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Factors affecting BIM implementation: evidence from countries with different income levels

Mohammad S. Al-Mohammad and Ahmad Tarmizi Haron
Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Gambang, Malaysia

Muneera Esa
School of Housing, Building and Planning, Universiti Sains Malaysia, Penang, Malaysia

Mohammad Numan Aloko
Department of Civil Engineering, Kandahar University, Kandahar, Afghanistan

Yasir Alhammadi
College of Engineering, Prince Sattam bin Abdulaziz University, Al Kharj, Saudi Arabia

K.S. Anandh
Department of Civil Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur, India, and

Rahimi A. Rahman
Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Gambang, Malaysia and General Educational Department, Daffodil International University, Dhaka, Bangladesh

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Abstract

Purpose – This study aims to empirically analyze the symmetries and asymmetries among the critical factors affecting building information modeling (BIM) implementation between countries with different income levels. To achieve that aim, the study objectives are to identify: critical factors affecting BIM implementation in low-, lower-middle-, upper-middle- and high-income countries; overlapping critical factors between countries with different income levels; and agreements on the critical factors between countries with different income levels.

Design/methodology/approach – This study identified potential BIM implementation factors using a systematic literature review and semi-structured interviews with architectural, engineering and construction (AEC) professionals. Then, the factors were inserted into a questionnaire survey and sent to AEC professionals

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in Afghanistan, India, Malaysia and Saudi Arabia. The collected data was analyzed using the following techniques and tests: mean, standard deviation, normalized value, Kruskal–Wallis, Dunn and Mann–Whitney.

Findings – Five critical factors overlap between all countries: "availability of guidelines for implementing BIM," "cost-benefit of implementing BIM," "stakeholders' willingness to learn the BIM method," "consistent views on BIM between stakeholders" and "existence of standard contracts on liability and risk allocation." Also, the criticality of the factors often differs between income levels, especially between low- and high-income countries, suggesting a significant gap between low- and high-income countries in BIM implementation.

Originality/value – This study differs from prior works by empirically analyzing the symmetries and asymmetries in BIM implementation factors between countries with different income levels (i.e. low-, lower-middle-, upper-middle- and high-income countries).

Keywords Automation, Building technology, Building information modeling, Construction innovation, Construction management, Income level

Paper type Research paper

1. Introduction

The architecture, engineering and construction (AEC) industry used traditional approaches to reduce project duration, save construction costs and maintain proper quality (Bynum *et al.*, 2013). However, projects in the AEC industry are becoming more complex and difficult to manage. Therefore, AEC professionals seek efficient innovation in design and construction methods (Cooke and Williams, 2009). Building information modeling (BIM) offers an alternative to traditional design and construction practices. The two primary principles of BIM include a better collaboration environment between stakeholders and a data-rich model for the facility (McCuen *et al.*, 2012). In addition, BIM bridges the communication gaps and poor lifecycle data exchanging that often plague the AEC industry (Succar, 2009). As a result, BIM can accelerate the schedule, reduce project costs and provide better construction projects (Bynum *et al.*, 2013). With such gains, the positive role of BIM in the AEC industry cannot be neglected.

Given these benefits, several governments and professional bodies have committed resources toward BIM implementation. However, such efforts are insufficient to spread BIM across the AEC industry due to many challenges (Ahuja *et al.*, 2016; Tai *et al.*, 2020). For example, as a high-income country, Saudi Arabia needs to re-engineer many construction projects to successfully transition toward BIM (Al-Yami and Sanni-Anibire, 2021). In middle-income countries, including Malaysia and India, BIM implementation is costly due to the high learning curve and demand for additional resources (Ahuja *et al.*, 2018). Finally, low-income countries, such as Afghanistan, face challenges in identifying appropriate projects to implement BIM (Al-Mohammad *et al.*, 2021). Although these challenges might be unique to a country, prior works also show that some challenges recur irrespective of income levels. For example, interoperability and legal issues are the key challenges to BIM implementation in Afghanistan, Malaysia and Saudi Arabia (Al-Mohammad *et al.*, 2021; Rogers *et al.*, 2015; Al-Yami and Sanni-Anibire, 2021). In other words, the critical factors affecting BIM implementation between countries with different income levels might overlap and vary.

Countries with different income levels and economic conditions have distinct financial capabilities to implement BIM (World Bank, 2021). However, financial resources are not the only prerequisite for successful BIM implementation. Other factors, including human, technical and organizational aspects, should also be considered for successful BIM implementation (Tai *et al.*, 2020). Furthermore, BIM implementation is also subject to the perceptions of adopters (Faisal Shehzad *et al.*, 2020). Comparing the factors affecting BIM implementation would reveal the major shortfall areas in all and specific income levels. As a result, the following research questions have emerged:

RQ1. What are the critical factors affecting BIM implementation in low-, lower-middle-, upper-middle- and high-income countries?

RQ2. What are the overlapping critical factors between countries with different income levels?

RQ3. What are the symmetries and asymmetries on the critical factors between countries with different income levels?

Answering these questions would allow academics, AEC professionals and policymakers to formulate regional and international BIM implementation strategies collaboratively.

This study empirically analyzes the symmetries and asymmetries among the critical factors affecting BIM implementation between countries with different income levels. To achieve that aim, the study objectives are to identify:

- critical factors affecting BIM implementation in low-, lower-middle-, upper-middle- and high-income countries;
- overlapping critical factors between countries with different income levels; and
- symmetries and asymmetries on the critical factors between countries with different income levels.

This study uses empirical data from four nations, Afghanistan, India, Malaysia and Saudi Arabia, to represent low-, lower-middle-, upper-middle- and high-income countries. These countries were selected due to the following reasons:

- all four countries are late entrants in BIM implementation and have low BIM implementation rates (Al-Mohammad *et al.*, 2021; Ahuja *et al.*, 2018; Othman *et al.*, 2020; Al-Yami and Sanni-Anibire, 2021);
- engagement and experience of the authors in the local AEC industry; and
- accessibility and reachability of the authors to AEC professionals in those four countries to obtain a sufficient sample size.

Achieving the study aim contributes to the existing knowledge by understanding the symmetries and asymmetries of BIM implementation factors. The study findings benefit policymakers in supporting BIM implementation in the local AEC industry. Furthermore, countries with similar income levels and AEC environments may use the findings to prepare strategies to increase the success of BIM implementation.

2. Literature review

2.1 Comparative review of building information modeling implementation: global context

BIM has transformed the AEC industry toward better project performance (McCuen *et al.*, 2012). High-income countries, such as the UK, the USA and Australia, have taken early and bold steps to increase BIM implementation. These steps include mandating BIM implementation and establishing strategies and guidelines (Juszczyk *et al.*, 2015; Aibinu and Venkatesh, 2014). Singh (2017) explored BIM implementation statuses in high-income countries, including Finland, Norway, Denmark, Sweden, Singapore and France. The work concluded that BIM implementation had increased because of several initiatives, including submissions in the Industry Foundation Class (IFC) format, government mandate, BIM-oriented building design standards and financial facilitation. However, some high-income countries are reluctant to implement BIM. For example, Gerges *et al.* (2017) showed that BIM implementation is low in high-income countries in the Middle East, including Saudi Arabia, Kuwait, Oman and the UAE.

Middle-income countries are also making serious efforts to become BIM implementers. For example, the remarkable development in China and India has led to higher interest in implementing BIM (Ahuja *et al.*, 2016; Tai *et al.*, 2020). Comparatively, Malaysia has shown more initiatives since 2007 (Othman *et al.*, 2020). Also, the Malaysian government mandated BIM use for any public project above MYR100m (Othman *et al.*, 2020). However, despite such initiatives and interest, BIM implementation in these countries was described as low (Othman *et al.*, 2020; Liao and Teo, 2017). Examples of other middle-income countries with low BIM implementation rates include Vietnam, Nigeria and Pakistan (Dao *et al.*, 2020a, 2020b; Babatunde *et al.*, 2021; Masood *et al.*, 2013).

Conversely, only a few works have focused on BIM implementation in low-income countries. For example, Gamil and Rahman (2019) concluded that BIM implementation in Yemen is low despite the high awareness of BIM benefits. At the same time, Al-Mohammad *et al.* (2021) found that BIM implementation in Afghanistan is in the early stages due to the lack of appropriate projects.

Overall, BIM implementation around the world is inconsistent. Even high-income countries are attaining different levels of BIM implementation. Moreover, low- and middle-income countries have lower BIM implementation rates than high-income countries.

2.2 Comparative review of building information modeling implementation in Afghanistan, India, Malaysia and Saudi Arabia

BIM has already been used in Saudi Arabia. For example, Baik *et al.* (2014) established the Hijazi architectural elements library to reduce the time for creating the Jeddah Historical Building Information Modeling (JHBIM) model. Then, Baik *et al.* (2015) proposed a framework to integrate JHBIM and Geographic Information System (GIS). Al-Sulaihi *et al.* (2015) developed a BIM model to detect and track indoor environmental problems for educational buildings. Ahmed and Asif (2020) developed a BIM-based retrofit model for conducting energy, economic and environmental analyses. Alrashed and Kantamaneni (2018) proposed a five-dimensional (5D) BIM model to estimate bill of quantity and apprise construction costs. Prior works attempted to develop BIM implementation frameworks and strategies (Almuntaser *et al.*, 2018; Alhumayn *et al.*, 2017), investigate BIM implementation barriers (Banawi, 2018; Al-Hammadi and Tian, 2020), BIM awareness among subcontractor firms (Aljobaly and Banawi, 2020) and BIM implementation benefits and statues (Al-Yami and Sanni-Anibire, 2021). These works suggest that BIM has been used in the AEC industry. However, BIM awareness and implementation in Saudi Arabia are still low (Aljobaly and Banawi, 2020; Al-Yami and Sanni-Anibire, 2021).

Unlike Saudi Arabia, prior works on Malaysia explored BIM implementation levels in different disciplines. For example, Tabatabaeea *et al.* (2021) identified the risk factors affecting BIM implementation in industrialized building systems (IBS). Wong *et al.* (2015) examined BIM capabilities in quantity survey practice and found that many quantity surveys are still unsure of the capabilities of BIM. Othman *et al.* (2020) explored a low BIM implementation level in the architectural firms in Malaysia. Similarly, Hanafi *et al.* (2016) reported a low BIM status denominated among architectural practices in the Malaysian AEC industry. Hamid *et al.* (2018) concluded that BIM implementation for the interior design industry is very low. The Malaysian government showed some initiatives by developing a BIM implementation guideline and mandating BIM implementation in specific types of projects. However, Malaysia's Construction Industry Development Board (CIDB) reported that the local BIM implementation is considerably low at 17% despite financial facilitation and other initiatives from the government (CIDB, 2017).

In India, Ahuja *et al.* (2016) developed a model using the technology–organization–environment framework to study the factors affecting BIM implementation in architectural firms and the reasons for the low implementation. The findings revealed that BIM implementation in architectural firms is at the experimentation stage, and the full potential of BIM has not been explored (Ahuja *et al.*, 2018). Mohanta and Das (2021) investigated BIM implementation in green buildings in Eastern India and found that its use is limited to visualization. Finally, Charlesraj and Dinesh (2020) identified that four-dimensional (4D) BIM implementation in India is considerably low despite the high awareness.

Compared with the rest of the countries, Afghanistan has received less attention. However, Al-Mohammad *et al.* (2021) analyzed that BIM implementation in Afghanistan is low due to high implementation costs, insufficient client demand and inappropriate projects to implement BIM.

2.3 Factors affecting building information modeling implementation in low-, middle- and high-income countries

Previous works on factors to BIM implementation covered several countries with different income levels. Table 1 presents the critical factors affecting BIM implementation in low-, middle- and high-income countries.

The most dominant critical factors for BIM implementation in high-income countries are the newness of BIM in the local market, market demand for BIM and the availability of guidelines for implementing BIM. External motivations, such as market demand and BIM implementation guidelines, play a significant role in BIM implementation decisions in high-income countries (Kim *et al.*, 2020; Hong *et al.*, 2018; Georgiadou, 2019; Gerrish *et al.*, 2017; Wang *et al.*, 2019). High-income countries have also developed BIM implementation guidelines to ensure adoption success (Othman *et al.*, 2020). Preferences in project delivery method and clarity of roles and responsibilities in BIM-based projects are also critical factors affecting BIM implementation in high-income countries (Bynum *et al.*, 2013; Georgiadou, 2019; Hong *et al.*, 2018; Liao *et al.*, 2019). The roles and responsibilities in BIM projects are also complex due to implementing new processes and working methods (Dao *et al.*, 2020a, 2020b; Liao *et al.*, 2019). Moreover, developing the required organizational capabilities and individual competencies for BIM is time-consuming, even in high-income countries (Georgiadou, 2019; Kim *et al.*, 2020; Liao *et al.*, 2019; Poirier, 2015). Given the varying understanding of BIM, AEC professionals view BIM as a modeling software, and others view it as a database (Hong *et al.*, 2018). This gap in the fundamental understanding of BIM makes it an unfavorable choice among industry professionals (Rogers *et al.*, 2015). Finally, the existence of standard contracts on liability, risk allocation and data sharing are among the main factors to successful BIM implementation in high-income countries (Georgiadou, 2019; Bynum *et al.*, 2013; Liao *et al.*, 2019; Wang *et al.*, 2019).

Middle-income countries share some similar factors to BIM implementation with high-income countries. Those factors include preferences in project delivery method, stakeholders' willingness to learn the BIM method, the existence of a BIM project champion, resources required for continuous training, user-friendliness of BIM software, the existence of standard contracts on data security and user confidentiality. However, two factors are not critical in high-income countries, including interoperability between software in exchanging information and the cost–benefit of implementing BIM. Those two factors reflect the financial capability when implementing BIM as payments for new software and hardware,

Table 1. Critical factors affecting BIM implementation in low-, middle- and high-income countries

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

Notes: 1. Gamil and Rahman (2019); 2. Hong *et al.* (2019); 3. Georgiadou (2019); 4. Kim *et al.* (2020); 5. Liao *et al.* (2019); 6. Poirier *et al.* (2015); 7. Bynum *et al.* (2013); 8. Tang *et al.* (2020); 9. Gerrish *et al.* (2017); 10. Wang *et al.* (2019); 11. Al-Mohammad *et al.* (2021); 12. Cao *et al.* (2017); 13. Wan *et al.* (2019); 14. Holmström *et al.* (2015)

continuous maintenance, training fees and improper interoperability cause additional costs to the organizations (Rogers *et al.*, 2015).

In low-income countries, such as Afghanistan and Yemen, the cost–benefit of implementing BIM and the availability of guidelines for implementing BIM are the key factors affecting BIM implementation. However, to put into perspective, the cost–benefit of implementing BIM is not the critical factor affecting BIM implementation in high-income countries. This situation might be due to the limited financial capability and unstable economic conditions in low-income countries (World Bank, 2021). As a result, the government in those countries lacks strategies and initiatives, such as BIM implementation guidelines (Al-Mohammad *et al.*, 2021; Gamil and Rahman, 2019).

In addition, stakeholders' willingness to learn the BIM method and the existence of standard contracts on data security and user confidentiality are common factors to BIM implementation in all income levels. This situation indicates that the behavior of stakeholders toward BIM and contractual relationships are major areas that should be considered when implementing BIM regardless of income levels. Similar to the high-income countries, factors to BIM implementation that affect the low-income countries are: local industry's awareness of BIM, consistent views on BIM between stakeholders, market demand for BIM, presence of appropriate projects to implement BIM and presence of public–private partnership in realizing BIM projects. Although differences in income levels exist, factors to BIM implementation can be similar.

2.4 Positioning this study

The above review suggests the following:

- factors to BIM implementation can be similar irrespective of income levels;
- some factors can exist in several income levels; and
- some factors can be country-specific.

In other words, given the differences in the AEC industry environments, individual attitudes and level of resources between countries with different income levels, the importance of these factors may significantly differ. Prior works have identified and discussed the factors affecting BIM implementation in a local context. However, those works did not empirically compare the factors between income levels. To fill that gap, this study aims to empirically analyze the symmetries and asymmetries among the critical factors affecting BIM implementation between countries with different income levels.

3. Methodology

3.1 Survey development

This study seeks to obtain quantitative data through questionnaire surveys on the factors affecting BIM implementation between countries with different income levels. A questionnaire can capture a large number of responses to represent a wider population, especially in scattered and remote locations (Rowley, 2014). Previous construction management works also used a questionnaire survey for quantitative research (Babatunde *et al.*, 2021; Radzi *et al.*, 2022). The survey development entailed conducting a systematic literature review (SLR) and semi-structured interviews with AEC professionals.

Initially, the survey was drafted based on the SLR results. SLR is an effective way of assessing available evidence on a particular subject. It encourages scholars to expand the search boundaries and search for relevant works beyond their subject areas and networks (Kamal and Irani, 2014). SLR was deemed appropriate to capture factors to BIM implementation that have been widely addressed in the literature. The review process encompassed searching in Scopus because it has been extensively used for literature review in the construction management domain (King *et al.*, 2022). The review includes articles with the following terms in the title, abstract or keywords: "building information modelling" or "building information modeling" or "BIM." The inclusion criteria include English-written articles in the engineering field published from the past decade. In addition, the articles should be published in journals with at least three publications on the topic based on the search results. The search retrieved 851 articles from the Scopus database. These papers were screened and checked using their titles and abstracts for relevance. Then, the final set of papers was selected considering duplicate papers, inclusion and exclusion criteria and their quality. At the end of this process, 29 articles progressed to the data extraction stage. The SLR results suggest that scholars used positive factors (e.g. drivers and critical success factors) and negative factors (e.g. barriers, hindrances, risks, challenges, causes, issues and problems). This study adopted the term "factor" to obtain a comprehensive list of the affecting factors. Table 2 presents the 19 factors to BIM implementation developed from the SLR.

After synthesizing factors to BIM implementation through SLR, this study conducted semi-structured interviews with six AEC professionals with at least ten years of experience

ID	Factors	Source
F01	Local industry's awareness of BIM	1, 2, 3, 4, 31
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, 30
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, 30
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, 30
F11	Presence of appropriate projects to implement BIM	4, 6, 7, 9, 21, 22, 30
F12	User-friendliness of BIM software	3, 10, 11, 14, 23, 24, 25, 26, 27, 30
F13	Interoperability between software in exchanging information	3, 10, 11, 14, 23, 24, 26, 27, 28, 30
F14	Cost–benefit of implementing BIM	1, 2, 3, 10, 11, 14, 24, 26, 27, 30, 31
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, 30, 31
F19	Presence of PPP in realizing BIM projects	4, 6, 7, 9, 30

Notes: 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.* (2020); 26. Eleftheriadis *et al.* (2018); 27. Chu *et al.* (2018); 28. Khanzadi *et al.* (2020); 29. Holmström *et al.* (2015); 30. Al-Mohammad *et al.* (2021); 31. Gamil and Rahman (2019)

Table 2.
List of potential factors affecting BIM implementation

across the four countries. The main purpose of the semi-structured interview was to revise the survey in terms of completeness, technicality and language based on expert knowledge. This step is important in eliminating any problems that emerged during the survey development (e.g. inadequate BIM-related technical terms). The AEC professionals were also allowed to remove any irrelevant factors and add potential factors that have not been covered. The questionnaire was then finalized based on the given recommendations and suggestions.

The questionnaire was divided into two main parts. Part I is related to the respondent profile. In Part II, the respondents were asked to give their opinions on the criticality of the identified factors based on a five-point Likert scale (1 = not critical, 2 = slightly critical, 3 =moderately critical, 4 = critical and 5 = very critical). The five-point scale is very popular in construction management research because it provides a convenient judgment scale for respondents (King *et al.*, 2022; Radzi *et al.*, 2022). The survey was designed in English to avoid information loss during the translation process (Ervin and Bower, 1952).

3.2 Data collection

After finalizing the survey, this study gathered data from AEC professionals across the four countries using an online survey platform. As the sampling frame was not available for this study, the sample was a non-probability sample. The non-probability sampling technique can be used to obtain a representative sample (Wilkins, 2011). This technique is useful when a random sampling cannot be used to select respondents from the whole population. However, respondents can be selected based on their willingness to participate in the study (Ma *et al.*, 2018). First, the purposive sampling technique was applied to ensure the desirable criteria. The criteria for selecting the respondents include professionals who have more than five years of working experience in the AEC industry (Doan *et al.*, 2020; Hong *et al.*, 2019; Hong *et al.*, 2018). Then, this study used a snowball sampling method to collect a valid sample size because BIM implementation in the four countries is low (Al-Mohammad *et al.*, 2021; Ahuja *et al.*, 2018; Othman *et al.*, 2020; Al-Yami and Sanni-Anibire, 2021). As a result, the authors initially identified eligible respondents who could answer the questionnaire using their communications and referral networks. The respondents were also requested to nominate other knowledgeable individuals to increase the response rate. After multiple reminders and interactions, this study collected 101, 93, 445 and 115 valid responses from Afghanistan, India, Malaysia and Saudi Arabia. The sample size might seem small (except for Malaysia). However, it is still appropriate to conduct statistical analyses because the central limit theorem holds when the sample size exceeds 30 (Ott and Longnecker, 2008).

3.3 Data analysis

3.3.1 Reliability testing. The Cronbach α is the most popular index for reliability testing of Likert scales. Its value ranges between 0 and 1. A value closer to 1 indicates higher reliability of the developed instrument (Cronbach, 1951). The results show that Cronbach's α value is 0.733, 0.953, 0.638 and 0.610 for Afghanistan, India, Malaysia and Saudi Arabia, respectively. These values are greater than the acceptable level of 0.50, indicating acceptable consistency and reliability of the questionnaire responses (King *et al.*, 2022; Radzi *et al.*, 2022).

Before embarking on ranking analysis, the data were processed using the two standard deviations technique to capture any potential data that statistically affected the results (e.g. outliers). This process includes computing the intervals of two standard deviations for each country. The variables with means outside the two intervals were considered outliers. As such, for India, "existence of a BM project champion" (mean = 3.452) and "existence of local laws to protect individuals involved in BIM projects" (mean =3.452) were outside the two intervals of 3.454 and 3.807. For Malaysia, "existence of standard contracts on data security and user confidentiality" had a mean equal to 1.321, which was outside the interval ranges (1.966 and 4.672). Similarly, for Saudi data, "the newness of BIM in the local market" possessed a mean of 1.739, which was not inside the two standard deviation intervals (1.858 and 4.480). As a result, these factors were considered outliers and were not included in the subsequent analysis.

Finally, the collected data was scrutinized by screening through the respondent profile (Table 3). Table 3 shows that respondents possessing zero to five years of AEC working experience are dominant. The Kruskal–Wallis test was performed to examine any significant differences between the AEC experience categories in each country. The results illustrate no significant differences in the means among AEC experience categories in Afghanistan. However, out of 11 critical factors, only "the time required for training" has significantly different means among the AEC professionals in India. As for Malaysia, there are significant differences in the opinions of the AEC professionals on the six critical factors. Finally, the AEC professionals in Saudi Arabia have consistent views on most critical factors. In other words, there are minimal significant differences between the AEC experience categories. Therefore, the subsequent analyses do not involve comparing between AEC experience categories.

3.3.2 Mean ranking analysis. After removing the outliers, the mean ranking technique was used to rank the factors according to their means. Standard deviation was then computed to differentiate between factors with the same means. In other words, a smaller standard deviation indicates a smaller difference between responses, and the corresponding factor should be ranked higher. The normalized value technique was then used to identify the critical factors to BIM implementation. The normalized value method was used because the mean ranking alone tends to select almost half of the factors (Phang *et al.*, 2020). Normalized values greater than 0.50 indicate that the factor is critical (King *et al.*, 2022; Radzi *et al.*, 2022).

3.3.3 Overlap analysis. The overlap analysis technique was built upon the ranking analysis results to identify the unique and overlapping critical factors between countries with different income levels (King *et al.*, 2022). The overlap analysis is a decision-making technique that compares symmetries and asymmetries between multiple groups (Heberle *et al.*, 2015). Prior works support using this technique to identify the critical pandemic impacts on AEC organizations (King *et al.*, 2022). This technique uses circles to visualize a group. Factors overlapping in at least two groups shape the overlap, and those unique to a specific group represent the non-overlapping part.

3.3.4 Agreement analysis. The Kruskal–Wallis test was conducted to identify any significant differences in the means of the factors between Afghanistan, India, Malaysia and Saudi Arabia. Kruskal-Wallis is a non-parametric test that can analyze Likert responses from at least three groups when the normality assumption is unjustified (Field, 2013). The null hypothesis entails no significant differences in means between groups (e.g. countries). When the hypothesis did not hold, the Dunn test was used as a *post hoc* analysis to investigate which

	Afghanistan		India		Malaysia		Saudi Arabia	
AEC experience	Frequency	(%)	Frequency	(%)	Frequency	(%)	Frequency	(%)
0–5	67	13.91	67	72.04	225	50.56	16	66.34
6 to 10	26	46.09	19	20.43	140	31.46	53	25.74
>10	8	40.00	7	7.53	80	17.98	46	7.92
Total	101	100.00	93	100.00	445	100.00	115	100.00

Table 3.
Respondent profile

pair of groups the differences exist. Finally, the Mann–Whitney test was used to examine any possible discrepancy in the means of the factors in two different countries (Love *et al.*, 2004).

4. Results

4.1 Results for mean ranking analysis

Table 4 shows the results of ranking the factors affecting BIM implementation. The means of the factors to BIM implementation were converted into normalization values to identify the critical factors across the four countries. As a result, 10, 11, 6 and 11 factors are critical to BIM implementation in Afghanistan, India, Malaysia and Saudi Arabia, respectively. Inspired by Chan *et al.* (2018) and Ma *et al.* (2020), the top five factors affecting BIM implementation across the four countries are discussed.

"Stakeholders' willingness to learn the BIM method" is the most critical factor affecting BIM implementation in Afghanistan (mean = 4.228). This result is consistent with a prior finding on stakeholders in Afghanistan have no intention to learn or implement BIM (Al-Mohammad *et al.*2021). The second factor is "interoperability between software in exchanging information" (mean = 4.069), followed by "cost-benefit of implementing BIM" (mean = 4.030), "availability of guidelines for implementing BIM" (mean = 3.921) and "presence of public-private partnership in realizing BIM projects" (mean = 3.840).

Conversely, "the time required for training" is the most critical factor to BIM implementation in India (mean = 3.731). This result is in line with Ahuja *et al.* (2018), concluding that most BIM adopters and non-adopters feel that attaining a full-scale BIM implementation and sufficient BIM training is a lengthy process. "Local industry's awareness of BIM" is ranked second (mean = 3.731), followed by "clarity of roles and responsibilities in BIM-based projects" as the third (mean = 3.699). The fourth and fifth factor to BIM implementation in India are "existence of standard contracts on liability and risk allocation" (mean = 3.688) and "preferences in project delivery method" (mean = 3.688). It is worth mentioning that the former two factors have the same means. However, "existence of standard contracts on liability and risk allocation" has a lower standard deviation (SD = 0.9888) than "preferences in project delivery method" (SD = 1.0319). This result implies that the data related to "existence of standard contracts on liability and risk allocation" is less spread out but closer to the mean. Thus, "existence of standard contracts on liability and risk allocation" is ranked higher.

As for Malaysia, the most critical factor to BIM implementation is "availability of guidelines for implementing BIM" (mean = 4.467). According to Othman *et al.* (2020), the absence of a clear guideline is one of the main reasons for slow BIM implementation in Malaysia. The second most critical factor in Malaysia is "stakeholders' willingness to learn the BIM method" (mean = 4.094), followed by "cost-benefit of implementing BIM" (mean = 4.016), "preferences in project delivery method" (mean = 3.813) and "consistent views on BIM between stakeholders" (mean = 3.802).

In Saudi Arabia, "consistent views on BIM between stakeholders" is the most critical factor to BIM implementation (mean = 3.739). In Saudi Arabia, there is a varying understanding of BIM, creating difficulties in explaining BIM to the stakeholders. Thus, a common understanding of BIM processes is lacking (Aljobaly and Banawi, 2020). "Availability of guidelines for implementing BIM" is ranked second (mean = 3.739), followed by "cost-benefit of implementing BIM" (mean = 3.730), "local industry's awareness of BIM" (mean = 3.713) and "interoperability between software in exchanging information" (mean = 3.635).

4.2 Results for overlap analysis

According to the overlap analysis technique (Table 4), five critical factors to BIM implementation are overlapped between all income levels. These factors are F18, F14, F05,

Table 4. Ranking of factors affecting BIM implementation

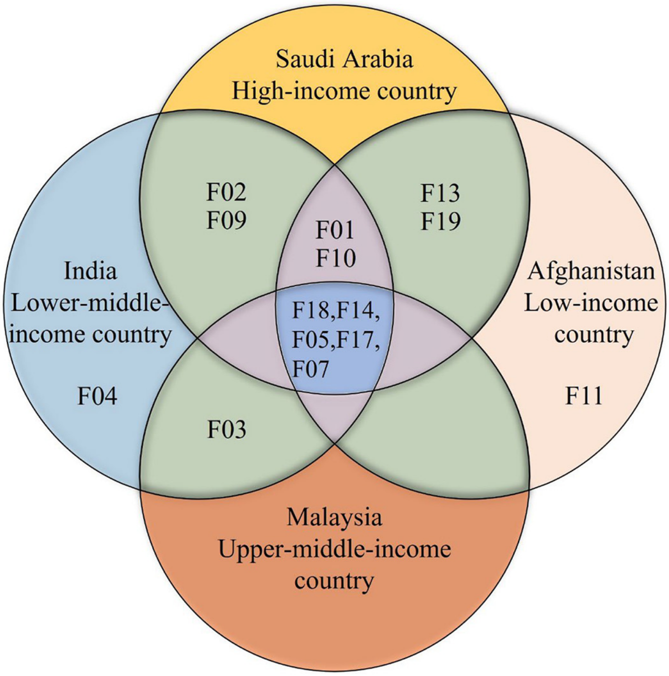
ID	Total (N = 754)				Afghanistan (N = 101)				India (N = 93)				Malaysia (N = 445)				Saudi Arabia (N = 115)			
	MS	SD	NV	R	MS	SD	NV	R	MS	SD	NV	R	MS	SD	NV	R	MS	SD	NV	R
F18	4.182	0.9887	1.000	1	3.921	1.0068	0.825*	4	3.645	1.0698	0.600*	9	4.467	0.7425	1.000*	1	3.739	1.2984	1.000*	2
F14	3.926	0.9682	0.812	2	4.030	1.0436	0.887*	3	3.624	1.0926	0.500*	11	4.016	0.8395	0.746*	3	3.730	1.1722	0.995*	3
F05	3.887	1.0265	0.783	3	4.228	0.9368	1.000*	1	3.645	1.1194	0.600*	10	4.094	0.8356	0.790*	2	2.983	1.1469	0.532*	11
F07	3.753	0.8485	0.685	4	3.634	0.9770	0.661*	7	3.667	1.0144	0.700*	6	3.802	0.6688	0.626*	5	3.739	1.1477	1.000*	1
F13	3.629	0.8670	0.593	5	4.069	0.8861	0.910*	2	3.602	1.1242	0.400	12	3.533	0.6725	0.474	8	3.635	1.1342	0.935*	5
F17	3.565	1.0989	0.546	6	3.396	0.9174	0.525*	9	3.688	0.9888	0.800*	4	3.616	1.1001	0.521*	6	3.417	1.2909	0.801*	10
F02	3.414	1.0144	0.435	7	3.030	1.1615	0.316	11	3.731	1.0849	1.000*	1	3.398	0.9062	0.398	9	3.557	1.1097	0.887*	7
F01	3.406	1.1196	0.429	8	3.356	1.1797	0.503*	10	3.731	1.2260	1.000*	2	3.270	1.1106	0.326	10	3.713	0.8862	0.984*	4
F03	3.402	1.1872	0.426	9	2.782	1.2618	0.175	13	3.688	1.0319	0.800*	5	3.813	0.7820	0.632*	4	2.122	1.3964	0.000	15
F10	3.393	0.9218	0.420	10	3.663	1.0609	0.678*	6	3.667	1.1641	0.700*	8	3.222	0.7812	0.300	11	3.591	0.9356	0.909*	6
F19	3.258	0.8657	0.321	11	3.840	1.0171	0.779*	5	3.570	0.9824	0.250	13	2.998	0.5946	0.173	13	3.504	1.0872	0.855*	8
F04	3.243	1.0285	0.309	12	2.475	1.0158	0.000	15	3.699	1.0403	0.850*	3	3.544	0.7833	0.480	7	2.383	1.0138	0.161	13
F11	3.101	1.1079	0.205	13	3.426	1.1945	0.542*	8	3.516	1.1094	0.000	15	3.189	0.9658	0.281	12	2.139	1.0164	0.011	14
F09	3.098	1.0117	0.203	14	2.733	1.1991	0.147	14	3.667	1.1164	0.700*	7	2.978	0.7649	0.162	14	3.426	1.2914	0.806*	9
F12	2.822	0.9874	0.000	15	2.941	1.1386	0.266	12	3.559	1.1746	0.200	14	2.690	0.7462	0.000	15	2.635	1.2091	0.317	12

Notes: MS = mean score; SD = standard deviation; R = rank; normalized value (NV) = (mean − minimum mean)/(maximum mean − minimum mean) *Indicates that the factor is critical (normalized value $\geq$ 0.50)

F17 and F07. Two critical factors (F01 and F10) overlap between Afghanistan, India and Saudi Arabia. In addition, two critical factors overlap between India and Saudi Arabia (F02 and F09) and Saudi Arabia and Afghanistan (F13 and F19). Only one critical factor (F03) overlaps between India and Malaysia. The non-overlapping factors that are unique in a specific income level are F11 and F04 in Afghanistan and India. Figure 1 shows the overlapping and non-overlapping critical factors between income levels.

4.3 Results for agreement analysis

Table 5 shows the results of the agreement analysis of the critical factors between countries with different income levels. The results show that there are consistent views on the criticality of the following critical factors (p-value ≥ 0.05): "market demand for BIM" (F10), "the time required for training" (F02), "resources required for continuous training" (F09),



Notes: F01: Local industry's awareness of BIM; F02: The time required for training; F03: Preferences in project delivery method; F04: Clarity of roles and responsibilities in BIM-based projects; F05: Stakeholders' willingness to learn the BIM method; F07: Consistent views on BIM between stakeholders; F09: Resources required for continuous training; F10: Market demand for BIM; F11: Presence of appropriate projects to implement BIM; F13: Interoperability between software in exchanging information; F14: Cost–benefit of implementing BIM: F17: Existence of standard contracts on liability and risk allocation: F18: Availability of guidelines for implementing BIM: F19: Presence of PPP in realizing BIM projects

Figure 1.
Overlapping and non-overlapping critical factors between all income levels

Table 5.
Results for agreement analysis

ID	Factor	Afghanistan/low-income ($N = 101$)			India/lower-middle income ($N = 93$)			Malaysia/upper-middle income ($N = 445$)		
		MS	SD	NV	MS	SD	NV	MS	SD	NV
F05	Stakeholders' willingness to learn the BIM method	4.228	0.9368	1.000	3.645	1.1194	0.600	4.094	0.8356	0.790
F13	Interoperability between software in exchanging information	4.069	0.8861	0.910	–	–	–	–	–	–
F14	Cost–benefit of implementing BIM	4.030	1.0436	0.887	3.624	1.0926	0.500	4.016	0.8395	0.746
F18	Availability of guidelines for implementing BIM	3.921	1.0068	0.825	3.645	1.0698	0.600	4.467	0.7425	1.000
F19	Presence of PPP in realizing BIM projects	3.840	1.0171	0.779	–	–	–	–	–	–
F10	Market demand for BIM	3.663	1.0609	0.678	3.667	1.1641	0.700	–	–	–
F07	Consistent views on BIM between stakeholders	3.634	0.9770	0.661	3.667	1.0144	0.700	3.802	0.6688	0.626
F17	Existence of standard contracts on liability and risk allocation	3.396	0.9174	0.525	3.688	0.9888	0.800	3.616	1.1001	0.521
F01	Local industry's awareness of BIM	3.356	1.1797	0.503	3.731	1.2260	1.000	–	–	–
F02	The time required for training	–	–	–	3.731	1.0849	1.000	–	–	–
F03	Preferences in project delivery method	–	–	–	3.688	1.0319	0.800	3.813	0.7820	0.632
F09	Resources required for continuous training	–	–	–	3.667	1.1164	0.700	–	–	–

Notes: *p-value lower than 0.05 indicates a significant difference in perceptions toward the given BIM implementation factors. The table presents the results of the agreement analysis for the overlapping and critical factors only

(*continued*)

ID	Factor	Country/country income level Saudi Arabia/high income ($N = 115$)			Agreement	
		MS	SD	NV	p-value	Statistically different opinion
F05	Stakeholders' willingness to learn the BIM method	2.983	1.1469	0.532	0.000*	AFG&IND, AFG&SAU, IND&MYS, IND&SAU and MYS&SAU
F13	Interoperability between software in exchanging information	3.635	1.1342	0.935	0.005*	AFG&SAU
F14	Cost–benefit of implementing BIM	3.730	1.1722	0.995	0.005*	AFG&IND, AFG&SAU and IND&MYS
F18	Availability of guidelines for implementing BIM	3.739	1.2984	1.000	0.000*	AFG&MYS, IND&MYS and MYS&SAU
F19	Presence of PPP in realizing BIM projects	3.504	1.0872	0.855	0.022*	AFG&SAU
F10	Market demand for BIM	3.591	0.9356	0.909	0.729	None
F07	Consistent views on BIM between stakeholders	3.739	1.1477	1.000	0.428	None
F17	Existence of standard contracts on liability and risk allocation	3.417	1.2909	0.801	0.201	None
F01	Local industry's awareness of BIM	3.713	0.8862	0.984	0.036*	AFG&IND and AFG&SAU
F02	The time required for training	3.557	1.1097	0.887	0.288	None
F03	Preferences in project delivery method	–	–	–	0.443	None
F09	Resources required for continuous training	3.426	1.2914	0.806	0.303	None

Table 5.

"preferences in project delivery method" (F03). However, those four factors are not critical for all income levels. "Existence of standard contracts on liability and risk allocation" (F17) and "consistent views on BIM between stakeholders" (F07) are the critical factors for all income levels with consistent views on the criticalities. In other words, these two factors are critical in all countries, irrespective of income levels.

However, there are some discrepancies between the means of the critical factors. "Cost-benefit of implementing BIM" (F14), "stakeholders" willingness to learn the BIM method" (F05), "interoperability between software in exchanging information" (F13) and "presence of public-private partnership in realizing BIM projects" (F19) have significantly higher mean in Afghanistan than other countries. These results imply that those four factors can promote or impede BIM implementation in Afghanistan more than in other countries. By contrast, Afghanistan has a significantly lower mean for "local industry's awareness of BIM" (F01) than India and Saudi Arabia. In other words, BIM awareness is more important to address in India and Saudi Arabia than in Afghanistan. Malaysia has a significantly higher mean for "availability of guidelines for implementing BIM" (F18) than Afghanistan, India and Saudi Arabia. Although Malaysia has developed some BIM implementation guidelines, more guidelines are needed to promote BIM implementation in the AEC industry. From the analysis, it can be drawn that there are symmetries and asymmetries between the criticality of the critical factors. Also, the criticality of the factors often differs between income levels, especially between low- and high-income countries, suggesting a significant gap between low- and high-income countries. The next subsection gives more specific insights into these discrepancies.

5. Discussion

This section discusses the overlapping critical factors between different income levels. It also summarizes the potential reasons for the significantly different views on the overlapping critical factors to BIM implementation in low-, lower-middle-, upper-middle- and high-income countries, as shown in Table 6.

5.1 Critical factors for all income levels

Availability of guidelines for implementing BIM. Successful BIM implementation requires guidelines as a part of the implementation strategy (Othman *et al.*, 2020). The absence of guidelines can contribute to poor implementation due to the lack of knowledge on BIM implementation procedures (Mehran, 2016). Although many guidelines have been developed to facilitate the transformation process, these guidelines are not universal. Existing guidelines are often developed to suit the local requirements and AEC environment, which vary from country to country (Hong *et al.*, 2018). Organizations act on their initiatives and develop guidelines to maintain strong competitors in the local market (Dang *et al.*, 2020). The problems in these guidelines include inconsistency in the developed standards. As a result, considerable confusion arises among AEC professionals in determining the appropriate guidelines for BIM implementation (Rogers *et al.*, 2015). Therefore, establishing uniform and regional-specific guidelines based on the regional context is crucial. The mean of this critical factor is significantly higher for Malaysia than other countries. This result is presumably because Malaysia shows more initiatives toward BIM. For example, the Malaysian government established the National Steering Committee of BIM in 2013. The committee, including government bodies, professional bodies, private organizations and academia, is responsible for developing a BIM roadmap to foster BIM implementation in Malaysia (Hanafi *et al.*, 2016). Such initiatives can increase the BIM implementation rate by

ID	Factor	Differences	Potential reasons
F18	Availability of guidelines for implementing BIM	MYS > AFG MYS > IND MYS > SAU	This might be attributed to the initiatives of Malaysian government and enforcement, such as BIM implementation guidelines and BIM implementation mandate. By contrast, other countries lack such initiatives
F14	Cost–benefit of implementing BIM	AFG > IND MYS > IND AFG > SAU	Both India and Saudi Arabia have a higher-income level, and their economic conditions are more stable. Conversely, Afghanistan faces financial difficulties and unique economic conditions due to military conflict Also, the cost of BIM implementation in Malaysia is reflected by the "downtime" necessary for individual and organizational learning. Thus, it is considered a considerable investment for organizations
F05	Stakeholders' willingness to learn the BIM method	AFG > IND MYS > IND AFG > SAU MYS > SAU IND > SAU	Lower-income countries might view learning BIM and its associated tools as expensive, and AEC organizations have no intention or motivation to update their workflow. Conversely, Saudi Arabia, as a high-income country, may mandate individuals to have in-house BIM personnel and implement new technologies to achieve "Vision 2030"
F01	Local industry's awareness of BIM	IND > AFG SAU > AFG	The difference in perception is due to the lack of initiatives in Afghanistan, such as seminars, conferences, workshops, publications and media on BIM. The Afghanistan government lacks initiatives, innovations and strategies to maintain long-term growth. As a post-conflict low-income country, the reconstruction of infrastructure, economic recovery and resurrecting the AEC industry is a daunting task. Therefore, implementing new technologies, such as BIM, and increasing its awareness may not be priorities for the Afghanistan government
F13	Interoperability between software in exchanging information	AFG > SAU	Improper interoperability causes additional costs for organizations, including investing in new software and hardware. In addition, organizations lack resources in a low-income and post-conflict country, such as Afghanistan
F19	Presence of PPP in realizing BIM projects	AFG > SAU	The Saudi government allocated a substantial budget to involve the private sector in contracts with operations and maintenance activities. This has led to more private investments in construction projects and played a critical role in maintaining the AEC competency in the region. In other words, there are many opportunities for the private sector to participate in economic development

Table 6. Potential reasons for the significant different mean scores between countries

providing practical solutions in streamlining the BIM implementation process (Jin *et al.*, 2017).

Cost–benefit of implementing BIM. AEC organizations and professionals often wonder whether the money allocated for BIM investment can yield worthwhile returns. The financial-related benefits are undeniably a strong motivator to implement BIM (Tai *et al.*, 2020). However, stakeholders claim insufficient justification for implementing BIM because its value and benefits are poorly identified. The reason is strongly linked to the lack of well-documented benefits and case studies on BIM (Chiu and Lai, 2020). In addition, the level of resources in an organization plays a significant role in the BIM implementation decision because BIM implementation requires allocating funds for software and hardware, continuous maintenance and staff training (Won *et al.*, 2013). Therefore, small and medium enterprises consider BIM as unaffordable because of their limited financial resources (Zhou *et al.*, 2019). The results also show that Afghanistan has a significantly higher means than India and Saudi Arabia for this factor. Both India and Saudi Arabia have a higher income level than Afghanistan. Organizations in India and Saudi Arabia are more likely to handle costs incurred by BIM implementation because of the higher income level, better industry environment and more stable economic conditions (Amarkhil and Elwakil, 2021). Any extra costs threaten organizations in non-high-income countries, especially low-income countries such as Afghanistan (Al-Mohammad *et al.*, 2021). Malaysia also has a significantly higher means than India for this factor. BIM investment costs and its unclear return on investments are the major barriers to BIM implementation in both countries (Ahuja *et al.*, 2018; Sinoh *et al.*, 2020). However, the cost of BIM implementation in Malaysia is reflected by the "downtime" necessary for individual and organizational learning between six and 12 months, causing serious financial difficulties for organizations (Rogers *et al.*, 2015).

Stakeholders' willingness to learn the BIM method. Willingness to learn new knowledge and implement modern technologies is vital. However, at the individual level, the absence of motivation due to perceived complexity, and a time-consuming learning process can negatively influence decisions in BIM implementation. Learning BIM and its associated tools and implementation processes may take a long time (Rahman *et al.*, 2019; Rahman and Ayer, 2019). The negative impact of the learning period is reflected by a lower productivity rate and additional resources required for building staff competencies (Rogers *et al.*, 2015). This impact makes BIM an unappealing choice because organizations need to wait for a long time to realize the benefits of BIM implementation (Liao *et al.*, 2019). In other words, AEC professionals entrench themselves in the traditional design and construction methods (Liao *et al.*, 2019). This finding indicates that the willingness to learn and implement BIM directly influences stakeholder behavior. The results show that there are significant differences in almost all income levels. These differences might be because lower-income countries view learning BIM and its associated tools as expensive due to the lack of available funds. As a result, AEC organizations in Afghanistan are comfortable with current practice and have no intention or motivation to update their workflow (Al-Mohammad *et al.*, 2021). By contrast, Saudi Arabia, as a high-income country, has more capacity to allocate resources for staff training and acquire BIM-related software and hardware. Therefore, the Saudi government is pressured to have skilled local BIM personnel. As a result, the Saudi government is mandating local AEC professionals to enhance their competency and learn new construction technologies, including BIM (Al-Yami and Sanni-Anibire, 2021).

Consistent views on BIM between stakeholders. It is common for AEC professionals to have a varying understanding of BIM. Inconsistencies in the understanding are due to the lack of awareness of BIM, its use and capabilities (Rogers *et al.*, 2015). For example, BIM users usually view BIM as a database to extract project details, while non-BIM users view BIM as modeling software (Hong *et al.*, 2018). These findings suggest that prior experience in BIM impacts the understanding level of BIM among AEC professionals (Rahman *et al.*, 2019; Rahman and Ayer, 2019). This situation illustrates that the limited understanding of BIM may negatively impact decision-makers on the value of BIM implementation in organizations.

Existence of standard contracts on liability and risk allocation. BIM promotes collaboration between multiple parties in a digital manner. As a result, there is often a back-and-forth data exchange between project parties. However, some individuals may make unauthorized changes to the BIM model (Dao *et al.*, 2020). These changes may include errors, inaccuracies or incomplete data input, which raises issues when such defects occur, especially when concealed or causing additional costs (Babatunde *et al.*, 2021). This situation often emerges when the contractual relationships between project parties are not delineated, and their boundaries are poorly defined (Fan, 2014). Although many works have focused on solving this issue, poor contractual frameworks and liability risk remains a major concern among project stakeholders.

5.2 Critical factors for Afghanistan, India and Saudi Arabia

Local industry's awareness of BIM. BIM awareness is an important driver for implementing BIM. For example, a high level of BIM awareness can attract client interest and willingness to implement it (Dang *et al.*, 2020). The more exposure of the stakeholders to BIM, the more benefits they realize. BIM awareness is critical in providing evidence on the improvements BIM can deliver to the AEC industry (Hong *et al.*, 2018). Clients are more open to taking risks and investing in BIM with such awareness because the financial implications are justified (Tai *et al.*, 2020). Project stockholders can justify the low BIM implementation rate by having a technology irrelevant and useless due to low BIM awareness (Al-Mohammad *et al.*, 2021). In other words, different levels of BIM awareness have different effects on stakeholder understanding about BIM implementation necessity in organizations (Hong *et al.*, 2018). Therefore, attaining a high awareness level of BIM is essential. The results show that Afghanistan has a significantly lower mean than India and Saudi Arabia for this factor. This finding is consistent with Al-Mohammad *et al.* (2021), indicating that low AEC industry awareness of BIM is not critical for BIM implementation in Afghanistan. Conversely, the lack of BIM awareness is a major barrier to BIM implementation in India and Saudi Arabia (Al-Yami and Sanni-Anibire, 2021; Ahuja *et al.*, 2018). BIM awareness can be raised through additional initiatives, such as seminars, conferences and workshops. Publications and media also play a critical role in spreading knowledge about BIM (Rogers *et al.*, 2015). These initiatives are usually done in the presence of the government and professional bodies. However, the government of Afghanistan lacks initiatives, innovations and strategies in implementing emerging technologies (World Bank, 2021). As a low-income country, the reconstruction of infrastructure, economic recovery and resurrecting of the AEC industry is a daunting task (Amarkhil and Elwakil, 2021). Implementing new technologies, such as BIM, and increasing its awareness may not be a priority for the Afghan government.

Market demand for BIM. Organizational innovation is strongly driven by external motivations, such as market demand. Although market demand can encourage AEC organizations to invest in BIM, there are different reasons for BIM's scarcity in the AEC industry. For example, clients should pay higher fees for design professionals (Bynum *et al.*, 2013). Also, untrusted knowledge sources and empirical works on BIM benefits raise doubts about BIM value (Chiu and Lai, 2020). In a technical sense, BIM as a digital technology does not provide practical solutions for problems related to interoperability between software required for different tasks. This disadvantage negatively affects the demand pull and technology push (Rogers *et al.*, 2015). In other words, clients only demand BIM if the return on investment outweighs the costs involved in the BIM implementation process (Liao *et al.*, 2019).

5.3 Critical factors for Afghanistan and Saudi Arabia

Interoperability between software in exchanging information. Interoperability is the ability to exchange information between software considering different environments to facilitate automation. With a high level of interoperability, project stakeholders can use the BIM model data across the project lifecycle (Rogers *et al.*, 2015). For example, clients can benefit from the data for future use, including better schedules in the construction phase and facility management in the operation phase (Chiu and Lai, 2020). However, interoperability remains one of the most important barriers to BIM implementation in the global AEC industry (Bynum *et al.*, 2013). To minimize interoperability problems, the IFC data format was developed. Nevertheless, AEC professionals are still uncomfortable with such solutions due to transferring loss and errors (Aibinu and Venkatesh, 2014). Significant blame is usually placed on software vendors for providing solutions that lack a common platform for exchanging information (Rogers *et al.*, 2015). Data sharing using the existing collaboration tools and IFC format is still problematic and requires significant improvement (Al-Mohammad *et al.*, 2021). In low-income countries, such as Afghanistan, local organizations lack resources because the government has limited financial capabilities to fund projects (World Bank, 2021). As a result, these countries are most likely to face improper interoperability issues from outdated software and hardware.

Presence of public–private partnership in realizing BIM projects. Public–private partnership (PPP) projects mainly focus on procurement benefits that require a suitable platform for data exchanging and management (Ren *et al.*, 2020). BIM can be an ideal platform in PPP projects because the common data exchange inherent in the BIM environment can be effectively used throughout the PPP project cycle (Tai *et al.*, 2020). The results show that the mean of this factor in Afghanistan is significantly higher than in Saudi Arabia. This result might be attributed to the higher PPP implementation rate in Saudi Arabia, as privatization is among the main national agendas (Al-Yami and Sanni-Anibire, 2021). The Saudi government allocated a substantial budget to involve the private sector in contracts with operation and maintenance activities. In other words, there are many opportunities for the private sector to engage in economic development in Saudi Arabia.

5.4 Critical factors for India and Malaysia

Preferences in project delivery method. There exist different project delivery methods used by different countries. One project delivery method might be superior to other methods to use BIM. For example, the findings of Bynum *et al.* (2013) showed that the respondents in the USA select design-build (DB) and IPD as the optimal project delivery methods for BIM. By contrast, design–bid–build (DBB) was not selected by most respondents. This finding indicates that AEC professionals view BIM to be more effective in one project delivery method than the others. However, the most common project delivery method in Malaysia and India is DBB. Therefore, the focus in both countries might turn into the advanced level of BIM implementation, such as project delivery method, rather than the basics, such as BIM awareness.

5.5 Critical factors for India and Saudi Arabia

"The time required for training" and "resources required for continuous training." Education and training are key elements for successful BIM implementation (Ahuja *et al.*, 2018). As individual competencies are the fundamental building blocks of organizational competency, organizations need to upskill staff and expand their BIM competency (Succar, 2009). To do so, employees should undergo a series of BIM training courses and programs covering overall BIM implementation in the AEC industry due to organizational changes and new workflows (Rahman *et al.*, 2019; Rahman and Ayer, 2019). Unfortunately, employees tend to resist change as BIM software learning curves and costs are a problem. In addition, older employees have strong resistance because they have been using 2D CAD for a long time (Ahn *et al.*, 2016). BIM training demands BIM experts to increase BIM competency among employees (Ahuja *et al.*, 2018). Therefore, organizations must handle payments incurred from hiring BIM experts and up-to-date BIM software in the market.

5.6 Study implication

5.6.1 Theoretical implication. Unlike prior works that focus on a single country, this study contributes to the existing body of knowledge by comparing the factors affecting BIM implementation between countries with different income levels. This study's findings provide a better understanding of how different income levels perceive BIM implementation. The findings demonstrate that common factors to BIM implementation recur in different income levels. Examples include the need for BIM implementation guidelines, BIM benefits reinforcement, convincing the AEC professionals to learn BIM, promoting BIM understanding and contractual frameworks on liability and risk allocation. These examples represent five major areas that should be addressed at all income levels. The overlapping critical factors between two- or three-income levels should also be addressed. These findings are useful for research communities from different countries to share efforts and resources to address the overlapping critical factors. As the AEC professionals provided their understandings based on their regions, addressing the local critical factors should promote local BIM implementation. In other words, BIM implementation strategies specific to each country are also needed. Future works can establish BIM implementation roadmaps within each country, considering the common and unique factors.

5.6.2 Practical implication. In practice, the limited resources require the governments and policymakers to prioritize resources to address the critical factors rather than all factors. By identifying the overlapping critical factors, governments and policymakers in the four countries are informed of specific areas that be overcome or enhanced. They can use the critical overlapping factors to strengthen the impact of drivers and reduce the impact of the barriers when implementing BIM. The study findings are beneficial for AEC professionals to collaboratively develop international BIM implementation strategies that are often absent in the literature. Other nations can learn from the experience of the countries in this study to enhance BIM implementation in their respective local AEC industry.

6. Conclusion

Due to different income levels, not every country can implement BIM at the same pace. Countries with less income might naturally face additional challenges in BIM implementation. This study empirically analyzed the symmetries and asymmetries among the critical factors affecting BIM implementation between countries with different income levels. The SLR and semi-structured interviews with AEC professionals revealed 19 factors affecting BIM implementation. A questionnaire survey was disseminated to AEC professionals in Afghanistan, India, Malaysia and Saudi Arabia (i.e. each country represents different income levels). The data was analyzed using the mean, standard deviation and normalized value techniques. The critical overlapping factors were then identified using the overlap analysis technique. Finally, Kruskal–Wallis, Dunn and Mann–Whitney tests were used to explore any significant differences in the means of the factors between the countries.

The results revealed that countries with different income levels have distinct critical factors to BIM implementation. However, among the distinct critical factors, five critical factors overlap between all income levels: "availability of guidelines for implementing BIM," "cost-benefit of implementing BIM," "stakeholders' willingness to learn the BIM method," "existence of standard contracts on liability and risk allocation" and "consistent views on BIM between stakeholders." In other words, these are the critical factors affecting BIM implementation irrespective of income levels. Countries intending to implement BIM should consider addressing these five critical factors to facilitate the BIM implementation process.

In addition to overlapping critical factors, the results revealed the following critical factors exist for countries with different income levels:

- Low-income countries: "presence of appropriate projects to implement BIM," "interoperability between software in exchanging information" and "presence of public-private partnership in realizing BIM projects."
- Lower middle-income countries: "clarity of roles and responsibilities in BIM-based projects," "the time required for training," "resources required for continuous training" and "preferences in project delivery method."
- Upper middle-income countries: "preferences in project delivery method."
- High-income countries: "local industry's awareness of BIM," "market demand for BIM," "interoperability between software in exchanging information" and "presence of public-private partnership in realizing BIM projects," "the time required for training" and "resources required for continuous training."

The results of agreement analysis suggest that the importance of promoting BIM understanding and establishing contracts on liability and risk allocation is consistent disregard of a country's income level. The need for BIM implementation guidelines is more critical in Malaysia. BIM benefits reinforcement and convincing stakeholders to implement BIM are critical in Afghanistan. There is an agreement between Afghanistan, India and Saudi Arabia on the need for market demand for BIM. Promoting the AEC industry awareness of BIM in India is essential. Mann–Whitney test results suggest interoperability between software and PPP in realizing BIM are more critical in Afghanistan than Saudi Arabia. Moreover, India and Malaysia have consistent views on the role of project delivery methods in promoting BIM implementation. Finally, India and Saudi Arabia have consistent views on the time and resources required for continuous training.

Although the objectives of this study were achieved, there are some limitations worth stating. The sample size for Afghanistan, India and Saudi Arabia is relatively small. The interpretation and generalization of the findings can be enhanced in future works by using a higher sample size. Furthermore, the respondents were selected based on their AEC experience. Collecting data from knowledgeable individuals in BIM can be a future research direction. As this study is quantitative in nature, the qualitative part was neglected. A wider scope of data collection (e.g. qualitative data) across the four countries can provide more opportunities for comparing and explaining some findings, especially for those critical factors with significantly different means between income levels. Agreement analysis was conducted for the overlapping critical factors only. There might be inconsistency in the views toward other factors. Therefore, the results of the Kruskal–Wallis and Mann–Whitney tests should be interpreted with caution. Despite the limitations, the findings of this study provide greater insights and empirical evidence on the overlapping critical factors to BIM implementation in low-, lower-middle-, upper-middle- and high-income countries that are missing in the literature. These findings are of great value to academics and AEC professionals.

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Corresponding author
Rahimi A. Rahman can be contacted at: arahimirahman@ump.edu.my