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Factors affecting BIM implementation in Saudi Arabia: a critical analysis

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Abstract

Purpose – This study examines the underlying relationships between the critical factors of building information modeling (BIM) implementation and the factors' groupings among architecture, engineering and construction (AEC) organizations in Saudi Arabia. The objectives of the study are to (1) identify the critical factors for BIM implementation, (2) analyze the interrelationships between the critical factors and (3) compare the critical factors between the different organizational characteristics.

Design/methodology/approach – First, potential factors were identified through a systematic literature review and interviews with AEC professionals. Then, a questionnaire survey was sent to AEC professionals and the collected data were analyzed using the following techniques and tests: mean score ranking, standard deviation, normalized value, factor analysis (FA), analysis of variance (ANOVA) and post-hoc Tukey test.

Findings – The analyses show that 14 factors are critical for BIM implementation in Saudi Arabia. The top critical factors include the existence of standard contracts on data security and user confidentiality, consistent views on BIM among stakeholders and the availability of guidelines for implementing BIM. Of the 14 critical factors, 9 can be grouped into 4 underlying factors: environmental, governmental, legal and organizational. The analysis shows that the criticality of the most critical factors grouped by the FA varies between different levels of BIM competency. Finally, the presence of public–private partnerships (PPPs) in realizing BIM projects is a new and emerging critical factor for BIM implementation in Saudi Arabia.

Originality/value – This study differs from prior works on BIM implementation in Saudi Arabia by using FA to explore the underlying relationships among factors of BIM implementation and the factors' groupings. Based on the FA results, a roadmap for implementing the BIM was developed. These findings will help to purposefully and efficiently customize BIM implementation strategies and initiatives to ensure successful BIM implementation in Saudi Arabia.

Keywords Automation, Building information modeling, Inferential statistics, Multivariate analysis, Saudi Arabia

Paper type Research paper

1. Introduction

Building information modeling (BIM) has revolutionized the architecture, engineering and construction (AEC) industry by enhancing construction performance throughout the entire

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project life cycle (Poirier *et al.*, 2015). The implementation of BIM has immense potential to overcome the deficiencies that have persisted for decades in the AEC industry. For instance, BIM can increase the labor productivity of construction projects (Poirier *et al.*, 2015). Moreover, BIM improves communication, which can efficiently reduce project duration and cost (Cao *et al.*, 2017). Furthermore, BIM implementation positively impacts the AEC industry by preserving the quality of construction projects, which benefits project stakeholders and society as a whole. With such a high reputation, the AEC industry would become more attractive to foreign investors, thereby accelerating a nation's infrastructure development (Othman *et al.*, 2020). The refusal of BIM implementation can, therefore, seriously damage a nation's economy.

The AEC industries are driven to implement BIM owing to its potential benefits (Munir *et al.*, 2021). Consequently, several high-income nations, such as the UK and USA, have attained a high level of BIM implementation (Aibinu and Venkatesh, 2014; Won *et al.*, 2013). Other high-income nations, including Saudi Arabia, continue to struggle with BIM implementation (Almuntaser *et al.*, 2018). In other words, even high-income countries face distinct challenges when implementing BIM in the local AEC industry. In Saudi Arabia, the lack of client interest, interoperability issues and lack of awareness are recurrent barriers to BIM implementation (Banawi, 2018). Furthermore, perceptions and attitudes of AEC industry professionals regarding BIM vary by geographical location, organizational characteristics and individual preferences (Al-Mohammad *et al.*, 2023a). Stakeholders should comprehend the fundamental causes of BIM implementation failures to develop effective BIM implementation strategies. Therefore, it is essential to identify and understand the critical BIM implementation factors in the local context, including Saudi Arabia.

Saudi Arabia exerts considerable effort to achieve "Vision 2030." The vision includes the largest development budget for Saudi Arabia (Al-Yami and Sanni-Anibire, 2019). In line with "Vision 30," the AEC industry was assigned a critical role. The AEC industry must adapt to this challenge by adopting modern construction technologies and techniques. Therefore, there has never been a better time for Saudi Arabia to take advantage of technological advances such as BIM. As an indispensable step in successful BIM implementation, prior works have provided insights into the factors of BIM implementation in Saudi Arabia, including Al-Yami and Sanni-Anibire (2019), Banawi (2018), Almuntaser *et al.* (2018) and Sodangi *et al.* (2018). However, the use of descriptive statistics to analyze the factors generates limitations in data comprehension (Byrne, 2007). In contrast, factor analysis (FA) can explore the underlying relationships between critical factors and their groupings. By focusing on these groupings, policymakers, industry practitioners and researchers in Saudi Arabia can obtain results that will facilitate BIM implementation in the local AEC industry. Consequently, project stakeholders can allocate resources to address these groupings simultaneously. Therefore, in order to develop the most suitable strategies for the local AEC industry, it is crucial to further examine the underlying relationships between the critical factors of BIM implementation.

This study examined the underlying relationships between the critical factors of BIM implementation and their groupings in Saudi Arabia. To achieve this objective, the following objectives were accomplished: (1) identify the critical factors for BIM implementation, (2) analyze the interrelationships between the critical factors and (3) compare the critical factors between the different organization characteristics. This study contributes to the body of knowledge by analyzing the factors of BIM implementation and examining their underlying relationships, highlighting a need for additional solutions in Saudi Arabia.

2. Literature review

2.1 BIM in Saudi Arabia

In Saudi Arabia, BIM is already in use. For example, Baik *et al.* (2014) established the Hijazi architectural element library using laser scanners and image survey data. The library reduces the time required to create the Jeddah historical building information modeling (JHBIM) model. One year later, Baik *et al.* (2015) proposed a framework to integrate JHBIM and a geographic information system (GIS). Al-Sulaihi *et al.* (2015) developed a framework for integrating indoor environmental quality data in educational buildings using a BIM model. This model can be used to detect and track indoor environmental problems. Ahmed and Asif (2020) developed a BIM-based retrofit model that can be used for conducting energy, economic and environmental analyses. Finally, Alrashed and Kantamaneni (2018) proposed a 5D BIM model for cost-benefiting housing that can accurately estimate the bill of quantity and appraisal of construction costs.

Despite these efforts, the BIM implementation rate in Saudi Arabia has been low. Using a case study approach, Almuntaser *et al.* (2018) and Al-Yami and Sanni-Anibire (2019) found that the lack of client demand for BIM was the main barrier to BIM implementation in Saudi Arabia. However, although case studies can improve our understanding a particular context, the findings cannot be generalized. Sodangi *et al.* (2018) assessed subcontractor firms' levels of awareness and readiness to implement BIM. However, this study did not analyze the critical factors for BIM implementation. Aljobaly and Banawi (2020), Banawi (2018), Al-Hammadi and Tian (2020) and Alhumayn *et al.* (2017) identified and prioritized barriers to BIM implementation in Saudi Arabia. However, prior works employed the mean score technique and relative importance index (i.e. descriptive statistics) to analyze and prioritize the barriers.

The above review suggests that prior works on BIM in Saudi Arabia have shed light on factors related to BIM implementation. However, a focus on exploring the underlying relationships between these factors is still lacking. Although ranking analysis is important for prioritizing the factors, the analysis alone is inadequate for understanding the characteristics of BIM implementation and the derivation of critical factors (Mom *et al.*, 2014). FA can determine a small set of factor categorizations and show the relationships between a set of interrelated variables (Hair *et al.*, 2010). Understanding the patterns and relationships between these factors can provide profound insights into the data (Byrne, 2007). In other words, identifying the underlying relationships and factor groupings can significantly facilitate the development of BIM implementation frameworks and roadmaps. Therefore, it is worth examining the underlying relationships between the critical factors of BIM implementation and their groupings in the Saudi Arabian.

2.2 BIM in Middle Eastern countries

In addition to Saudi Arabia, prior works have explored BIM implementation levels and challenges in Middle Eastern countries. In the United Arab Emirates (UAE), BIM was mandated in the emirate of Dubai. However, the other emirates rarely used BIM. The low BIM implementation rate is strongly associated with resistance to change, lack of awareness of BIM benefits and lack of BIM standards (Mehran, 2016). More recently, Omar and Dulaimi (2021) found that BIM implementation in the UAE is poor. The study concluded that most BIM implementers only used BIM for clash detection and acquiring building permits in response to the specific requirements of the local AEC market. Khodeir and Nessim (2017) and Marzouk *et al.* (2022) stated that BIM implementation in Egypt is in the development stage because of several barriers, including high implementation cost, lack of experience in BIM projects and lack of training. Hatem *et al.* (2018) investigated the BIM implementation level and barriers in the Iraqi AEC industry. The findings show that the policymakers' role in promoting BIM implementation remains inactive. Furthermore, Iraqi AEC organizations used traditional design methods (e.g. 2D CAD), suggesting that BIM in Iraq is at a level 0. Jordan and Bahrain also share similar low BIM implementation rates and barriers to BIM implementation, including a lack of BIM knowledge and awareness of BIM benefits (Ahmed and Suliman, 2020; Hyarat *et al.*, 2022). Prabhakaran *et al.* (2021) indicated that macroscale

BIM maturity in Qatar is not mature. In addition, AEC organizations in Qatar do not receive adequate support to promote BIM implementation at the microscale level (Prabhakaran *et al.*, 2021). Marefat *et al.* (2019) found that BIM implementation for construction safety in Iran is low because of the lack of experience and training, absence of guidelines and stakeholders' unwillingness to change their practices. Finally, Gerges *et al.* (2017) found that BIM implementation was low in Middle Eastern countries, including Kuwait, Oman and the UAE.

2.3 BIM in high-income countries (non-Middle Eastern countries)

Several high-income AEC industry players adopt policies and initiatives to foster BIM implementation because of BIM benefits. For instance, the UK government mandated the use of BIM in public projects (Aibinu and Venkatesh, 2014). The USA and Denmark advised architectural organizations and contractors to submit Industry Foundation Class (IFC) files when dealing with publicly funded projects (Won *et al.*, 2013). In addition, the BIM implementation rate in North American countries, including the USA, has reached approximately 72% (Juszczyk *et al.*, 2015). In Taiwan, there are high levels of BIM implementation in the AEC industry (Chong *et al.*, 2017). Singh (2017) investigated BIM implementation levels in high-income countries, including Sweden, Norway, Finland, Singapore, Denmark and France. The work concluded that BIM implementation had increased because of several policies and initiatives, such as government mandates, submissions in the IFC format, the development of BIM standards and financial incentives. In other words, BIM implementation in these nations is well established because governments have taken steps toward increasing the BIM implementation rate.

2.4 Factors affecting BIM implementation

Identifying the main factors affecting BIM implementation is a prerequisite for any attempt to increase BIM implementation in any country (Belayutham *et al.*, 2018). Although BIM awareness is an important driver and the first step in the BIM implementation process (Ahmed and Kassem, 2018), it is a significant barrier in several countries (Dang *et al.*, 2020; Maskil-Leitan *et al.*, 2020; Abbasnejad *et al.*, 2020). The lack of awareness of BIM and its benefits generates resistance to change into a new workflow and practice. According to Arayici *et al.* (2011), a lack of BIM awareness and understanding prevents AEC organizations from exploring BIM capabilities and using BIM tools. This factor is strongly related to the absence of case studies on the well-documented financial implications of implementing BIM (Hong *et al.*, 2019). Thus, the implementation of BIM by stakeholders is unjustified. This situation affects market demand for BIM. Tai *et al.* (2020) attributed the lack of BIM demand to a low BIM awareness. AEC organizations are reluctant to implement BIM because of their weak environmental forces and motivation (Babatunde *et al.*, 2020). Furthermore, construction projects vary in budget and size. The selection criteria for these projects for pilot BIM are still lacking (Won *et al.*, 2013). Therefore, project characteristics should be considered when selecting suitable projects to pilot the BIM (Al-Mohammad *et al.*, 2023a).

BIM enables multidisciplinary collaboration (Tang *et al.*, 2020). However, the use and exchange of digital data in a BIM environment raises concerns among project stakeholders regarding data security (Al-Mohammad *et al.*, 2023a). Some individuals may make unauthorized modifications to the BIM model (Dao *et al.*, 2020). These modifications include errors and inaccurate data input, resulting in disputes and confusion regarding the responsible party (Almarri *et al.*, 2019). Project members tend to reject BIM models that have been modified or updated by others. This is certainly the case when the rights and responsibilities of project members are not defined (Al-Mohammad *et al.*, 2023b). Critical data are not shared if data security is not assured (Cao *et al.*, 2017). This concern raises the question of how business knowledge can be protected. Furthermore, BIM models contain valuable information that can be used for specific purposes. For instance, the client may use the final

BIM model for facility management, while disregarding the contributions of other parties (Wang *et al.*, 2019). However, neither a consensus nor a general rule exists regarding who has the right to own the digital product (Almarri *et al.*, 2019). In summary, the literature has established that legal problems are a major factor affecting global BIM implementation (Georgiadou, 2019; Díaz *et al.*, 2017; Ma *et al.*, 2018).

BIM implementation requires a significant investment in resources (Abbasnejad *et al.*, 2020). Among these resources, BIM training has been identified as a major factor in determining the success or failure of BIM implementation (Kim *et al.*, 2020). BIM training is essential for enhancing organizational BIM capabilities (Kamel and Memari, 2019). As the views of AEC professionals on BIM are inconsistent (e.g. some view BIM as modeling software and others as a database), training is necessary to reduce the problem of the lack of BIM understanding (Hong *et al.*, 2019). However, employees lack time to build competency because of the steep BIM learning curve (Rahman *et al.*, 2019). Consequently, organizations have to wait a long time to measure BIM training outcomes, making BIM an unappealing choice (Liao *et al.*, 2019). Therefore, willingness to learn BIM affects BIM implementation decisions. As BIM and its associated tools are still evolving, continuous training is critical to keep the employees abreast of the up-to-date software and the latest advancements in BIM (Almuntaser *et al.*, 2018). Although BIM champions can disseminate the latest information on BIM across different disciplines, this position is unavailable in most organizations (Olugboyega and Windapo, 2022). Therefore, the decision to implement or continue BIM is affected.

BIM non-implementers frequently question whether the long-term financial benefits outweigh the upfront BIM implementation costs (Tai *et al.*, 2020). BIM investment involves huge initial capital, including purchasing proper hardware and BIM software, maintenance cost and cost of BIM training (Dang *et al.*, 2020; Kamel and Memari, 2019; Eleftheriadis *et al.*, 2018). Organizations must purchase high-performance computers with certain specifications to operate BIM tools (Wang and Lu, 2022). In addition, it is necessary to allocate funds to purchasing BIM software in the market and new versions of software that emerge frequently (Love and Matthews, 2019). To maintain a competitive advantage and enhance its reputation in the AEC market, organizations must improve BIM competency among staff (Rahman *et al.*, 2019). This requires hiring BIM experts to train the staff through a series of training programs and courses on BIM implementation across the entire project lifecycle, which are not free of charge (Liu *et al.*, 2019). Furthermore, data sharing between different modeling tools remains problematic (Wan *et al.*, 2019). Although the industry foundation class (IFC) was established as a potential solution for interoperability problems, it does not guarantee error-free data sharing (Aibinu and Venkatesh, 2014). Investing in new software is an alternative. However, it incurs additional costs for organizations to handle (Rogers *et al.*, 2015).

Successful BIM implementation requires a set of policies and initiatives such as BIM implementation guidelines as part of the strategy (Othman *et al.*, 2020). BIM implementation guidelines are regarded as major contributors to BIM implementation, irrespective of a country's income level (e.g. low-, middle- and high-income) (Al-Mohammad *et al.*, 2023b). While several BIM implementation guidelines have been developed by pioneer countries in BIM implementation, such as the UK and USA, they are neither available nor suitable for other AEC contexts (Hong *et al.*, 2019). Different AEC environments and requirements require different guidelines (Rogers *et al.*, 2015). In the absence of uniform guidelines, organizations develop their own to maintain competitiveness, resulting in inconsistent standards (Dang *et al.*, 2020). Furthermore, various countries use different project delivery methods. However, BIM may be more effective in one project delivery method than in others. For instance, design/build and Integrated Project Delivery (IPD) methods offer the optimal conditions for utilizing BIM software (Bynum *et al.*, 2013). Therefore, project delivery method preferences affect BIM implementation decisions. Finally, opportunities for public–private partnerships (PPP) to engage in infrastructure development are increasing (Poirier *et al.*, 2015). Within the

BIM environment, PPP can leverage BIM capabilities for data management and exchange (Al-Mohammad *et al.*, 2023b).

2.5 Positioning of this study

The above review illustrates that the rates of BIM implementation in high-income countries are inconsistent. Due to several initiatives and policies, non-Middle Eastern countries have attained higher BIM implementation rates than Middle Eastern countries. This review also illustrates that existing research provides insights into BIM implementation factors in the Middle East, including Saudi Arabia. However, prior works, specifically in Saudi Arabia, have analyzed the factors using descriptive statistics. Therefore, the focus on exploring the underlying relationships between critical factors and their groupings in the context of Saudi Arabia is still missing. Neglecting the underlying relationships and groupings prevents stakeholders from prioritizing resources to ensure successful BIM implementation. Therefore, it is essential to explore underlying relationships and groupings. This study adopted FA to explore the underlying relationships among the critical factors in BIM implementation and their groupings to fill that gap.

3. Methodology

This study began by developing a questionnaire survey using a systematic literature review (SLR) and interviews with AEC professionals. The questionnaire was disseminated to AEC professionals and analyzed using the mean score, standard deviation and normalized value techniques. Then, FA was used to explore the underlying relationships between the factors in BIM implementation and their groupings. Finally, an analysis of variance (ANOVA) and *post-hoc* Tukey tests were used to examine any inconsistencies in the views toward the critical factors of BIM implementation. Figure 1 shows the methodology used in this study.

3.1 Developing the questionnaire survey

This study employed a questionnaire to collect quantitative information on the factors affecting BIM implementation. A survey is suitable for collecting more responses from a large number of people to represent a population and is appropriate for quantitative research (Kothari, 2004). In addition, certain data analysis techniques, such as FA, require a sufficient sample size, which can be effectively collected through surveys (Pallant, 2010). The data generated from a survey can be used to develop overall patterns and underlying relationships between variables (Rowley, 2014). Prior works with similar objectives and natures have also used surveys. For instance, Babatunde *et al.* (2020) used a survey to identify the barriers and strategies for implementing BIM in Nigeria and Olugboyega and Windapo (2022) used a survey to explore barriers to BIM adoption in South Africa, and Mom *et al.* (2014) used a survey to develop critical success factors for BIM adoption in Taiwan.

The initial version of the questionnaire was established using the SLR. The Scopus database was selected for the search process because: (1) it is a commonly used search engine for literature reviews in the construction management domain (Munianday *et al.*, 2022); (2) it is a popular database that indexes construction management research publications (Wuni *et al.*, 2019); and (3) it includes more recent journals compared to other databases (Yu *et al.*, 2018). The review process started with a search of journals containing the terms “building information modeling,” “building information model,” and “BIM” in the title, abstract, or keywords. The last decade was chosen as the timeframe for the search because BIM is rapidly evolving technology (Santos *et al.*, 2017).

Therefore, this study focused on articles from the last decade to ensure that the extracted factors were not outdated. The inclusion criteria were English-language engineering articles

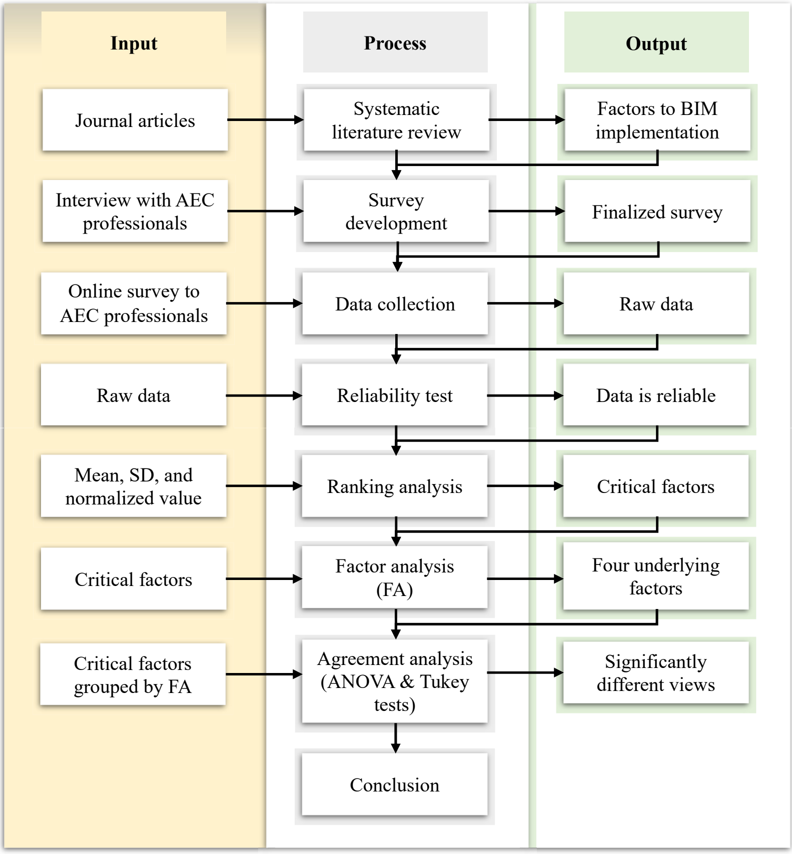

Figure 1. Overview of the study's methodology

published during the selected timeframe. In addition, articles should be published in journals with at least three publications on the topic to ensure that the journal regularly publishes articles on the topic (Al-Mohammad *et al.*, 2023b). Finally, three quality assessment criteria were developed to ensure the credibility of the selected articles: (1) is the paper peer-reviewed; (2) are the implementation factors addressed related to BIM; and (3) does the paper provide an adequate literature review of the study domain?

The search strings were used to retrieve 851 articles from the Scopus database. These papers were screened using a multi-stage process, including the removal of duplicate papers, checking titles and abstracts for relevance, checking articles against inclusion and exclusion criteria and quality assessment. At the end of this process, 29 articles progressed to the data-extraction stage. Then, positive factors (e.g. critical success factors and drivers) and negative factors (e.g. challenges and barriers) to BIM implementation were extracted from the articles. Finally, the variables were combined and the term "factor" was adopted.

Appendix 1 shows the 19 potential BIM implementation factors identified from the SLR process. Before distributing the questionnaire, interviews were conducted with six AEC professionals with more than 10 years of work experience in the Saudi Arabian AEC industry. The purpose of the interviews was to verify the survey's completeness and clarity. This step was essential to ensure that the terms and language used in the survey were appropriate and that respondents could complete the survey with minimal confusion (Dao *et al.*, 2020). The questionnaire was finalized based on the knowledge and recommendations of AEC professionals. Such recommendations are essential for matching theory and practice.

The survey was conducted in two stages. The first part aimed to collect the respondents' demographic information. The second part asked the respondents to evaluate the criticality of the 19 BIM implementation factors using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The five-point scale is a common scale for measuring variables in construction management and a convenient judgment scale for respondents (Dao *et al.*, 2020; Olugboyega and Windapo, 2022; Mom *et al.*, 2014).

3.2 Data collection

After finalizing the survey, this study collected data from AEC professionals with knowledge of BIM as the target population. As there was no sampling frame, this study deployed a non-probability sampling technique to obtain a representative sample. This technique allows for the selection of participants based on their willingness to participate in the study when random sampling is not applicable (Ma *et al.*, 2018). Owing to the shortage of BIM implementers in Saudi Arabia (Almuntaser *et al.*, 2018), the snowball sampling technique was used to obtain a sufficient sample size. Due to the difficulties in identifying eligible respondents, the snowball technique has also been used in previous construction management research, including Georgiadou (2019) and Munir *et al.* (2021). It allows gathering and sharing information about respondents through referrals or social networks (Al-Mohammad *et al.*, 2023b). Finally, participants who were initially contacted were asked to share information about other potential participants to increase the response rate.

After multiple reminders and interactions, a total of 115 valid responses were obtained. Although the sample size may seem small, it is still appropriate for the study's statistical analyses because the central limit theorem holds when the sample size is greater than 30 (Ott and Longnecker, 2008). Moreover, construction management works of a similar nature have a comparable sample size (e.g. 73 in Babatunde *et al.* (2019) and 87 in Liao *et al.* (2019)). In addition, there is a limited number of individuals with appropriate BIM knowledge in Saudi Arabia (Sodangi *et al.*, 2018; Al-Yami and Sanni-Anibire, 2019). Therefore, this makes the sample valid for data analysis.

Appendix 2 presents the survey profiles of respondents. Most respondents were male and aged between 31 and 45 years old. The majority have more than six years of working experience in the AEC industry and represent contractors. About 53% of the respondents were not professionals in BIM. This is consistent with a recent finding that AEC professionals in Saudi Arabia have minimal knowledge of BIM (Al-Hammadi and Tian, 2020). In summary, the experience of respondents in the AEC industry provides reliability to the collected data. Therefore, the data can be relied upon as representative of the Saudi Arabian AEC industry.

3.3 Data analysis

3.3.1 Reliability testing. Before analyzing the data, the internal consistency reliability was assessed using Cronbach's alpha, as used by (Hong *et al.*, 2019; Phang *et al.*, 2020; Babatunde *et al.*, 2020). Its value ranges from 0.00 to 1.00. A value closer to 1.00 gives higher reliability of the developed questionnaire. Conversely, a value closer to 0.00 indicates that the questionnaire should be further improved to increase the internal consistency for each factor (Al-Mohammad *et al.*, 2023a). The Cronbach's alpha value of the collected data was 0.610, which is acceptable at $\geq$ 0.60 for further analysis (Nunnalyy, 1978).

3.3.2 Ranking analysis. After testing reliability, we calculated the mean score to prioritize the factors for BIM implementation. The standard deviation (SD) was computed to differentiate between factors using the same means. For example, if two factors have the same mean, the factor with a lower SD should be ranked higher because its data are less spread out but closer to the mean (Al-Mohammad *et al.*, 2023b). Finally, the normalized value technique was used to identify critical factors. Unlike the mean score that selects almost half of the factors, the normalized value technique represents the respondents' aggregated perceived criticality toward a particular factor (Phang *et al.*, 2020). Therefore, the latter technique is more appropriate for selecting the critical factors (Sinoh *et al.*, 2020). Construction management research supports the use of the mean score, SD and normalized value techniques to identify critical factors, success factors and barriers to BIM implementation (Liao and Teo, 2017; Al-Mohammad *et al.*, 2023a; Munianday *et al.*, 2022).

3.3.3 Factor analysis (FA). After identifying the critical factors, the FA was used to explore the underlying relationships and groupings. FA is an effective method for identifying representative relationships among sets of interrelated variables (Hair *et al.*, 2010). It is a powerful method for grouping variables into a more critical set of factors based on the factor scores of the responses (Pallant, 2010). FA encompasses multivariate statistical procedures used for several purposes, including identifying the underlying relationships between variables (Williams *et al.*, 2010). Therefore, this study used FA to uncover the underlying relationships between the factors in BIM implementation and their groupings. During FA, principal component analysis (PCA) with varimax rotation was used to group the factors. Previous works in the BIM field have adopted FA to uncover the underlying relationships between variables and their groupings (Sinoh *et al.*, 2020; Ozorhon and Karahan, 2017; Liao *et al.*, 2019).

3.3.4 Agreement analysis. The survey sample was divided into subgroups according to profession (architect, engineer and contractor) and BIM competency (not professional, somewhat professional and professional). An ANOVA test was performed to understand the differences in respondents' perceptions of the critical factors of BIM implementation grouped by FA. ANOVA was adopted as a parametric test because of its robustness and superior performance over non-parametric tests when analyzing small samples (Field, 2013). In contrast, the *post-hoc* Tukey test determines the subgroups in which differences are observed (Liu *et al.*, 2019). Compared to the sample size in previous works, such as 100 in Liu *et al.* (2019) and 81 in Jin *et al.* (2017), the sample size of 115 in this study was considered reasonable. Construction management studies have adopted similar tests for comparing means from three or more groups and analyzing data from Likert scale questions (Ozorhon and Karahan, 2017; Troiani *et al.*, 2020; Almarri *et al.*, 2019). A p-value less than 0.05 indicates inconsistent views toward the given critical factors grouped by FA (Field, 2013).

4. Results

4.1 Results of ranking analysis

Table 1 lists the ranking analysis results for the factors related to BIM implementation. The mean criticality scores of the factors ranged from 1.739 to 3.896. Factors with normalized values not less than 0.50 are identified as critical factors for BIM implementation in Saudi Arabia. Table 1 indicates that 14 of the initial 19 factors had normalized values of not less than 0.50. Therefore, these 14 factors were deemed critical for BIM implementation in Saudi Arabia. "Existence of standard contracts on data security and user confidentiality" (F15) is the top factor affecting BIM implementation with the highest mean score (mean = 3.896). This indicates that this is the most critical factor hindering or promoting BIM implementation in the AEC market in Saudi Arabia. This finding agrees with those of Aljobaly and Banawi (2020) and Al-Hammadi and Tian (2020), indicating that contractual frameworks for BIM projects are absent in Saudi Arabia. "Consistent views on BIM between stakeholders" (F07) and "availability of guidelines for implementing BIM" (F18) have an equal mean score (3.739). However, the standard deviation of the former (SD = 1.1477) was lower than that of the latter

ID	Description	Mean	SD	Normalization	Rank
F15	Existence of standard contracts on data security and user confidentiality	3.896	0.9494	1.000*	1
F07	Consistent views on BIM between stakeholders	3.739	1.1477	0.927*	2
F18	Availability of guidelines for implementing BIM	3.739	1.2984	0.927*	3
F14	Cost-benefit of implementing BIM	3.730	1.1722	0.923*	4
F01	Local industry's awareness of BIM	3.713	0.8862	0.915*	5
F13	Interoperability between software in exchanging information	3.635	1.1342	0.879*	6
F10	Market demand for BIM	3.591	0.9356	0.859*	7
F02	The time required for training	3.557	1.1097	0.843*	8
F19	Presence of public–private partnership in realizing BIM projects	3.504	1.0872	0.819*	9
F09	Resources required for continuous training	3.426	1.2914	0.782*	10
F17	Existence of standard contracts on liability and risk allocation	3.417	1.2909	0.778*	11
F08	Existence of a BIM project champion	3.209	1.1735	0.681*	12
F16	Existence of local laws to protect individuals involved in BIM projects	3.052	1.1761	0.609*	13
F05	Stakeholders' willingness to learn the BIM method	2.983	1.1469	0.577*	14
F12	User-friendliness of BIM software	2.635	1.2091	0.415	15
F04	Clarity of roles and responsibilities in BIM-based projects	2.383	1.0138	0.298	16
F11	Presence of appropriate projects to use BIM	2.139	1.0164	0.185	17
F03	Preferences in project delivery method	2.122	1.3964	0.177	18
F06	The newness of BIM in the local market	1.739	1.1927	0.000	19

Note(s): SD = Standard deviation
Normalized value = (mean – minimum mean)/(maximum mean – minimum mean)
* Indicates that the factor is critical (normalized value ≥ 0.50)

Table 1.
Ranking of factors to BIM implementation

(SD = 1.2984). Therefore, "consistent views on BIM between stakeholders" is ranked higher (second), followed by "availability of guidelines for implementing BIM" (third). The fourth most critical factor is the cost-benefit of implementing BIM' (F14: mean = 3.730), followed by the local industry's awareness of BIM' (F01: mean = 3.713). The 14 critical factors revealed by the data analysis techniques were subject to FA, as discussed in the subsequent subsection.

4.2 Results of factor analysis

This study applied FA to examine the underlying relationships between the 14 critical factors of BIM implementation and their groupings. To conduct this analysis, at least 50 samples are required (Hair *et al.*, 2010). In response to this, this study's sample size is adequate to conduct FA since the number of critical factors and samples are 14 and 115, respectively. In contrast, the Kaiser–Meyer–Olkin (KMO) test for measuring sampling adequacy recorded a value of 0.630. This value is above the acceptable level of 0.60, indicating that the data are factorable (Field, 2013). Bartlett's test of sphericity is 0.000, which is less than 0.05, implies that the data are suitable for the FA (Pallant, 2010). In addition, a commonality value threshold of 0.40 was adopted to represent the total variance that a critical factor shares with other critical factors (Hair *et al.*, 2009). The communality values for the BIM implementation factors ranged from 0.494 to 0.795, exceeding the threshold value of 0.40. Therefore, it is appropriate to conduct an FA because the sample size, KMO results and communality values are satisfactory. Hair *et al.* (2009) suggests that variables with factor loadings exceeding 0.50 should be retained because they significantly contribute to the interpretation of the factor group. As a result, only 9 of the

14 critical factors for BIM implementation had factor loadings above 0.50 (ranging from 0.501 to 0.880). Therefore, only these nine critical factors were included in the FA (Table 2).

For factor extraction, PCA was used to identify underlying grouped factors. Table 2 summarizes the FA results after the varimax rotation. Four underlying factors with eigenvalues greater than 1.00 were extracted (ranging between 1.194 and 1.684) (Pallant, 2010). The four underlying factors explained 61.441% of the total variance, which is greater than 50%. This indicates that the data can be effectively extracted and the four underlying factors can adequately represent the data (Zhang *et al.*, 2019). As shown in Table 2, the nine critical factors for BIM implementation were categorized into four meaningful groupings, with three variables belonging to underlying factor 1, two variables belonging to underlying factor 2, two variables belonging to underlying factor 3 and two variables belonging to underlying factor 4. Based on the analysis results, the four underlying factors were named as follows: (1) environmental, (2) governmental, (3) legal and (4) organizational.

4.3 Results of the agreement analysis

ANOVA and Tukey's tests were performed to determine any significant differences in the responses' mean scores based on the respondents' profession and BIM competency. Table 3 shows the results of the agreement analysis for the nine critical factors grouped by FA.

The results of the ANOVA test suggest that there are consistent views among various respondents' professions (e.g. architect, engineer and contractor) on the criticality of the following critical factors (p-value $\geq$0.05): "interoperability between software in exchanging information" (F13), "market demand for BIM" (F10), "availability of guidelines for implementing BIM" (F18), "existence of standard contracts on liability and risk allocation" (F17), "existence of local laws to protect individuals involved in BIM projects" (F16) and "consistent views on BIM between stakeholders" (F07). However, "local industry's awareness of BIM" (F01), "existence of standard contracts on data security and user confidentiality"

ID	Description	Factor loadings 1	2	3	4
Underlying factor 1: Environmental					
F13	Interoperability between software in exchanging information	0.805			
F10	Market demand for BIM	0.668			
F01	Local industry's awareness of BIM	0.618			
Underlying factor 2: Governmental					
F18	Availability of guidelines for implementing BIM		0.784		
F15	Existence of standard contracts on data security and user confidentiality		0.729		
Underlying factor 3: Legal					
F17	Existence of standard contracts on liability and risk allocation			0.880	
F16	Existence of local laws to protect individuals involved in BIM projects			0.501	
Underlying factor 4: Organizational					
F19	Presence of public–private partnership in realizing BIM projects				0.699
F07	Consistent views on BIM between stakeholders				0.690
Eigenvalue		1.684	1.455	1.197	1.194
Variance (%)		18.708	16.166	13.299	13.269
Cumulative percent variance (%)		18.708	34.874	48.172	61.441

Note(s): Extraction method: PCA. Rotation method: varimax with Kaiser normalization

Table 2. Results of FA on factors to BIM implementation

Agreement between professions										
	Overall			Mean		ANOVA			Tukey	
ID	Mean	SD	A	E	C	*F*-value	*p*-value	A & E	A & C	E & C
F13	3.635	1.134	4.069	3.526	3.458	2.979	0.055	0.123	0.056	0.957
F10	3.591	0.936	3.828	3.605	3.438	1.594	0.208	0.598	0.180	0.685
F01	3.713	0.886	4.276	3.579	3.479	9.083	0.000*	0.003*	0.000*	0.845
F18	3.739	1.298	4.138	3.474	3.708	2.222	0.113	0.095	0.033	0.678
F15	3.896	0.949	4.138	3.447	4.104	7.006	0.001*	0.007*	0.986	0.003*
F17	3.417	1.291	3.414	3.447	3.396	0.017	0.983	0.994	0.998	0.982
F16	3.052	1.176	3.483	3.026	2.813	3.056	0.051	0.249	0.040	0.671
F19	3.504	1.087	3.828	3.658	3.188	3.886	0.023*	0.793	0.031*	0.107
F07	3.739	1.148	3.897	3.684	3.688	0.361	0.698	0.737	0.722	1.000
Agreement between different levels of BIM competency										
	Overall			Mean		ANOVA			Tukey	
ID	Mean	SD	N	S	P	*F*-value	*p*-value	N & S	N & P	S & P
F13	3.635	1.134	3.279	3.565	4.387	11.725	0.000*	0.501	0.000*	0.014*
F10	3.591	0.936	3.426	3.391	4.065	5.909	0.004*	0.986	0.005*	0.020*
F01	3.713	0.886	3.262	3.826	4.516	32.192	0.000*	0.005*	0.000*	0.002*
F18	3.739	1.298	3.393	3.783	4.387	6.632	0.002*	0.407	0.001*	0.183
F15	3.896	0.949	3.656	3.696	4.516	10.610	0.000*	0.981	0.000*	0.003*
F17	3.417	1.291	3.328	3.391	3.613	0.503	0.606	0.978	0.580	0.809
F16	3.052	1.176	2.820	2.739	3.742	8.275	0.000*	0.952	0.001*	0.004*
F19	3.504	1.087	3.262	3.522	3.968	4.605	0.012*	0.575	0.008*	0.278
F07	3.739	1.148	3.721	3.870	3.677	0.198	0.821	0.860	0.984	0.818

Note(s): A: Architect; E: Engineer; C: Contractor; N: Not professional; S: Somewhat professional and P: Professional
**p*-value lower than 0.05 indicates a significant difference in perceptions towards the given BIM implementation factors

Table 3.
Results of agreement analysis on factors to BIM implementation

(F15) and "presence of public–private partnership in realizing BIM projects" (F19) have significantly different means across the three categories. The results of the *post-hoc* Tukey test suggest that the "local industry's awareness of BIM" is more critical for architects than for engineers and contractors. In addition, the "existence of standard contracts on data security and user confidentiality" is more critical for architects and contractors than for engineers. Finally, the presence of PPPs in realizing BIM projects is more critical for architects than for contractors. In other words, the critical factors with a significantly higher mean were more critical in addressing the profession that scored that mean.

Furthermore, the results of the ANOVA test suggest that there are consistent views among different BIM competencies (e.g. not professional, somewhat professional and professional) on the criticality of the following critical factors (p-value ≥ 0.05): "existence of standard contracts on liability and risk allocation" (F17) and "consistent views on BIM between stakeholders" (F07). However, the following seven critical factors have significantly different means across the three BIM competency categories: "interoperability between software in exchanging information" (F13), "market demand for BIM" (F10), "local industry's awareness of BIM" (F01), "availability of guidelines for implementing BIM" (F18), "existence of standard contracts on data security and user confidentiality" (F15), "existence of local laws to protect individuals involved in BIM projects" (F16) and "presence of public-private partnership in realizing BIM projects" (F19). Most of these differences are between non-professionals and professionals and between somewhat professionals and professionals.

This suggests that BIM professionals are more likely to have different views on the criticality of the critical factors for BIM implementation.

5. Discussion

5.1 Underlying factor 1: environmental

"Local industry's awareness of BIM." There is much confusion in the stockholder's mind regarding BIM (Rogers *et al.*, 2015). This confusion arises because of a lack of BIM awareness and its tangible benefits. Increased awareness of new technologies in the AEC market can reduce adoption risk and encourage implementation among stakeholders (Dang *et al.*, 2020). Therefore, BIM awareness is crucial and must precede its implementation. A low awareness level impacts stakeholders' perceptions of the necessity and value of BIM in organizations. This finding is consistent with that of Al-Yami and Sanni-Anibire (2019), who found that BIM awareness across the AEC industry in Saudi Arabia is low. The ANOVA results suggest significant differences in respondents' opinions based on their profession. This factor is perceived to be more critical for architects than for engineers and contractors. This is likely because architects are more likely to show more initiative in implementing BIM and encourage other professionals to use it (Rogers *et al.*, 2015). ANOVA also showed significant differences in the responses between any pair of BIM competency categories. The BIM professional category scored the highest, while the non-professional category scored the lowest. This illustrates that BIM professionals are more aware that awareness precedes and plays a vital role in implementing new technology in the AEC industry. A higher awareness level of stockholders resulted in higher BIM implementation in the local market.

"Interoperability between software in exchanging information." One of the most critical barriers to BIM implementation in the AEC industry is its interoperability (Abbasnejad *et al.*, 2020, Munir *et al.*, 2021). Interoperability problems may create additional time and costs by using and investing in new software. Although the (IFC) data format is useful for transferring data, model errors and data loss continue to occur (Aibinu and Venkatesh, 2014). According to Alhumayn *et al.* (2017), the interoperability between various programs negatively affects BIM implementation decisions in Saudi Arabia. The analysis of the responses suggests significantly different means based on BIM competencies. BIM professionals recorded a higher mean than non-professionals and somewhat professionals. This may be attributed to the greater experience and exposure of BIM professionals to BIM projects. BIM professionals might experience more data sharing and transferring problems than other team members because of their engagement at different levels and stages of the BIM project life cycle.

"Market demand for BIM." BIM awareness would enhance market demand and the client's willingness to use BIM, particularly for the Saudi Arabian government, which is the largest public client (Sodangi *et al.*, 2018). However, client demand encourages firms and stakeholders to implement BIM in the long run owing to BIM's numerous benefits and improvement opportunities. However, clients in Saudi Arabia continue to question BIM's ability to improve construction projects (Almuntaser *et al.*, 2018). ANOVA revealed statistically significant differences in opinions based on BIM competency. "Market demand for BIM" is more important for BIM professionals. This explains why BIM professionals acknowledge the significant role of the AEC market and client demand when making BIM implementation decisions.

5.2 Underlying factor 2: governmental

"Existence of standard contracts on data security and user confidentiality." In relation to the quantitative aspect of BIM, the data were digitalized and parameterized. Therefore, e-communication between project teams involves dealing with and storing a large amount of data (Fan, 2014). If data security is not ensured, organizations refrain from providing sensitive or critical data. The literature establishes that data security and privacy can undermine BIM implementation in the AEC industry (Chong *et al.*, 2017). This is especially true in the Saudi Arabian scenario, where the data management platform is unprepared for BIM technology (Aljobaly and Banawi, 2020). Therefore, the establishment of a data management policy is crucial. ANOVA suggested significantly different means based on the respondents' profession and BIM competency. Both architects and contractors ranked this factor higher than engineers. In addition, BIM professionals had a higher mean than non- and somewhat professionals. This is because stockholders are sensitive to data security when dealing with BIM data. The key point of differentiation lies in the poorly defined responsibility for handling digital data. The party that hosts the model can collaborate with organizations that provide services and data security throughout the project cycle (Chong *et al.*, 2017).

"Availability of guidelines for implementing BIM." Shifting from the current work practice and environment to BIM is not easy for organizations and employees. No uniform global guidelines exist to facilitate the transformation process (Othman *et al.*, 2020). Organizations planning to implement BIM either adopt established pioneer countries' guidelines, such as the UK, or develop their own guidelines to meet their needs and maintain local competitiveness. However, such guidelines may not be 100% suitable for AEC industries in other countries because they were designed for a specific local industrial environment (Dang *et al.*, 2020). However, the Saudi Arabian government lacks BIM implementation guidelines and strategies, which explains why the respondents require directions and instructions (Sodangi *et al.*, 2018). Therefore, the establishment of local BIM implementation guidelines is essential (Van Tam *et al.*, 2023). The ANOVA results showed significantly different means based on BIM competency; this factor obtained a higher mean from BIM professionals. This is because different levels of BIM competency affect the AEC professionals' perceptions of BIM. Some BIM users view BIM as software, whereas others view it as a whole process. In addition, the greater the engagement of AEC professionals in BIM projects, the greater their experience with BIM. Therefore, BIM professionals can recognize the key elements that make BIM implementation successful in the AEC industry.

5.3 Underlying factor 3: legal

"Existence of standard contracts on liability and risk allocation." BIM is a collaborative technology among project stakeholders. Therefore, project stakeholders' roles and responsibilities should be clearly defined early in the contract documents to avoid potential conflicts (Dao *et al.*, 2020). Poor contractual relationships result in liability risk, which means that the contractor or designer is responsible for any incomplete data input or defects (Babatunde *et al.*, 2020). Otherwise, claims may arise and negatively impact project performance (Dao *et al.*, 2020). A similar situation exists in Saudi Arabia, where AEC professionals believe that the participants' responsibilities in BIM projects are neither specified nor made clear (Al-Hammadi and Tian, 2020).

"Existence of local laws to protect individuals involved in BIM projects." In BIM projects, each party believes that it has the right to own the BIM model, including the owner who pays for the design and the designer who creates it. This results in an uncollaborative work environment and stockholder resistance to learning or implementing BIM because of intellectual property rights and ownership concerns (Fan, 2014). Therefore, stockholders are hesitant to implement BIM because of ambiguous contractual relationships and inadequate rights protection (Chong *et al.*, 2017). In Saudi Arabia, there is no legal practice guide or support that specifies who owns the model and how data will be exchanged between team members, causing confusion and undermining BIM implementation (Alhumayn *et al.*, 2017). Therefore, it is essential to establish a comprehensive and well-defined contractual relationship that protects the rights of project stakeholders. A significant difference in the responses was found between BIM professionals and other BIM competency categories. BIM professionals perceived this factor as more important than other categories. This may be because there is no common rule or method for calculating the parties' participation proportion in the BIM model. BIM professionals emphasize this factor because of the importance of a well-defined copyright policy that defines the parties' rights to owning the model.

5.4 Underlying factor 4: organizational

"Consistent views on BIM between stakeholders." Understanding BIM, its application and its capabilities is crucial for implementing decisions (Arayici *et al.*, 2011). In a technical sense, some AEC professionals view BIM as 3D CAD. Others have used tools without a fundamental understanding of BIM (Rogers *et al.*, 2015). However, it is common for BIM users and non-users to have different views on BIM. According to Hong *et al.* (2019), 42.65 and 43.33% of BIM and non-BIM users view BIM as a modeling software and database, respectively. Although these two percentages represent the majority, the results indicate that BIM users and non-users perceive the concept differently. This understanding gap makes BIM unattractive to some AEC professionals. Therefore, an understanding of BIM and the services offered can promote its implementation.

"Presence of public-private partnership in realizing BIM projects." A low BIM understanding influences the decision-makers' perceptions of BIM advantages, values and uses. For example, PPP can be a typical platform for BIM, because it provides a suitable environment for data sharing and exchange. In addition, PPP is often concerned with procurement benefits, which can be achieved through lifecycle information exchange and management (Ren *et al.*, 2020). Therefore, understanding BIM and its capabilities is crucial for promoting its implementation. The ANOVA results revealed significant differences between architects and contractors on the basis of profession and between BIM professionals and non-professionals on the basis of BIM competency. In line with "Vision 2030," the role of PPP in Saudi Arabia is expected to increase. PPP can help bridge the funding gaps caused by low oil prices. Implementing BIM in PPP has the potential to diffuse BIM effectively throughout the AEC industry. This would also provide concrete evidence of BIM benefits that would encourage AEC professionals to implement BIM in the public and private sectors.

5.5 Comparison with prior works

A comparison of the results of this study with those of prior works reveals similarities and differences between the BIM implementation factors (see Table 4). The majority of results were consistent with the BIM implementation factors from previous works. However, one critical factor in this study differs from prior works, which is the "presence of public-private partnership in realizing BIM projects." Saudi Arabia is one of the largest contributors to the global AEC industry in terms of the number of new developmental projects. In line with "Vision 2030," the government encourages private investment in economic development to reduce reliance on oil revenues (Al-Yami and Sanni-Anibire, 2019). One of the cornerstone policies of "Vision 2030" is PPP and privatization. In particular, the government offers more opportunities for the private and public sectors to cooperate in realizing construction projects. BIM implementation in these projects exposes the public and private sectors to their capabilities and benefits. Therefore, this situation may be a critical factor in BIM implementation in Saudi Arabia.

Factors	This study	1	2	3	4	5	6	7
		Source						
Interoperability between software in exchanging information	*		*			*		
Market demand for BIM	*	*	*			*	*	
Local industry's awareness of BIM	*		*	*				*
Availability of guidelines for implementing BIM	*			*		*		*
Existence of standard contracts on data security and user confidentiality	*			*	*		*	
Existence of standard contracts on liability and risk allocation	*		*		*		*	
Existence of local laws to protect individuals involved in BIM projects	*		*			*		
Presence of public–private partnership in realizing BIM projects	*							
Consistent views on BIM between stakeholders	*			*		*		

Note(s): 1. Almuntaser *et al.* (2018), 2. Al-Yami and Sanni-Anibire (2019), 3. Aljobaly and Banawi (2020), 4. Banawi (2018), 5. Alhumayn *et al.* (2017), 6. Al-Hammadi and Tian (2020) and 7. Sodangi *et al.* (2018)

Table 4.
Comparison of factors to BIM implementation in Saudi Arabia

5.6 Roadmap to BIM implementation in Saudi Arabia

Figure 2 shows a roadmap for effective BIM implementation in Saudi Arabia, which was developed based on the FA results. Specifically, a roadmap was developed by answering the following three questions to provide clear directions for each component: (1) Which entity can help the BIM implementation process? (2) What actions should be taken to enhance BIM implementation in Saudi Arabia? (3) Who would benefit from these actions? Answering these questions and the FA results provide clear directions for Saudi Arabia toward a higher BIM implementation rate. For example, regarding the environmental component, the government and associated professional bodies can create a BIM market by applying BIM to pilot projects. In addition, the government organizes free-of-charge workshops in which academics can introduce and create awareness regarding BIM. Professional bodies can also invite BIM

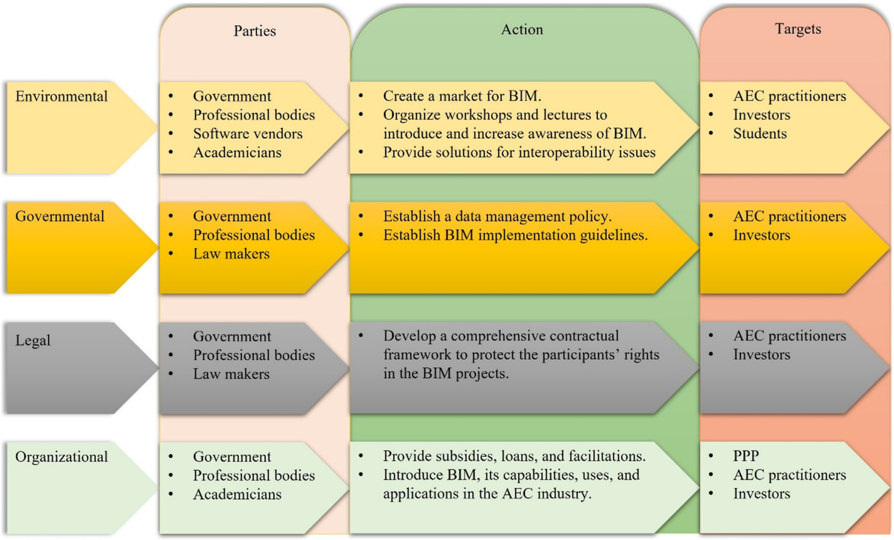

Figure 2.
Roadmap to BIM implementation in Saudi Arabia

experts to share their experience with other AEC professionals. Furthermore, software vendors can provide solutions for interoperability issues. Regarding the governmental component, the government can establish BIM implementation guidelines in consultation with AEC and BIM professionals. Regarding the legal component, the government, professional bodies and lawmakers can establish contractual frameworks and laws for BIM projects. This is to define the boundaries of the participating parties and protect their rights in BIM projects. Regarding the organizational component, the government provides facilitation, such as loans and subsidies, to those intending to implement BIM. In addition, academics can participate by giving lectures on BIM and its uses, capabilities and applications in the AEC industry. Professional bodies can then share BIM-based case studies as examples of BIM application in the AEC industry.

5.7 Study implication

5.7.1 Theoretical implications. Unlike prior works that have focused on exploring and prioritizing factors for BIM implementation, this study identifies the underlying relationships between the critical factors of BIM implementation in Saudi Arabia and their groupings. The underlying factors represent the latent constructs that are missing in BIM studies in Saudi Arabia. The underlying factors are useful for scholars to develop frameworks and strategies to increase BIM implementation at the national level. Additionally, this new latent construct should assist scholars in conducting further research to assess the readiness of the AEC industry in Saudi Arabia to implement BIM. This enabled the identification of gaps in BIM implementation for further solutions. Other countries with similar characteristics (e.g. Middle Eastern countries) can use these findings to increase BIM implementation in the local AEC industry. This study illustrates that insufficient extrinsic motivations, legal issues and lack of governmental and organizational support hinder BIM implementation in Saudi Arabia. These findings are crucial for providing future directions and specific shortfall areas that researchers should target when identifying approaches to enhance BIM implementation. Finally, the results suggest that individuals with different BIM competencies are more likely to have different views on BIM. Therefore, professionals with different BIM competencies require different approaches and strategies to address BIM implementation factors.

5.7.2 Practical implications. In practical implications, this study's findings can help decision-makers undertake deliberate actions to overcome the shortcomings of BIM implementation in Saudi Arabia. These findings call for the government to identify approaches and create an enabling environment through policies and initiatives to aid BIM implementation (e.g. developing BIM implementation guidelines and creating a market for BIM). In addition, the findings of this study emphasize the need for the government, lawmakers and professional bodies to create clear contractual and legal frameworks that can delineate relationships between project parties. This demonstrates that BIM implementation in PPP projects can be promoted in other construction projects in Saudi Arabia. Therefore, the government should devote sufficient attention and effort to implementing BIM in PPP projects.

6. Conclusion

This study examined the underlying relationships between the critical factors of BIM implementation in Saudi Arabia and their groupings. 19 factors related to BIM implementation were identified using SLR and interviews with AEC professionals. A questionnaire survey was distributed to AEC professionals to solicit opinions on the criticality of the factors in BIM implementation. The obtained data were analyzed using the mean score, standard deviation, normalized value and FA techniques. The critical factors grouped by FA were analyzed using the ANOVA and *post-hoc* Tukey tests to test any significant differences in the means of the factors between respondent professions and BIM competencies.

The results revealed that 14 factors related to BIM implementation are critical to the AEC industry in Saudi Arabia. Of these, nine critical factors were grouped by FA. The nine critical factors are "interoperability between software in exchanging information", "market demand for BIM", "local industry's awareness of BIM", "availability of guidelines for implementing BIM", "existence of standard contracts on data security and user confidentiality", "existence of standard contracts on liability and risk allocation", "existence of local laws to protect individuals involved in BIM projects", "presence of public-private partnership in realizing BIM projects" and consistent views on BIM between stakeholders. The FA groups the nine critical factors into four underlying factors: environmental, governmental, legal and organizational. These underlying factors are crucial for facilitating BIM implementation in Saudi Arabia. This study further concluded that the role of PPP in implementing and promoting BIM in Saudi Arabia is significant. Finally, ANOVA and Tukey tests that industry experience and positioning affect individual perspectives of the critical factors.

Creating a motivating environment and market are necessary to justify the need to implement BIM for stakeholders. Developing guidelines is also necessary to provide clear directions and intrusions to stakeholders regarding the processes involved in BIM implementation. Furthermore, there is a need to establish legal frameworks to protect stakeholder rights and define their boundaries in BIM projects. This study contributes to the body of knowledge by examining the underlying relationships between the critical factors of BIM implementation in Saudi Arabia and their groupings. Researchers can use these findings to focus on underlying factors rather than all factors when enhancing BIM implementation in Saudi Arabia. The AEC industry can also devote sufficient attention to these underlying factors to facilitate the BIM implementation process.

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Appendix 1

ID	Factors	Source
F01	Local industry's awareness of BIM	1, 2, 3, 4
F02	The time required for training	3, 4, 5, 6, 7, 8, 9
F03	Preferences in project delivery method	3, 4, 6, 7, 12, 13, 14, 15, 16
F04	Clarity of roles and responsibilities in BIM-based projects	4, 6, 7, 8, 15, 16, 17, 18
F05	Stakeholders' willingness to learn the BIM method	3, 4, 5, 7, 19
F06	The newness of BIM in the local market	4, 5, 6, 7, 13, 14, 15, 16
F07	Consistent views on BIM between stakeholders	4, 5, 6, 7, 8, 16, 18
F08	Existence of a BIM project champion	3, 4, 10, 20, 19
F09	Resources required for continuous training	3, 4, 5, 7, 19
F10	Market demand for BIM	4, 6, 7, 9, 21, 16
F11	Presence of appropriate projects to implement BIM	4, 6, 7, 9, 21, 22
F12	User-friendliness of BIM software	3, 10, 11, 14, 23, 24, 25, 26, 27
F13	Interoperability between software in exchanging information	3, 10, 11, 14, 23, 24, 26, 27, 28
F14	Cost-benefit of implementing BIM	1, 2, 3, 10, 11, 14, 24, 26, 27
F15	Existence of standard contracts on data security and user confidentiality	3, 4, 7, 19, 29
F16	Existence of local laws to protect individuals involved in BIM projects	3, 4, 7, 19, 29
F17	Existence of standard contracts on liability and risk allocation	6, 7, 13, 14, 16, 18, 22
F18	Availability of guidelines for implementing BIM	4, 6, 7, 13, 14, 16, 18, 21, 22
F19	Presence of public-private partnership in realizing BIM projects	4, 6, 7, 9

Note(s): 1. Dang *et al.* (2020), 2. Maskil-Leitan *et al.* (2020), 3. Abbasnejad *et al.* (2020), 4. Hong *et al.* (2019), 5. Kim *et al.* (2020), 6. Liao *et al.* (2019), 7. Georgiadou (2019), 8. Fini *et al.* (2018), 9. Poirier *et al.* (2015), 10. Love and Matthews (2019), 11. Wan *et al.* (2019), 12. Tang *et al.* (2020), 13. Gerrish *et al.* (2017), 14. Díaz *et al.* (2017), 15. Wu *et al.* (2014), 16. Bynum *et al.* (2013), 17. An *et al.* (2020), 18. Wang *et al.* (2019), 19. Cao *et al.* (2017), 20. Lin and Cheung (2020), 21. Yilmaz *et al.* (2019), 22. Ma *et al.* (2018), 23. De Gaetani *et al.* (2020), 24. Kamel and Memari (2019), 25. Liu *et al.* (2019), 26. Eleftheriadis *et al.* (2018), 27. Chu *et al.* (2018), 28. Khanzadi *et al.* (2020) and 29. Holmström *et al.* (2015)

Table A1. List of potential BIM implementation factors identified from the literature

Appendix 2

Type of distribution	Description	Frequency	Percentage	Cumulative (%)
Gender	Male	94	81.74	81.74
	Female	21	18.26	100.00
	Total	115	100.00	
Age	18–30	34	29.56	29.56
	31–45	54	46.96	76.52
	>45	27	23.48	100.00
	Total	115	100.00	
Experience	0–5	16	13.91	13.91
	6–10	53	46.09	60.00
	11–15	34	29.57	89.57
	>15	12	10.43	100.00
	Total	115	100.00	
Profession	Architect	29	25.22	25.22
	Engineer	38	33.04	58.26
	Contractor	48	41.74	100.00
	Total	115	100.00	
BIM competencies	Not professional	61	53.04	53.04
	Somewhat professional	23	20.00	73.04
	Professional	31	26.96	100.00
	Total	115	100.00	

Table A2.
Profiles of the respondents

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