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Identifying and prioritizing obstacles to the implementation of building information modeling in sustainable construction projects in Iran using hybrid Fuzzy Delphi-BWM approach

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Abstract:

With the growing global adoption of Building Information Modeling (BIM) technology in the construction industry, this innovative approach has also gained momentum in countries like Iran. However, its practical implementation continues to face numerous challenges. To support broader adoption-particularly within the context of sustainable construction projects, which emphasize environmental, economic, and social considerations throughout the project lifecycle-it is crucial to identify and address these barriers. This study aims to identify and prioritize the key obstacles to BIM implementation in sustainable construction projects in Iran. An initial list of challenges was developed based on a comprehensive literature review and validated through the Fuzzy Delphi Method (FDM), which resulted in the identification of 31 relevant obstacles. Among these, ten were selected as the most critical for further analysis. The Best-Worst Method (BWM) was then applied to rank these barriers. Pairwise comparisons between the best and worst criteria were conducted, and the resulting optimization model was solved using Lingo 18 software. The findings reveal that the most significant challenges are: (1) the absence of clearly defined processes for applying BIM in sustainable building projects (weight = 0.12), (2) the lack of standardized guidelines for BIM integration (weight = 0.107), and (3) the absence of a legal framework for BIM implementation (weight = 0.106). These insights can inform policymakers and stakeholders seeking to improve BIM adoption in the context of sustainable development.

Keywords: Building information modeling; Sustainable; Fuzzy Delphi method; Best-worst method; Sustainable construction projects

1. Introduction

The construction industry is among the world's largest consumers of natural resources and a leading contributor to environmental pollution. The extensive use of raw materials, high energy consumption, and waste generation in construction projects present significant obstacles to achieving sustainable development. To address these challenges, integrating advanced digital technologies within a sustainability framework has emerged as an effective strategy for balancing construction activities with environmental protection goals [1].

Amid increasing concerns about environmental sustainability, the construction sector requires a fundamental transformation in how buildings are designed, constructed, and operated. Sustainable development-centered on a balance between economic, social, and environmental dimensions-plays a critical role in this transformation. In this context, BIM stands out as a promising technology with the potential to enhance project quality, reduce resource waste, and support sustainability goals. However, the effective application of BIM in sustainable construction requires a clear understanding of its capabilities, implementation strategies, and the barriers that hinder its adoption [2].

Furthermore, the increasing complexity of construction projects and rising client expectations have underscored the need for improved coordination and communication among stakeholders. BIM, as an integrated digital solution, can help streamline workflows, reduce costs and delays, and improve overall project outcomes. Yet, numerous barriers-particularly in developing countries like Iran-continue to limit the widespread use of BIM in sustainable project [3]. Despite the growing global interest in BIM, relatively few studies have explored the barriers to its adoption in sustainable construction projects within the context of developing countries. This gap is especially pronounced in Iran, where sustainable practices are increasingly necessary due to urbanization, environmental concerns, and resource constraints. Understanding and addressing the barriers to BIM adoption in this context is therefore critical for accelerating progress toward sustainable construction.

This study aims to identify and prioritize the key barriers to BIM adoption in sustainable construction projects in Iran. The fuzzy Delphi Method is utilized to gather expert opinions and screen a comprehensive list of obstacles. Following this, the Best-Worst Method (BWM), a robust multi-criteria decision-making technique, is applied to rank the identified barriers according to their significance.

The structure of the paper is organized as follows:

Section 2 provides a comprehensive review of the existing literature related to Building Information Modeling (BIM) and its integration into sustainable construction. This section also highlights recent developments, research gaps, and the rationale for conducting this study.

Section 3 provides a detailed description of the research methodology. It includes the data collection process, justification for selecting the fuzzy Delphi method for screening barriers, and the use of the Best-Worst Method (BWM) for prioritizing the key obstacles.

Section 4 presents and discusses the results of the analysis. The identified barriers are ranked based on expert evaluations, and the significance of each barrier is analyzed in the context of sustainable construction in Iran.

Section 5 concludes the paper by summarizing the key findings, outlining practical implications for stakeholders, and offering suggestions for future research to enhance BIM adoption in sustainable projects.

2. Literature review

In this section, the theoretical foundations related to BIM are first introduced and explained, and its importance in sustainable building projects is examined. Then, previous studies related to the barriers and challenges of implementing BIM in sustainable projects are reviewed to provide the necessary theoretical framework for a more in-depth analysis of these barriers in the present research.

2.1 Building information modeling in sustainable building projects

The key impact of sustainable buildings emerges when highly efficient building performance helps address issues among stakeholders-including owners, users, and consumers-despite constraints such as time limitations and construction costs. Due to the silos and fragmentation associated with delivering multiple buildings, providing valuable, sustainable buildings for users becomes challenging. BIM offers an online platform that enables users to collaborate throughout the building delivery project lifecycle on an integrated digital platform. BIM facilitates the resolution of practical issues, particularly during the design stage, by using highly effective and data-driven environmental strategies.

For example, designers typically receive design feedback based on energy consumption analysis. This includes information such as the building's projected energy consumption, expected CO_2 emissions, and whether the building meets performance criteria. The intelligent data generated by the BIM model can perform whole-building energy analysis, simulate performance, and visualize the appearance [4]. This provides designers with direct feedback to test design solutions and allows them to improve the building's performance over its entire lifecycle.

Using BIM during the design phase can also evaluate a wide range of construction options and their associated environmental impacts. Martin, for instance, developed a conceptual BIM model to assess the diversity of material combinations in sustainable buildings and the underlying factors influencing the overall embodied impact of building design [5].

The main advantage of adopting BIM technology in sustainable buildings is that it provides data for sustainability assessments and energy performance evaluations. This significantly enhances the design value of a sustainable construction project. Previous studies have shown that using BIM technology plays a critical role in reducing waste, which is an important aspect of sustainable project [6]. Monitoring the normal operational performance of sustainable buildings throughout their life cycle processes is essential to ensure actual performance. BIM technology, with its visualization features, offers an online platform that supports the provision, integration, and exchange of operational data throughout the construction lifecycle [7].

Olawumi [8] conducted a study aiming to evaluate the perceived benefits of integrating BIM initiatives with sustainability practices in construction projects. The Delphi survey technique was used to gather expert panel opinions on thirty-six identified benefits. Statistical tools were applied to analyze the derived data, and the consensus reached by the expert panel was confirmed through inter-rater agreement statistics. The three most significant benefits identified included: enhancing the overall quality and efficiency of projects; improving the ability to simulate building performance and energy consumption; and facilitating the development of better design outputs and multiple design alternatives.

Gariava [9] highlighted that BIM has become an effective tool for supporting construction solutions, thanks to its ability to store all information within a single digital model and organize interactions among all project participants.

Santos et al. [10] reviewed eight papers addressing the role of BIM in sustainable construction from a perspective that previous reviews had not covered. Rather than focusing on the application of BIM at different project stages, the authors aimed to understand the evolution and development of literature in this field concerning sustainability dimensions. Additionally, the researchers noted that it is only in recent years that studies have begun to focus on integrating all three pillars of sustainability (environmental, economic, and social) with BIM. Khanzadi et al [11] investigated the applications of BIM in relation to key performance indicators (KPIs) of construction projects in Iran. The aim of this study was to identify and prioritize BIM applications according to KPIs during the construction phase of project life cycles in Iran. The findings indicated that quality improvement, sustainable construction, and cost reduction are the three key indicators that can benefit most from BIM applications during the construction phase.

Ahmadvand et al. [12] evaluated the role of BIM in the successful execution of construction projects in Iran. This descriptive-analytical and survey-based study aimed to assess BIM's role in the effective implementation of civil engineering projects in Iran. The results showed that among the main factors analyzed, "management problems" had the highest importance weight (0.352), followed by "security issues," "operational issues," "technical issues," and "economic issues."

Bokonova et al. [13] explored the role of BIM in advancing sustainable construction. The authors emphasized that BIM can improve the design and construction quality of buildings, reduce resource consumption, and enhance occupant comfort. Through modular design and the use of local, low-carbon materials, BIM can help lower energy consumption and evaluate the integration of renewable energy systems like solar panels and wind turbines. By enabling simulation and data updates during the design and operation phases, BIM supports better decision-making to conserve natural resources and reduce waste.

Shuvo Dip Datta et al. [14] conducted a systematic review identifying forty-six positive factors and twenty-one barriers related to the use of BIM in sustainable construction projects. The main environmental benefits included reducing carbon emissions and material waste. Economically, key advantages were increased design efficiency, reduced overall project costs, and improved productivity. Socially, enhancing safety and health was among the top benefits. In contrast, the lack of qualified experts was identified as the greatest barrier to BIM adoption in sustainable projects. Other significant challenges included high training and recruitment costs, resistance in the industry to moving away from traditional methods, and the absence of clear guidelines for BIM implementation in sustainable projects. This study aimed to integrate BIM and sustainability concepts within the architecture, engineering, and construction (AEC) industry and proposed strategies to improve quality and foster sustainable development.

Akbari et al. [15] discussed how linking BIM and sustainability encompasses various aspects, such as environmental life cycle assessment, life cycle cost analysis, social life cycle assessment, construction waste management, green building practices, and leveraging new technologies. BIM provides a dynamic platform enabling comprehensive analysis of environmental, social, and economic impacts across a building's entire life cycle-from initial design through construction, operation, maintenance, and demolition. This capability helps optimize material and energy use and reduce carbon footprint, enhances user comfort and safety from a social perspective, and economically leads to cost savings and profitability by identifying issues early and evaluating design alternatives. Thus, BIM-based life cycle assessment is considered a key tool in realizing sustainable, resilient, and user-centered built environments.

2.2 Barriers and challenges in the application of building information modeling

BIM technology is typically used for very large-scale projects, which require significant financial investment in construction management. BIM has become widely popular in the management of construction projects, helping project teams to reduce both construction costs and energy consumption. However, there remain numerous limitations and risk factors in the development and management of construction projects. Therefore, compared to projects that do not use BIM, it is crucial to identify and effectively control the key limitations and influencing factors in BIM-based projects [30].

Research on the barriers and challenges of BIM began in 2005, but interest surged after 2014 as the importance of identifying and addressing these barriers became evident. In 2014, Zahrizan et al. [31] conducted field research in Malaysia and identified key barriers such as a lack of BIM knowledge, insufficient demand from employers, reluctance among contractors and consultants to adopt BIM, and inadequate information about BIM itself.

In 2015, Hsu et al. [32] examined the legal challenges of implementing BIM in Taiwan, highlighting issues such as model ownership rights, inconsistencies across different software packages, software-generated errors, and the implications of BIM on construction contracts and tool counts. Additionally, research conducted in Finland during the same year identified obstacles in measuring building performance during the operational phase, including the need for standardization in information exchange between BIM software and specialized performance analysis tools, as well as determining the required levels of detail [33].

In 2016, the Canadian construction industry faced challenges such as selecting appropriate BIM software and a lack of client demand for BIM implementation [34]. A study conducted in Egypt in 2018 [35] revealed that the primary challenges were insufficient in-house training programs and a lack of research into the economic benefits of BIM.

Zhao et al. [36] also reviewed significant barriers to BIM development in Australia, noting issues such as inadequate knowledge and expertise, technological challenges, data ownership problems, and limited participation and data sharing among stakeholders.

In 2017, research in China indicated that while the construction industry had largely overcome initial learning barriers associated with BIM, it continued to face challenges such as effective information exchange across disciplines and the

need for acceptance and support from senior management within organizations [37].
In 2019, Chan et al. [38] explored barriers to BIM implementation in Hong Kong, identifying stakeholder resistance to change, lack of organizational support structures, and the absence of standardized BIM guidelines as major obstacles. Finally, a study by Saka and Chan [39] in Nigeria in 2020 highlighted significant barriers, including resistance to change and the high perceived risks associated with BIM implementation in small and medium-sized enterprises (SMEs).
Rouhani [40], in 2022 conducted a study prioritizing the barriers to implementing BIM in Iran's construction industry. According to this paper, the most significant challenges and obstacles to adopting and implementing BIM in Iran's construction sector, ranked in order of importance, include: lack of organizational policy and roadmaps, insufficient awareness and support from senior management, the industry's unpreparedness, limited consideration of BIM's various aspects in current contracts, and the absence of practical guidelines and standards. Additionally, the report notes that a global study identified 14 major benefits of BIM for contractors, the most important of which include reducing errors and omissions, increasing collaboration between contractors, clients, and consultants, minimizing rework, and enhancing the organization's image.
Zahedi [12], in 2023, developed the first official roadmap for BIM implementation in Iran, which includes 53 specific actions across six key areas such as cultural development, education, drafting regulations, improving contracts, and quality assessment. This roadmap was designed based on in-depth interviews with Iranian experts and aims to address issues like the absence of clear laws, shortage of skilled personnel, high initial costs, and inadequate managerial support. The paper emphasizes that gradually implementing this roadmap could pave the way for sustainable BIM development in Iran.
Rashidi [42], in 2025, using the Delphi method and interviews with 12 Iranian experts, identified 26 key barriers to BIM adoption in Iran's architecture, engineering, and construction (AEC) industry. These include a lack of government support, insufficient training and awareness, cultural resistance to change, high software costs, and a significant gap between academia and industry. The study also suggests solutions such as strengthening supportive policies, cultural awareness initiatives, and offering specialized training courses to help reduce these barriers. The main goal of the paper is to create a foundation for accelerating and expanding the use of BIM in Iran.Several studies have identified various barriers to the adoption of BIM in sustainable construction projects. These are summarized in Table 1.

Table 1. Obstacles and challenges of building information modeling in sustainable buildings.

Criterion	Sub-indicators	**Reference**
Economic constraint	Lack of clear objectives and concerns about future costs	[16]
	Unpredictable costs of technical training	[16]
	High costs of BIM software and programs	[17]
	Absence of policies for BIM software procurement and suitable contracts	[18]
	Frequent need for additional and related resources and high economic costs	[19]
	Expensive costs for specific information systems integrating BIM with sustainable buildings	[17]
Public participation	Lack of clear BIM standards applicable to sustainable buildings	[20]
	Insufficient understanding of processes and workflows required for BIM and sustainability	[21]
	Shortage of interdisciplinary experts in BIM and sustainability	[22]
	Absence of precise practical processes for applying BIM technology in sustainable buildings	[23]
	Difficulty obtaining accurate information on BIM application in sustainable buildings	[12]
	Lack of precise processes for implementing BIM technology in sustainable buildings	[24]
	Low level of BIM users' engagement in sustainable building projects	[20]
Technology	Incompatibility between BIM data and requirements of sustainable building applications	[17]
	Lack of clear definitions for operational data exchange	[21]
	Unreliable estimates in energy analysis when using BIM for sustainable buildings	[21]
	Limited quantitative research on BIM technology in sustainable buildings	[25]
	Incompatibility issues among different software packages	[17]
	Lack of support for sustainability analysis tools	[26]
	Absence of defined BIM data specific to sustainable buildings	[23]
	Challenges in risk allocation and sharing related to BIM	[27]
Program management	Lack of a comprehensive framework and implementation plan	[28]
	Insufficient attention and support from senior management	[29]
	Absence of a legal framework for BIM application	[16]
	More time required to adapt to new technologies	[26]
	Failure to implement open-source principles for software development	[22]

3. Analytical framework: Expert-based fuzzy Delphi screening and BWM ranking

The following methods were used in this study to identify the constraints on the application of BIM in sustainable buildings.

3.1 Fuzzy Delphi method

The Delphi method was first introduced by Dalkey and Helmer in 1963 [43]. This technique is a survey-based approach relying on expert opinions and is characterized by three main features: anonymity of responses, iteration and controlled feedback, and, finally, statistical aggregation of group responses. The Delphi method is a systematic way to gather and coordinate informed judgments from a group of experts about a specific question or issue. In many real-world situations, expert judgments cannot be expressed and interpreted as precise quantitative numbers. In other words, crisp data and exact numbers are often inadequate for modeling real-world systems due to the inherent ambiguity and uncertainty in decision-makers' judgments. To overcome this challenge, Lotfi Zadeh introduced the "Fuzzy Set Theory" in 1965, which serves as an effective tool for dealing with ambiguity and uncertainty in decision-making processes. Therefore, in this study, the Fuzzy Delphi Method was used to validate and screen the identified indicators. The steps of the Fuzzy Delphi Method are as follows [44]:

1. **Identifying the research indicators** through a comprehensive review of the theoretical foundations and relevant literature.

2. **Collecting expert opinions:** In this step, after identifying the criteria, a decision-making group consisting of experts relevant to the research topic is formed. Questionnaires are then distributed to determine the relevance of the identified indicators to the main topic of the study and to screen them. Linguistic variables from Table 2 are used to express the importance of each indicator. In this study, a triangular membership function is applied.

3. **Confirmation and screening of indicators:** This step is carried out by comparing the acquired value of each indicator with the threshold value $\tilde{S}$. The threshold is determined based on the subjective judgment of the decision-maker, and it directly affects the number of factors being filtered. There is no simple or standard method for setting the threshold value. In this study, a value of **0.6** has been selected as the threshold.

To do this, the triangular fuzzy numbers reflecting the experts' opinions are first calculated. Then, to find the average of the opinions from n respondents, the fuzzy average is computed. The fuzzy number τ for each indicator is calculated using the following formulas [45].

$$\tilde{\tau}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \quad i = 1,2,\cdots,n \quad j = 1,2,\cdots,m \tag{1}$$

$$a_j = \sum \frac{a_{ij}}{n} \tag{2}$$

$$b_j = \sum \frac{b_{ij}}{n} \tag{3}$$

$$c_j = \sum \frac{c_{ij}}{n} \tag{4}$$

In the above relationships, the index i refers to the expert, and the index j refers to the decision-making index. Also, the defuzzified value of the average fuzzy number is obtained from the following equation [4].

$$\text{Crisp} = \frac{(a+b+c)}{3} \tag{5}$$

3.2 Application of the Best-Worst Method (BWM)

The best-worst method (BWM), a multi-criteria decision-making approach, evaluates a set of options according to several criteria to select the best option. Based on the best-worst method presented by Rezaei (2015) [47], the best and worst criteria are determined by the decision maker and a pairwise comparison is made between each of these two criteria (best and worst) and other criteria; Then a max-min optimization problem is formulated and solved to determine the weight of different criteria; Also, in this method, a formula is considered to calculate the inconsistency rate in order to check the validity of the comparisons.

3.2.1 Steps of the BWM

Step 1: Determining the set of decision criteria: In this step, we consider the criteria $\{c1, c2, \cdots, cn\}$ that are used to reach a decision.

Step 2: Determine the best (for example, the most desirable, most important) and worst (for example, the least important, most unpleasant) criteria. At this stage, the decision maker determines the best and worst criteria in general. No comparison is made at this stage.

Step 3: Specify the preference of the best criterion over other criteria using numbers between 1 and 9.

Table 2. Linguistic terms and fuzzy Delphi numbers [41].

Triangular fuzzy numbers	Language expressions
(0,0,0.25)	very little
(0,0.25,0.5)	low
(0.25,0.5,0.75)	medium
(0.5,0.75,1)	much
(0.75,1,1)	Very much

The best vector compared to others can be represented as:

$$A_B = (a_{B1}, a_{B2}, \cdots, a_{Bn}) \tag{6}$$

where a_{Bj} indicates the superiority of the best criterion B for criterion j. Obviously, the following relationship holds.

$$a_{BB} = 1 \tag{7}$$

Step 4: Specify the preference of all criteria over the worst criterion using numbers between 1 and 9. The superiority vector of other criteria over the worst criterion is:

$$A_w = (a_{1w}, a_{2w}, \cdots, a_{nw})^T \tag{8}$$

where a_{jw} shows the superiority of criterion j over the worst criterion, W. Obviously, the following relationship holds.

$$a_{ww} = 1 \tag{9}$$

Step 5: finding the optimal values of the weights $(w_1*, w_2*, \cdots, w_n*)$: The optimal weight for the criteria, the weight in which, for each pair $\frac{w_b}{w_j}$ and $\frac{w_j}{w_w}$, the following relationship is established.

$$\frac{w_b}{w_j} = a_{Bj} \text{ and } \frac{w_j}{w_w} = a_{jw}$$

To satisfy these conditions for all j, we need to find a solution where the maximum absolute differences $|\frac{w_b}{w_j} - a_{Bj}|$ and $|\frac{w_j}{w_w} - a_{jw}|$ are minimal for all j. Considering the non-negativity of the counters and the conditions of the sum of the weights, the following problem is obtained.

$$\min\max J |\frac{w_b}{w_j} - a_{Bj}|, |\frac{w_j}{w_w} - a_{jw}| \tag{10}$$

$$\begin{aligned} &\text{s.t.} \\ &\sum_j w_j = 1 \\ &W_j \geq 0, \quad \text{for all } j \end{aligned} \tag{11}$$

The model problem of relations (10) and (11) can be converted into the following problem.

$$\min \xi \tag{12}$$

$$\begin{aligned} &\text{s.t.} \\ &|\frac{w_b}{w_j} - a_{Bj}| \leq \xi, \quad \text{for all } j\text{'s} \\ &|\frac{w_j}{w_w} - a_{jw}| \leq \xi, \quad \text{for all } j\text{'s} \\ &\sum_j w_j = 1 \\ &W_j \geq 0, \quad \text{for all } j \end{aligned} \tag{13}$$

By solving the above problem, the optimal weights $(w_1*, w_2*, \cdots, w_n*)$ and ξ^* are obtained.

In the following, using ξ^*, we introduce the compatibility ratio. The larger the value of ξ^*, the higher the value of the consistency ratio and the less reliable the comparisons.

3.2.2 Compatibility ratio

The pairwise comparison is fully consistent when the following relationship holds for all j:

$$a_{Bj} \times a_{jW} = a_{BW}$$

where:

- a_{Bj} is the preference of the **best** criterion B over criterion j,
- a_{jW} is the preference of criterion j over the **worst** criterion W, and
- a_{BW} is the preference of the **best** criterion B over the **worst** criterion W.

Since:

$$a_{Bj} \times a_{jW} = a_{BW} \text{ and } a_{BW} \in \{1, 2, 3, \cdots, 9\},$$

the maximum value of ξ can be obtained.
Using the compatibility index (from the reference table) and its relationship, the compatibility ratio (CR) is calculated (Table 3). This ratio lies within the range [0,1]:

- The closer to 0, the more compatible and stable the comparisons.
- The closer to 1, the less compatible and stable the comparisons.

Relation (12) and (13) is a non-linear model that Rezaei (2016) transformed into a linear model (relation (10)-(3)). In this linear model, the weights of the indices are also calculated. One of the advantages of this linear model is the calculation of the incompatibility rate without using the compatibility index. That is, the value of ξ^1 is the same as the inconsistency rate. Also, the weights of this linear model are more accurate.

$$\min \xi^l \tag{14}$$

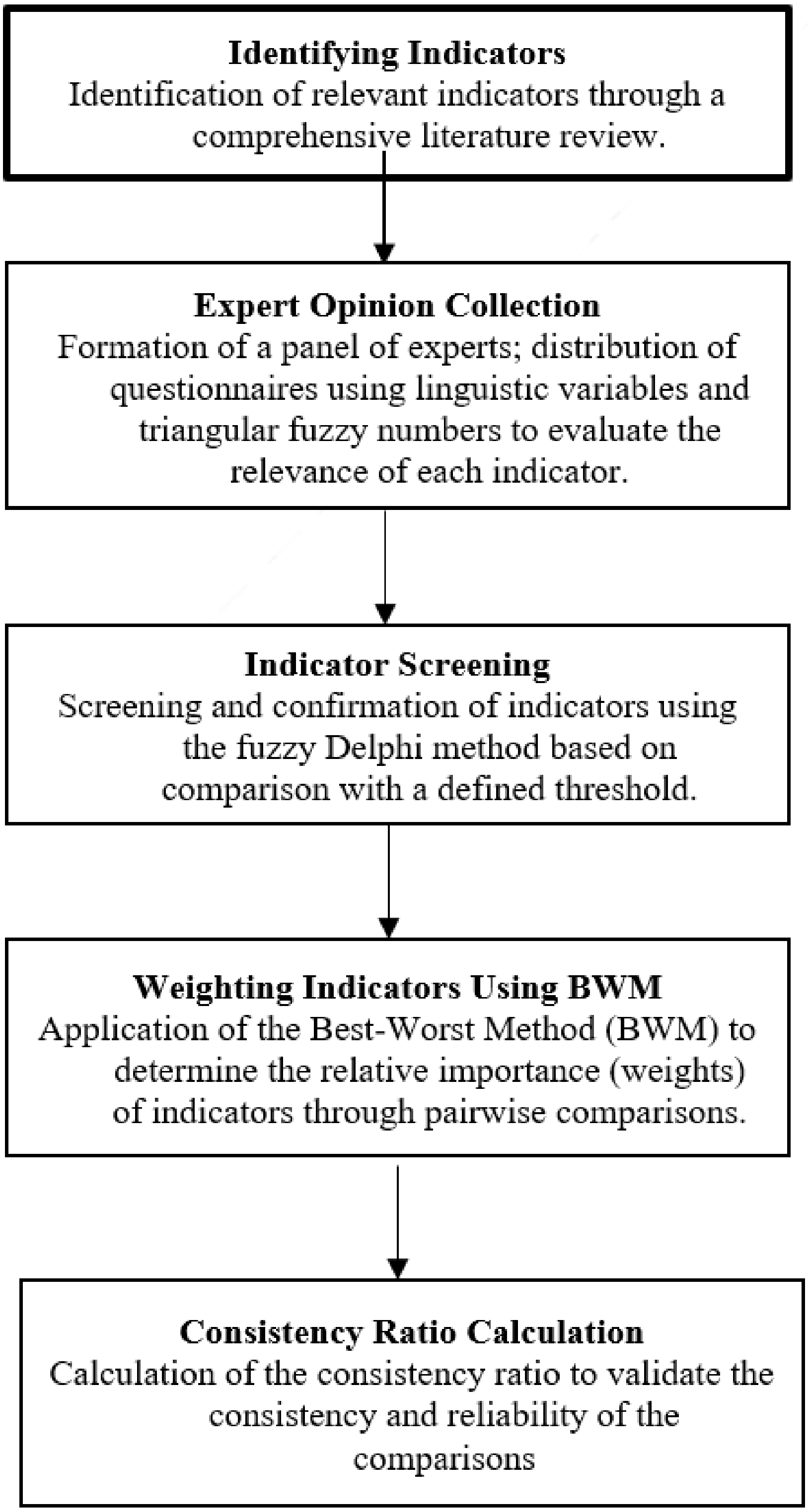
$$\begin{aligned} &\text{s.t.} \\ &|w_b - a_Bj.w_j| \leq \xi^l, \quad \text{for all } j\text{'s} \\ &|w_j - a_jw.w_w| \leq \xi^l, \quad \text{for all } j\text{'s} \\ &\sum_j w_j = 1 \\ &Wj \geq 0, \quad \text{for all } j \end{aligned} \tag{15}$$

Table 3. Compatibility index of BWM method [46].

a_{Bw}	1	2	3	4	5	6	7	8	9
Compatibility index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23
	Compatibility rate $= \frac{\xi^*}{\text{compatibility index}}$								

3.3 Flowchart methodology

A flowchart summarizing the research methodology is presented in subsection 3.3, illustrating the main steps followed in this study.



4. Results

This section presents the findings of the study in detail. It begins with the analysis of the collected data, followed by the results from the two rounds of the Fuzzy Delphi Method. The subsequent part outlines the process of calculating the weights and relative importance of the identified factors through pairwise comparisons of the main criteria. Finally, the section reports the overall weights, highlighting the most and least significant barriers and challenges to BIM adoption in sustainable construction projects in Iran.

4.1 Data analysis

To better understand the profile of participants who completed the pairwise comparison questionnaire, this section provides an overview of their demographic characteristics. Respondents are described in terms of gender, age, years of work experience in project management, and level of education. The detailed distribution of respondents is presented in Table 4.

4.2 The results of the first phase of fuzzy Delphi

In the first phase, a questionnaire containing 31 identified obstacles and challenges to the application of Building Information Modeling (BIM) in sustainable projects in Iran was distributed among the expert panel members. Respondents were asked to evaluate each criterion using linguistic variables as defined in the questionnaire. The preliminary results of their evaluations are presented in Table 5. During follow-up interviews with the expert group, five additional criteria were proposed and subsequently incorporated into the fuzzy Delphi questionnaire. These additional criteria are as follows:

1. Transitioning from conventional engineering and modeling systems to a BIM-based structure requires substantial time and financial resources.
2. The availability of skilled engineers in the BIM field is limited.
3. Training human resources to operate BIM-related software demands significant time and cost.
4. Personnel proficient in BIM software often lack sufficient technical and operational insight and may rely solely on software-generated outputs.
5. The integration of scheduling techniques or economic efficiency tools in BIM, which could have a transformative effect on projects, remains largely unused.

Table 5 shows the number of experts' opinions on research indicators. To fuzzify the numbers, we first convert them into a fuzzy number based on the spectrum of Table 2, then based on relations (2) to (4), the fuzzy average of the scores is obtained, and then by relation (5), the fuzzy average is converted into a definite number. The results of all fuzzification calculations in the first stage of Delphi are given in Table For example, the criterion of row 1 of fuzzy Delphi calculations is as follows:
0 experts gave a very low score, 2 experts gave a low score, 6 experts gave an average score, 2 experts gave a high score, and 0 experts gave a very high score. Therefore, the fuzzy and non-fuzzy score is as follows:

$$\begin{aligned}\text{fuzzy score} = &\frac{1}{10}[0\times(0,0,0.25)+2\times(0,0.25,0.5)\\&+6\times(0.25,0.5,0.75)+2\times(0.5,0.75,1)\\&+0\times(0.75,1,1)]=(0.25,0.5,0.75)\end{aligned}$$

$$\text{fuzzy score} = \frac{0.25+0.5+0.75}{3} = 0.5$$

In this research, the threshold value is 0.6, the results show that 10 obstacles have been approved, and 21 obstacles have obtained an average of less than 0.6, which is shown in Table 6 of the results.

4.3 The results of the second phase of fuzzy Delphi

In this stage, 10 obstacles that were confirmed in the first stage were designed in a new questionnaire and provided to the experts. Also, in this round, the definitive average of

Table 4. Distribution of respondents.

Category		Abundance	Percent
gender	Man	8	80%
	Female	2	20%
age	25 to 30	2	20%
	30 to 35	3	30%
	35 to 40	4	40%
	40 and up	1	10%
Experience in project management	Less than 1 year	2	20%
	1 to 5 years	4	40%
	5 to 10 years	2	20%
	More than 10 years	2	20%
education	Bachelor	5	50%
	Masters	4	40%
	PHD	1	10%

Table 5. The results of experts' opinions.

Criterion	Under the criteria	Impact rate				
		Very little	Low	Medium	Much	Very much
Economic constraint	Lack of clarity of purpose and concern about future costs	0	2	6	2	0
	Unpredictable costs of technical education	0	3	4	3	0
	High costs of software and program BIM	1	4	3	2	0
	Lack of BIM software procurement policies and appropriate contracts	0	1	3	4	2
	Frequent need for additional and related resources and high economic costs	0	1	8	1	0
	Expensive costs for specific information systems that integrate BIM technology with sustainable buildings	0	1	6	3	0
Public participation	Lack of clear BIM application standards in sustainable buildings	0	0	4	5	1
	Lack of understanding of processes and workflows required for BIM and sustainability	0	0	4	5	1
	Lack of interdisciplinary experts in BIM and sustainability	0	1	5	4	0
	Lack of detailed application processes for BIM technology in sustainable buildings	0	1	2	7	0
	It is difficult to obtain detailed information on the application of BIM in sustainable buildings	1	1	5	3	0
	Lack of detailed processes for applying BIM technology in sustainable buildings	0	2	3	4	1
	Low level of involvement of BIM users in sustainable building	0	3	6	1	0
Technology	Incompatibility between BIM data and the requirements of sustainable building applications	0	2	6	1	1
	Lack of a clear definition of operational management data exchange	0	1	7	2	0
	Unreliable estimates for energy analysis in the use of BIM in sustainable buildings	1	0	6	3	0
	A quantitative research on BIM technology in sustainable buildings	0	2	6	1	1
	Incompatibility problems between different software packages	0	3	3	2	2
	Lack of support for stability analysis tools	1	2	4	3	0
	Lack of BIM data definitions for sustainable buildings	0	3	4	2	1
	Difficulty in allocating and sharing risks related to BIM	0	2	4	4	0
Program management	Lack of a comprehensive framework and implementation plan	1	2	2	4	1
	Lack of attention and support from senior management	0	3	5	2	0
	Lack of a legal framework for BIM application	0	2	2	5	1
	More time is needed to adapt to new technologies	0	1	3	4	2
	Failure to implement open source principles for software development	0	2	5	2	1
Cultural and human	Changing an engineering and modeling system to a BIM structure requires time and money	0	1	4	3	2
	Skilled engineers in this field are limited	0	0	4	4	2
	Training human resources to work with BIM-related software requires time and money	0	1	3	4	2
	The forces that master this software do not have enough technical and operational vision and will be satisfied only with the outputs of the software.	0	2	4	2	2
	The presence of scheduling techniques or economic productivity in BIM, which has a surprising effect on projects, is only a revolutionary and unused presence	0	0	3	5	2

Table 6. The results of the first phase of fuzzy Delphi.

Criterion	Under the criteria	Fuzzy score	Non-fuzzy score	Condition
Economic constraint	Lack of clarity of purpose and concern about future costs	(0.25,0.5,0.75)	0.500	Rejection
	Unpredictable costs of technical education	(0.25,0.5,0.75)	0.500	Rejection
	High costs of software and program BIM	(0.175,0.4,0.65)	0.408	Rejection
	Lack of BIM software procurement policies and appropriate contracts	(0.425,0.675,0.875)	0.658	Confirmation
	Frequent need for additional and related resources and high economic costs	(0.25,0.5,0.75)	0.500	Rejection
	Expensive costs for specific information systems that integrate BIM technology with sustainable buildings	(0.3,0.55,0.8)	0.550	Rejection
Public participation	Lack of clear BIM application standards in sustainable buildings	(0.425,0.675,0.9)	0.667	Confirmation
	Lack of understanding of processes and workflows required for BIM and sustainability	(0.425,0.675,0.9)	0.667	Confirmation
	Lack of interdisciplinary experts in BIM and sustainability	(0.325,0.575,0.825)	0.575	Rejection
	Absence of detailed application processes for BIM technology in sustainable buildings	(0.4,0.65,0.9)	0.650	Confirmation
	It is difficult to obtain accurate information on the application of BIM in sustainable buildings	(0.275,0.5,0.75)	0.508	Rejection
	Lack of detailed processes for applying BIM technology in sustainable buildings	(0.35,0.6,0.825)	0.592	Rejection
	Low level of participation of BIM users in sustainable building	(0.2,0.45,0.7)	0.450	Rejection
Technology	Incompatibility between BIM data and the requirements of sustainable building applications	(0.275,0.525,0.75)	0.517	Rejection
	Lack of clear definition of operational management data exchange	(0.275,0.525,0.775)	0.525	Rejection
	Unreliable estimates for energy analysis in the use of BIM in sustainable buildings	(0.3,0.525,0.775)	0.533	Rejection
	A quantitative research on BIM technology in sustainable buildings	(0.275,0.525,0.75)	0.517	Rejection
	Incompatibility problems between different software packages	(0.325,0.575,0.775)	0.558	Rejection
	Lack of support for stability analysis tools	(0.25,0.475,0.725)	0.483	Rejection
	Lack of BIM data definitions for sustainable buildings	(0.275,0.525,0.75)	0.517	Rejection
	Difficulty in assigning and sharing risks related to BIM	(0.3,0.55,0.8)	0.550	Rejection
Program management	Lack of a comprehensive framework and implementation plan	(0.325,0.55,0.775)	0.550	Rejection
	Lack of attention and support from senior management	(0.225,0.475,0.725)	0.475	Rejection
	Lack of legal framework for BIM application	(0.375,0.625,0.85)	0.617	Confirmation
	More time is needed to adapt to new technologies	(0.425,0.675,0.875)	0.658	Confirmation
	Failure to implement open source principles for software development	(0.3,0.55,0.775)	0.542	Rejection
Cultural and human	Changing an engineering and modeling system to a BIM structure requires time and money	(0.4,0.65,0.85)	0.633	Confirmation
	Skilled engineers in this field are limited	(0.45,0.7,0.9)	0.683	Confirmation
	Training human resources to work with BIM-related software requires time and money	(0.425,0.675,0.875)	0.658	Confirmation
	The forces that master this software do not have enough technical and operational vision and will be satisfied only with the outputs of the software	(0.35,0.6,0.8)	0.583	Rejection
	. The presence of scheduling techniques or economic productivity in BIM, which has a surprising effect on projects, is only a revolutionary and unused presence	(0.475,0.725,0.925)	0.708	Confirmation

the first round has been placed so that the experts can be informed of the average value of each index in the previous stage. The results of the second phase of fuzzy Delphi are given in Table 7. In this round, in a similar way, the fuzzy average scores are calculated using relations (1) to (3), and definite scores are calculated by relation (4).

4.4 Calculate the weight and importance of factors

In the previous stage, research factors were introduced and confirmed. In this section, the weight and importance of these criteria are calculated. In this step, the best-worst (BWM) technique is used for weighting.

4.4.1 Determining the most important and least important indicators

In the first step of the best-worst method, the most important (best) and least important (worst) criteria should be determined. In this research, using the opinions of research experts, first in the main criteria and then among the sub-criteria of each criterion, the most important (The best) and the least important (worst) criteria were determined. In this section, the opinion of 10 experts has been used.

4.4.2 Forming pairwise comparisons of main criteria and calculating weights

In this step, pairwise comparisons of the best criterion with other criteria (BO) and pairwise comparison of other criteria with the worst criterion (OW) should be formed and provided to the expert to answer the paired comparisons, then after answering, to determine the weight. Enter the algorithm of the BWM method, which is given below for the first expert. To calculate the weight of the criteria, we first make a pairwise comparison of the best criterion, C3, with other criteria. Also, through a similar pairwise comparison, we also form other criteria with the worst criterion, namely C7, which is given in tables BO and OW, respectively. The results of pairwise comparison of criteria are given in Table 8. This table is the opinion of the first expert in relation to the score of the best and worst indicators.
According to Table 6 and using the model of relation (1), the linear model of the best-worst method is formed for the main criteria, which is given below. In this model, W is the weight of the criteria and Z is the compatibility rate of this paired comparison, which is a number between 0 and 1, and the closer this number is to zero, the higher the compatibility of the paired comparison. As can be seen in the first line

Table 7. The results of the second phase of fuzzy Delphi.

code	Criterion	The fuzzy score of the second stage	Non-fuzzy score of the second stage	The non-fuzzy score of the first stage	difference
C1	Lack of BIM software procurement policies and appropriate contracts	(0.4,0.65,0.85)	0.633	0.658	-0.025
C2	Lack of clear BIM application standards in sustainable buildings	(0.45,0.7,0.925)	0.692	0.667	0.025
C3	Lack of understanding of processes and workflows required for BIM and sustainability	(0.475,0.725,0.925)	0.708	0.667	0.041
C4	Lack of detailed application processes for BIM technology in sustainable buildings	(0.375,0.625,0.875)	0.625	0.650	-0.025
C5	Lack of legal framework for BIM application	(0.325,0.575,0.8)	0.567	0.617	-0.050
C6	More time is needed to adapt to new technologies	(0.45,0.7,0.9)	0.683	0.658	0.025
C7	Changing an engineering and modeling system to a BIM structure requires time and money	(0.425,0.675,0.875)	0.658	0.633	0.025
C8	Skilled engineers in this field are limited	(0.5,0.75,0.925)	0.725	0.683	0.042
C9	Training human resources to work with BIM-related software requires time and money	(0.45,0.7,0.9)	0.683	0.658	0.025
C10	The presence of scheduling techniques or economic productivity in BIM, which has a surprising effect on projects, is only a revolutionary and unused presence.	(0.5,0.75,0.925)	0.725	0.708	0.017

Table 8. Pairwise comparison of criteria (first expert).

BO	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C3	3	5	1	2	2	6	9	5	2	6

OW	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C7	3	2	9	8	4	2	1	2	4	2

of this model, the objective function is called, that is, we are looking to decrease the value of z (min=z). And from the second line onwards, there are the constraints of the problem, which are changed in the direction of satisfying the goal of the problem, so that the best result or the weight of the criteria (Ws) is obtained.
Then Lingo 18 software is used to solve this model. Lingo software is a powerful software for solving optimization models. The output of this software is shown in Table 9, which is the weight of the criteria (W) and the compatibility rate (z).
According to Table 9, according to the first expert, the measure of lack of understanding of the processes and workflows required for BIM and sustainability with a weight of 0.251 ranks first, the measure of the lack of accurate application processes for BIM technology in sustainable buildings with a weight of 0.146 ranks second. And training human resources to work with BIM-related software requires time and money, with a weight of 0.134, it has been ranked third. The compatibility rate of the first expert is equal to 0.0408, which shows its acceptable compatibility.

4.4.3 Calculate the final weight

In a similar way for other experts, the weight calculation process is done with the BWM method, where the final weights are given for each expert. The final weight is obtained from the average weight of experts for each criterion (Table 10). The results are given in Table 9. According to Table 9, the criterion of lack of precise application processes for BIM technology in sustainable buildings with a

Table 9. The output of the BWM model of criteria (first experiment).

Variable	Value	Reduced cost
Z	0.4085603E-01	0.000000
W3	0.2509728	0.000000
W1	0.9727626E-01	0.000000
W2	0.5836576E-01	0.000000
W4	0.1459144	0.000000
W5	0.1342412	0.000000
W6	0.4863813E-01	0.000000
W7	0.2334630E-01	0.000000
W8	0.5836576E-01	0.000000
W9	0.1342412	0.000000
W10	0.4863813E-01	0.000000

Table 10. The final weight of the criteria.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	Final weight	rank
C1	0.097	0.086	0.092	0.025	0.046	0.059	0.144	0.025	0.054	0.149	0.078	10
C2	0.058	0.134	0.139	0.131	0.055	0.024	0.072	0.132	0.279	0.050	0.107	2
C3	0.251	0.067	0.069	0.048	0.138	0.118	0.096	0.058	0.097	0.074	0.102	6
C4	0.146	0.038	0.139	0.258	0.138	0.047	0.096	0.072	0.162	0.099	0.120	1
C5	0.134	0.019	0.025	0.072	0.024	0.118	0.257	0.048	0.081	0.280	0.106	3
C6	0.049	0.134	0.139	0.096	0.055	0.212	0.058	0.096	0.065	0.134	0.104	4
C7	0.023	0.089	0.055	0.144	0.069	0.078	0.058	0.257	0.123	0.050	0.095	7
C8	0.058	0.222	0.055	0.058	0.092	0.039	0.144	0.144	0.026	0.074	0.091	9
C9	0.134	0.086	0.240	0.072	0.138	0.118	0.025	0.096	0.065	0.060	0.103	5
C10	0.049	0.124	0.046	0.096	0.246	0.188	0.048	0.072	0.046	0.029	0.095	8
Compatibility rate	0.040	0.047	0.038	0.030	0.029	0.023	0.031	0.031	0.045	0.017	0.033	

weight of 0.12 ranks first, the criterion of lack of clear BIM application standards in sustainable buildings with a weight of 0.107 ranks second and the criterion of lack of a legal framework for BIM application with The weight of 0.106 has won the third place. The final consistency rate (Z) of the main criteria is equal to 0.033, which shows its acceptable consistency.

5. Conclusion

This section presents the overall prioritization of obstacles and challenges associated with the implementation of Building Information Modeling (BIM) in sustainable construction projects in Iran (Table 11).

The findings indicate that the most significant challenge in implementing BIM for sustainable buildings concerns public participation, particularly the absence of detailed application processes for its use. This reveals a critical deficiency in the operational framework required for successful BIM integration, underscoring the need for clear, step-by-step guidelines and protocols to ensure effective application in sustainable practices. The second-ranked challenge is the lack of standardized BIM procedures in sustainable construction. The absence of such standards not only limits efficiency but also fosters uncertainty among practitioners, leading to inconsistent project outcomes. Developing clear, universally accepted standards is therefore essential to encourage widespread adoption and enhance collaboration among all project participants.

From a program management perspective, the third major challenge is the absence of a comprehensive legal framework for BIM application. Without regulatory support, the perceived risks of adoption increase, as organizations may hesitate to invest in BIM without clarity on legal responsibilities and protections. Establishing a robust legal framework would provide both guidance and assurance, thereby fostering broader implementation in sustainable construction projects.

The fourth-ranked challenge relates to the extended adaptation period required for new technologies. Transitioning to advanced methodologies such as BIM can be challenging, particularly in markets still developing familiarity with sustainable practices. Organizations must allocate sufficient time for training and adaptation to ensure all team members can apply BIM effectively.

Ranking fifth, the demand for training personnel to operate BIM-related software underscores the cultural and human dimensions of implementation. Comprehensive training programs are critical, as a skilled workforce is indispensable for the successful deployment of BIM technologies. However, such programs often require significant investments of time and financial resources, creating barriers for organizations with constrained budgets.

The sixth challenge again pertains to public participation, specifically the limited understanding of the processes and workflows necessary to integrate BIM with sustainability goals. Without clear knowledge of how BIM supports sustainable practices, stakeholders may resist engagement, leading to delays and inefficiencies.

The seventh challenge involves the lack of scheduling techniques or economic efficiency tools embedded within BIM, despite their potential to enhance project performance. Implementing these tools requires shifts in both mindset and practice, which may encounter resistance. Organizations should advocate for contemporary project management approaches that fully exploit BIM's capabilities to optimize economic outcomes.

The eighth challenge concerns the transition from traditional engineering and modeling systems to BIM, which demands considerable time and financial investment. This transition represents not merely a technical upgrade but also a cultural transformation. Resistance from team members accustomed to conventional methods is common, necessitating effective change management strategies to promote innovation and adoption.

The ninth challenge is the shortage of engineers proficient in both BIM and sustainable construction practices. This skills gap slows implementation and can only be addressed through targeted training initiatives and partnerships with academic institutions to develop a workforce capable of applying BIM effectively to sustainable projects.

The tenth challenge relates to the lack of BIM software procurement policies and suitable contract frameworks, representing a significant economic constraint. In the absence of clear procurement guidelines, organizations may struggle

Table 11. The most important obstacles and challenges of using building information modeling for sustainable projects in Iran.

rank	Criteria	Obstacles and challenges
1	Public participation	Lack of detailed application processes for BIM technology in sustainable buildings
2	Public participation	Lack of clear BIM application standards in sustainable buildings
3	Program management	Lack of legal framework for BIM application
4	Program management	More time is needed to adapt to new technologies
5	Cultural and human	Training human resources to work with BIM-related software requires time and money
6	Public participation	Lack of understanding of processes and workflows required for BIM and sustainability
7	Cultural and human	The presence of scheduling techniques or economic efficiency in BIM, which has a surprising effect on projects
8	Cultural and human	Changing an engineering and modeling system to a BIM structure requires time and money
9	Cultural and human	Skilled engineers in this field are limited
10	Economic	Lack of BIM software procurement policies and appropriate contracts

to acquire appropriate tools or negotiate BIM-compliant contracts, leading to inconsistent application. Developing standardized procurement policies and contract templates would support smoother integration.

In conclusion, addressing these challenges is crucial for the effective implementation of BIM in sustainable building projects. Stakeholders must collaborate to establish standardized procedures, formulate comprehensive legal frameworks, and invest in human capital through targeted capacity-building programs. Overcoming these barriers will enable the construction industry to fully realize BIM's potential, advancing sustainability, efficiency, and innovation in building practices.

Authors contributions
Authors have contributed equally in preparing and writing the manuscript.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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