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Root factors limiting BIM implementation in developing countries: sampling the Turkish AEC industry

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Abstract

Purpose – Despite several advantages of Building Information Modelling (BIM) technology, BIM has not been adopted and implemented extensively in developing countries. Consequently BIM remains at a beginner level in developing countries. To increase the level of BIM implementation, first, knowing the root factors that resist BIM implementation is necessary to know. Therefore, the objective of this study was to identify the factors that limit BIM implementation in developing countries, specifically in the Turkish Architecture, Engineering and Construction (AEC) industry.

Design/methodology/approach – A questionnaire was designed with 46 influencing causes (ICs) identified through a systematic literature review. In total, 141 survey results were returned from architects and engineers, and reliability analysis, exploratory factor analysis, and confirmatory factor analysis were conducted. Furthermore, a structural equation model (SEM) was developed to identify the root factors of BIM implementation.

Findings – Eight root factors affecting the prevalent use of BIM technology in the Turkish construction industry were determined and grouped into three categories based on BIM implementation level. Problems with the BIM transition process and a lack of management support are the most influential root factors limiting BIM implementation. Lack of incentives, lack of BIM education, bias regarding BIM technology and BIM-based software problems form the second group of root factors that have a significant effect. Awareness and lack of communication amongst stakeholders were identified as root factors that had a moderate effect.

Research limitations/implications – This study contributes to the knowledge body by revealing eight root factors limiting BIM implementation in the Turkish AEC industry which can be generalised to most developing countries. Therefore, the outcomes of this study may be used as a practical reference for future research aimed at improving BIM adoption in developing countries through governmental, educational, and managerial solutions.

Originality/value – Several studies have identified the challenges and barriers of BIM implementation in the construction industry using qualitative and quantitative analyses and projected the current state. Unlike previous studies, this study comprehensively and quantitatively determined the root factors that constrain the use of BIM in Turkey using exploratory factor analysis, confirmatory factor analysis, and structural equation modelling to present a structural model.

Keywords Building Information Modelling (BIM), BIM implementation, BIM adoption, Root factors, Structural equation modelling, Developing countries

Paper type Research paper

1. Introduction

The modern construction industry requires continuous changes and development of systems to ensure efficient time and cost management. Therefore, with the development of technology, design tools have evolved and changed. Initial developments began with the development of computer-aided design (CAD) programs. Building information modelling (BIM) has been developed to meet the requirements and expectations of the construction industry.

BIM is defined as shared physical and functional information of a built asset within a single agreed source of information called a "common data environment" to facilitate collaborative information processing activities across the asset lifecycle by ISO 19650–1:2018 (BSI, 2018). From a process perspective, BIM is defined as a facility that enables information management throughout the lifecycle of a building (Isikdag, 2015).

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Compared to the use of traditional delivery methods in the process of a project, BIM technology has several advantages, such as enabling users, environmental representatives, contractors, subcontractors, and operators to be involved in the design process. Moreover, possible problems, particularly clashes, are avoided with the necessary visualisations by constructing designs in an environment that simulates the real world in a three-dimensional (3D) building information model (Azhar, 2011). Furthermore, the information stored digitally in the building information model can be utilised to solve problems in case of technical problems during use or operation after the construction of the building (Sacks *et al.*, 2018). The rise of BIM implementation in the last decade stems from its position in the organisational communication between stakeholders in all construction processes, from design to maintenance. It is debatable whether BIM implementation has a positive effect on increasing productivity in the construction sector and reducing the adverse impacts of fragmentation and insufficient interoperability (Aladag *et al.*, 2016). The fact that it has become a necessity to use it more in public projects has been realised because worldwide governments are becoming aware of the benefits of BIM implementation.

BIM has been adopted and extensively implemented in developed countries (the United States of America, Canada, the United Kingdom, France, etc.). Antwi-Afari *et al.* (2018) reported that BIM implementation is widely established in developed countries, such as the United Kingdom (Eadie *et al.*, 2013; Khosrowshahi and Arayici, 2012), the United States (Wong *et al.*, 2011; Becerik-Gerber and Kensek, 2010; Jung and Lee, 2015; Haliburton, 2016), Australia (Gu and London, 2010; Hong *et al.*, 2018), South Korea (Kim *et al.*, 2016; Won *et al.*, 2013), and Nordic countries (Jensen and Johannesson, 2013; Wong *et al.*, 2009). Therefore, studies conducted in these countries are common.

Although the use of BIM is rapidly increasing worldwide, it is still in its beginning phase in Turkey (Aladag *et al.*, 2016; Simsek and Uzun, 2021) like in other developing countries. According to Antwi-Afari *et al.* (2018), developing countries, such as India (Nanajkar, 2014; Ahuja *et al.*, 2016), Singapore (Liao and Teo, 2017), Nigeria (Amuda-Yusuf, 2018; Olanrewaju *et al.*, 2020; Olugboyega and Windapo, 2021), Iraq (Hatem *et al.*, 2018), China (Zhang *et al.*, 2020; Tu *et al.*, 2021; Zhao and Wu, 2017; Zhou *et al.*, 2019), Iran (Hosseini *et al.*, 2016), Jordan (Btoush and Haron, 2017), and Malaysia (Rogers *et al.*, 2015; Yaakob *et al.*, 2016; Sinoh *et al.*, 2020), the implementation of BIM is lagging. However, significant attempts have been made to investigate the limiting causes of BIM implementation and how BIM can be adapted to the construction industries in developing countries (Shahruddin *et al.*, 2022; Sinoh *et al.*, 2020).

Turkey has a strong and rising economy according to its gross domestic product (GDP) (United Nations Statistics Division, 2018). The Turkish economy is heavily reliant on the construction industry (Reina and Tulacz, 2014). The construction industry in Turkey contributes approximately 30% of the economy in terms of GDP. According to the Engineering News Record's (ENR) "Top 250 International Contractors List" for 2021, Turkey came in second with 39 contractor businesses, accounting for approximately 16% of the top contractors (Engineering News Record, 2021). Given the significance of Turkey as a major contributor to the global construction industry, it is critical that the Turkish AEC business utilises technology, such as BIM, to stay competitive (Ezcan *et al.*, 2013).

However, numerous studies have shown that the AEC industry in Turkey is slow to adopt innovation (Turkish Contractors Association, Analysis of Turkish Construction Industry-January 2016), new technology (Simsek and Uzun, 2021), and information management (Elmalı and Bayram, 2022). BIM implementation in the Turkish AEC industry is considerably low, with only 16.36% of construction firms adopting it (Turkey BIM Report, 2020). According to the analysis of the Turkish Contractors Association, Turkish contractors should increase their competitiveness in international markets and their corporate performance to earn a sufficiently high income. Therefore, BIM has become even more crucial for them to increase the number and size of their projects by providing engineering, procurement, and construction services.

To address this challenge, it is critical for the construction industry to clearly identify the root factors limiting BIM implementation in order to better understand and suggest strategic proposals.

Several prominent studies have identified the obstacles and challenges of BIM implementation using only a literature review or descriptive analysis, particularly ranking the factors/causes as adopted methodology. Previous studies have presented several obstacles to BIM implementation, including managerial skills, organisational structure (Won *et al.*, 2013; Chien *et al.*, 2014; Aladag *et al.*, 2016; Chan *et al.*, 2019a), technical requirements (Chien *et al.*, 2014; Aladag *et al.*, 2016; Ma *et al.*, 2020), resistance to change (Chan *et al.*, 2019a; Khoshfetrat *et al.*, 2020; Evans and Farrel, 2021), financial requirements/support (Ma *et al.*, 2020), human resources/people dimension (Chien *et al.*, 2014; Khoshfetrat *et al.*, 2020), and absence of standards (Aladag *et al.*, 2016; Tan *et al.*, 2019; Chan *et al.*, 2019a; Evans and Farrel, 2021).

As seen from a brief review of related research, several obstacles were identified, all of which are important; however, it is unclear which of them are the most influential root factors. Therefore, in the first stage, it is impossible to take precautions or make strategic plans to mitigate these effects. From this perspective, knowing the root factors limiting BIM implementation is crucial for constituting a strategic plan to mitigate these effects.

To fill this gap in the literature, the primary objectives of the current research are threefold: (1) to determine the root factors related to limiting BIM implementation. (2) Modelling the determined root factors may help identify the significance of each factor in the construction industry. This model may help implement actions to overcome existing obstacles. Finally, (3) this study addresses the research and knowledge gap by identifying the root factors limiting BIM implementation in the Turkish construction industry that can be generalised to almost all developing countries. Unlike previous studies, the present study seeks original factors that limit BIM implementation while considering existing obstacles. These differences are a crucial dissimilarity from previous studies.

2. Research background and gaps in literature

2.1 Research background

The reasons why BIM technology is not extensively used in the construction industry could be categorised in four stages by examining pioneering studies: BIM practices (Tsai *et al.*, 2014; Chien *et al.*, 2014; Ozorhon and Karahan, 2016; Olawumi and Chan, 2018), BIM awareness (Bryde *et al.*, 2013; Bouguerra *et al.*, 2020), organisation (Takim *et al.*, 2013; Tsai *et al.*, 2014; Chien *et al.*, 2014; Morlhon *et al.*, 2014; Ding *et al.*, 2015; Ozorhon and Karahan, 2016), and BIM education (Morlhon *et al.*, 2014; Amuda-Yusuf, 2018; Bouguerra *et al.*, 2020).

2.1.1 BIM practices. "Technological innovation" in the construction industry refers to the application of new technologies to visibly enhance the design and construction of structures by reducing construction costs, increasing building performance, and/or advancing business performance (Toole, 1998). Generally, "technological innovation" encompasses all stakeholders in the industry. Among the limiting reasons for the adoption and BIM implementation as a technological innovation related to BIM practices, the process of transition to BIM and the process of BIM usage can be classified as two crucial causes. In particular, possible risks, uncertainties, and a lack of management are critical factors in these processes (Toole, 1998).

2.1.2 BIM awareness. Depending on various factors in relation to the society adopting the innovation, the adoption of technological innovation can occur over a long or short period of time. In fact, the adoption of technology is directly proportional to the awareness of the adoption of BIM applications as technological innovation. In particular, in national adoption, it is necessary for countries to create distinct BIM strategies based on their awareness of the scope and benefits of this novel technology (Liu *et al.*, 2018). It is necessary to have general BIM knowledge to reduce the resistance to change related to BIM implementations, to know the benefits to be obtained by using BIM-based programs, and raise awareness of this issue (Khosrowshahi and Arayıcı, 2012).

2.1.3 Organisation. BIM technology allows differentiation and focuses on the market with the services it offers (Tsai *et al.*, 2014). Furthermore, there is a reciprocal relationship between the necessity of implementing innovations for an organisation to meet expectations while surviving in a competitive environment in the long run and the organisation's role in adopting and using innovations in the sector. Managing the process and technological changes within the organisation is of critical importance in the adoption of BIM (Khosrowshahi and Arayıcı, 2012); therefore, organisational influencers can be included among the critical limitations of BIM implementation.

2.1.4 BIM education. The knowledge of stakeholders and staff in the sector about technological innovation affects the adoption rate of innovation (Toole, 1998). Although the use of BIM in the construction industry increases the tendency to work cooperatively, higher and professional education cannot keep up with this orientation (Becerik-Gerber *et al.*, 2011). Reluctance to change and innovation in the construction industry and lack of experienced/trained BIM practitioners/technicians/trainers have a slowing effect on the adoption and use of BIM technology (Rooney, 2014). BIM education-related factors, which are thought to help accelerate the BIM learning curve, are key limiting factors for BIM implementation.

2.2 Gaps in the literature

Although BIM technology is a new research subject, several noteworthy BIM-related studies have been conducted from different perspectives, including the pre-construction and post-construction BIM implementation/areas of use of BIM (Aladag *et al.*, 2016; Bouguerra *et al.*, 2020), BIM benefits (Bryde *et al.*, 2013), challenges and barriers (Chien *et al.*, 2014; Vass and Gustausson, 2017; Tan *et al.*, 2019; Chan *et al.*, 2019a, b; Park *et al.*, 2019; Ma *et al.*, 2020; Evans and Farrel, 2021; Tam *et al.*, 2021), maturity levels (Succar, 2009), process management of construction phases (Morlhon *et al.*, 2014), and adoption (Park *et al.*, 2019; Manzoor *et al.*, 2021; Tam *et al.*, 2021). Studies have also been conducted to investigate the critical success factors of BIM implementation and adoption (Tsai *et al.*, 2014; Morlhon *et al.*, 2014; Ozorhon and Karahan, 2016; Antwi-Afari *et al.*, 2018; Amuda-Yusuf, 2018; Olawumi and Chan, 2018; Chan *et al.*, 2019b; Dao *et al.*, 2021), critical risk factors (Chien *et al.*, 2014; Khoshfetrat *et al.*, 2020), and drivers (Olanrewaju *et al.*, 2021) related to the use of BIM/BIM implementation in developed countries. Shahruddin *et al.* (2022) interpreted the meaning structure of architects' actions, behaviours, and performances in a building information modelling (BIM) environment. Elgewely *et al.* (2021) proposed a virtual reality (VR) platform for construction detailing that provides experiential learning in a zero-risk environment.

The literature contains a number of researches on BIM implementation in different regions, such as South Korea (Kim *et al.*, 2016; Won *et al.*, 2013), the Czech Republic (Nyvlt, 2018), Taiwan (Badrinath and Hsieh, 2019; Tsai *et al.*, 2014), the United Kingdom (Dakhil *et al.*, 2019), and Singapore (Liao and Teo, 2017). However, studies on the use of BIM technology in the Turkish AEC industry are limited.

Elmalı and Bayram (2022) examined civil engineers' and architects' awareness levels in the public and private sectors of BIM implementation in the Turkish AEC industry using descriptive statistical methods (mean, frequency, and percentage) and ranking analysis. Akcay (2022) identified the primary challenges to BIM implementation in mega construction projects using descriptive and ranking analyses. Simsek and Uzun (2021) sought to develop a mathematical process for determining the features of components impacting value and arriving at a value-based land share using a 3D virtual BIM model. Tezel *et al.* (2021) examined the relationship between facility management and BIM use with descriptive statistics using data obtained from a questionnaire survey and semi-structured interviews. Erpay and Sertyesilisik (2021) developed a preliminary checklist template that can be used as input to the contract phase of BIM-based construction projects. Moreover, Yilmaz *et al.* (2019) proposed eight BIM capability and maturity models identified in the literature based on several criteria. Aladag *et al.* (2016) investigated challenges and benefits of BIM implementation in the Turkish construction industry using focus group discussions, and analysed basic ranking technique. Koseoglu *et al.* (2018) investigated the relationship between the BIM and lean concepts. Koseoglu and Nurtan-Gunes (2018) examined lean interactions resulting from mobile BIM processes through a framework by focussing on digital transformations performed at construction sites. Alshorafa and Ergen (2020) identified the LOD for BIM implementation in large-scale projects in Turkey, Qatar, and Saudi Arabia. Moreover, there are studies in which variables affecting the success of BIM use were determined, and factor analysis was applied to the variables (Ozorhon and Karahan, 2016) to identify the relationship between individual-level collaboration and BIM implementation (Ozturk, 2019). Despite the significance of this issue, the number of previous studies on BIM implementation in the Turkish AEC industry lags the rate of BIM implementation in construction firms. Existing studies on BIM implementation have attempted to identify the causes of obstacles. However, no research has determined the root factors limiting BIM implementation either in common BIM or in Turkey and developing countries. Therefore, there is a gap in the literature on BIM research in developing countries.

When examining the methodologies adopted in previous studies, it can be seen that some of these studies employed qualitative research method: case study (Alshorafa and Ergen, 2021; Koseoglu and Nurtan-Gunes, 2018); focus group interviews (Aladag *et al.*, 2016; Gu and London, 2010); decision-making trial and evaluation laboratory method (Chuan *et al.*, 2014), Delphi method (Evans and Farrel, 2021; Khoshfetrat *et al.*, 2020). The remaining studies adopted quantitative methods, composing a questionnaire with a literature review and analysing the data using descriptive statistics (Gnah and John, 2015), different ranking techniques (Chan *et al.*, 2019a, b; Amuda-Yusuf, 2018), and hypothesis tests with few exceptions. Some scholars have used different methods, such as interpretive structural modelling (Tan *et al.*, 2019), and structural equation modelling (Park *et al.*, 2019; Sinoh *et al.*, 2020). Several studies reviewed the literature to compose the questionnaire; however, a systematic review has not been conducted. Only a few studies have used systematic reviews (Sinoh *et al.*, 2020). It is evident from this brief review that there have been several attempts at BIM studies; however, these efforts have failed to provide an extensive analysis of the root factors that limit BIM implementation. To develop effective BIM implementation methods, a greater understanding of the root factors is required, particularly in countries where BIM is relatively new, such as the Turkish construction sector.

Although the number of studies on BIM is increasing daily, it is noteworthy that the number of studies using this modelling method remains low. When the limited researches modelled the variable and examined BIM, it is evident that the studies focused on modelling the relationship between BIM attributes and environmental sustainability (Mirpanahi and Noorzai, 2021); collaborative innovation activities and BIM application (Qiao *et al.*, 2021); impact of BIM drivers and awareness on the project lifecycle (Olanrewaju *et al.*, 2021); risks associated with BIM implementation and adoption (Zhao *et al.*, 2017, 2018); work-based education and BIM adoption (Semaan *et al.*, 2021); teamwork efficiency and BIM-based collaborative design (Wang *et al.*, 2021); continuous use intention of BIM (Cui *et al.*, 2021); factors hindering BIM implementation (Liao *et al.*, 2019); factors predicting the behavioural resistance to BIM implementation (Wang *et al.*, 2020); critical BIM adoption drivers across the infrastructure construction sector (Belay *et al.*, 2021); the impact of organisation size and project type on BIM adoption (Hong *et al.*, 2019); the BIM-related factors affecting the project performance (Tam *et al.*, 2021); the strategies improving the organisational BIM capabilities (Munianday *et al.*, 2022).

When the above studies were analysed, it was observed that the number of studies conducted with the structural equation model (SEM) has increased in the last three years. In addition, no study has focused on the root factors that limit BIM implementation using SEM.

This study highlights the root factors limiting BIM implementation specific to the Turkish AEC industry which can be generalised to all developing countries. In this regard, influencing causes (ICs) are derived from the literature through a systematic literature review (SLR). Exploratory factor analyses were performed to determine the factors. Subsequently, confirmatory factor analysis was applied to validate the latent factors, and SEM was conducted to establish the root factors limiting BIM implementation.

Similar to previous studies, this study employed a questionnaire survey. Unlike previous studies, the questions of the survey were composed by utilising a SLR, which provides more reliable and objective criteria for the questionnaire. Moreover, in contrast to previous studies, deeper quantitative statistical methods were used, and a model was developed to identify the root factors limiting BIM implementation.

3. Research method and approach

A comprehensive methodological approach of this study is presented in Figure 1. The research began with a SLR to determine the ICs for restrained BIM implementation. This was followed by the organisation and validation of the questionnaire. Data collection began with an online survey of the participants. This was followed by data analysis and reliability analysis of the obtained data. Exploratory factor analysis (EFA) was then performed to identify the latent factors, which involved factor extraction and factor rotation. Subsequently, based on the determined latent factors, SEM was constructed to identify the root factors limiting BIM implementation. Statistical calculations were performed using Statistical Package for the Social Sciences (SPSS) 22.0, and LISREL 8.7.

3.1 Identifying the influencing causes (ICS) affecting the prevalent use of BIM technology

The first stage of this study involved the determination of ICs that affect the use of BIM technology for all pre-construction and post-construction stages related to BIM practices, BIM awareness, BIM organisation, and BIM education. Conducting SLR, extensive literature was examined. SLR is identified as a method-driven, transparent, and reproducible method (Booth *et al.*, 2012) for analysing and understanding all research related to a certain issue, subject, or phenomenon (Wolfswinkel *et al.*, 2013). SLR decreases prejudice by performing extensive literature searches in relation to published and unpublished research and also provides a record of reviewers' decisions, processes, and findings (Tranfield *et al.*, 2003). Unlike other methods such as citation-based approaches, SLR is a powerful tool for evaluating published work in the scientific field. In the present study, the renowned three-stage approach was used to identify causes. It involves "planning the review," "conducting the review," and "documenting the review" stages, which are presented in Figure 2.

The research question was designated at the planning stage and a review protocol was developed. First, primary studies were identified in the transitive review phase. Subsequently, the identified studies were selected, extracted, analysed, and synthesised, respectively. Finally, the outputs obtained from the literature were published as a report during the examination and documentation phase.

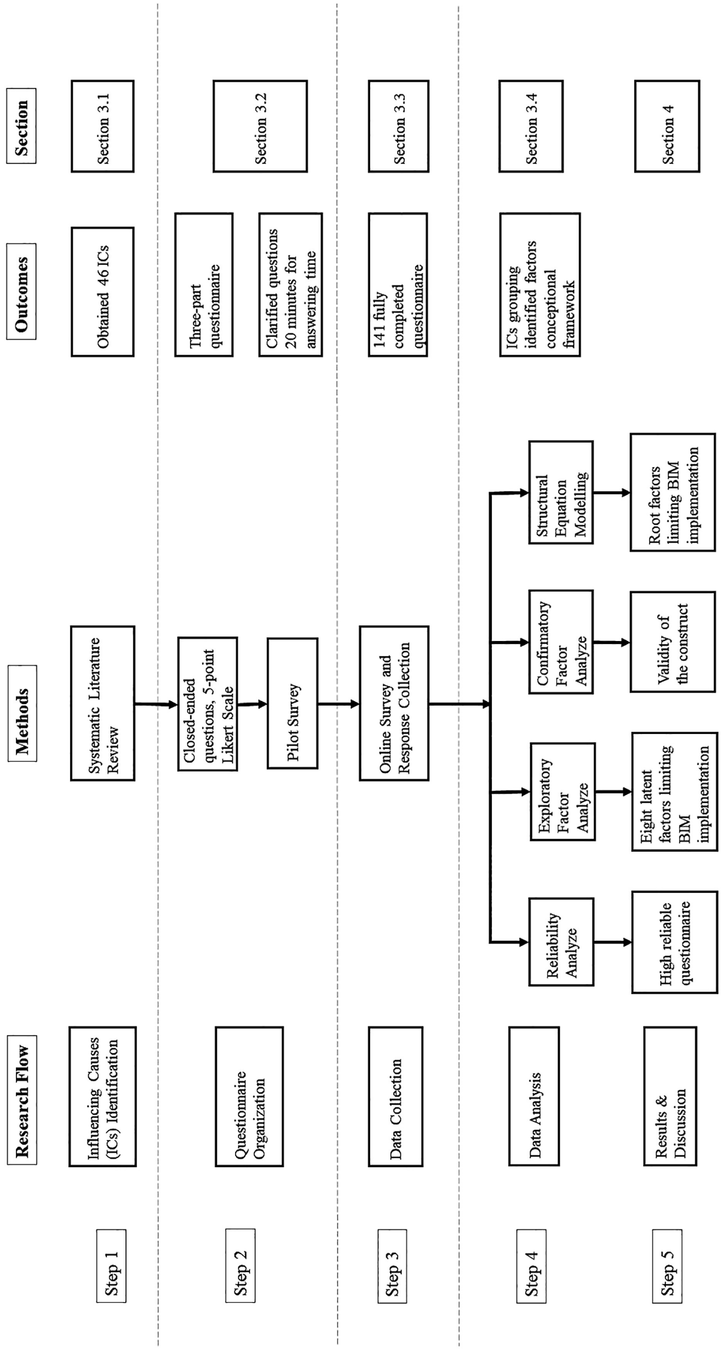

Figure 1.
Research methodology framework

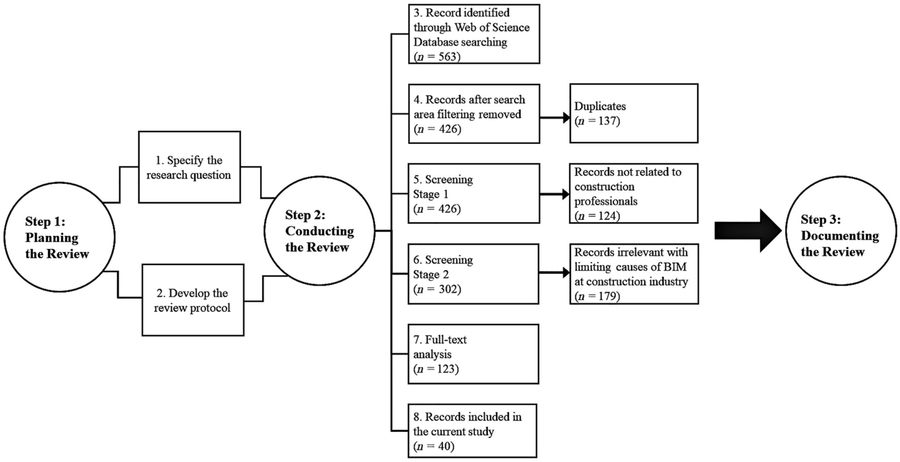

Figure 2.
Stages of systematic literature review

Web of Science (WoS) search engines were used to find scientific papers regarding BIM implementation. WoS was considered for its accuracy, comprehensiveness, and skilled coverage of several study fields (Hong and Chan, 2014). The search was limited to English-language articles and review papers published in academic journals between 2007 and 2021. Keywords were used to set search parameters in the WoS database. The search parameters were remarked as keywords: (1) for population, "CONSTRUCTION PROFESSIONALS"; (2) for outcomes, "BIM ADOPTION CHALLENGES", AND "BIM ADOPTION OBSTACLES", AND "CONSTRUCTION INDUSTRY".

In total, 563 journal articles were identified during the initial search. Experts recommend that at least two authors work independently to assess studies that meet the review's defined inclusion and exclusion criteria (Templier and Paré, 2015). Therefore, the findings were confirmed by a crosscheck among the authors within the criteria. Based on the study topic, researchers should define inclusion and exclusion criteria (Kitchenham and Charters, 2007). This portion of the method scans all of the grey and irrelevant literature using well-stated specified inclusion and exclusion criteria, such as "Articles that are irrelevant with BIM implementation or adoption" or "Articles that are unrelated to the construction industry"

Based on WoS categories, engineering civil, construction building technology, management, multidisciplinary engineering, and architecture were selected for filtering as search fields. After filtering 426 articles remained. Both authors then reviewed and examined each of the 426 abstracts, introductions, and conclusion sections. In total, 124 journal articles that were not related to construction professionals at the first stage of screening were removed. Following this step, 179 articles that were irrelevant to BIM implementation or adoption were excluded. The remaining 123 articles were analysed based on their full text. Ultimately, 40 articles were selected for thorough examination to identify ICs. The 40 selected articles were coded in order to relate the key study findings to particular causes categories, taking into consideration BIM practices, BIM awareness, BIM organisation, and BIM education. Eventually, 46 ICs that were directly related to these four categories were determined and are listed in Table 1

3.2 Organizing the questionnaire

Based on SLR, a questionnaire was organised and administered to architects and engineers working in architectural offices and construction companies in Turkey that do not use BIM

Table 1. Influential causes (ICs) limiting the BIM implementation

Main category	ICs coded as	Influential causes	References
Obstacles related to BIM practices	P1	Thought of increasing design duration and cost	[1–5]
	P2	Thought of negative effect on workflow, productivity, and efficiency	[2], [6–9]
	P3	Resistance to change	[2], [5], [9–13]
	P4	Lack of government support and legislation	[5], [7], [9], [11], [13–24]
	P5	Lack of governmental initiatives	[15], [17–18], [20–22]
	P6	Lack of BIM use among project stakeholders	[5], [8–9], [13], [17], [19–20], [25]
	P7	Poor knowledge sharing among stakeholders	[2], [4–5], [7], [9], [18–20], [26]
	P8	Lack of stakeholders' involvement	[2–5], [7], [20–21], [25], [27–29]
	P9	Difficulty of learning BIM-based software	[8], [11–12], [20–21], [24–25]
	P10	Licence problem of BIM-based software	[8], [13], [21], [25–26]
	P11	Fear of data loss during file transfer	[2], [5], [9–10], [14], [23], [26]
	P12	Increased workload due to BIM library preparation	[9], [19], [24]
	P13	Difficulties in version control due to model updates	[7–10], [16], [21], [25], [27]
Obstacles related to BIM awareness	A1	Not being aware of accessibility to design-making process data	[1], [3–4], [20], [24]
	A2	Not being aware of accessibility to construction process data	[1], [3–4], [20], [24]
	A3	Not being aware of accessibility to management process data	[1], [3–4], [20], [24], [28]
	A4	Not having knowledge about analysing alternative design options	[1–4], [20–21], [30–31]
	A5	Not having knowledge about effective scheduling and cost estimation	[1–3], [20–21], [31]
	A6	Not having knowledge about clash detection	[2–3], [7], [21–22], [27], [32]
	A7	Not being aware of possibility for quick and easy intervention	[1], [3], [20], [27]
	A8	Not having knowledge about file format sufficiency	[7], [26], [28]
	A9	Not having knowledge about simulation possibility	[1–3], [12], [24]
Obstacles related to organisation	O1	Lack of top and mid management support	[7–8], [11], [16], [19–22], [31], [33–35]
	O2	Not to be included in competitive construction environment	[2], [5], [11], [20], [32], [36]
	O3	Lack of skilled personnel	[7], [9–10], [16–21], [37]
	O4	Additional expenditure for consultancy	[16], [26–28], [33], [37]
	O5	Considering personnel training expenditure as additional expenditure and waste of time	[2], [13–14], [18], [27], [35]

(*continued*)

Table 1.

Main category	ICs coded as	Influential causes	References
	O6	High initial investment cost (software, hardware, training)	[2], [7], [9], [13], [20–21], [27], [35], [38]
	O7	The notion that there will be no return on investment	[14], [19], [27], [39]
	O8	Require high motivation	[9], [11], [18], [20], [22], [34]
	O9	Difficulty of personnel adoption	[11–13], [18]
	O10	Lack of client's request regarding the use of BIM	[2], [13], [17–18], [20], [31], [33], [36–39]
	O11	Need for significant organisational structure change	[8], [18], [20], [27]
	O12	Need for change in decision-making	[9–10], [12]
	O13	Lack of time for learning due to the nature of the industry	[8–9], [12–13], [25]
	O14	Fail to implement immediately after BIM trainings	[8], [17], [29]
	O15	Need of additional expenditures for legal disputes and software updates	[5], [7], [16], [20], [27]
	O16	Rising of workload with data transfer	[2], [7], [16], [27]
	O17	Lack of project experience of the firm	[5], [7], [16–17], [19–21], [27]
	O18	Lack of training and consultancy	[11], [15], [17], [39]
Obstacles related to BIM education	E1	Lack of BIM-related courses at higher education	[2], [13], [17], [40]
	E2	Lack of BIM expert academicians	[2], [10], [13], [26]
	E3	Lack of professional chambers' informative activities presenting the differentiation between traditional and BIM project delivery systems	[6], [13], [24]
	E4	Lack of informative documents for BIM implementation provided by government and professional chambers	[5], [17], [22], [26]
	E5	Lack of resources in Turkish	[12–13], [17], [40]
	E6	Lack of training opportunities	[2], [13], [17–18], [28]

Note(s): [1] Ganah and John (2015), [2] Aladag *et al.* (2016), [3] Antwi-Afari *et al.* (2018), [4] Olanrewaju *et al.* (2021), [5] Chan *et al.* (2019a), [6] Morlhon *et al.* (2014), [7] Chien *et al.* (2014), [8] Amuda-Yusuf (2018), [9] Khoshfetrat *et al.* (2020), [10] Gu and London (2010), [11] Takim *et al.* (2013), [12] Tan *et al.* (2019), [13] Evans and Farrel (2021), [14] Howard and Björk (2008), [15] Succar (2009), [16] Won *et al.* (2013), [17] Ozorhon and Karahan (2016), [18] Chan *et al.* (2019b), [19] Ma *et al.* (2020), [20] Tsai *et al.* (2014), [21] Attarzadeh *et al.* (2015), [22] Bouguerra *et al.* (2020), [23] Dao *et al.* (2021), [24] Tam *et al.* (2021), [25] Olawumi and Chan (2018), [26] Aibinu and Ventkatesh (2014), [27] Bryde *et al.* (2013), [28] Kivits and Furneaux (2013), [29] Boktor *et al.* (2014), [30] Ahn *et al.* (2014), [31] Lee *et al.* (2015), [32] Tulubas Gokuc and Arditi (2017), [33] Linderoth (2010), [34] Ding *et al.* (2015), [35] Park *et al.* (2019), [36] Lindblad and Guerrero (2020), [37] Succar *et al.* (2013), [38] Hosseini *et al.*, (2018), [39] Vass and Gustavsson (2017), [40] Türkyılmaz (2016), P: practices, A: awareness, O: organisation and E: education technology. The questionnaire comprised three main parts. To measure all the causes limiting extensive BIM implementation, the first part of the questionnaire comprises four fragments that can be summarised as related to BIM practices, BIM awareness, organisation and BIM education, and demographic variables. The survey comprised 46 ICs (13 for practices, 9 for awareness, 18 for organisation, and 6 for education) that were to be assessed on a 5-point Likert-type scale, with 1 representing "not severe" and 5 representing "most severe." All participants rated the importance of the 46 ICs affecting BIM use according to their presumptions and anticipation.

The second part contained one question that was included to gain insights into the participants' general perception of the level of BIM implementation in the Turkish AEC industry on a 5-point Likert scale.

The participants' personal and sociodemographic information was obtained in the third part, which comprised questions focussing on profession, gender, education, experience in the construction industry, and occupation.

A pilot survey was conducted prior to the main survey. The primary objective of the pilot survey was to evaluate the clarity of the questions to eliminate any obstacles or unclear statements in the language and to estimate how long it would take a participant to complete the survey. A pilot survey was conducted by distributing twenty questionnaires to engineers and architects who had more than five years of experience in the Turkish AEC industry. The final version of the questionnaire was created based on feedback and ideas received from the pilot survey.

3.3 Administration process of questionnaire and participants' profile

The target population of this research included Turkish architects and engineers. The sample group contains architects and engineers work in companies that do not use BIM technology. The questionnaires were sent to 600 people via e-mail, consisting of architects and engineers, from 07 July 2021 to 14 November 2021. In total, 152 questionnaires were returned, of which 11 were extracted because of missing data, and 141 completed questionnaires were used as material for the current study.

3.4 Data analysis

The participants' responses were coded and analysed using the Statistical Package for Social Sciences (SPSS) 22.0 and LISREL 8.7 software to perform several statistical tests, such as reliability analysis, exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modelling (SEM).

To determine the internal consistency among questions using a Likert scale in a survey, reliability should be measured (Nunnally and Bernstein, 2007). Cronbach's alpha (α) was utilised to determine the statistical reliability and validity of the participants' replies. The α coefficient range from "0" to "1"; the minimum acceptable reliability threshold was determined as 0.7 (Cronbach, 1951; Tavakol and Dennick, 2011).

To achieve the main objective of this study, it is important to identify the underlying factor structure. To highlight the key factors, the responses for the 46 ICs contained in the questionnaire were imported into the SPSS program and subjected to EFA using varimax rotation (eigenvalue = 1 cut-off). Accordingly, the main factors were identified as ICs, with a factor loading greater than 0.4 (Nunnally and Bernstein, 2007).

Following the EFA analysis, confirmatory factor analysis (CFA) was performed on all identified ICs using LISREL software to construct validity. Construct validity refers to how successfully a hypothesised factor has been quantified (Lavrakas, 2008) and survey questions with higher construct validity can better assess the characteristics they claim to reveal. CFA was utilised as the primary indicator of validity. Multiple fit indices were selected to demonstrate evidence of good model-data fit, including the chi-square (χ^2) test statistic, comparative fit index (CFI), and root mean square error of approximation (RMSEA). In a CFA, the path coefficients among variables are referred to as effect sizes, which have values of less than 0.1 for small effects, around 0.3 for medium effects, and greater than or equal to 0.5 for large effects (Lohmöller, 1982). In this study, associations with path coefficients of 0.5 or greater and t-values of more than 2.58 were considered significant (99% confidence level).

Finally, an SEM was developed using LISREL 8.7 to identify the root factors limiting BIM implementation quantitatively. This analysis provides an opportunity to confirm the sufficiency of the model concerning the relationship between measurement paths and latent variables. While there are several outlooks for the adequacy of path coefficients above the 0.1 threshold, a path coefficient of 0.2 is recommended (Chin, 1998). The higher the path coefficient, the stronger is the relationship between the independent and dependent constructs of a path (Lohmöller, 1982).

4. Results

4.1 Respondent profile

When the demographic characteristics of the sample group were examined, 105 (74.5%) participants were architects available, 36 (25.5%) were civil engineers; 70 (49.6%) were male and 71 (50.4%) were female. In total, 105 (74.5%) held a bachelor's degree, 34 (24.1%) held a master's degree, and 2 (1.4%) held a doctorate degree. Although people with postgraduate degrees are in the sector, most architects and engineers have a bachelor's degree. In total, 86 of participants (61.0%) 0–5 years, 21 (14.9%) 6–10 years, 17 (12.0%) 11–15 years, 10 (7.2%) 16–10 years, and 7 (4.9%) aged 21 years or more had professional experience. Furthermore, 118 participants (83.7%) occupied the private sector, whereas 23 (16.3%) worked in the public sector. When the distribution was analysed according to project type, 71 (50.4%) participants worked in residential areas, 34 (24.1%) worked in non-residential buildings or facilities projects, and 36 (25.5%) worked in other projects.

Out of 600 surveys sent, 141 responses were received, representing a 25.3% response rate. When conducting surveys, the appropriate response rate for research in the construction field is between 20 and 30% (Akintoye, 2000). Therefore, the response rate is considered acceptable.

4.2 Reliability and validity of questionnaire results

The Cronbach's α coefficient of the dataset for the 46 ICs affecting BIM implementation and the level of use of BIM technology in the Turkish construction industry was determined to be 0.961, which is above the minimum threshold of 0.7 (Tavakol and Dennick, 2011).

4.3 Designating latent factors limiting the BIM implementation-EFA

The lighting factor structure is significant because an elementary aim of this study is to investigate the root factors limiting BIM implementation. Prior to reaching this aim, exploratory factor analyses (EFA) was performed to identify the latent factors. In this study, the EFA was extracted using the principal component method and the Kaiser normalisation of rotation for varimax was applied. ICs with a loading factor greater than 0.5 were determined to be the primary factors. Table 2 summarises the 46 ICs, along with their factor loadings and coefficient alpha reliabilities.

The sample adequacy value for Kaiser–Meyer–Olkin (KMO) is 0.865, which is greater than 0.5, indicating that the sampling was adequate for factor analysis (Pallant, 2005). Bartlett's test on the data reported a significant value of χ^2 (6345.31), $p < 0.001$, indicating that correlations between items were sufficiently substantial to perform EFA. The loadings of ICs

Factors	Code of ICs	Exploratory factor analyse Eigen value	% Of variance	Factor loadings	Confirmatory factor analyse Standardised coefficients
Factor 1 (ALB)	A8	17.564	17.225	0.869	*0.90*
	A6			0.864	*0.87*
	A4			0.862	*0.92*
	A2			0.860	*0.86*
	A3			0.857	*0.85*
	A7			0.849	*0.87*
	A5			0.843	*0.89*
	A1			0.839	*0.85*
	A9			0.833	*0.86*
Factor 2 (LMS)	O6	4.814	12.354	0.823	*0.86*
	O5			0.809	*0.85*
	O4			0.766	*0.82*
	O7			0.681	*0.74*
	O8			0.678	*0.71*
	O1			0.598	*0.70*
	O3			0.559	*0.75*
	O9			0.554	*0.65*
	O2			0.490	*0.67*
Factor 3 (PBT)	O17	3.511	10.991	0.716	*0.75*
	O14			0.702	*0.73*
	O16			0.676	*0.78*
	O18			0.655	*0.67*
	O13			0.604	*0.83*
	O15			0.576	*0.79*
	O12			0.556	*0.75*
	O11			0.499	*0.78*
	O10			0.478	*0.69*
Factor 4 (LBE)	E4	2.311	10.227	0.807	*0.88*
	E1			0.803	*0.80*
	E2			0.800	*0.85*
	E3			0.793	*0.88*
	E6			0.682	*0.74*
	E5			0.629	*0.67*
Factor 5 (BSP)	P11	1.851	7.631	0.785	*0.80*
	P13			0.780	*0.80*
	P12			0.724	*0.88*
	P10			0.670	*0.72*
	P9			0.554	*0.50*
Factor 6 (LIB)	P4	1.481	5.812	0.736	*0.69*
	P5			0.725	*0.93*
	P6			0.508	*0.69*
Factor 7 (LCS)	P7	1.169	5.014	0.777	*0.89*
	P8			0.745	*0.88*
Factor 8 (BBT)	P1	1.154	4.342	0.790	*0.68*
	P2			0.685	0.81
	P3			0.543	0.58
Total explained variance			73.597	$\chi 2$/df	2.20
Kaiser–Meyer–Olkin (KMO) value			0.865	*RMSEA*	0.04
Barlett's test of sphericity	Approx. chi-square	6345.315		*CFI*	0.96
	df	1,035		*GFI*	0.97
	p	0.000		*AGFI*	0.91

Table 2.
Results of EFA and CFA

onto their corresponding grouping were then revealed using a varimax rotation, as indicated in Table 2. All component loadings exceeded 0.40, implying that all ICs placed onto their respective factors are critical (Hair *et al.*, 2006).

EFA revealed eight factors with eigenvalues greater than 1, accounting for 73.59% of the total variance. Each factor was assigned a name corresponding to the nature of latent factors which load onto that particular component. The interpretations, labels, and abbreviations for each of these components are as follows:

(1) Factor 1: Awareness and knowledge level of BIM (ALB);

(2) Factor 2: Lack of management support (LMS);

(3) Factor 3: Problems with BIM transition process (PBT);

(4) Factor 4: Lack of BIM education and training opportunities (LBE);

(5) Factor 5: BIM-based software problems (BSP);

(6) Factor 6: Lack of incentives for BIM (LIB);

(7) Factor 7: Lack of communication between project stakeholders regarding the use of BIM (LCS) and

(8) Factor 8: Bias regarding BIM technology (BBT).

4.4 Confirmatory factor analyse

The results of the CFA supported the use of an eight-factor model to identify the root factor limiting BIM implementation. Table 2 lists the CFA results, where all the standardised coefficients are equal to or higher than 0.5. Goodness of fit (GOF) was proposed to evaluate the model. The results were satisfactory, with a value of $x^2/df = 2.20 < 3.00$ was obtained. The comparative fit index (CFI) was 0.96, the root mean square error of approximation (RMSEA) was 0.04, and the goodness of fit index (GFI) was 0.97. These results indicated a good model fit. The fitness ratios of the model indicate that the CFA model fits the data well. Therefore, the model allows the verification of the measurement scales. Therefore, all ICs and latent factors included in the hypothetical model were considered reliable, and SEM was utilised to test the theoretical model.

4.5 Evaluation of measurement model

After the CFA checked the validity of the measurement scale, a hypothetical model was constructed and eight hypotheses were developed (Figure 3). Each path in the model presents a hypothetical relationship between a pair of constructs.

Regarding the eight latent factors (ALB, LMS, PBT, LBE, BSP, LIB, LCS, and BBT), root factors limiting the BIM implementation was considered. Therefore, eight hypotheses were established (paths in Figure 3) to identify the root factors limiting the BIM implementation.

H1. ALB has a direct effect on BIM implementation.

H2. LMS has a direct effect on BIM implementation.

H3. PBT has a direct effect on BIM implementation.

H4. LBE has a direct effect on BIM implementation.

H5. BSP has a direct effect on BIM implementation.

H6. LIB has a direct effect on BIM implementation.

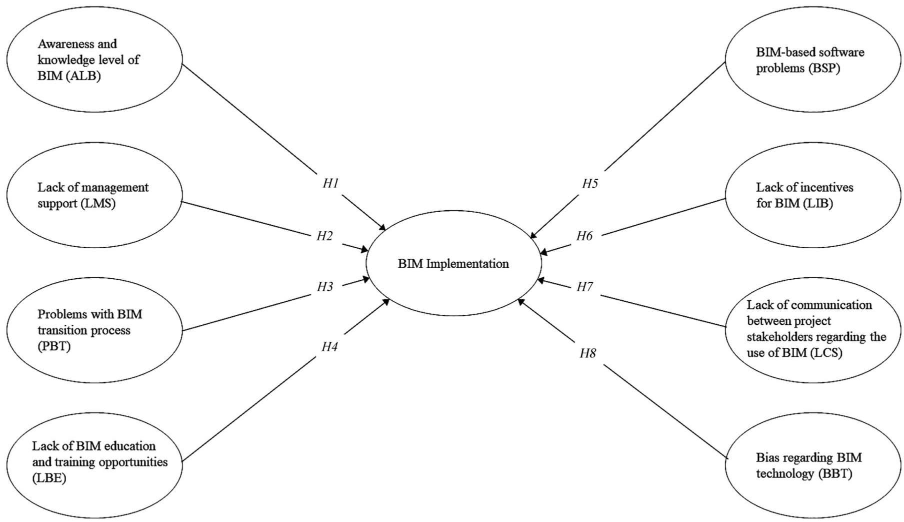

Figure 3.
Hypothetical model of root factors limiting the BIM implementation

H7. LCS has a direct effect on BIM implementation.

H8. BBT has a direct effect on BIM implementation.

4.5.1 Reliability testing. Regarding the conceptual model (Figure 3), SEM was developed (Figure 4), which presents the standardised path coefficients of each hypothesis. The measurement model's convergent validity and individual item reliability values, which were concurrently produced, must be evaluated.

The construct's reliability can be quantified using two methods: Cronbach's alpha (α) (CA) and composite reliability (CR) (Hair *et al.*, 2011). Because the indicators are not equally reliable, the rule of thumb for both reliability criteria is that they must be greater than 0.70. Because CR (weighted) is more accurate than CA (unweighted), it should be evaluated and reported. Both CA and CR assessed the reliability of the model constructs in this study. The degree to which items regularly display the hidden construct is referred to as construct reliability (Hair *et al.*, 2014). In the present study, CR for all constructs/latent variables exceeded the recommended cut-off of 0.70 and ranged between 0.734 and 0.966, and all CA values surpassed the recommended cut-off of 0.70 and ranged from 0.724 to 0.968, as listed in Table 3.

4.5.2 Validity testing. The data were validated after review for reliability. The Average Variance Extracted (AVE) test (Fornell and Larcker, 1981) was used to evaluate the internal consistency of the construct by assessing the amount of variance captured by a latent variable from its measurement items to the amount of variance captured by measurement errors.

According to Fornell and Larcker (1981) and Hair *et al.* (2011), the AVE should be greater than 0.5, indicating that the latent variables accounted for at least 50% of the measurement variance. In this study, all AVE values ranged from 0.56 to 0.79, exceeding the required AVE of >0.50, supporting the use of all constructs (Table 3).

4.6 Evaluation of structural model

After determining the reliability and validity of the measurement model, its structure was tested. Four distinct tests were conducted to establish the inner model, as indicated by Urbach and Ahlemann (2010), Hair *et al.* (2017), and Ramayah *et al.* (2016): coefficient of determination (R^2), GOF measures, t-value test, and path coefficient.

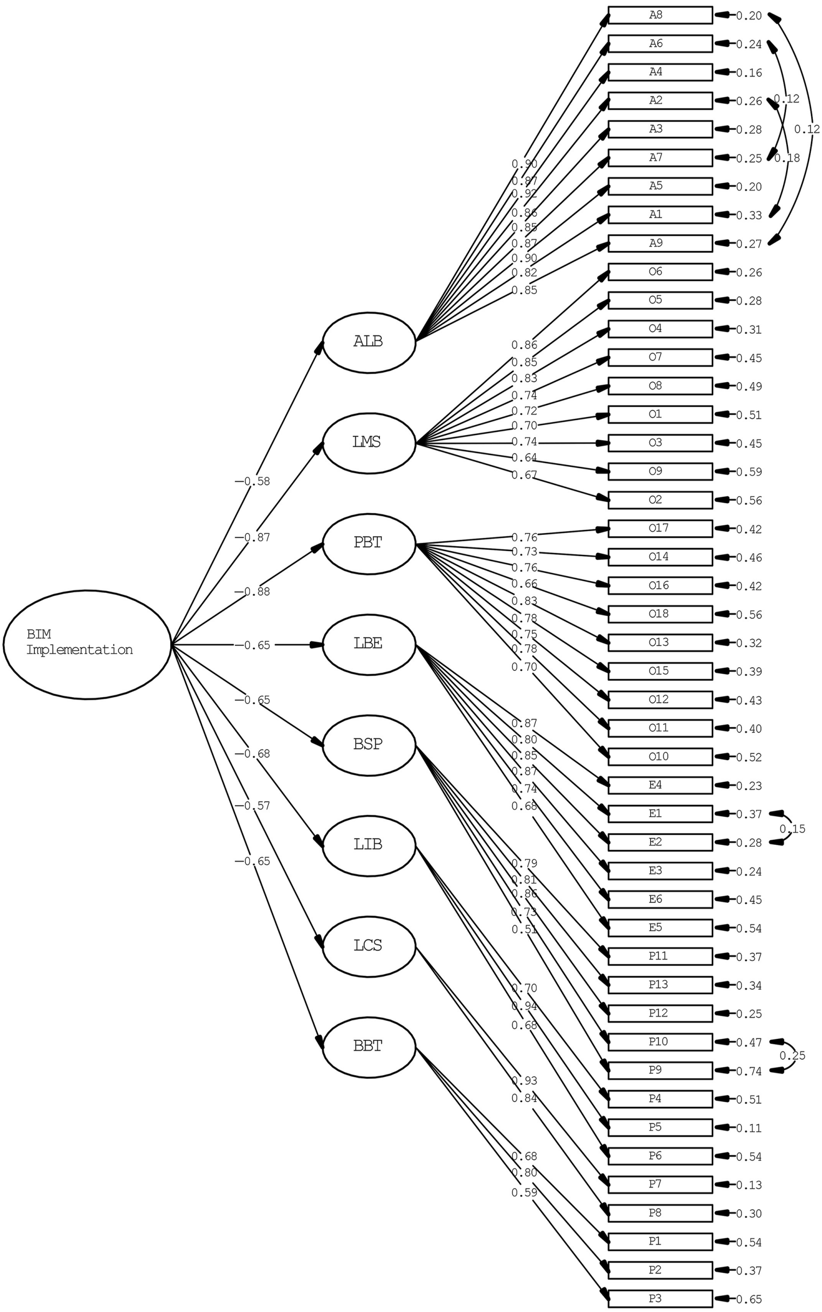

Figure 4.
Proposed latent variable model

Note(s): chi-Square = 2225.33, df = 1021, *P*-value = 0.00000, RMSEA = 0.04

The model was assessed based on first GOF measures in Table 4.

Meanwhile, t-value test, path coefficient values and R^2 values were used for evaluating the results presented in Table 5.

The coefficient of determination, often known as R^2, is a crucial measure for evaluating the structural model. The R^2 value indicates how much variance in the endogenous variable can be explained by one or more exogenous factors (s). The R^2 values, which reflect the ability of the exogenous variables to explain the endogenous variables, determine the structural model's quality. R^2 levels exceeding 0.67 are regarded as strong, and values between 0.33 and 0.67 are considered moderate, while R^2 values between 0.19 and 0.33 are considered weak, and R^2 values less than 0.19 are deemed unacceptable (Urbach and Ahlemann, 2010). Hair *et al.* (2017) considered the model to be considerable if $R^2 = 0.75$, moderate if $R^2 = 0.50$, and weak if $R^2 = 0.25$. As presented in Table 5, the R^2 values of the current study range between 0.33 and 0.77.

Constructs/Latent variables	CR	Cronbach's alpha (CA)	AVE
ALB	0.966	0.968	0.76
LMS	0.921	0.920	0.57
PBT	0.920	0.920	0.56
LBE	0.916	0.916	0.65
BSP	0.862	0.866	0.56
LIB	0.822	0.802	0.61
LCS	0.879	0.875	0.79
BBT	0.734	0.724	0.58

Table 3. Reliability results and AVE results of constructs/latent factors

Fit index	Suggested values	Observed values	Evaluation
χ^2/df	χ^2/df ≤ 3	2.17	Excellent
GFI	$0.95 \leq$ GFI ≤ 1.00	0.96	Excellent
AGFI	$0.90 \leq$ AGFI ≤ 1.00	0.92	Excellent
NFI	$0.95 \leq$ NFI ≤ 1.00	0.96	Excellent
CFI	$0.95 \leq$ CFI ≤ 1.00	0.95	Excellent
RMSEA	$0 \leq$ RMSEA ≤ 0.05	0.04	Excellent

Table 4. Summary statistics of model fitness indices

Hypothetical paths and expected influences	Path coefficient*	t-value (1-tail)	R^2	Interpretation
H1: ALB → BIMP	−0.58*	−6.77	0.34	Supported
H2: LMS → BIMP	−0.87*	−10.29	0.75	Supported
H3: PBT → BIMP	−0.88*	−9.11	0.77	Supported
H4: LBE → BIMP	−0.65*	−7.46	0.43	Supported
H5: BSP → BIMP	−0.65*	−6.89	0.42	Supported
H6: LIB → BIMP	−0.68*	−6.36	0.46	Supported
H7: LCS → BIMP	−0.57*	−6.46	0.33	Supported
H8: BBT → BIMP	−0.68*	−5.65	0.42	Supported

Note(s): *All standardised path coefficient estimates are expected to be significant at $p < 0.01$; ALB: awareness and knowledge level of BIM; LMB: lack of management support; PBT: problems with BIM transition process; LBE: lack of BIM education and training opportunities; BSP: BIM-based software problems; LIB: lack of incentives for BIM; LCS: lack of communication between project stakeholders regarding the use of BIM; BBT: bias regarding BIM technology and BIMP: BIM implementation

Table 5. Standardised coefficient estimates of the model

The SEM revealed that all hypotheses in the conceptual model were supported. Table 5 presents that the *t-values* for each hypothesis exceed the critical two tailed *t-value* of 2.58 at the 0.01 significance level. The fully evaluated model is illustrated in Figure 4.

5. Discussion

The current study examined the root factors affecting BIM implementation in the Turkish construction industry in terms of challenges in the use of BIM by architects and engineers using data from 141 questionnaire respondents in the industry who work in companies that do not use BIM technology.

The EFA and CFA revealed eight IC factors that limit BIM implementation. With the construction of SEM, the root factors limiting BIM implementation were identified.

SEM supported all eight hypotheses. As shown in Figure 4 and Table 5, there are differences in the path coefficient values of the hypotheses. Path coefficient values that are approximately one imply a strong association, whereas values near zero indicate a weak relationship (Hair *et al.*, 2019). Therefore, the significance and effect of the root factors divided into three groups that path coefficient range between 1 and 0.81 are the most crucial and has very high effect; 0.80–0.61 has the high effect, and 0.60–0.40 have a moderate effect. While this does not imply that the determined root factors that are moderate and high do not have any significance with regard to BIM implementation, it will guide the determination of priority issues that need to be resolved.

Based on the path coefficient groupings, two root factors occur in the first group: "Problems with the BIM transition process (PBT)" is the most influential root factor limiting BIM implementation with a path coefficient of −0.88. The second important root factor is the "lack of management support in the use of BIM technology in the sector (LMS)" with −0.87 path coefficient, which is as significant as PBT. Although previous studies (Ganah and John, 2015; Vass and Gustavsson, 2017) identified these factors under the list of challenges and barriers to BIM implementation in different countries, this study revealed that "problems during the process of transition to BIM" and "lack of management support in the use of BIM" are the most significant limiting factors having significant effects on root factors for BIM implementation. The two root factors mentioned above are directly related with support of the management. This result is partially consistent with the research of Sinoh *et al.* (2020), who found that management and leadership have the strongest direct effect on BIM implementation, with a path coefficient of 0.457. In contrast, the current study revealed that in addition to management support problems faced during the transition phase to BIM are also significant factors limiting BIM implementation.

Undoubtedly, involvement and support management are critical to the success of technology implementation (Mitropoulos and Tatum, 2000; Françoise *et al.*, 2009). However, problems encountered during the transition process should not be ignored for successful BIM implementation. Consequently, the resistance to change decreased. As Yiing and Ahmad (2009) point out, top management is ultimately responsible for deciding whether to employ new software or technology. In fact, it is particularly true for companies that use a top-down management system, which is common in the construction industry, particularly in Turkey and other developing countries (Theong *et al.*, 2014). Therefore, the acceptance of innovation by management has a favourable impact on BIM implementation.

Within the high affecting root factors as the second group "Lack of incentives for BIM (LIB)" with −0.68 path coefficient; "Lack of BIM education and training opportunities (LBE)", "BIM-based software problems (BSP)", and "Bias regarding BIM technology (BBT)" with −0.65 path coefficients are considered. This result is partially consistent with that of previous studies.

Most previous studies highlighted the significant role of government support and incentives to BIM (Chan *et al.*, 2019b; Jiang *et al.*, 2022) with ranking and descriptive analysis. However, these efforts fail to determine the impact and size of the effect. Based on the findings of this research, lack of government support is a high effect root factor limiting BIM implementation.

Similarly, BIM-based software problems are also root factors limiting BIM implementation. Unlike Sinoh *et al.* (2020) that revealed software knowledge and problems and hardware availability are less significant than non-technical factors, this study ascertains that software problems are as much important as non-technical factors.

Unlike previous research, this study revealed the original root factor of LBE. Although the importance of BIM education has been highlighted in previous studies (Sinoh *et al.*, 2020; Elmalı and Bayram, 2022), there is no existing research that evaluates and incorporates the lack of BIM education as a latent factor at former researches. Some previous studies (Chan *et al.*, 2019a, 2019b; Liao *et al.*, 2019) have addressed this issue within the context of training. However, this subject gained a different perspective from this result. The number of qualified and skilled staff members using BIM is still lacking around the world. Arranging training with the firms for staff is neither sufficient nor economical. Higher education institutions in Turkey lack the expertise or resources required to create sufficient BIM-capable graduates for the AEC industry (Türkyılmaz, 2016). Departments of architecture and engineering in higher education could restructure their curricula and add BIM-related courses to educate undergraduates.

Among the moderate influential root factors as third group "Awareness and knowledge level of BIM (ALB)" with −0.58 and "Lack of communication between project stakeholders regarding the use of BIM (LCS)" with −0.57 path coefficients emerged as relatively high. The result regarding BIM awareness is partially consistent with previous research (Gamil and Rahman, 2019; Enshassi *et al.*, 2016) that which identified BIM awareness as only a criterion under the list of BIM implementation challenges/barriers. However, the lack of BIM awareness of BIM potential is a core factor of BIM implementation (Khoshfetrat *et al.*, 2020; Gamil and Rahman, 2019). Unlike these studies, the current research highlights BIM awareness with its impact and effect on BIM implementation. BIM awareness is required throughout a project's lifetime (design, construction, and operation), which is necessary for BIM adoption (Olanrewaju *et al.*, 2021).

A differentiation is revealed regarding the lack of communication among stakeholders between former and current research. Sinoh *et al.* (2020) stated that non-technical factors, such as communication, ranked higher than technical factors; however, communication among stakeholders has the least path coefficient (−0.57) among eight root factors that have considerably high effects. Sinoh *et al.* (2020) focused on the Malaysian AEC industry. Although Malaysia and Turkey are developing countries, their cultures are different: Malaysians are predominantly collectivists, whereas Turkish are uncertainty avoidant (Hofstede Insights, 2022). Therefore, cultural dissimilarities may explain this differentiation.

6. Conclusions

BIM technology has significant advantages for all stakeholders, particularly architects and engineers in the construction industry. Although the use of BIM has increased in many countries, the use of BIM is uncommon in Turkey and other developing countries. To promote BIM implementation in developing countries, the root factors limiting BIM implementation should first be known to find optimised solutions. Therefore, this study identifies the root factors limiting BIM implementation using SEM, which has been overlooked in previous research. This study is unique in that it assists construction researchers and stakeholders identify the primary factors that impede BIM implementation, which is critical for BIM implementation throughout a project's lifetime. Furthermore, this study is the first to develop a quantified model to demonstrate and measure the effect size of the root factors limiting BIM implementation which will be useful for policymakers in Turkey to devise appropriate frameworks for BIM adoption in the Turkish AEC industry, which could be generalised to other developing countries. This model would be valuable for construction stakeholders and firms to adopt BIM in their projects. Furthermore, this study has crucial management implications and empirical contributions for the AEC sector, which are outlined below.

6.1 Conceptual and empirical contributions

The proposed model proved the need for BIM implementation, particularly in the AEC industry of developing countries. This study identified the core causes of BIM implementation limitations using the proposed model. Consequently, the gap between BIM theory and practice is close. To the best of our knowledge, no study has investigated the root factors restraining BIM implementation in Turkish or other developing countries in the AEC industry. In the first stage of the study, ICs was identified using the SLR. This result paves the way for further research on the factors that hinder BIM implementation in developing countries, particularly in the field of construction management. To this end, the theoretical aspects of this study provide a mathematical framework for identifying and quantifying the root factors limiting BIM implementation in Tukey and other developing countries, which could be used successfully in Tukey and other developing countries. Using SEM, eight factors that limit BIM implementation in the Turkish construction industry were identified. Consequently, this study provides a framework for policymakers who are interns to incorporate BIM impartially. Furthermore, this study made several conceptual and empirical advances which are as follows:

(1) The study contributes to the conceptual framework by identifying and conceptualising additional components to be added to it, such as the influence of root factors restricting BIM implementation in the construction sector.

(2) Most BIM implementation studies have been conducted in developed countries (the UK, USA, Hong Kong, and Australia). Few studies have been conducted on BIM implementation in the Turkish construction industry; therefore, the findings of the current research may be generalised to developing countries. The present work lays a solid foundation for addressing BIM implementation to increase the dependability of local construction projects and close the knowledge gap highlighted earlier.

(3) This study's findings include a substantial prediction tool (SEM) for discussing the influence of limiting BIM implementation factors on the construction sector for the first time. Consequently, this tool has the potential to improve traditional BIM implementation in the construction industry, particularly in developing countries. This contribution is empirical in nature because it focused on evaluating a theoretical linkage between eight root factors limiting BIM implementation, which have not previously been tested.

(4) Regarding the geographical context, it is evident that BIM implementation remains at a low level, and this is projected to skyrocket over the next few years. The present empirical study provides evidence that there is a significant and negative impact of the root factors limiting BIM implementation in the construction industry. Consequently, this can encourage the Turkish government and other local organisations to implement BIM.

6.2 Managerial implications

The following managerial implications can be used by construction practitioners to understand the impact of root factors limiting BIM implementation.

Accordingly, "Problems with BIM transition process (PBT)" and "Lack of management support (LMS)" are the most influential root factors limiting the BIM implementation and thus are worthy of our attention. The following measures can be taken to mitigate the adverse effects of these factors.

(1) Regarding PBT, this study suggests that key stakeholders in the construction industry, such as top management, clients, chief contractors, and engineering companies, reduce their resistance to change and adopt dynamic and supportive attitudes toward BIM. Construction project owners, clients, and real-estate developers of construction projects are advised to be proactive in adopting BIM.

(2) Owing to stakeholders' resistance to changing from the industry's conventional 2D to 3D approach, a shift in perspective is required to enhance BIM adoption in construction projects in Turkey, as well as in most developing countries, by both private and public property developers.

(3) Regarding LMS, it is recommended that the up-down management create a dedicated BIM department to handle or support BIM deployment in their projects in the long run. Moreover, top management in construction organisations are urged to address gaps in their employees' skill sets by supporting them in attending appropriate BIM seminars, workshops, or conferences to improve their BIM capacity and knowledge.

(4) The use of new software and hardware is not the only method to implement BIM. In reality, this necessitates a change in conventional construction delivery processes. The early engagement of all the important stakeholders in a construction project is part of this transition. It guarantees that all stakeholders may contribute their knowledge and experience to create a digital model that requires as little change as possible as the project advances. Organisations and their management should be open to change to effectively implement BIM at the intra-firm level and adapt to industry development at the inter-firm level.

Lack of incentives for BIM (LIB)", "Lack of BIM education and training opportunities (LBE)", "BIM-based software problems (BSP)", "Bias regarding BIM technology (BBT)" constitute the second group root factors limiting the BIM implementation. To mitigate the adverse effects of these factors.

(1) Both universities and the government should take responsibility for LBE. Related departments of universities, particularly architecture and engineering departments, should update their education curricula and increase the number of BIM-related courses. Higher education institutions and the government should collaborate to develop a national BIM curriculum to fulfil the need for BIM proficiency among graduates entering the workforce. This guarantees that graduates entering the AEC sector have the necessary skills and expertise to apply BIM to their businesses. The creation of such a curriculum may be a subject of future research.

(2) The government should establish and fund educational programs for industry professionals and create a knowledge portal with historical performance data and lessons learnt to evaluate the most effective BIM implementation approaches. Furthermore, construction stakeholders should motivate their staff to acquire practical skills and real-world experience through frequent BIM training programs that help them stay updated and be aware of critical abilities that need to be improved.

(3) Initial investment is required to purchase new software, hold training programs, and hire consultants. Government financial incentives may be provided to relieve these companies' financial pressure.

(4) One of the main obstacles in the global AEC industry is the BIM software. Consequently, this study encourages further collaboration between software vendors and construction companies. The partnership is intended to help provide a greater degree of compatibility and lower the risk of data loss during data migration across the software. Moreover, complete migration to cloud BIM by both organisations and developers may reduce the severity of this problem.

(5) During the early phases of BIM implementation, the government should actively promote local BIM demand by granting incentives and financial subsidies to the local AEC industry as well as selecting a few pilot projects to introduce BIM to the ACE industry.

(6) The government should implement legislation and rules to encourage construction companies to use BIM during their project execution. The government should also provide an enabling environment for BIM users, including intellectual property protection, BIM rules, and a common contract for BIM implementation.

(7) The advantage of gaining a long-term competitive advantage as a result of successful BIM implementation as well as government subsidies can help industry participants overcome psychological barriers to change and initiate BIM implementation.

(8) Governments that are yet to take measures to incentivise BIM implementation could use these managerial strategies to develop and implement their plans and policies more strategically and efficiently. They can conditionally mandate BIM use in their construction and building projects, establish national data exchange standards for improved multidisciplinary model integration, and provide technical support by defraying a portion of the capital investments in software purchase, subscription, updating, and training.

"Awareness and knowledge level of BIM (ALB)" and "Lack of communication between project stakeholders regarding the use of BIM (LCS)" constitute the third group root factors limiting the BIM implementation. To mitigate the adverse effects of these factors.

(1) Information regarding BIM has to be synchronised with workflows to improve the awareness.

(2) Effective communication is crucial, allowing people to be involved in the implementation process while being simultaneously educated about organisational practices, expectations, and goals.

(3) As a controlling position, the project manager strives to establish and maintain good information resources, thereby improving communication quality. As a supporting job, the BIM coordinator helps project management, information transfer across projects, and communication. It has been argued that the activities of the controlling role have a significant influence on information quality. In contrast, when information on true facts and alternate routes is lacking, a lack of communication limits the prospects for collaboration. The capacity of project participants to inform the design early on is considerably strengthened by this method.

The suggested conceptual framework revealing the root factor groups is unique and can support BIM implementers in identifying particular modifications to their BIM implementation operations to improve BIM implementation more effectively. Consequently, the primary results of this work contribute to the BIM implementation scholarship. To reduce the effects of the root factors of BIM implementation, project teams, which include executives and workers from significant stakeholders, should adapt their usual work practices.

6.3 Limitations and future research

Despite the great efforts made in this study to contribute significantly to the identification of the root factors limiting BIM implementation, it has several limitations. These limitations will lead future studies. First, it was limited in terms of geographical location. The research instrument (questionnaire) was administered only to architects and engineers in Turkey. Future studies should seek to further explore other developing countries to improve the generalisability of the study which will build upon this work with new contributions. Besides architects and engineers, different stakeholders (contractors and material suppliers) should be incorporated into the sampling. Furthermore, the perception of ICs and root factors limiting BIM among the stakeholders could be examined at future studies. This study contributes to identifying the root factors hindering BIM implementation in developing countries by using SEM with theoretical conceptualisation. Future studies could use the innovation diffusion theory or examine roadmaps to overcome BIM implementation challenges and develop supportive strategies to increase BIM implementation in developing countries. Moreover, the developed SEM provided a good fit; future research could focus on the mediating influence of the demographic variables of participants.

References

Ahn, K., Kim, Y., Park, C., Kim, I. and Lee, K. (2014), "BIM interface for full vs. semiautomated building energy simulation", *Energy and Buildings*, Vol. 68, pp. 671-678.

Ahuja, R., Jain, M., Sawhney, A. and Arif, M. (2016), "Adoption of BIM by architectural firms in India: technology–organization–environment perspective", *Architectural Engineering and Design Management*, Vol. 12 No. 4, pp. 311-330.

Aibinu, A. and Ventkatesh, S. (2014), "Status of BIM adoption and the BIM experience of cost consultants in Australia", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 140 No. 3, 04013021.

Akcay, E.C. (2022), "Analysis of challenges to BIM adoption in mega construction projects", *IOP Conference Series: Materials Science and Engineering, Creative Construction Conference (CCC 2021)*, IOP Publishing, Budapest, Hungary, 28th-30th June 2021, Vol. 1218, No. 1, pp. 1-6, 012020.

Akintoye, A. (2000), "Analysis of factors influencing project cost estimating practice", *Construction Management and Economics*, Vol. 18 No. 1, pp. 77-89.

Aladag, H., Demirdögen, G. and Isık, Z. (2016), "Building Information Modeling (BIM) use in Turkish construction industry", *Procedia Engineering*, Vol. 161, pp. 174-179.

Alshorafa, R. and Ergen, E. (2020), "Identification of information requirements for implementing Building Information Modeling based on model uses", *Journal of Information Technology in Construction (ITcon)*, Vol. 25, pp. 561-574.

Alshorafa, R. and Ergen, E. (2021), "Determining the level of development for BIM implementation in large-scale projects: a multi-case study", *Engineering, Construction and Architectural Management*, Vol. 28 No. 1, pp. 397-423.

Amuda-Yusuf, G. (2018), "Critical success factors for building information modelling implementation", *Construction Economics and Building*, Vol. 18 No. 3, pp. 55-73.

Antwi-Afari, M.F., Li, H., Pärn, E.A. and Edwards, D.J. (2018), "Critical success factors for implementing building information modelling (BIM): a longitudinal review", *Automation in Construction*, Vol. 91, pp. 100-110.

Attarzadeh, M., Nath, T. and Tiong, R.L.K. (2015), "Identifying key factors for building information modelling adoption in Singapore", *Management, Procurement and Law*, Vol. 168 No. 5, pp. 220-231.

Azhar, S. (2011), "Building Information Modeling (BIM): trends, benefits, risks, and challenges for the AEC industry", *Leadership and Management in Engineering*, Vol. 11 No. 3, pp. 241-252.

Badrinath, A.C. and Hsieh, S.H. (2019), "Empirical approach to identify operational critical success factors for BIM projects", *Journal of Construction Engineering and Management*, Vol. 145 No. 3, 04018140.

Becerik-Gerber, B., Gerber, D. and Ku, K. (2011), "The pace of technological innovation in architecture, engineering, and construction education: integrating recent trends into the curricula", *Journal of Information Technology in Construction (ITcon)*, Vol. 16, pp. 411-432.

Becerik-Gerber, B. and Kensek, K. (2010), "Building information modeling in architecture, engineering, and construction: emerging research directions and trends", *Journal of Professional Issues in Engineering Education and Practice*, Vol. 136 No. 3, pp. 139-147.

Belay, S., Goedert, J., Woldesenbet, A., Rokooei, S., Matos, J. and Sousa, H. (2021), "Key BIM adoption drivers to improve performance of infrastructure projects in the Ethiopian construction sector: a Structural equation modeling approach", *Advances in Civil Engineering*, Vol. 2021, pp. 1-12.

Boktor, J., Hanna, A. and Menassa, C.C. (2014), "State of practice of building information modeling in the mechanical construction industry", *Journal of Management in Engineering*, Vol. 30 No. 1, pp. 78-85.

Booth, A., Papaioannou, D. and Sutton, A. (2012), *Systematic Approaches to a Successful Literature Review*, Sage Publications, London.

Bouguerra, K., Yaik-Wah, L. and Ali, K.N. (2020), "A Preliminary implementation framework of building information modelling (BIM) in the Algerian AEC industry", *International Journal of Built Environment and Sustainability*, Vol. 7 No. 3, pp. 59-68.

Bryde, D., Broquetas, M. and Volm, J.M. (2013), "The project benefits of building information modelling (BIM)", *International Journal of Project Management*, Vol. 31 No. 7, pp. 971-980.

BSI (2018), *EN ISO 19650-1: Organization of Information about Construction Works - Information Management Using Building Information Modelling—Part 1: Concepts and Principles, the International Organization for Standardization (ISO)*, British Standards Institution, London.

Btoush, M. and Haron, A.T. (2017), "Understanding BIM adoption in the AEC industry: the case of Jordan", *IOP Conferences Series: Materials Science Engineering, Global Congress on Construction, Material and Structural Engineering 2017 (GCoMSE2017)*, IOP Publishing, Johor Bahru, Malaysia, 28-29 August 2017, pp. 1-8.

Chan, D.W.M., Olawumi, T.O. and Ho, A.M.L. (2019a), "Perceived benefits of and barriers to building information modelling (BIM) implementation in construction: the case of Hong Kong", *Journal of Building Engineering*, Vol. 25, pp. 1-10.

Chan, D.W.M., Olawumi, T.O. and Ho, A.M.L. (2019b), "Critical success factors for building information modelling (BIM) implementation in Hong Kong", *Engineering, Construction and Architectural Management*, Vol. 26 No. 9, pp. 1838-1854.

Chien, K.-F., Wu, Z.-H. and Huang, S.-C. (2014), "Identifying and assessing critical risk factors for BIM projects: empirical study", *Automation in Construction*, Vol. 45, pp. 1-15.

Chin, W.W. (1998), "The partial least squares approach to structural equation modeling", in Marcoulides, G.A. (Ed.), *Modern Methods for Business Research*, Lawrence Erlbaum Associates Publishers, New Jersey, NJ, pp. 295-336.

Chuan, T.M., Ming, T.C. and Lin, A.F. (2014), "Business strategies of small and medium sized contractors in Malaysia", *International Review of Basic and Applied Sciences*, Vol. 2 No. 10, pp. 131-141.

Cronbach, L.J. (1951), "Coefficient alpha and the internal structure of tests", *Psychometrika*, Vol. 16, pp. 297-334.

Cui, Q., Hu, X., Liu, X., Zhao, L. and Wang, G. (2021), "Understanding architectural designers' continuous use intention regarding BIM technology: a China case", *Buildings*, Vol. 11 No. 10, 448, pp. 1-16.

Dakhil, A., Underwood, J. and Al Shawi, M. (2019), "Critical success competencies for the BIM implementation process: UK construction clients", *Journal of Information Technology in Construction (ITcon)*, Vol. 24, pp. 80-94.

Dao, T.N., Chen, P.H. and Nguyen, T.Q. (2021), "Critical success factors and a contractual framework for construction projects adopting building information modeling in Vietnam", *International Journal of Civil Engineering*, Vol. 19 No. 1, pp. 85-102.

Ding, Z., Zuo, J., Wu, J. and Wang, J.Y. (2015), "Key factors for the BIM adoption by architects: a China study", *Engineering, Construction and Architectural Management*, Vol. 22 No. 6, pp. 732-748.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C. and McNiff, S. (2013), "BIM implementation throughout the UK construction project lifecycle: an analysis", *Automation in Construction*, Vol. 36, pp. 145-151.

Elgewely, M.H., Nadim, W., ElKassed, A., Yehiah, M., Talaat, M.A. and Abdennadher, S. (2021), "Immersive construction detailing education: building information modeling (BIM)–based virtual reality (VR)", *Open House International*, Vol. 46 No. 3, pp. 359-375.

Elmalı, Ö. and Bayram, S. (2022), "Adoption of BIM concept in the Turkish AEC industry", *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, Vol. 46, pp. 435-452.

Engineering News Record (2021), available at: https://www.enr.com/toplists/2021-Top-250-International-Contractors-Preview (accessed 3 April 2022).

Enshassi, A., Ayyash, A. and Choudhry, R.M. (2016), "BIM for construction safety improvement in Gaza strip: awareness, applications and barriers", *International Journal of Construction Management*, Vol. 16 No. 3, pp. 249-265.

Erpay, M. and Sertyesilisik, B. (2021), "Preliminary checklist proposal for enhancing BIM-based construction project contracts", *Journal of Information Technology in Construction*, Vol. 26, pp. 341-365.

Evans, M. and Farrel, P. (2021), "Barriers to integrating building information modelling (BIM) and lean construction practices on construction mega-projects: a Delphi study", *Benchmarking: An International Journal*, Vol. 28 No. 2, pp. 652-669.

Ezcan, V., Goulding, J.S., Kuruoglu, M. and Rahimian, F.P. (2013), "Perceptions and reality: revealing the BIM gap between the UK and Turkey", *International Journal of 3-D Information Modeling (IJ3DIM)*, Vol. 2 No. 3, pp. 1-15.

Fornell, C. and Larcker, D.F. (1981), "Evaluating structural equation models with unobservable variables and measurement error", *Journal of Marketing Research*, Vol. 18 No. 1, pp. 39-50.

Françoise, O., Bourgault, M. and Pellerin, R. (2009), "ERP implementation through critical success factors' management", *Business Process Management Journal*, Vol. 15 No. 3, pp. 371-394.

Gamil, Y. and Rahman, I.A.R. (2019), "Awareness and challenges of building information modelling (BIM) implementation in the Yemen construction industry", *Journal of Engineering, Design and Technology*, Vol. 17 No. 5, pp. 1077-1084.

Ganah, A. and John, G.A. (2015), "Integrating building information modeling and health and safety for onsite construction", *Safety and Health at Work*, Vol. 6 No. 1, pp. 39-45.

Gu, N. and London, K. (2010), "Understanding and facilitating BIM adoption in the AEC industry", *Automation in Construction*, Vol. 19 No. 8, pp. 988-999.

Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E. and Tatham, R.L. (2006), *Multivariate Data Analysis*, 6th ed., Pearson Prentice Hall, Upper Saddle River, NJ.

Hair, J.F. Jr., Hult, G.T.M., Ringle, C.M. and Sarstedt, M. (2017), *A Primer on Partial Least Squares Structural Equation modeling (PLS-SEM)*, Sage Publications.

Hair, J.F., Ringle, C.M. and Sarstedt, M. (2011), "PLS-SEM: indeed a silver bullet", *The Journal of Marketing Theory and Practice*, Vol. 19 No. 2, pp. 139-152.

Hair, J.F. Jr, Sarstedt, M., Hopkins, L. and Kuppelwieser, G.V. (2014), "Partial least squares structural equation modeling (PLS-SEM): an emerging tool in business research", *European Business Review*, Vol. 26 No. 2, pp. 106-121.

Hair, J.F., Risher, J.J., Sarstedt, M. and Ringle, C.M. (2019), "When to use and how to report the results of PLS-SEM", *European Business Review*, Vol. 31 No. 1, pp. 2-24.

Haliburton, J.T. (2016), *Building Information Modelling and Small Architectural Practice: an Analysis of Factors Affecting BIM Adoption*, Doctoral dissertation, Texas A and M University, TX.

Hatem, W.A., Abd, A.M. and Abbas, N.N. (2018), "Barriers of adoption building information modeling (BIM) in construction projects of Iraq", *Engineering Journal*, Vol. 22 No. 2, pp. 59-81.

Hofstede Insight (2022), available at: https://www.hofstede-insights.com/country/turkey/ (accessed 1 April 2022).

Hong, Y. and Chan, D.W.M. (2014), "Research trend of joint ventures in construction: a two-decade taxonomic review", *Journal of Facilities Management*, Vol. 12 No. 2, pp. 118-141.

Hong, Y., Hammad, A.W.A., Sepasgozar, S. and Akbarnezhad, A. (2018), "BIM adoption model for small and medium construction organisations in Australia", *Engineering, Construction and Architectural Management*, Vol. 26 No. 2, pp. 154-183.

Hong, Y., Hammad, A.W. and Akbarnezhad, A. (2019), "Impact of organization size and project type on BIM adoption in the Chinese construction market", *Construction Management and Economics*, Vol. 37 No. 11, pp. 675-691.

Hosseini, M., Banihashemi, S., Chileshe, N., Namzadi, M.O., Udaeja, C., Rameezdeen, R. and McCuen, T. (2016), "BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model", *Construction Economics and Building*, Vol. 16 No. 3, pp. 71-86.

Hosseini, M.R., Pärn, E.A., Edwards, D.J., Papadonikolaki, E. and Oraee, M. (2018), "Roadmap to mature BIM use in Australian SMEs: competitive dynamics perspective", *Journal of Management in Engineering*, Vol. 34 No. 5, 05018008.

Howard, R. and Björk, B.C. (2008), "Building information modelling–experts' views on standardisation and industry deployment", *Advanced Engineering Informatics*, Vol. 22 No. 2, pp. 271-280.

Isikdag, U. (2015), "Enhanced building information models", *SpringerBriefs in Computer Science*, pp. 577-590.

Jensen, P.A. and Johannesson, E.I. (2013), "Building information modelling in Denmark and Iceland", *Engineering, Construction and Architectural Management*, Vol. 20 No. 1, pp. 99-110.

Jiang, R., Wu, C., Lei, X., Shemery, A., Hampson, K.D. and Wu, P. (2022), "Government efforts and roadmaps for building information modeling implementation: lessons from Singapore, the UK and the US", *Engineering, Construction and Architectural Management*, Vol. 29 No. 2, pp. 782-818.

Jung, W. and Lee, G. (2015), "The status of BIM adoption on six continents", *World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering*, Vol. 9 No. 5, pp. 512-516.

Khoshfetrat, R., Sarvari, H., Chan, D.W.M. and Rakhshanifar, M. (2020), "Critical risk factors for implementing building information modelling (BIM): a Delphi-based survey", *International Journal of Construction Management*, Vol. ahead-of-print No. ahead-of-print, pp. 1-10.

Khosrowshahi, F. and Arayici, Y. (2012), "Roadmap for implementation of building information modeling in the UK construction industry", *Engineering, Construction and Architectural Management*, Vol. 19 No. 6, pp. 610-635.

Kim, S., Park, C.H. and Chin, S. (2016), "Assessment of BIM acceptance degree of Korean AEC participants", *KSCE Journal of Civil Engineering*, Vol. 20 No. 4, pp. 1163-1177.

Kitchenham, B. and Charters, S. (2007), "Guidelines for performing systematic literature reviews in software engineering", Version 2.3 Technical Report EBSE-2007-01, Software Engineering

Group, School of Computer Science and Mathematics, Keele University, Department of Computer Science, University of Durham, Joint Report, Durham, UK.

Kivits, R.A. and Furneaux, C. (2013), "BIM: enabling sustainability and asset management through knowledge management", *The Scientific World Journal*, Vol. 2013, pp. 1-14, 983721.

Koseoglu, O. and Nurtan-Gunes, E.T. (2018), "Mobile BIM implementation and lean interaction on construction site: a case study of a complex airport project", *Engineering, Construction and Architectural Management*, Vol. 25 No. 10, pp. 1298-1321.

Koseoglu, O., Sakin, M. and Arayici, Y. (2018), "Exploring the BIM and lean synergies in the Istanbul Grand Airport construction project", *Engineering, Construction and Architectural Management*, Vol. 25 No. 10, pp. 1339-1354.

Lavrakas, P.J. (2008), "Construct validity", in Lavrakas, P.J. (Ed.), *Encyclopedia of Survey Research Methods*, SAGE Publications, London.

Lee, S., Yu, J. and Jeong, D. (2015), "BIM acceptance model in construction organizations", *Journal of Management Engineering*, Vol. 31 No. 3, 04014048.

Liao, L. and Teo, E.A.L. (2017), "Critical success factors for enhancing the building information modelling implementation in building projects in Singapore", *Journal of Civil Engineering and Management*, Vol. 23 No. 8, pp. 1029-1044.

Liao, L., Teo, E.A.L. and Chang, R. (2019), "Reducing critical hindrances to building information modeling implementation: the case of the Singapore construction industry", *Applied Sciences*, Vol. 9 No. 18, pp. 1-21.

Lindblad, H. and Guerrero, J.R. (2020), "Client's role in promoting BIM implementation and innovation in construction", *Construction Management and Economics*, Vol. 38 No. 5, pp. 468-482.

Linderoth, H.C. (2010), "Understanding adoption and use of BIM as the creation of actor networks", *Automation in Construction*, Vol. 19 No. 1, pp. 66-72.

Liu, B., Li, Y., Xue, B., Li, Q., Zou, P.X.W. and Li, L. (2018), "Why do individuals engage in collective actions against major construction projects?- An empirical analysis based on Chinese data", *International Journal of Project Management*, Vol. 36 No. 4, pp. 612-626.

Lohmöller, J.B. (1982), "An overview of latent variables path analysis", *Paper Presented at the Annual Meeting of the American Educational Research Association*, New York, NY, 19-23 March.

Ma, X., Darko, A., Chan, A.P.C., Wang, R. and Zhang, B. (2020), "An empirical analysis of barriers to building information modelling (BIM) implementation in construction projects: evidence from the Chinese context", *International Journal of Construction Management*, Vol. ahead-of-print No. ahead-of-print, pp. 1-9, doi: 10.1080/15623599.2020.1842961.

Manzoor, B., Othman, I., Gardezi, S.S.S. and Harirchian, E. (2021), "Strategies for adopting building information modeling (BIM) in sustainable building projects—a case of Malaysia", *Buildings*, Vol. 11 No. 6, pp. 1249-1314.

Mirpanahi, M.V. and Noorzai, E. (2021), "Modeling the relationship between critical BIM attributes and environmental sustainability criteria using PLS-SEM technique", *Journal of Architectural Engineering*, Vol. 27 No. 4, 04021037.

Mitropoulos, P. and Tatum, C.B. (2000), "Forces driving adoption of new information technologies", *Journal of Construction Engineering and Management*, Vol. 126 No. 5, pp. 340-348.

Morlhon, R., Pellerin, R. and Bourgault, M. (2014), "Building information modeling implementation through maturity evaluation and critical success factors management", *Procedia Technology*, Vol. 16 No. 2014, pp. 1126-1134.

Munianday, P., Radzi, A.R., Esa, M. and Rahman, R.A. (2022), "Optimal strategies for improving organizational BIM capabilities: PLS-SEM approach", *Journal of Management in Engineering*, Vol. 38 No. 3, 04022015.

Nanajkar, A. (2014), "Implementing Building Information Modeling (BIM) at AEC firms in India", Master's thesis, North Dakota State University of Agriculture and Applied Science, Fargo, ND.

Nunnally, J.C. and Bernstein, I.H. (2007), *Psychometric Theory*, McGraw-Hill, New York, NY.

Nyvlt, V. (2018), "The role of managing knowledge and information in BIM implementation processes in the Czech Republic", *MATEC Web of Conferences, 9th International Scientific Conference Building Defects (Building Defects 2017), EDP Sciences*, Vol. 146, pp. 1-6, České Budějovice, Czech Republic, November 23-24, 2017.

Olanrewaju, O.I., Babarinde, S.A., Chileshe, N. and Sandanayake, M. (2021), "Drivers for implementation of building information modeling (BIM) within the Nigerian construction industry", *Journal of Financial Management of Property and Construction*, Vol. 26 No. 3, pp. 366-386.

Olanrewaju, O.I., Chileshe, N., Babarinde, S.A. and Sandanayake, M. (2020), "Investigating the barriers to Building Information Modeling (BIM) implementation within the Nigerian construction industry", *Engineering, Construction and Architectural Management*, Vol. 27 No. 10, pp. 2931-2958.

Olawumi, T.O. and Chan, D.W.M. (2018), "Critical success factors for implementing building information modeling and sustainability practices in construction projects: a Delphi survey", *Sustainable Development*, Vol. 27, pp. 587-602.

Olugboyega, O. and Windapo, A.O. (2021), "Structural equation model of the barriers to preliminary and sustained BIM adoption in a developing country", *Construction Innovation*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/CI-04-2021-0061.

Ozorhon, B. and Karahan, U. (2016), "Critical success factors of building information modeling implementation", *Journal of Management in Engineering*, Vol. 33 No. 3, 04016054.

Ozturk, G.B. (2019), "Interoperability in building information modeling for AECO/FM industry", *Automation in Construction*, Vol. 113, 103122.

Pallant, J. (2005), *SPSS Survival Manual*, Open University Press, Berkshire.

Park, E., Kwon, S.J. and Han, J. (2019), "Antecedents of the adoption of building information modeling technology in Korea", *Engineering, Construction and Architectural Management*, Vol. 26 No. 8, pp. 1735-1749.

Qiao, S., Wang, Q., Guo, Z. and Guo, J. (2021), "Collaborative innovation activities and BIM application on innovation capability in construction supply chain: mediating role of explicit and tacit knowledge sharing", *Journal of Construction Engineering and Management*, Vol. 147 No. 12, 04021168.

Ramayah, T., Cheah, J.-H., Chuah, F., Ting, H. and Memon, M.A. (2016), *Partial Least Squares Structural Equation Modeling (PLS-SEM) Using SmartPLS 3.0: an Updated and Practical Guide to Statistical Analysis*, Pearson, Singapore.

Reina, P. and Tulacz, G.J. (2014), "ENR 2014 top 250 international contractors", *Engineering News Record (ENR)*, California, available at: https://www.enr.com/articles/1348-enrs-2014-top-international-contractors?v=preview (accessed 2 April 2022).

Rogers, J., Chong, H.-Y. and Preece, C. (2015), "Adoption of building information modelling technology (BIM): perspectives from Malaysian engineering consulting services firms", *Engineering, Construction and Architectural Management*, Vol. 22 No. 4, pp. 424-445.

Rooney, K. (2014), "BIM education - global summary report – 2013", *The Australian National Building Specification system (NATSPEC) Construction Information, V1.0*, Sydney, pp. 1-10, available at: https://www.acif.com.au/sb_cache/associationnews/id/153/f/BIM%20Education%20Paper%20-%20Final.pdf (accessed 20 March 2021).

Sacks, R., Eastman, C., Lee, G. and Teicholz, P. (2018), *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, and Facility Managers*, 3rd ed., John Wiley & Sons, Hoboken, NJ.

Semaan, J., Underwood, J. and Hyde, J. (2021), "An investigation of work-based education and training needs for effective BIM adoption and implementation: an organisational up skilling model", *Applied Sciences*, Vol. 11 No. 18, pp. 18646-18725.

Shahruddin, S., Zairul, M., Haron, A.T. and Fared, M.M. (2022), "Performance-based identity in a BIM environment: an architect's perceptions and experiences", *Open House International*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/OHI-07-2021-0147.

Simsek, N.C. and Uzun, B. (2021), "Building information modelling (BIM) for property valuation: a new approach for Turkish condominium ownership", *Survey Review*, Vol. 2021, pp. 1-22. doi: 10.1080/00396265.2021.1905251.

Sinoh, S.S., Othman, F. and Ibrahim, Z. (2020), "Critical success factors for BIM implementation: a Malaysian case study", *Engineering, Construction and Architectural Management*, Vol. 27 No. 9, pp. 2737-2765.

Succar, B. (2009), "Building information modelling framework: a research and delivery foundation to industry stakeholders", *Automation in Construction*, Vol. 18, pp. 357-375.

Succar, B., Sher, W. and Williams, A. (2013), "An integrated approach to BIM competency assessment, acquisition and application", *Automation in Construction*, Vol. 35, pp. 174-189.

Takim, R., Harris, M. and Nawawi, A.H. (2013), "Building information modeling (BIM): a new paradigm for quality of life within Architectural, Engineering and Construction (AEC) industry", *Procedia - Social and Behavioral Sciences*, Vol. 101, pp. 23-32.

Tam, N.V., Diep, T.N., Toan, N.Q. and Quy, N.L.D. (2021), "Factors affecting adoption of building information modeling in construction projects: a case of Vietnam", *Cogent Business and Management*, Vol. 8, 1918848.

Tan, T., Chen, K., Xue, F. and Lu, W. (2019), "Barriers to Building Information Modeling (BIM) implementation in China's prefabricated construction: an Interpretive Structural Modeling (ISM) approach", *Journal of Cleaner Production*, Vol. 219, pp. 949-959.

Tavakol, M. and Dennick, R. (2011), "Making sense of Cronbach's alpha", *International Journal of Medical Education*, Vol. 2, pp. 53-55.

TCA-Turkish Contractors Association, Analysis of Turkish Construction Industry-January 2016, available at: http://www.tmb.org.tr/file/10787 (accessed 20 October 2021) (in Turkish).

Templier, M. and Paré, G. (2015), "A framework for guiding and evaluating literature reviews", *Communications of the Association for Information Systems*, Vol. 37, 6, pp. 112-137.

Tezel, E., Alatli, L. and Giritli, H. (2021), "Awareness and use of BIM for FM: empirical evidence from Turkey", in Jylhä, T. (Ed.), *The 20th EuroFM Research Symposium*, 16-17 June 2021, EuroFM, Netherlands, pp. 1-93.

Theong, M.C., Tan, C.M. and Ang, F.L. (2014), "Business strategies of small and medium sized contractors in Malaysia", *International Review of Basic and Applied Sciences*, Vol. 2 No. 10, pp. 131-141.

Toole, T.M. (1998), "Uncertainty and home builders' adoption of technological innovations", *Journal of Construction Engineering and Management*, Vol. 124 No. 4, pp. 323-332.

Tranfield, D., Denyer, D. and Smart, P. (2003), "Towards a methodology for developing evidence-informed management knowledge by means of systematic review", *British Journal of Management*, Vol. 14 No. 3, pp. 207-222.

Tsai, M.H., Mom, M. and Hsieh, S.H. (2014), "Developing critical success factors for the assessment of BIM technology adoption: part I. methodology and survey", *Journal of the Chinese Institute of Engineers*, Vol. 37 No. 7, pp. 845-858.

Tu, B., Zuo, J., Chang, R.D., Webber, R.J., Xiong, F. and Dong, N. (2021), "A system dynamic model for assessing the level of BIM implementation in construction phase: a China case study", *Engineering, Construction and Architectural Management*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/ECAM-10-2021-0895.

Türkyılmaz, E. (2016), "YBM'nin Mimarlık Eğitim Programı ile Bütünleşmesi Üzerine Bir Çalışma", *Megaron*, Vol. 11 No. 1, pp. 78-88 (in Turkish).

Tulubas Gokuc, Y. and Arditi, D. (2017), "Adoption of BIM in architectural design firms", *Architectural Science Review*, Vol. 60 No. 6, pp. 483-492.

Turkey BIM Report – General Trends and Expectations Research Report (2020), available at: https://biblus.accasoftware.com/en/bim-in-turkey-an-overview-on-the-level-of-adoption/ (accessed 2 April 2022).

United Nations Statistics Division (2018), "National Accounts", *United Nations Statistics*, available at: https://unstats.un.org/unsd/demographic-social/products/dyb/ (accessed 27 March 2022).

Urbach, N. and Ahlemann, F. (2010), "Structural equation modeling in information systems research using partial least squares", *Journal of Information Technology Theory and Application*, Vol. 11 No. 2, pp. 5-40.

Vass, S. and Gustavsson, T.K. (2017), "Challenges when implementing BIM for industry change", *Construction Management and Economics*, Vol. 35 No. 10, pp. 597-610.

Wang, G., Wang, P., Cao, D. and Luo, X. (2020), "Predicting behavioural resistance to BIM implementation in construction projects: an empirical study integrating technology acceptance model and equity theory", *Journal of Civil Engineering and Management*, Vol. 26 No. 7, pp. 651-665.

Wang, J., Yuan, Z., He, Z., Zhou, F. and Wu, Z. (2021), "Critical factors affecting team work efficiency in BIM-based collaborative design: an empirical study in China", *Buildings*, Vol. 11 No. 10, pp. 1486-1523.

Wolfswinkel, J.F., Furtmueller, E. and Wilderom, C.P.M. (2013), "Using grounded theory as a method for rigorously reviewing literature", *European Journal of Information Systems*, Vol. 22 No. 1, pp. 45-55.

Won, J., Lee, G., Dossick, C. and Messner, J. (2013), "Where to focus for successful adoption of building information modeling within organization", *Journal of Construction Engineering and Management*, Vol. 139 No. 11, 04013014.

Wong, A.K.D., Wong, F.K.W. and Nadeem, A. (2009), "Comparative roles of major stakeholders for the implementation of BIM in various countries", in Wamelink, H., Prins, M. and Geraedts, R. (Eds), *Proceedings of the International Conference Changing Roles*, 5-9 October 2009, Delft University of Technology, Delft, pp. 23-33.

Wong, A.K.D., Wong, F.K.W. and Nadeem, A. (2011), "Government roles in implementing building information modelling systems: comparison between Hong Kong and the United States", *Construction Innovation*, Vol. 11 No. 1, pp. 61-76.

Yaakob, M., Ali, W.N.A.W. and Radzuan, K. (2016), "Critical success factors to implementing building information modeling in Malaysia construction industry", *International Review of Management and Marketing*, Vol. 6 No. S8, pp. 252-256.

Yiing, L.H. and Ahmad, K.Z.B. (2009), "The moderating effects of organizational culture on the relationships between leadership behaviour and organizational commitment and between organizational commitment and job satisfaction and performance", *Leadership and Organization Development Journal*, Vol. 30 No. 1, pp. 53-86.

Yilmaz, G., Akcamete, A. and Demirors, O. (2019), "A reference model for BIM capability assessments", *Automation in Construction*, Vol. 101, pp. 245-263.

Zhang, R., Tang, Y., Wang, L. and Wang, Z. (2020), "Factors influencing BIM adoption for construction enterprises in China", *Advances in Civil Engineering*, Vol. 2020, 8848965.

Zhao, X. and Wu, G.D. (2017), "Assessing risks associated with BIM adoption: an empirical study in China", in Wang, Y., Pang, Y., Shen, G.Q.P. and Zhu, Y. (Eds), *Proceedings of the International Conference on Construction and Real Estate*, 10-12 November 2017, American Society of Civil Engineers, Guangzhou, pp. 47-57.

Zhao, X., Feng, Y., Pienaar, J. and O'Brien, D. (2017), "Modelling paths of risks associated with BIM implementation in architectural, engineering and construction projects", *Architectural Science Review*, Vol. 60 No. 6, pp. 472-482.

Zhao, X., Wu, P. and Wang, X. (2018), "Risk paths in BIM adoption: empirical study of China", *Engineering, Construction and Architectural Management*, Vol. 25 No. 9, pp. 1170-1187.

Zhou, Y., Yang, Y. and Yang, J.-B. (2019), "Barriers to BIM implementation strategies in China", *Engineering, Construction and Architectural Management*, Vol. 26 No. 3, pp. 554-574.

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