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DOI
10.1016/j.rineng.2024.102987

Publication date
2024

Document Version
Final published version

Published in
Results in Engineering

Citation (APA)
Alshibani, A., Aldossary, M. S., Hassanain, M. A., Hamida, H., Aldabbagh, H., & Ouis, D. (2024). Investigation of the driving power of the barriers affecting BIM adoption in construction management through ISM. *Results in Engineering*, *24*, Article 102987. https://doi.org/10.1016/j.rineng.2024.102987

Results in Engineering 24 (2024) 102987

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Investigation of the driving power of the barriers affecting BIM adoption in construction management through ISM

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ARTICLE INFO

Keywords:
BIM
ISM
Construction management
Contractors
Barriers
Saudi Arabia

ABSTRACT

Building Information Modelling (BIM) is a rising digital medium that is gaining popularity in the construction sector. Although BIM usage has been mandated in the public construction sector in Saudi Arabia, its adoption remains limited. This paper aims to investigate the driving power of the barriers affecting BIM adoption in construction management through Interpretive Structural Modeling (ISM). A literature review and expert meetings were conducted to identify the potential barriers faced by contractors and consultants in BIM usage in the construction management sector. Two different techniques were utilized to rank the identified barriers to adopting BIM in construction management. The first technique, the Relative Importance Index (RII), evaluates and assesses the barriers from both the contractors and consultants' perspectives. The second technique, Interpretive Structural Modeling (ISM), identifies the driving power of barriers and understands the correlations among them. A total of sixty-nine responses were analyzed using the RII. Cronbach's alpha was utilized to assess the collected data's reliability. The findings from the ISM were validated by experts to establish relationships among the identified barriers. The ISM reveals that the top driving barrier to BIM adoption is the "Lack of skilled and experienced personnel", followed by "Lack of awareness", "Communication issues" and "Longer setup time". The findings of this study could assist local authorities develop an incentive program to encourage contractors and consultants to adopt BIM in construction management.

1. Introduction

Building Information Modeling (BIM) is an evolving technology and process used in the construction industry to assist in visualizing design and managing projects throughout their life cycle. It integrates multiple layers of information that enhances the data exchange among the participating project parties in construction projects from the design phase to demolition. The exchanged data includes, but is not limited to, architectural, structural, plumbing, HVAC, and electrical design of the facility [1]. BIM continues to be a useful tool for cost and schedule control [2]. It assists in tracking ongoing project activities by comparing actual performance with the original baseline, providing a precise representation of the project's status and inducing clarity. As a result, the responsible party for any schedule delay and cost overrun can be easily identified, and therefore making claims and disputes less likely to occur [3]. The approach utilized to structure information such as cost estimates, cost forecasts and expenditures, is the cost management system [4].

BIM offers numerous benefits to owners, designers, and builders. For owners, BIM enhances facilities management, reduces financial risks, and improves design evaluation. Designers can use BIM to enhance code compliance, integrate sustainability, and improve design accuracy. For builders, it enables more accurate quantity takeoffs, cost estimation, and better site safety planning. Additionally, facilities managers benefit from

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https://doi.org/10.1016/j.rineng.2024.102987
Received 6 August 2024; Received in revised form 14 September 2024; Accepted 21 September 2024

centralized data, allowing for more efficient operations and maintenance [5]. Arayici and Egbu [6] explain how BIM adoption can enhance project management, improve communication, and reduce errors, particularly in remote construction, by facilitating stakeholder collaboration. The adoption of BIM faces several challenges, particularly in small and medium-sized projects [7]. Alaboud and Alshahrani [8] noted that while numerous studies have been conducted to identify the challenges of BIM adoption, relatively few have evaluated the significance and impact of these barriers within the construction management sector. In addition, meetings with five local experts in construction project management in the Eastern Province of Saudi Arabia revealed that construction contractors and consultants in the region still rely on traditional practices for construction project management.

Previous studies have used the RII method to identify barriers to BIM adoption in the construction industry, often assuming these barriers are independent. However, this assumption may not always be accurate, potentially limiting the relevance of the results. This research aims to address these limitations by proposing a new approach that integrates RII with Interpretive Structural Modeling (ISM) to identify and assess the driving barriers to BIM adoption faced by contractors and consultants in construction project management."

1.1. Problem statement and research objectives

Engineering, procurement, and construction (EPC) contractors and consultants globally, are increasingly integrating BIM technology into their project workflows. However, the construction sector in the Eastern Province of Saudi Arabia still heavily relies on conventional methods for task such as developing design drawings, quantity take-offs, and managing cost estimates. These conventional approaches often lead to errors in cross-discipline coordination, increasing the risk of change orders, costly disputes, and project delays. While several studies, such as [8,9], have identified barriers to BIM adoption in Saudi Arabia's construction industry or in facilities management [e.g., Ref. [10], no research has yet focused on identifying BIM adoption barriers in construction management across different stakeholders. This study seeks to identify and assess the primary driving power of barriers that contractors and consultants encounter when implementing BIM for construction project management in Saudi Arabia. The study specifically targets professionals working in medium to large construction organizations. The study is conducted in the Eastern Province of Saudi Arabia. Furthermore, the study combined RII and ISM techniques to rank and determine the correlation among the identified driving power behind the barriers to BIM adoption in construction. This approach will assist decision-makers to develop clear and effective strategies to facilitate BIM adoption in construction management.

2. Research methodology

The methodology set for achieving the stated objectives involves several stages. First, a comprehensive review of the literature was conducted to identify the barriers to BIM adoption in construction/construction management. Following this, industry experts in construction project management were interviewed to uncover any additional barriers that may not have been covered in the literature. The identified barriers were then evaluated for their importance through a questionnaire survey, which included both the barriers found in the literature and those proposed by local experts.

Before the questionnaire was distributed, a pilot study was conducted. This involved meetings with experts to assess the effectiveness of the developed questionnaire, ensuring its relevance and clarity. The refined questionnaire was then shared with targeted professionals in construction project management in the Eastern Province of Saudi Arabia.

Once the data was gathered, it underwent a process of cleaning and filtering. The reliability of the data was assessed using Cronbach's alpha. The barriers were then ranked according to their Relative Importance Index (RII) values, with separate rankings provided for contractors and consultants. To further analyze the data, an agreement index was established between the rankings of contractors and consultants.

The study utilized Interpretive Structural Modelling (ISM) to categorize, prioritize, and identify correlations among the barriers related to BIM adoption. The ISM findings were then validated with survey data collected from both contractors and consultants. Finally, the study provided a set of recommendations based on the analysis.

2.1. Data collection and analysis

To evaluate the importance of barriers to adopting BIM in construction project management, a questionnaire was developed and reviewed with three experts. The questionnaire has two sections: the first section collects respondents' professional background and BIM experience, while the second section ranks the importance of each barrier according to the following scale: "Extremely important," "Very important," "Important," "Somewhat important," or "Not important.". The survey was distributed online to contractors and consultants from medium to large-sized companies in Saudi Arabia's Eastern Province. This resulted in 39 valid responses from contractors and 30 valid responses from consultants. Equations (1) and (2) were applied to calculate the sample size for contractors and consultants in Saudi Arabia's Eastern Province. The target sample size is over 30 respondents, exceeding the required sample size, which was calculated as follows:

$$\mathrm{n}_0 = \frac{(\mathrm{pxq})}{(\mathrm{v})^2} \tag{1}$$

$$\mathrm{n} = \frac{\mathrm{n}_0}{\left[1 + \left(\frac{\mathrm{n}_0}{\mathrm{N}}\right)\right]} \tag{2}$$

where:n_0 = The first sample's estimated sizep = The characteristics of the population to be measured in the targeted populationsq = 1-p (completion of p)V = The maximum permitted percentage of standard error (set to be 10 % in this study)n = The size of sampleN = The population sizeNote: p and q are set to be .5 for maximizing the sample size.

The total number of registered contractors in the Eastern Province Chamber is 609, but information was only available for 200 contractors. Hence, the required size of the sample is determined as follows.

- $\mathrm{n}_0 = \frac{(0.5)^*(1-0.5)}{0.1^2} = 25$ respondents (1)
- $\mathrm{n} = \frac{25}{1+\frac{25}{200}} = 22.2 \approx 23$ respondents (2)

The adopted calibration of RII values is presented in Table 1, which is utilized to analyze and prioritize these barriers [11]. The RII for each barrier is calculated as follow:

$$RII = \frac{\sum\limits_{i=0}^{4} (\alpha i)(xi)}{4\sum_{i=1}^{4} (xi)} X100\% \tag{3}$$

where: RII = Relative Importance Index,αi = The allocated weight to response (i)xi = The allocated frequency to (i)

Table 1
Adopted calibration to RII values.

Range of RII Value	Expression of the Rate of Importance
Less than 12.5 %	Not Important (NI)
12.5 %–37.5 %	Somewhat Important (SI)
37.5 %–62.5 %	Important (I)
62.5 %–87.5 %	Very Important (VI)
More than 87.5 %	Extremely Important (EI)

The contractor respondents have between 5 and over 20 years of experience in the construction industry. Of these, 55 % have more than 10 years of experience and represent various fields, including Architecture/Building Engineering, Mechanical Engineering, and Civil/Construction Engineering. In contrast, the consultant respondents come from diverse professional backgrounds such as architecture, project management, digital construction, BIM specialization, and project control. Their experience in the construction sector ranges from 5 to over 35 years, with 80 % having more than 5 years of experience, and 60 % having over 10 years of experience.

2.2. Data reliability

The data gathered from the questionnaire survey was evaluated for internal consistency using Cronbach's alpha. This step is critical for ensuring the reliability of the measurements and results. The main goal of assessing data reliability is to verify that the findings and conclusions are based on accurate and trustworthy information. Reliable data increases confidence in the outcomes and helps minimize the risk of making poor recommendations or decisions by reducing potential errors or biases in the analysis.

Cronbach's alpha provides a numerical value range from 0 to 1. The closer the value is to one, the higher the consistency among the items. To calculate Cronbach's alpha, the intercorrelations between all items in the scale are considered. The following equation, as outlined by Vaske et al. [12], is used for this calculation:

$$a = \frac{N}{N-1}\left(\frac{\sigma_x^2 - \sum_{i=1}^{N}\sigma_{yi}^2}{\sigma_x^2}\right) \tag{4}$$

where:N $=$ The number of questionnaire items on a scale.σ_x^2 $=$ The observed total score variance, andσ_{yi}^2 $=$ The variance of item i for respondent y.

It should be noted that an α value of .9, or higher is considered an excellent reliability, while an α value between .8 and .89 is considered good. An α value ranging between .7 and .79 is considered acceptable. An α value below .7 is considered questionable (not acceptable). The output of the analysis and the collected data reliability was acceptable with an α value of .71.

Further testing of how well a variable (barrier) performs compared to the others is conducted using item-total statistics. As shown in Table 2, the best-performing item (barrier) is "Limitations in technological support and integration" with an item-total correlation of $r = .573$. In contrast, the item with the lowest item-total correlation is "Lack of Skilled and Experienced Personnel" ($r = .082$). If this correlation is close to zero, it may indicate that the item does not measure the same construct as the other items, and its removal from the scale should be considered.

The last column in the table, "Cronbach's Alpha if Item Deleted," shows how data reliability would be affected if the item under consideration was removed. For instance, removing "Lack of Skilled and Experienced Personnel" would cause the data reliability to drop from .71 to .675. Similarly, removing "Uniqueness of Construction Projects and their Associated Complexity" and "Coding and Interface Models Limitations" would also impact reliability. Therefore, these barriers should be treated with extra care.

3. Literature review

This section examines previous studies for the purpose of identifying the relevant barriers to BIM utilization in construction project management.

Table 2
Item-total statistics.

	SMBD[a]	SVBD[b]	Corrected Item-Total Correlation	CABD[c]
Compatibility and interoperability of BIM	52.48	48.830	.278	.706
Setup costs	52.31	49.793	.301	.705
Lack of skilled and experienced personnel	52.48	51.116	.082	.725
Lack of implementation procedures, methods, and standards	52.55	50.613	.142	.718
Insufficient BIM teaching in the academic sector	52.48	49.687	.163	.718
Resistance to change	52.79	47.241	.356	.697
Lack of support by authority (upper management or policy makers)	52.38	47.030	.385	.695
Lack of awareness (through seminars, training programs, etc.)	52.76	44.333	.558	.675
Legal and liability risks	52.93	48.209	.216	.714
Uniqueness of construction projects and its associated complexity	52.79	43.456	.491	.679
Companies are satisfied with their current practices	53.03	50.177	.140	.720
Coding and interfaces models limitations	53.03	44.463	.565	.675
Limitations in technological support and integration	52.86	44.766	.573	.675
Lack of demand on BIM	53.45	51.899	.003	.737
Communication issues (e.g. unwillingness to share information)	52.86	44.695	.490	.681
Longer setup time	53.45	47.328	.304	.703

[a] SMBD mean if barrier deleted.
[b] SVBD mean variance if barrier deleted.
[c] Cronbach's alpha if barrier deleted.

3.1. Previous studies

Eadie et al. [13] investigated the utilization of BIM throughout the project life cycle in the UK. The study revealed that BIM is used mostly during the design phase. The financial benefits of BIM utilization were found to be most significant for stakeholders and clients, followed by facilities managers. Costin et al. [14] reviewed the literature and conducted an analysis of BIM utilization in transportation infrastructure. The study covered 189 published reports, conference proceedings, and journal articles related to BIM in this field. The analysis addressed various aspects, encompassing presents topics and tendencies, benefits, barriers, and more. The study indicated a substantial increase in BIM usage for transportation infrastructure.

Reza Hosseini et al. [15] studied the state of BIM in Iran, focusing on the barriers and drivers to its adoption. The study identified key barriers, including market structure, project nature, the business environment, and insufficient government and policy support. On the other hand, monetary gains and increased competitiveness were noted as major drivers. Jin et al. [16] explored BIM practices and perceptions in China, through surveying BIM professionals. The study demonstrated that the primary beneficiary of BIM is the owner, with its top benefits being the reduction of rework and design errors. Marefat et al. [17] studied BIM's impact on project safety and the barriers to adoption in Iran, using SPSS for correlation analysis. The study indicated that insufficient personnel training is the primary barrier to BIM utilization in the Iranian construction industry. Sun et al. [18] conducted a literature review for identifying negative factors restricting BIM utilization in construction. Twenty-two factors were highlighted and classified under five groups: cost, technology, management, legal and personal. The study further identified research directions for improving BIM theory and its successful application. Nasila and Cloete [19] examined BIM adoption in

Kenya's construction industry, focusing on its current use, benefits, and barriers. The study used principal components analysis to identify key benefits and barriers. Chi-square tests were applied to explore relationships between these factors. The study found that improved communication is the greatest benefit of BIM, while high software costs were the main barrier.

In a study conducted in 2018, Hong et al. [20] introduced a BIM utilization model for different sizes of Australian contractors. The study assessed the benefits, costs, and barriers of implementing BIM by surveying 80 organizations. Descriptive statistics were used to gauge BIM understanding, while structural equation modeling explored correlations among factors affecting BIM implementation. The correlation analysis revealed that staff capability positively influences organizational knowledge-support systems. Diaz [21] analyzed the BIM applications in the AEC industry, focusing on its advantages, benefits, barriers and the integration of time and cost dimensions for asset life cycle management. The study identified several barriers to BIM implementation, including technical issues, high training needs, legal obstacles, and economic difficulties associated with system upgrades. Olawumi et al. [22] utilized the Delphi method to identify key barriers for integrating BIM as well as sustainability initiatives in construction.

Stanley and Thurnell [23] explored the obstacles to implementing 5D BIM. The main identified obstacles were software incompatibility, high initial cost, and lack of industry standards for model coding. Al-Gahzari [24] examined construction stakeholders' views on the lack of BIM adoption in Saudi Arabia using the Delphi technique and a questionnaire survey. The study found that cultural barriers, technology adoption issues, and legal and procedural barriers were the main obstacles. Yu and Bai [25] proposed BIM-based approach for cost compilation by discussing the need information throughout the project life cycle. Saka and Chan [26] assessed the experiences of different size construction firms on the barriers to adopting and implementing BIM. The study revealed the most important factors and the gap growing between developed and developing nations.

Sriyolja et al. [27] explored obstacles to adopting BIM in construction by reviewing 26 academic papers and conference articles. They categorized the identified barriers into 15 types, including "cost, legal issues, expertise, interoperability, awareness, cultural factors, processes, management practices, market demand, project size, technology issues, skills, training, contractual matters, and standards". Makabate et al. [28] reviewed global challenges in adopting BIM in the construction domain through a five-phase review of literature. Tanko et al. [29] explored the applications of BIM in Malaysia. Based on a survey of 100 BIM-adopting professionals, the study found that BIM is widely used for quantifying work quantity, detecting clashes, planning construction site, and 4D simulation.

Ola-Ade et al. [30] examined the views of quantity surveyors in Nigeria, on the utilization of 5D BIM in infrastructural projects. The study found that 5D BIM can improve project planning, reduce errors and rework, and improve stakeholder collaboration. Hadi [31] conducted a comprehensive literature review on BIM adoption, concluding that BIM significantly improves project life cycles from planning to post-construction and that its benefits outweigh the challenges encountered by construction practitioners. In 2020, Afshari and Emami [32] conducted a comprehensive review to examine the factors contributing to project cost overruns. The study uncovered that the utilization of BIM as tool for minimizing project cost has shown a substantial positive effect on reducing project expenses.

Liu et al. [33] investigated the use of BIM for construction simulation analysis. The study revealed that BIM usage in construction project management can significantly increase the quality of construction projects. Al-Musawi and Naimi [34] examined the use of manual calculations for estimating project costs, and found that BIM technology is a reliable tool for cost estimation. In 2024, Nsimbe and Junzhen [35] explored the impact of BIM on project cost management, focusing on its application in development projects in the Mombasa Port Area. The study analyzed how BIM facilitates stakeholder collaboration, indicated barriers to BIM usage during construction, and assessed how BIM utilization improves project transparency. Alasmari et al. [36] discussed the integration of BIM into life cycle costing (LCC). The study revealed that one of the benefits of integrating BIM with LCC is enabling decision-makers to select sustainable construction materials.

Lu et al. [37] conducted a survey of literature on the integration of LCC and life cycle assessment (LCA) with BIM. They also discussed future research directions for academic and corporate researchers. Zubair et al. [38] introduced a new method for optimizing selection of material, maintenance as well as waste processing in construction design. The method integrated several tools: BIM, LCA, geographic information systems (GIS). Yılmaz et al. [39] investigated barriers to BIM usage in the Turkish HVAC industry, through surveying over 40 companies. The study identified "Deficiencies of Infrastructure and Lack of Qualified Personnel (DIP)" as the most important barrier, tailed by "Lack of Documentation and Specifications (LDS)", "Deficiencies of Case Studies and Project Drawings (DCP)", and "Lack of Motivation and Resistance to BIM (LMR)".

Bamgbose et al. [40] investigated BIM usage barriers among small and medium Nigerian construction firms. Analyzing quantitative data from 182 participants using SPSS, they identified five key factors: "functionality and compatibility," "risk and unavailability of BIM resources," "inadequate BIM awareness," "insufficient client demand and support," and "skills gaps among stakeholders". Al-Raqeb et al. [41] explored the reasons for the lack of BIM adoption in public projects in Kuwait and proposed a BIM/MPW integrated framework. Through interviews with MPW stakeholders, the study identified barriers such as insufficient senior management support, an unskilled workforce, and insufficient awareness about BIM's role in sustainability and circularity.

Funtík et al. [42] studied the barriers of BIM usage in the construction domain across different countries. They compared these barriers with the usage of BIM in Slovakia. Zhang et al. [43] proposed a model for investigating the barriers faced by construction professionals in adopting and utilizing BIM technology. Their study also outlined future research directions for BIM. Elagiry et al. [44], in a study conducted in Itali, found that BIM technologies alone are insufficient for complete digitalization in renovation projects. Their research, which included surveys, interviews, and a workshop, highlighted the need for these technologies to be complemented by stakeholder awareness.

3.2. *Identifying barriers to BIM adoption in construction project management*

Table 3 presents the final list of 16 barriers to adopting BIM in construction project management in Saudi Arabia. Fifteen barriers to BIM adoption were identified through a comprehensive literature review, encompassing a wide range of global research on BIM implementation challenges. These barriers reflect commonly recognized issues within the construction industry, such as high implementation costs, lack of skilled personnel, and resistance to change. However, during interviews with local experts, an additional barrier, "insufficient teaching of BIM in the academic sector", was proposed. This barrier is particularly relevant in the local context, as the limited integration of BIM into the academic curriculum may hinder the development of a workforce proficient in BIM. The inclusion of this barrier highlights the importance of localizing global research findings to account for regional challenges and suggests that for successful BIM adoption in the Eastern Province of Saudi Arabia, educational institutions must play a more active role in training future industry professionals. Table 3 consists of three columns. The first column lists the code assigned to each identified barrier. The second column presents the title of the barrier, as agreed upon by local experts. The third column indicates the source of the barrier, whether it was identified in previous studies, or suggested by expert(s).

Table 3

Summary of the barriers.

No.	Identified Barrier	Reference
B1	Compatibility and interoperability of BIM	[15,17–19,21–24,46,47]
B2	Setup costs (training, license, hardware … etc.)	[13–16,18–24]
B3	Lack of skilled and experienced personnel	[13,15,17,19,20,22,24]
B4	Lack of implementation procedures, methods, and standards	[14,15,17–19,22,23]
B5	Insufficient BIM teaching in the academic sector	Added by Experts
B6	Resistance to change	[13–20,22–24]
B7	Insufficient support of the technology	[14–19,22,24]
B8	Lack of awareness (through seminars, training programs … etc.)	[14–16,18,19,21,22,24,47]
B9	Legal and liability risks	[13,14,18,19,21–24]
B10	Uniqueness of construction projects and its associated complexity	[14,18,22,23]
B11	Companies are satisfied with their current practices	[12,14,19,22,23,46]
B12	Coding and interfaces models limitations	[14,18,23]
B13	Limitations in technological support and integration	[15,19,22,24]
B14	Lack of demand on BIM	[13,15–19,22,24]
B15	Communication issues (e.g. unwillingness to share information)	[13,20]
B16	Longer setup time	[22,24]

4. Findings and discussion

After verifying the reliability of data, the RII values were calculated for all barriers, as indicated in Table 4. The quantification of the importance level (IR) was carried out according to Table 1.

The analysis indicates that a total of 14 barriers were identified as very important (VI), representing 87.5 % of the identified barriers. The remaining two barriers, which were perceived as important (I), accounting for 12.5 % of the barriers. As illustrated, there has been a consensus on the ranking of barriers 3,8, and 16 by both respondent groups: contractors and consultants.

4.1. Agreement's level of between the stakeholders

To determine the level of agreement between contractors and consultants, the Spearman coefficient of rank correlation was determined based on the rankings assigned to the barriers, using the equation below:

$$\rho = 1 - \left[6\sum D^2 \Big/ N\left(N^2 - 1\right)\right] \tag{5}$$

where:ρ = Spearman coefficient of rank correlation$\sum D^2$ = Sum of the squared differences in ranks of the paired comparison$N$ = Number of parameters for which the ranking is made

The Spearman coefficient of rank correlation was found to be .83, indicating a high level of agreement between the stakeholders: contractors and consultants, as indicated in Table 5, which provides the levels of the different agreement on the barriers' ranking.

4.2. Development of the Interpretive Structural Modeling (ISM)

ISM is a methodical use of graph theory that helps organize complex relationships among elements (barriers) in a hierarchical structure [45]. ISM is employed to categorize and prioritize the barriers to BIM adoption. These barriers include technical challenges like compatibility and interoperability, organizational challenges such as a shortage of skilled personnel and resistance to change, and external challenges like insufficient support for the technology. The finding of ISM can assist stakeholders for understanding the critical barriers in BIM adoption and their interrelationships, thereby aiding in developing targeted strategies to tackle the identified barriers. The following steps were performed to develop the ISM model for BIM barriers.

1. **Identification of the barriers:** Sixteen barriers of adopting BIM are identified as indicated earlier.
2. **Establishing relationships:** Relationships among these barriers were established through pairwise comparisons by two experts' judgment presenting contractors and consultants.
3. **Structural Self-Interaction Matrix (SSIM):** An SSIM was devised to capture the direct impact of one barrier on another. This SSIM was then transformed into an "initial reachability matrix".
4. **Reachability matrix formation:** The reachability matrix was refined by incorporating transitivity rules, ensuring that if barrier (A) impacts barrier (B) and barrier (B) impacts barrier (C), then barrier (A) also impacts barrier (C). The reachability matrix is derived from the adjacency matrix by replacing (V) with (1), (A) with (0), and (X) with (1) and (O) with (0), for mutual influence. This matrix represents direct relationships between variables.

Table 5

Definitions of the different levels of agreement on the ranking of the barriers.

Spearman's coefficient of rank correlation	Agreement level
.1–.3	Low
.3–.5	Moderate
.5–.7	Moderate to high
.7–1	High

Table 4

Ranking of the barriers (consultants vs. contractors' perspectives).

	Barriers	Consultants			Contractors			Consultants & Contractors
		RII (%)	IR	R	RII (%)	IR	R	R
B1	Compatibility and interoperability of BIM	76.0	VI	3	80.8	VI	1	1
B2	Setup costs (training, license, hardware … etc.)	79.3	VI	1	77.6	VI	2	1
B3	Lack of skilled and experienced personnel	76.0	VI	3	76.3	VI	3	3
B4	Lack of implementation procedures, methods, and standards	73.3	VI	6	73.7	VI	4	6
B5	Insufficient BIM teaching in the academic sector	76.0	VI	3	73.1	VI	4	4
B6	Resistance to change	70.0	VI	7	71.2	VI	6	7
B7	Insufficient support of the technology	78.0	VI	2	69.9	VI	7	5
B8	Lack of awareness (through seminars, training programs … etc.)	70.7	VI	7	69.9	VI	7	8
B9	Legal and liability risks	67.3	VI	12	69.2	VI	9	10
B10	Uniqueness of construction projects and its associated complexity	70.0	VI	7	68.6	VI	10	9
B11	Companies are satisfied with their current practices	65.3	VI	14	67.9	VI	11	11
B12	Coding and interfaces models limitations	65.3	VI	14	66.7	VI	12	13
B13	Limitations in technological support and integration	68.7	VI	10	64.1	VI	13	12
B14	Lack of demand on BIM	57.3	I	12	62.8	VI	14	15
B15	Communication issues (e.g. unwillingness to share information)	68.7	VI	10	62.2	I	14	14
B16	Longer setup time	57.3	I	16	53.8	I	16	16

Note: RII = Relative importance index; IR = Importance rating; R = ranking.

5. **Level partitioning:** to determine the hierarchy or level of each barrier, use the transitive closure matrix to establish the levels. Each barrier is assigned a level based on its influence and the influences on it
6. **Development of ISM model**: Based on the partitioned levels, a directed graph (digraph) is constructed to depict the ISM model, illustrating the relationships and hierarchies among the barriers. The highest-level barriers are least influenced and influence other barriers, while the lowest level barriers are the most influenced.
7. **Validation of the developed model**: Review the model for accuracy and consistency to check if the relationships and hierarchy make sense and adjust, if necessary
8. **Analysis and interpretation:** Examine the model to identify key barriers, their roles, and how they impact each other. This analysis assists in understanding the structure and identifying key areas for intervention or focus.

An ISM was developed to categorize and prioritize the barriers. This method offers a thorough comprehension of the primary barriers to BIM adoption and their interconnections, linking theoretical models with practical insights. It assists stakeholders devise targeted strategies for the efficient utilization of BIM in the construction sector.

4.2.1. Development of Structural Self-Interaction Matrix (SSIM)

Upon the identification of the barriers, the SSIM is developed using the following symbols to define the relationships among the barriers: The symbol (V) indicates that Barrier i impacts Barrier j., The symbol (A) indicates that Barrier i is impacted by Barrier j, The symbol (X) indicates that both Barriers i and j impact each other, while the symbol (O) indicates that there is no correlation between the barriers. The relative correlations among the barriers are defined according to an understanding of how one element impacts, or is related to another. The relationships were determined based on experts' input. Two experts representing contractors and consultants were asked to fill the ISM matrix and then conduct meetings till the final matrix is agreed upon, as depicted in Table 6.

4.2.2. Development of initial and final reachability matrix

As illustrated in Table 7, the SSIM is transformed into a 0–1 matrix, referred to as initial matrix reachability, which was used to partition the barriers into hierarchical levels, in which (1) represents a relationship's presence, while (0) represents a relationship's absence, as follows: (V) → (1) (Influence), (A) → (1) (Influenced by), (X) → (0) (Mutual influence), and (O) → (0) (No relationship). The final reachability matrix is driven by updating the initial reachability matrix after applying Warshall's Algorithm, which includes both direct and indirect relationships among the barriers. This matrix assists in understanding the overall influence structure among the barriers, as presented in Table 8.

4.2.3. Partitioning the reachability matrix

Upon the development of the reachability matrix, partitioning is performed for determining the different barriers' levels. This is carried out through iterative calculations to establish the reachability set, antecedent set, and intersection set for each element (barrier), as shown in Table 9.

4.2.4. Development of the interpretive structural model & digraph

At this stage, the barriers are plotted in a hierarchy diagram based on their levels. The highest-level barriers will be those that are least influenced and influence other barriers, while the lowest level barriers are the most influenced. Fig. 1(a) depicts the barriers' partitions graph and Digraph graph. As depicted in Fig. 1(b), according to the reachability matrix, the final ISM model is constructed by the replacement of element nodes and displaying their hierarchical relationships to represent the relationships among the barriers visually. The analysis of the ISM generated the following hierarchical structure.

- High influence barriers: B3, which suggests that this barrier is crucial for adopting BIM in construction management.
- Moderate Influence barriers: B8, B15, and B16, which suggest that these barriers are important for adopting BIM in construction management, but their impacts are not as critical as B3.
- Low Influence barriers: B1, B2, B4, B5, B6, B7, B9, B10, B11, B12, B13, B14.

4.2.5. Interpretation and analysis

As depicted in Fig. 1, the model visually represents the structured complexity of the barriers. B3, "Lack of skilled and experienced personnel" is the key driving power barrier which represents the most significant barriers, while barriers "B1, B2, B4, B5, B5, B6, B7, B9, B10, B11, B12, B13, B14" have the lowest levels and are the most influenced barriers. Looking at the relationships among the barriers as depicted in the model, it can be noted that for instance the "Setup costs", (B2) which is the most important barrier from the contractors' perspective, is influenced by other barriers (B3, B4, B8, B15, and B16), in which B3, B8, and B15 are driving power barriers, while B4 is influenced barrier. Therefore, focusing and improving B3, "Lack of skilled and experienced personnel" will improve B8 "Lack of awareness" and B15 "Communication issues" and B16 "Longer setup time", thus improving the "Setup costs" barrier (B2) directly. In other word focusing on level 1 and level 2 barrier leads to improving other lower-level barriers. This can help in understanding the complexity and interdependence of the barriers.

Table 6
Structural self-interaction matrix (SSIM).

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
B1	X	V	O	V	V	A	V	A	O	A	V	A	O	X	O	A
B2			O	V	V	O	V	A	O	A	V	X	O	A	A	O
B3				V	V	O	V	O	O	V	V	V	O	O	O	V
B4					V	O	V	A	A	A	V	A	O	A	O	A
B5						A	V	A	O	X	X	X	A	X	O	A
B6							V	A	O	A	V	A	O	A	O	A
B7								A	O	X	X	X	A	X	O	A
B8									O	V	V	O	O	O	O	O
B9										A	V	V	V	O	O	O
B10											X	X	X	X	A	A
B11												X	X	X	O	A
B12													X	X	O	A
B13														A	O	A
B14															O	A
B15																O
B16																X

Table 7
Initial Reachability Matrix.

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	Driving Power
B1	1	1	0	1	1	0	1	0	0	0	1	0	0	1	0	0	7
B2	0	1	0	1	1	0	1	0	0	0	1	1	0	0	0	0	6
B3	0	0	1	1	1	0	1	0	0	1	1	1	0	0	0	1	8
B4	0	0	0	1	1	0	1	0	0	0	1	0	0	0	0	0	4
B5	0	0	0	0	1	0	1	0	0	1	1	1	0	1	0	0	6
B6	1	0	0	0	1	1	1	0	0	0	1	0	0	0	0	0	5
B7	0	0	0	0	0	0	1	0	0	1	1	1	0	1	0	0	5
B8	1	1	0	1	1	1	1	1	0	1	1	0	0	0	0	0	9
B9	0	0	0	1	0	0	0	0	1	0	1	1	1	0	0	0	5
B10	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	12
B11	0	0	0	0	1	0	1	0	0	1	1	1	1	1	0	0	7
B12	1	1	0	1	1	1	1	0	0	1	1	1	1	1	0	0	11
B13	0	0	0	0	1	0	1	0	0	1	1	1	1	0	0	0	6
B14	1	1	0	1	1	1	1	0	0	1	1	1	1	1	0	0	11
B15	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	0	3
B16	1	0	0	1	1	1	1	0	0	1	1	1	1	1	0	1	11
Dependence Power	7	7	1	10	13	6	14	1	2	11	15	11	7	8	1	2	

Table 8
Final reachability matrix (FRM).

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	Driving Power
B1	1	1	0	1	1	1*	1	0	1*	1*	1	1*	1*	1	0	0	12
B2	1*	1	0	1	1	1*	1	0	1*	1*	1	1	1*	1*	0	0	12
B3	1*	1*	1	1	1	1*	1	0	1*	1	1	1	1*	1*	0	1	14
B4	1*	1*	0	1	1	1*	1	0	1*	1*	1	1*	1*	1*	0	0	12
B5	1*	1*	0	1*	1	1*	1	0	1*	1	1	1	1*	1	0	0	12
B6	1	1*	0	1*	1	1	1	0	1*	1*	1	1*	1*	1*	0	0	12
B7	1*	1*	0	1*	1*	1*	1	0	1*	1	1	1	1*	1	0	0	12
B8	1	1	0	1	1	1	1	1	1*	1	1	1*	1*	1*	0	0	13
B9	1*	1*	0	1	1*	1*	1*	0	1	1*	1	1	1	1*	0	0	12
B10	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	0	12
B11	1*	1*	0	1*	1	1*	1	0	1*	1	1	1	1	1	0	0	12
B12	1	1	0	1	1	1	1	0	1*	1	1	1	1	1	0	0	12
B13	1*	1*	0	1*	1	1*	1	0	1*	1	1	1	1	1*	0	0	12
B14	1	1	0	1	1	1	1	0	1*	1	1	1	1	1	0	0	12
B15	1*	1	0	1*	1*	1*	1*	0	1*	1	1*	1*	1*	1*	1	0	13
B16	1	1*	0	1	1	1	1	0	1*	1	1	1	1	1	0	1	13
Dependence Power	16	16	1	16	16	16	16	1	16	16	16	16	16	16	1	2	

4.2.6. Validation of the results

The results obtained from applying ISM were validated with one contractor and one consultant through sharing the results to ensure the model's findings are accurate and actionable. The experts agreed on the add value of utilizing ISM modeling in the analysis. Following these steps can assist in gaining a comprehensive understanding of the barriers and devising practical strategies to address them. Table 10 compares the ranking of the identified barriers using the results obtained from the RII and ISM. The differences between the two techniques are due the fact that applying RII assumes that the barriers are independent and has no correlation with other barriers, which is not true in many cases.

4.3. Experts' contribution to the results

The study's results were shared with local professionals to obtain their feedback. The experts provided their opinion of the most impactful barriers to BIM utilization in construction project management, as follows.

- The compatibility and interoperability of BIM software can pose significant challenges for small contractors, as major hardware and software upgrades can be a substantial investment. However, addressing the barrier of lack of skilled and experienced personnel (Level 3), as suggested by ISM, can improve the compatibility and interoperability of BIM software.
- The setup costs required to initiate BIM, including training, licenses, and hardware can be extremely challenging for midsize contractors. Thus, contractors must carry out an economic analysis to ensure that the benefits outweigh the costs of adopting BIM. However, focusing on longer setup time (level 2), as proposed by ISM, can help reduce setup costs by shortening the setup duration.
- The lack of skilled and experienced personnel to operate BIM in construction management is a key barrier that should be considered (level 1), as proposed by ISM. Addressing this barrier can help improve other barriers required for a well-established plan. This includes training existing personnel, which can be costly due to the unavailability of licensed centers. It also requires the contractors to hire new engineers proficient in BIM, which will impact the costs of construction projects.
- The lack of implementation procedures, methods, and standards is one of the most impactful barriers to BIM utilization in construction management. This barrier can be mitigated by addressing the Lack of awareness (level 2) and the lack of skilled and experienced personnel (Level 1).
- Consistency in rankings: The comparison of ISM and RII-based ranking revealed some discrepancies. This occurs because the two techniques operate under different assumptions. The RII assumes that all barriers are independent, while ISM uses pairwise comparison to establish the relationships among all barriers.

5. Conclusion and recommendations

BIM is a digital technology that integrates data layers to facilitate the efficient sharing of engineering and architectural documents among

Table 9
Level partitioning.

Barrier	Reachability Set R (Mi)	Antecedent Set A (Ni)	Intersection Set R (Mi)∩A(Ni)	Level
B1	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B2	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B3	3	3	3	3
B4	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B5	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B6	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B7	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B8	8,	8,	8,	2
B9	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B10	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B11	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B12	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B13	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B14	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,	1, 2, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14,	1
B15	15,	15,	15,	2
B16	16,	3, 16,	16,	2

construction project stakeholders. Despite its potential, the utilization of BIM remains low among contractors and consultants in Saudi Arabia. This paper presents a study conducted for identifying and evaluating the main barriers to BIM utilization in the region.

The five key barriers identified are: BIM compatibility and interoperability, setup costs (training, licenses, hardware, etc.), lack of skilled personnel, insufficient implementation procedures and standards, and inadequate BIM education in academia. To understand the correlation among the identified barriers, the study applied ISM methodology to determine the diving power of each barrier. This helps decision-makers develop strategic plans to improve BIM adoption in construction management in Saudi Arabia. According to the ISM results, the strategic plan should consider improving skilled and experienced personnel. This can be achieved by offering training, facilitating access to licenses, and investing in hardware. Addressing these areas is expected to minimize setup costs and improve BIM compatibility and interoperability, yielding the most significant returns for BIM adoption in construction management. It should be noted that while this research introduces comprehensive understating, some limitations should be considered. The study's geographic focus on a specific pool of professionals in Saudi Arabia's Eastern Province may limit the generalizability of the findings to other locations or industry stakeholders. Further, the dependency on qualitative and quantitative data from interviews, surveys, and literature reviews might not capture all the barriers to BIM adoption. Incorporating alternative methodologies, such as case studies, could offer a more complete understanding of the temporal and contextual dynamics affecting BIM adoption.

To promote greater BIM adoption, several measures are recommended. First, the development and dissemination of standard procedures and guidelines for BIM in construction project management are essential for reducing legal risks for contractors. Additionally, offering training programs and raising awareness about BIM's benefits through specialized engineering associations can further support its adoption. Implementing incentives for BIM use in public projects will also provide users with a competitive advantage. Lastly, attracting international BIM suppliers and service providers to invest in Saudi Arabia is crucial for improving licensing, technical support, and overall adoption of BIM in the country.

ISM helps in understanding which barriers have the most significant influence and which are influenced by others. Based on the hierarchical

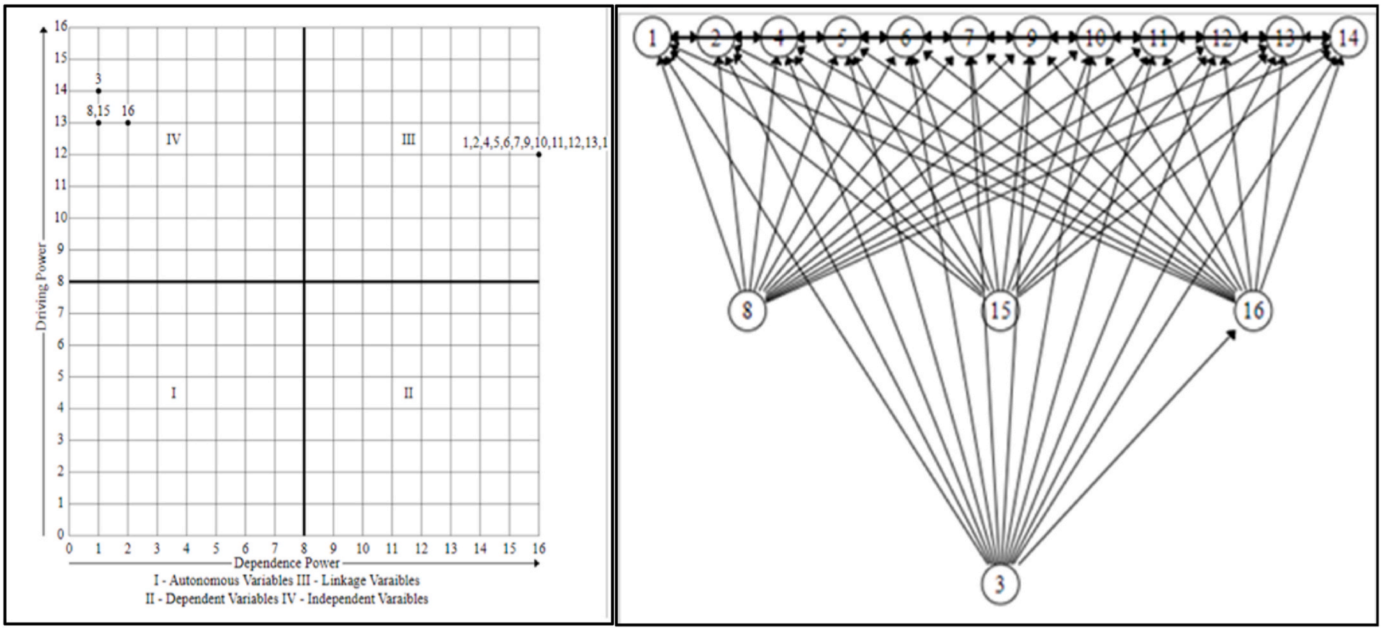

Fig. 1. (a) Barriers partitions graph and (b) Digraph graph.

Table 10
ISM vs. RII.

	Rank															
	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16
ISM	5	5	1	5	5	5	5	2	5	5	5	5	5	5	2	4
Consultants	3	1	3	6	3	7	2	7	12	7	14	14	10	12	10	16
Contactors	1	2	3	4	4	6	7	7	9	10	11	12	13	14	14	16
Consultants & Contractors	1	1	3	6	4	7	5	8	10	9	11	13	12	15	14	16

structure and relationships among these barriers, decision-makers can develop strategies to tackle the most critical barriers, focusing on the root causes and key influencing barriers for effective solutions.

Based on the findings of this study, several recommendations can be made for future research. To enhance BIM software compatibility and integration, future studies should focus on the following key areas: developing universal standards and protocols; analyzing successful case studies to identify practical solutions for integration challenges; evaluating the long-term financial benefits of BIM adoption compared to initial setup costs; investigating government and industry programs that offer financial support or incentives to reduce adoption barriers; and developing cost-effective tools and methods for hardware, licensing, and training to make BIM more accessible for small and medium-sized businesses and emerging markets.

CRediT authorship contribution statement

Adel Alshibani: Writing – review & editing, Writing – original draft, Supervision, Project administration, Data curation, Conceptualization. **Mubarak S. Aldossary:** Writing – original draft, Data curation. **Mohammad A. Hassanain:** Writing – review & editing, Formal analysis. **Hamza Hamida:** Formal analysis, Conceptualization. **Hashim Aldabbagh:** Formal analysis, Conceptualization. **Djamel Ouis:** Writing – review & editing, Validation.

Declaration of competing interest

"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".

Data availability

Data will be made available on request.

Acknowledgement

The authors thank King Fahd University of Petroleum and Minerals for the support and facilities that made this research possible.

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