understanding of BIM and provide actionable guidance, helping construction stakeholders prepare more effectively for BIM projects.

This study is structured as follows: Section 2 presents the existing literature on BIM adoption studies across different countries and Türkiye to highlight the research gap and the novelty of this work. It is followed by Section 3 in which research methodology of the study is outlined, and Section 4 in which SEM findings are presented, respectively. After discussing the determined finding in Section 5, Section 6 concludes the practical and theoretical implications, limitations and recommendations for future research.

2. STUDIES ON BIM ADOPTION FOR CONSTRUCTION INDUSTRIES

In this section, summary of the studies which are focusing on “BIM adoption across various construction industries and for Turkish construction industry” are presented respectively.

2.1. BIM Adoption Studies across Various Construction Industries

Countries have conducted research to develop distinct BIM adoption frameworks, driven by factors such as their unique levels of development, technological capabilities, and awareness. The existing literature comprises a substantial number of investigations examining BIM adoption within the construction industries of various countries [2], [7], [14-42]. This diversity arises from the differences in BIM policy implementations across nations, resulting in customized adoption strategies for each country. The existing BIM studies on BIM adoption/acceptance in leading countries (China, South Korea, Singapore, Hong Kong, Australia, Taiwan, etc.) can be summarized as follows:

In Australia, a framework grounded in the Innovation Diffusion Theory (IDT) was proposed to examine BIM adoption challenges within small and medium-sized enterprises (SMEs), revealing that only 5% of SMEs reached BIM competency at Level 3, while most remained at Levels 1 and 2 [22]. The importance of staff capabilities was further emphasized as a critical driver of adoption [23]. In Europe, studies have highlighted several facilitating factors. For example, in Spain, the uptake of BIM was closely associated with technological skill development, a culture of collaboration, and backing from senior management. [39]. [38] highlighted the slow pace of BIM adoption in South Korea and proposed a model aimed at enhancing its uptake within the industry. Similarly, [16] focused on identifying strategic approaches to support BIM adoption by examining the varying intentions and attitudes of stakeholders in the South Korean construction industry. Another study [7] proposed a discriminant BIM acceptance readiness model for South Korea, addressing the gap between high BIM adoption rates and low user proficiency. As a sum, in South Korea, research pointed to a gradual evolution in both organizational competencies and user perceptions, with multiple studies indicating that perceptions toward BIM and its strategic value have improved over time [16], [38]. Additionally, [91] compared BIM adoption between Korean and the US and significant differences were identified in how individual and organizational intentions toward BIM acceptance relate to each other, how perceived usefulness influences organizational intention, and how consensus on appropriation affects BIM acceptance. In China, [20] highlighted that despite the numerous potential advantages of BIM, its uptake within the Chinese construction industry remains limited. To address this, they developed a TAM to better understand the factors influencing BIM adoption. In China, factors such as project scale, institutional frameworks, government-led incentives, and the maturity of technical capabilities have been emphasized as critical to successful BIM implementation [20], [25]. Similarly, in Taiwan, BIM adoption has been shaped by strong governmental policy support, competitive industry dynamics, and the availability of technological infrastructure, particularly within architectural firms [41]. In the context of Hong Kong, research based on surveys and expert interviews has identified a range of critical success factors specific to BIM implementation, underscoring the importance of both organizational and contextual elements [27]. These studies suggest that in advanced economies where digital transformation is actively supported by policy and regulation, BIM adoption is closely related to institutional readiness, workforce competence, and a culture of innovation.

2.2. BIM Adoption Studies for Turkish Construction Industry

Given that BIM adoption in Türkiye is still in its early stages, existing studies in the context of Turkish construction industry tend to focus predominantly on the benefits, barriers, and driving factors associated with its implementation. [43] studied BIM usage in the Turkish construction industry, finding limited adoption but growing awareness of its benefits. [44] developed BIM process maps for creating a BIM implementation plan, while [45] examined the BIM transition process in Turkish construction companies, analyzing the pre-transition, transition, and post-transition phases. [9] identified the existence of limited understanding of BIM benefits and a lack of skilled labor as the prominent barriers in BIM adoption through surveys of architectural and engineering firms. [46] proposed a roadmap for integrating BIM into traditional design processes in Türkiye whereas [12] analyzed the transition and implementation of BIM in three Turkish project offices. [47] investigated BIM implementation on a sample construction project, while [47] offered a strategic roadmap for BIM adoption, conducting interviews, SWOT analysis, and reviewing global best practices. [48] discussed the barriers in terms of their effects on BIM acceptance in the Turkish construction sector by prioritizing 280 data sets collected from architects and civil engineers with the Relative Importance Index (RII) method. On the other hand, [49] aimed to identify the critical success factors (CSFs) for BIM implementation among construction firms in the Turkish AEC industry with the help of SEM whereas [50] evaluated the CSFs of BIM implementation in the construction phase through case studies from Turkish construction industry. Another study performed by [51] revealed root factors that resist BIM implementation in the Turkish AEC industry. Although Türkiye was not directly chosen as the research focus, [88] primarily aimed to explore and identify the barriers to BIM implementation from the standpoint of public sector clients involved in construction projects within developing countries. To complement the analysis, enablers were also examined, as recognizing these facilitating factors can support stakeholders in mitigating the negative impacts of the identified barriers. The research methodology involved a comprehensive literature review, the collection of relevant case studies, and interviews conducted with professionals representing public clients in these case studies. Study reveals that unfavorable economic conditions, high costs, and unclear project benefits as the significant BIM adoption barriers. [89] examined the influence of project-based, company-based, and industry-based factors on BIM effectiveness in post-adoption using SEM. Their findings indicate that BIM effectiveness is primarily shaped by project- and company-level factors, with industry-level influences being indirect.

When the summaries of previous studies were evaluated, the importance of BIM adoption in the Turkish construction industry became evident once again. The common result of these studies is the necessity to increase the level of BIM adoption for the Turkish construction industry due to the lack of adequacy in its implementation even if the sectoral awareness of the benefits of BIM use is high [52]. To raise the adoption level in Türkiye, a tailored adoption model needs to be developed for Turkish construction industry. The literature review shows that even if some studies related to BIM adoption for Turkish construction industry exist, none of these studies has the objective of developing a solid model to enable this adoption.

3. RESEARCH METHODOLOGY

The study has an aim of developing a tailored BIM adoption model for Türkiye including the key factors influencing successful BIM adoption across Turkish construction companies. With this respect, research methodology adopted within the study is presented in Figure 1.

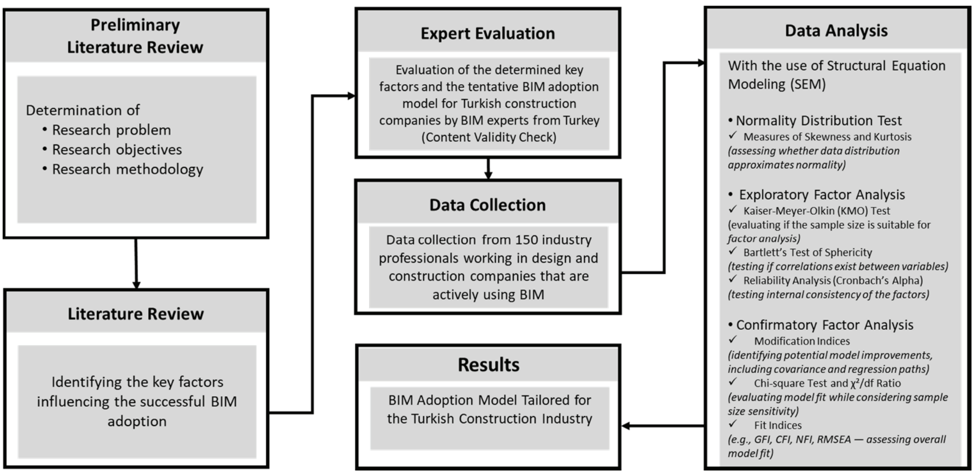

Figure 1 - Research Methodology

The methodology applied in this study is outlined in the following phases. First, a comprehensive literature review with a focus of ten years span was conducted to define the factors affecting BIM adoption in the construction industry by examining technological adoption, BIM integration, and BIM acceptance levels within the industry. Next, determined factors were categorized under Technology Acceptance Model (TAM) which was also constitutes the base of the tentative BIM adoption model for Türkiye. The factors under tentative model were then reviewed by 10 BIM experts from Türkiye to assess its validity and applicability for the Turkish construction industry. After finalizing the key factors and the tentative model, Structural Equation Modelling (SEM) method was used. For SEM analysis, AMOS software, which is widely recognized for SEM applications, was used to evaluate the data collected from 150 industry professionals from design and construction companies that are currently using BIM in their projects. The analysis included tests such as the normality distribution test, exploratory factor analysis, and confirmatory factor analysis to validate the model. The final output of this phase constitutes the validated BIM adoption model tailored for the Turkish construction industry.

3.1. Identification of Key Factors Influencing BIM Adoption in Turkish Construction Industry

TAM is widely used either for the adoption of information systems or testing user acceptance of new information technologies by individuals or societies [20], [53]. This model with a four-stage process aims not only to better understand user acceptance but also to provide theoretical guidelines for developing new technology systems. The first stage involves "external variables", followed by "perceived ease of use" and "perceived usefulness" in the second stage. The third stage includes "attitudes toward usage", and the final stage involves "behavioral intention". In the construction industry, TAM is frequently employed as a theoretical basis for creating models that evaluate the adoption or rejection of new technologies and approaches. In studies determining BIM adoption across various countries, TAM has been observed to be a commonly used model for assessing BIM adoption [54], [55]. Therefore, the tentative model presented in Figure 2 was constituted by using TAM as a foundation.

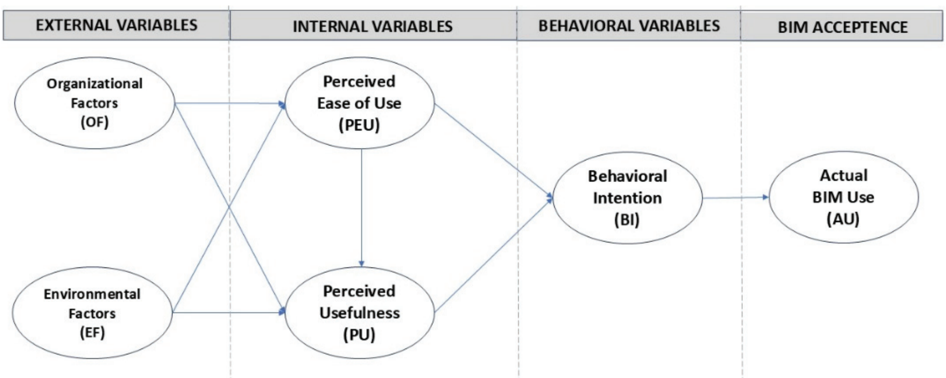

Figure 2 - Tentative BIM Adoption Model

The tentative adoption model includes four main stages: it starts with external variables, continues with internal and behavioral variables, and ends with BIM acceptance. Under external variables the tentative model consists of "Organization Factors (OF)", and "Environmental Factors (EF)" related to sectoral, financial and technical conditions. Internal variables that involve "Perceived Ease of Use (PEU)" and "Perceived Usefulness (PU)" were followed by "Behavioral Intention (BI)" and "Actual BIM Use (AU)", respectively.

After demonstrating the tentative model, a comprehensive literature review was conducted with a focus of ten years span for the identification of key factors influencing BIM adoption. To perform literature review, (BIM acceptance) OR (technology acceptance) OR (BIM adoption) OR (technology adoption) were used on Scopus scientific search engine. Thus, a total number of 35 studies related to BIM adoption in AEC industry were analyzed and a total number of 59 factors were identified [7], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [41], [42], [48], [53], [57], [58], [59], [60]. All determined factors were then grouped into the main categories under the tentative model, and objected for validation in terms of their suitability for Turkish construction industry.

3.2. Expert Evaluations

Expert opinion methodology was employed for testing the determined factors' validity. In this methodology, an expert is considered as someone who is qualified to answer questions posed by the researchers depending on her/his experience relevant to the research topic [61]. In the expert evaluation method, experts with knowledge in the subject matter provide insights into the developing study. These insights are then used to assess the draft material. Expert evaluation has a broad applicability in construction tasks such as decision-making and problem-solving [62]. Therefore, to evaluate both the tentative BIM adoption model and the sufficiency of determined factors affecting BIM adoption in the Turkish construction industry, 10 BIM experts from Turkish construction industry were contacted. Experts were selected among professionals with 5-10 years of BIM and industry experience. The number of experts involved in evaluations can vary, but approximately 5-7 experts gain acceptance in literature [63]. Therefore, the number of experts chosen for this study, also considering their high expertise in BIM implementations, is considered to be reliable.

To ensure content validity, the initially identified factors and the tentative BIM adoption model were reviewed by ten BIM experts with extensive BIM experience. Their feedback was used to verify whether each factor accurately represented the intended construct and was contextually relevant to the Turkish construction industry. Thus, content validity was established through expert consensus prior to the SEM analysis.

The demographic information of the experts are as follow: five participants are architects, and five are civil engineers. Seventy percent of the participants hold a Master's degree, 20% have a Doctorate, and 10% have a Bachelor's degree. Additionally, 40% of the experts work in large-scale companies, 30% of the experts in medium-sized companies, and 30% of the experts in small-scale companies.

As a result of the opinions received, the tentative BIM adoption model based on the presented factors was deemed sufficient for measuring the level of BIM adoption in the Turkish construction industry. Experts were also asked to evaluate the determined factors by using 1-7 Likert scale in terms their importance to shape the BIM adoption level in the Turkish construction industry. The data gathered from experts were then analyzed through Relative Importance Index (RII) method with an intention of using the most influential ones in the SEM analysis stage. RII is a highly accurate and commonly used method for analyzing the order of significance of the variables involved [64].

For the selection of salient factors, factors above the threshold of 0.8 according to RII analysis results were selected. As applied in [65], computed index values (IV) can be converted to five important levels as follows:

- $0.8 \leq IV \leq 1$ as to High (H),

- 0.6 ≤ IV < 0.8 as to High-Medium (HM),
- 0.4 ≤ IV < 0.6 as to Medium (M),
- 0.2 ≤ IV< 0.4 as to Medium-Low (ML),
- 0≤ IV< 0.2 as to Low (L).

Based on this assumption, it is accepted that factors with a significance of over 0.8 as the salient factors affecting. According RII analysis results, 26 observed variables under 6 latent factors were determined as output to be used in the following SEM analysis stage [66]. These factors were presented in Table 1.

Table 1 - Salient factors affecting BIM adoption in the Turkish construction industry

EXTERNAL VARIABLES	
Organizational Factors (OF)	**Environmental Factors (EF)**
OF1: Organizational culture [7], [14], [15], [17], [19], [23], [26], [28], [30], [38], [59], [60] **OF2:** Organizational leadership [8], [17], [22], [25], [26], [31], [36], [39] **OF3:** Organizational resistance for BIM use [7], [17], [22], [23], [28], [35], [38], **OF4:** Organizational awareness of BIM benefits [7], [14], [22], [35], [38], [48] **OF5:** Organizational demand for the use of Information Technology [7], [14], [22], [38]	**EF1:** Legal drivers/requirements [7], [14], [20], [21], [26], [30], [36], [38], [48] **EF2:** Stakeholder interaction [26], [31], [35], [36], [48], [57], [59] **EF3:** Value for money [18], [20], [22], [26], [48] **EF4:** Ease of use of the BIM interface [17], [26], [38] **EF5:** The accuracy and level of the information [23], [30],
INTERNAL VARIABLES	
Perceived Usefulness (PU)	**Perceived Ease of Use (PEU)**
PU1: Perception of the benefit in terms of improving decision-making processes [7], [14], [37], [38], [48] **PU2:** Perception of the benefits in terms of providing adequate insight into the project lifecycle [7], [14], [38], [58] **PU3:** Perception of the benefit in terms of improving project success [7], [14], [16], [20], [22], [34], [38] **PU4:** Perception of the benefits in terms of productivity and job performance improvement [7], [14], [16], [34], [37], [38], [48], [53], [57]	**PEU1:** Perceived ease of use regarding information exchange among stakeholders [7], [14], [16], [31], [36], [38] **PEU2:** Perception of BIM's ease of use in tasks [7], [14], [15], [16], [21], [29], [37], [38], [57], [59] **PEU3:** Perception of getting the expected result easily from using BIM [7], [14], [15], [16], [23], [29], [35]
BEHAVIORAL INTENTION (BI)	
BI1: Hedonic motivation [19], [21], [29], [36], [37], [53], [57] **BI2:** Recommending the use of BIM to another organization/user [7], [14], [16], [38] **BI3:** Continuity of BIM use in organization's activities [16], [19], [29], [37], [53] **BI4:** Continuity in expenses for BIM usage/adoption within financial budgets [17], [24], [36] **BI5:** Continuity of professional support within the organization to assist in the selection of BIM tools [7], [14], [36], [38] **BI6**: Information sharing and collaborative platform presence in industry [23], [27]	
ACTUAL BIM USE (AU)	
AU1: BIM usage level of the organization [30], [58] **AU2:** Meeting the BIM execution plan requirements **AU3:** The ratio of the number of projects using BIM to the total number of projects [29], [53]	

The external variables in Table 1 consists of “Organization Factors (OF)”, and “Environmental Factors (EF)” related to sectoral, financial and technical conditions. In general, organizational factors refer to the internal conditions, capabilities, and attitudes within an organization that affect its ability and willingness to successfully implement and integrate BIM into its processes. This includes elements such as leadership commitment, cultural openness to change, resistance levels, awareness of BIM benefits, and demand for digital technologies. Environmental factors refer to the external conditions and contextual influences that impact an organization’s decision to adopt and implement BIM. These include regulatory requirements, inter-organizational dynamics, perceived economic advantages, usability of BIM technologies, and the reliability and precision of BIM-generated information. Such factors originate outside the organization but significantly shape its BIM adoption behavior and strategy [67].

Internal variables involve “Perceived Ease of Use (PEU)” and “Perceived Usefulness (PU)”. PU is related to the organization/individual’s recognition that BIM utilization improves working ability and productivity whereas PEU is related to the organization/individual’s recognition that BIM utilization is not difficult [7], [14], [38].

On the other hand, “Behavioral Intention (BI)” refers to the willingness to recommend BIM to others in a collaborative relationship, and furthermore, the willingness to participate in the development of BIM application technologies [7], [14], [38]. Lastly, “Actual BIM Use (AU)”, refers to the measurable extent to which BIM is implemented within an organization’s projects and workflows. It encompasses the organization's overall level of BIM integration, its ability to fulfil BIM execution plan requirements, and the proportion of projects actively utilizing BIM relative to the total project portfolio. This construct reflects the practical, operational application of BIM beyond theoretical intention or planning. In sum, it refers to actual behaviors of people using BIM.

3.3. Structural Equation Modelling (SEM) Analysis

SEM has a wide application area to test and evaluate multivariate causal relationships [68]. The methodology enables us to test direct and indirect relationships determined as a result of literature review or observations to develop model. The methodology consists of series of analysis exploratory factor analysis, confirmatory factor analysis and path analysis [69]. While confirmatory factor analysis aims to estimate observed factors by considering latent variables [68], path analysis helps to find and measure causal relationship among observed variables [70]. The methodology is commonly used in engineering fields to propose models and measure relationships [68].

In the SEM analysis, confirmatory factor analysis is performed to estimate and analyze coherent of latent constructs. Latent variables are used to express the common title of observed variables. Therefore, data for latent variables is not necessary. The effect or measurement of latent variable is calculated from observed variables. However, observed variables require data collection [68]. With the analysis of collected data, error variance is calculated to create test and present holistic model by allowing simultaneous testing of connections between latent factors and observed variables. Moreover, the methodology enables to consider non-normally distributed data sets and data sets found missing data [71].

3.3.1. Data Collection

150 surveys were collected from civil engineers and architects involved in construction projects through face-to-face interviews. The survey had two sections: while descriptive information about the participants was gathered in the first part, participants were asked to evaluate BIM adoption factors using a 1-7 Likert scale (1 = strongly disagree, 7 = strongly agree in the second part. In this section, participants assessed 26 observed variables across 6 latent factors. Regarding sample size, different approaches exist in the literature. [72] recommend collecting 5 data points for each observed variable, which would require 130 data sets (5 × 26 observed variables).

3.3.2. Data Analysis

There are many package programs for the application of the SEM. The most famous among these are AMOS and LISREL. Within the scope of the study, considering its frequency in application in BIM analysis, the AMOS program was used. In the exploratory factor analysis and normality test, IBM SPSS statistical software package was used. The details of SEM analysis were summarized below. Before starting steps of SEM analysis (exploratory factor analysis, confirmatory factor analysis and structural analysis), the normality test was made by checking Skewness and Kurtosis values. These values should be between -1.5 and +1.5 [73]. The analysis results were found within the acceptable limits.

3.3.2.1. Exploratory Factor Analysis

In the SEM methodology, factor structures can be developed based on a literature review or confirmed through statistical analysis of observed variables. If the researcher finds out the factor structures as a literature review, the relationship between latent factor and observed variables needs to be analyzed and validated with exploratory factor analysis [74]. With the use of exploratory factor analysis, the variables that have uncertain relationships can be revealed and factor structures can be simplified. Kaiser Mayer Olkin (KMO) measure of sampling adequacy and Bartlett test of sphericity values were found out through the analysis. Therefore, correlations between variables and coherence of latent factor structure were tested. KMO value also indicates the sufficiency of data sample size for the analysis. The KMO value should be between 0 and 1. If the KMO value is closer to 1, the data sample size is more suitable to make an analysis. [75], [76], [77] defined perfect if the KMO value is more than 0.8. Moreover, the authors expressed that if the value is less than 0.5, the data sample size isn't enough to make an analysis. In the Bartlett test, the significance value (P value) should be lower than 0.05 [75], [76], [77]. KMO analysis results indicated that data sample size is enough to make an analysis (0.827>0.8). Additionally, p-value for Barlett test analysis was found as 0. Therefore, two criteria were met.

Another important control criterion for the data sample size is the diagonal values of correlation matrix. The values on the diagonal should be more than 0.5 [76]. As a result of analysis, all diagonal values were found under 0.5. Moreover, variance value should be checked. The variance explained should exceed 50% of the total variance. The analysis results showed that explained total variance is found as approximately 75.739% [75]. Moreover, factor loadings should be checked. If the factor loadings are lower than 0.5, the factors should be removed to increase reliability of factor structures [78]. The last analysis was performed to reveal the reliability of latent factor groups. The Cronbach Alpha values were calculated. The minimum value for the Cronbach value should be lower than 0.7 [76]. The findings were tabulated in Table 2.

Table 2 - Exploratory Factor Analysis Results

Factor	Loads	Cronbach Alpha	Factor	Loads	Cronbach Alpha
OF1	.808		PU1	.728	
OF2	.859		PU2	.814	.815
OF3	.825	.875	PU3	.823	
OF4	.758		PU4	.797	
OF5	.739		BI1	.836	
EF1	.850		BI2	.848	
EF2	.915		BI3	.777	.880
EF3	.959	.963	BI4	.791	
EF4	.938		BI5	.691	
EF5	.959		BI6	.719	
PEU1	.929		AU1	.957	
PEU2	.812	.872	AU2	.953	.963
PEU3	.873		AU3	.936	

3.3.2.2. Confirmatory Factor Analysis

If the researcher can reveal unobservable variable structures based on observation or theoretical knowledge, he/she can apply confirmatory factor analysis without the need for exploratory factor analysis [74]. Confirmatory factor analysis is also called as measurement model in the literature [79]. Confirmatory factor analysis uncovers the relationships between latent factor groups. In other words, all relationship possibilities are considered, and the most convenient relationships are tried to reveal. In the confirmatory factor analysis, errors, standardized residuals, modification indices and confirmatory tests (fit indices) are made. This step is indispensable part of SEM analysis, since it enables input to the path analysis [77]. Modification indices consist of “covariance correction” and “regression correction” indices. If these values are found as high, it means that there are relationships between variables. Moreover, this issue induces the high value for Chi-square value [80]. Within this context, the analysis results for “covariance correction” and “regression correction” indices were controlled via AMOS software. According to the analysis results, while the highest covariance was found between the error value of EF4 and BI factors as 9.491, the highest regression value was calculated between EF4 and BI2 as 10.046. These analysis results are used to improve covariance issue, if chi-square value is higher than 2-3 [81]. As a result of chi-square analysis, the value was found within acceptable limits (1.23). Another important assessment criteria are standardized residuals.

The standard residual analysis results showed that there is no need to remove variable found under latent factors, since they were found lower than 2.58 [81]. Finally, fit indices were calculated to verify the accuracy of the factor structures. In the literature, there is no consensus on the use of specific fit indices to verify them [82]. Within this context, Chi-square/degree of freedom, goodness-of-fit-index (GFI), comparative fit index (CFI), normed fit index (NFI) and root mean square of approximation (RMSEA) were used. In the literature, the analysis showed that if the Chi-square value is solely used, the analysis results are found sensible to sample size. Therefore, the authors proposed to divide the value to degree of freedom [82]. GFI index was developed to handle data sample size issue observed in Chi-square index. GFI is calculated as covariance and variance of model divided by variance and covariance of measurement value [77]. The NFI index is the difference between the Chi-square value and the Chi-square value when there is no relationship between the variables of the model being measured [77]. The CFI index is calculated by adding the sample size to the formula used in the calculation of the NFI index [77]. The RMSEA fit index is a statistic that provides information about the fit between the parameters and the main covariance matrix [77]. The analysis results were summarized in Table 3. All results are found to be acceptable.

Table 3 - Conformity Index Results of Confirmatory Factor Analysis

Fit Indices	Analysis Results	Threshold Values
χ^2/df	1.302	<3
CFI	0.970	0=unacceptable 1=the best fit
GFI	0.845	0=unacceptable 1=the best fit
NFI	0.885	0=unacceptable 1=the best fit
RMSEA	0.045	<0.1

Composite Reliability (CR) value was measured to measure the reliability of the structure revealed as a result of confirmatory factor analysis. The CR value should be higher than 0.6 [83]. The Conformity Index results were summarized in Table 4.

Table 4 - Conformity Index Results of Structural Model Analysis

	Environmental Factors	Actual BIM Use	Perceived Ease of Use	Perceived Usefulness	Behavioral Intention	Organizational Factors
CR value	0.876	0.96	0.88	0.83	0.86	0.96

3.3.2.3. Path Analysis

As mentioned above, path analysis helps to quantify the causal relationships among predefined observed variables. Moreover, the power of SEM analysis is related to consider the indirect impact of factors [68]. In the structural model analysis, the fit between latent factor structure is tested with the use of fit indices to develop final model [74], [79]. More technically, structural analysis involves measuring the amount of explained and unexplained variance between latent variables [84]. Additionally, fit indices were also tested, and the results were found within the acceptable range. Another assessment criteria are p-values. The values should be found at least less than 0.05. All values were under 0.01. Model fit indices are shown in Table 5, whereas Figure 3 presents the final BIM adoption model in Turkish construction industry.

Table 5 - Model Fit Indices

Fit Indices	Analysis Results	Threshold Values
χ^2/df	1.602	<3
CFI	0.938	0=unacceptable 1=the best fit
GFI	0.800	0=unacceptable 1=the best fit
NFI	0.853	0=unacceptable 1=the best fit
RMSEA	0.064	<0.1

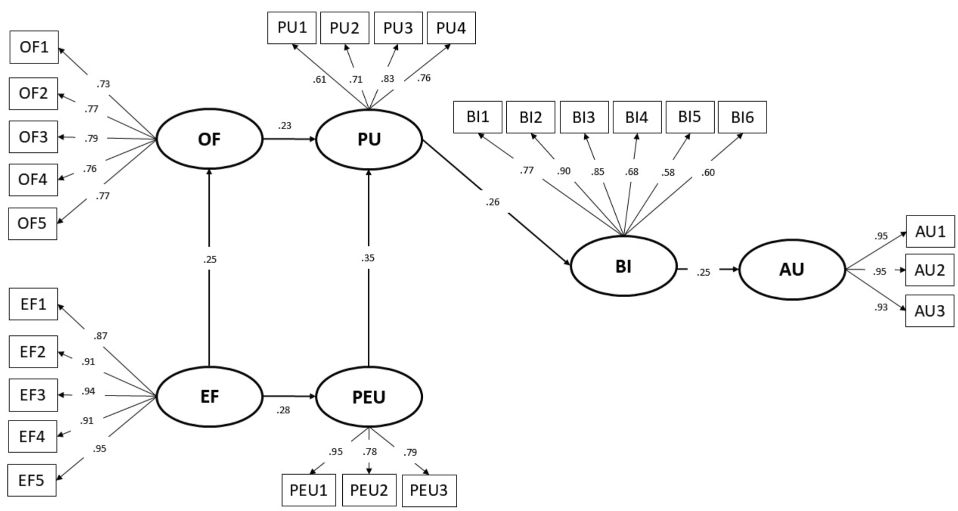

Figure 3 - Structural Model for BIM Adoption in Turkish Construction Industry

According to the analysis results, a significant relationship was found between the latent variables "Organizational Factors (OF)" and "Environmental Factors (EF)". Another finding is that "Environmental Factors" have a significant impact on "Perceived Ease of Use (PEU)". In predicting the latent variable "Perceived Usefulness (PU)", both "Organizational Factors (OF)" and "Perceived Ease of Use (PEU)" were found to have an effect. The analysis also showed that the latent variable "Perceived Ease of Use" does not have a direct effect on "Actual BIM Usage (AU)." Another important conclusion is that "Behavioral Intention (BI)" mediates the relationship between "Actual BIM Usage (AU)" and "Perceived Usefulness (PU)".

4. DISCUSSION OF THE FINDINGS

The findings of SEM analysis reveal that "Organizational Factors (OF)" are influenced by "Environmental Factors (EF)" that generally reflect market demands, regulatory requirements, financial support, and technological advancements. It is obvious that external forces will shape the internal structures and reorient organizations' strategies that support BIM transformation. This dynamic interaction is also valid for the Turkish construction companies as a result of supportive external environment in fostering digital transformation. In response to sectoral trends such as increasing demand for smarter buildings and sustainable designs along with the government regulations, the widespread adoption and use of BIM-based energy, lighting, indoor air quality, and other simulation tools in the design process is being promoted as a crucial digital construction technology for increasing the environmental sustainability of existing and new buildings. In terms of adapting to market demand, looking at the number of projects using BIM in Türkiye, it is evident that most of these are Public-Private Partnership (PPP) projects. PPP projects, which aim to reduce public financial deficits by attracting the private sector to public investments, have a significant contribution to the national economy [45]. This view is in line with [47], which emphasizes the importance of BIM in Türkiye's major public projects. However, unlike countries such as the UK where national BIM standards guide the process [8], Türkiye is still in the process of developing a clear and centralized roadmap, which may influence the pace of industry-wide adoption. A more coordinated national strategy could help bridge this gap and increase the effectiveness of BIM use. The Turkish construction industry, which is the strongest locomotive of development, could be revitalized by ensuring widespread use of BIM from two-dimensional design to facility management in these large-scale projects where substantial investments are made.

The findings of this study indicate that, among environmental factors, "The accuracy and level of the information (EF5)" holds the highest priority, whereas "Legal drivers/requirements (EF1)" shows the weakest relationship as a surprising result. This suggests that, rather than being motivated by external mandates, organizations are more influenced by the tangible, technical benefits that BIM offers such as precise, detailed, and reliable information. The accuracy and level of the information in BIM applications is critical because BIM is fundamentally an information-centric process. If the data within the BIM model is incomplete, outdated, or inaccurate, the benefits of BIM quickly diminish. For example, in facility management, inaccurate or incomplete information can lead to delays, errors, and higher operational costs, ultimately reducing the long-term value of BIM. This is why standards like The Construction Operations Building Information Exchange (COBie), which support the delivery of standardized asset information, highlight the need for not only consistent data formats but also for accurate, comprehensive information to fully realize BIM’s potential in facility management [92]. This indicates that the regulatory push of such legal drivers or standards is likely linked to their ability to indirectly enhance the technical and practical benefits of BIM. While legal mandates alone may not currently be the primary driver of adoption, when combined with legal drivers and/or standards that ensure high-quality, accurate, and comprehensive information, they can reinforce the operational value of BIM. Therefore, the unexpectedly low importance of EF1 is surprising, as it was assumed that compliance with legal requirements would indirectly support BIM’s information quality. However, the results indicate that, in practice, organizations place greater emphasis on the immediate and tangible benefits of BIM’s information quality rather than solely on meeting legal obligations. This result is also in line with studies conducted in developing countries contexts such as Malaysia [31] and Ghana [18], where technical and operational benefits were stronger motivators for BIM adoption than regulatory enforcement. In contrast, in countries with established mandates like the UK and Singapore [5], [6], legal frameworks play a dominant role.

Furthermore, as highlighted by [48], the lack of a mandatory BIM requirement during the building permit phase in Türkiye further limits BIM adoption. This limited regulatory push is associated with insufficient support systems, including training, infrastructure, and national standards. It suggests that legal mandates alone are insufficient unless accompanied by capacity-building efforts and stakeholder engagement. Many stakeholders remain hesitant toward compulsory BIM regulations when the necessary technical and organizational infrastructures are lacking. Therefore, for regulatory drivers to be truly effective, they must be supported by robust technical and organizational capacities, aligning well with our finding that the direct influence of legal requirements is currently limited.

Moreover, in the countries where BIM implementation is mandatory due to legal drivers/requirements, it has been seen that BIM has made considerable progress [47]. Since the legal framework for BIM in Türkiye is still developing and the policies in place are not stringent or well-enforced enough to significantly influence adoption behavior [8], EF1 has a lower perceived relationship with BIM adoption. As the legal framework matures and stronger regulatory mandates emerge, legal drivers may become a more significant factor, but for now, practical, operational benefits take precedence. In Turkish construction companies, EF5and EF4 are prioritized because they directly impact operational efficiency and project outcomes, which are the most immediate concerns for companies. The capacity of BIM to enhance information accuracy and detail, thereby improving quality and reducing errors, delays, and rework [85], aligns with the high importance placed on PU3, which exhibits the strongest causal relationship among the observed variables. Turkish construction companies’ perception of BIM benefits is primarily linked to the desire for improved project management and better outcomes. BIM's ability to provide accurate and detailed information aligns directly with the industry’s push for improving project success through high-quality delivery on time and within budget considerations. This alignment is driving the prioritization of factors like information accuracy and ease of use in BIM adoption.

SEM analysis revealed that EF2 had also significant impact on improving BIM usage within the organization. EF2 encapsulates the degree to which stakeholders actively engage with BIM processes, shaping their integration and impact throughout the project lifecycle [59].

The COVID-19 pandemic has led to changes in the way individuals' access information in Türkiye, as well as all over the world, changing internal expectations and making other factors more important for BIM adoption. This suggests that adoption processes are dynamic and subject to evolving priorities and new factors over time. It is also a fact that providing guidance and incentive actions within the organization, and management support to BIM processes will contribute to increasing BIM organizational familiarity as suggested by [28].

Regarding the Organizational Factors, although all factors under OF have close values to each other, OF1 had a relatively lower but still significant impact on improving BIM usage within the organization. While other factors like organizational leadership, awareness, and resistance play more prominent roles in driving change, organizational culture can be considered as a more subtle, long-term factor that requires a shift in mindset across all levels of the organization. Additionally taking in account of low BIM familiarity of Turkish construction companies [86], having a lower immediate impact on BIM adoption in Turkish construction companies seems reasonable since culture needs time to adjust, as employees and leadership need to gain experience with the technology before fully embracing it as a core part of the organizational identity companies. To overcome the immediate impact of organizational culture on BIM adoption companies would need to create a culture that values innovation, collaboration, continuous learning, and a deep understanding of the technology, which is still lacking in many cases.

[36] presents a systemic model integrating user, firm, and project-level factors for BIM adoption and identified "facilitating conditions" as the most critical factor for BIM adoption [36]. This factor is considered as "Perceived Usefulness (PU)" within this study. A key difference of [36]'s study from the current study was that the hypotheses on technological readiness did not show an impact on BIM adoption. This discrepancy may be due to mandatory BIM usage in Peru, where technological readiness is not a differentiating factor for adoption. However, in Türkiye, technological readiness plays a significant role, as shown by the impact of OF3 on organizational factors. Firms with low technological readiness (such as those in Türkiye) may face greater resistance to adopting new technologies due to having difficulty in establishing the necessary infrastructure. Employees may also be reluctant to adapt to new systems. This highlights the importance of creating a more open environment to technological change with the help of industry development levels and government regulations in BIM adoption.

According to SEM analysis results, PU was found to be affected by PEU and OF while influencing BI. Unlike, [60] found that organizational factors did not directly affect perceived usefulness. Considering the causal relationships between OF and PU, it is thought that organizational demand for IT use led to an observed change in analysis results compared to [60]. This is likely because, despite changes in BIM usage levels over the past years, there is still a lack of consistency in BIM usage within organizations. Increased frequency of use as a result of organizational demand will significantly affect the continuity of BIM usage and its adoption.

According to the SEM results, BI2 holds the highest importance for the BIM acceptance. The underlying reasons can vary. First, it helps to position technology as a proven, reliable solution rather than an emerging or experimental tool. Furthermore, it leads to overcoming resistance to change since recommendations can act as persuasive arguments that BIM is not just another trend but a valuable tool that delivers measurable results. Knowing that others have successfully made the transition to BIM can reassure hesitant organizations and ease the adoption process. Moreover, peer influence is particularly strong in industries like construction. When stakeholders hear about positive experiences from colleagues or partners or learn from each other's experiences, they are more likely to consider BIM as a viable tool for their own projects.

To enable effective implementation of the proposed BIM adoption model, firms can adopt a range of strategic and operational actions based on the key factors revealed in this study. Firstly, firms can focus on enhancing their organizational readiness through targeted training, leadership engagement, and internal awareness efforts to reduce resistance and build technological competence. Promoting collaboration among project stakeholders and aligning with industry-wide trends can further drive adoption. While legal requirements currently exert limited influence, proactive engagement with policy development and preparation for future mandates will position firms advantageously. Moreover, initiating pilot projects, selecting user-friendly tools, and appointing internal BIM champions, while actively involving key stakeholders in these processes, can enhance integration and collaboration across project teams. This stakeholder engagement not only fosters shared understanding and ownership but also strengthens perceived usefulness and ease of use, ultimately encouraging more consistent and confident BIM application throughout the organization. Finally, firms are encouraged to treat the model not just as an analytical tool but also as a practical roadmap allowing them to monitor their progress, identify bottlenecks, and guide decision-making throughout the BIM adoption process.

Compared to small and medium-sized enterprises (SMEs), large firms tend to benefit more from advanced BIM implementation. The adoption patterns in SMEs differ from those of larger firms, with this gap largely attributed to barriers specific to SMEs [22]. To facilitate the practical implementation of the proposed BIM adoption model, particularly among SMEs that often face financial and technical limitations, several context-sensitive strategies can be employed. A practical starting point may involve initiating a pilot project in collaboration with a stakeholder or client already familiar with BIM workflows. Such a controlled environment enables organizations to explore BIM processes incrementally, evaluate internal readiness, and gain tangible experience with minimal risk exposure. Studies show that for SMEs, the potential benefits of BIM are a primary driver of adoption, aligning with the significance of PU3 and PU4 in the SEM analysis results. Consequently, placing greater emphasis on actively engaging staff throughout the implementation process is essential [23].

Within the scope of organizational factors, organizational leadership plays a crucial role in supporting this function through the allocation of modest resources and by embedding BIM-related objectives into project performance metrics. In their study, [89] recommended several tools, policies, and strategies to hype the efforts of the public and private sectors for BIM adoption. As an extension of corporate culture, it is recommended that construction firms actively pursue strategies that enhance the effectiveness of BIM to support its broader implementation. Rather than avoiding expenditures due to cost concerns, firms should view investments in BIM-related hardware and software as strategic decisions, recognizing that long-term savings and efficiency gains significantly outweigh initial costs. Moreover, organizations should develop customized in-house BIM procedures that are tailored to their specific operational structures, project types, and expectations from BIM tools. Given that each company operates within a unique context, aligning a pre-existing BIM Execution Plan with the company's strategic vision and workflow requirements can facilitate smoother integration and maximize the value of BIM adoption [89].

From the environmental perspective, SMEs may respond more effectively to external requirements such as client-imposed BIM deliverables or public procurement standards, when these are framed not merely as compliance measures but as opportunities to build competitive advantage.

Furthermore, for addressing perceived ease of use and reduce technological resistance, the gradual introduction of accessible and cost-effective BIM tools, such as simplified 3D modelling software or collaborative platforms, can lower initial barriers. The findings of [90] indicate that while 3D visualization and 4D scheduling are the most commonly used BIM dimensions, the underutilization of 5D cost estimation highlights a critical gap with significant research potential, particularly regarding its impact on project efficiency and social cost considerations. Nevertheless, given the limited resources of SMEs, it has been observed that the cost of BIM implementation for these firms is higher than for their larger counterparts, primarily due to the disadvantages associated with software acquisition [22]. Therefore, prioritizing straightforward BIM applications such as clash detection, design visualization, or automated quantity takeoffs allows firms to realize early benefits and build confidence in digital workflows.

5. CONCLUSION

The construction industry lags other industries in terms of digitalization and technology adoption and BIM is seen as a new opportunity that can advance the construction industry in this race. Despite the consensus on the benefits of BIM for the construction industry, BIM adoption in Türkiye has not reached the desired levels. Although there are a few studies in Türkiye aimed at determining the necessary actions to accelerate sectoral BIM adoption, none of the studies on BIM usage focuses on developing a concrete model that enables this adoption. In this context, the aim of this study is to identify the salient factors influencing BIM adoption and develop an adoption model. In line with the aim, Structural Equation Modelling (SEM), a commonly used method for investigating relationships between variables in models with multiple dependent and independent variables, has been employed. This study offers a novel contribution by developing and empirically validating a BIM adoption model specifically tailored to the Turkish construction industry, combining internationally recognized constructs with local expert insights. Unlike prior studies that focus mainly on perceived benefits and barriers, the proposed model captures evolving adoption dynamics through a robust SEM-based framework, offering both theoretical depth and practical relevance for Türkiye.

According to the SEM analysis results, a significant relationship exists between "Organizational Factors" and "Environmental Factors" for BIM adoption in the Turkish construction industry. Furthermore, the SEM analysis reveals that "Environmental Factors" have a significant impact on "Perceived Ease of Use" while both "Organizational Factors" and "Perceived Ease of Use" influence the latent variable of "Perceived Usefulness". The analysis results also show that the latent variable of "Perceived Ease of Use" does not have a direct impact on BIM usage. Another significant finding is the mediating effect of "Behavioral Intention" between "Actual BIM usage" and "Perceived Usefulness".

Regarding the sectoral contributions of the study, the developed BIM adoption model can provide sector professionals with a perspective on which aspects to focus on to improve BIM adoption. Recent regulatory developments (such as Regulation Amending the Zoning Regulation for Planned Areas) stipulate that BIM use will become mandatory for large-scale public construction projects as of January 1, 2027. Given this projection, it would be beneficial for Turkish construction companies to focus on the factors presented by the model for preventing themselves from being caught unprepared for this situation. Additionally, the model can be used by firms to measure their own BIM adoption performance and for benchmarking between firms. In brief, developing a BIM adoption model for the Turkish construction industry allows construction companies to more effectively implement BIM in their specific contexts, address unique challenges, increase efficiency, ensure compliance, and foster collaboration. Ultimately, it can lead to improvements across the industry, contributing to better project outcomes, cost savings, and higher quality construction.

This study has some limitations. The data in this study were collected from architects and civil engineers, but the scope could be expanded with the integration of different stakeholders (such as mechanical, electrical engineers etc.) who can use BIM in mechanical, electrical, or ventilation projects. Second, the results may not be directly applicable to other countries, as the data were collected only from the participants located in Türkiye (a developing country where BIM has only been made mandatory in large-scale projects). In this regard, the findings of the study could be useful for guiding senior managers and BIM consultants in construction companies in developing countries, providing them with up-to-date information for better implementation processes. It is recommended that institutions aiming to implement BIM first make the necessary technical investments and then promote a suitable working environment within the organization for a new project management approach while ensuring behavioral continuity during this process. It should also be noted that external variables play a significant role in behavioral continuity. It is necessary to strengthen individuals' perceptions regarding the ease of use and the benefits that BIM will provide to achieve BIM adoption. In this regard, regular training and certifications on BIM can increase both knowledge levels and motivation within institutions. Presentations on BIM-related studies and the positive effects on sustainability, time, cost, and quality can contribute to changing perceptions by highlighting the benefits.

Acknowledgments

This work was supported by the Coordinatorship of Scientific Research Projects of Yildiz Technical University (Project Number: FAP-2021-4223). Extended version of factors and RII analysis results were also generated as an output of this project. Salient factors presented in this study, were determined based on these outputs.

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