Critical Strategies for Enhancing BIM Implementation in AEC Projects: Perspectives from Chinese Practitioners

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Abstract

The production of the architecture engineering and construction (AEC) industry is organized by projects. With the diffusion of information and communication technology in the industry, BIM is widely adopted in AEC projects. However, the systematic implementation of BIM in AEC projects experiences challenges. This study aims to identify critical strategies for enhancing BIM implementation within the AEC project context. Initially, 17 strategies are drawn from a comprehensive review of the relevant literature. Through a questionnaire survey with 116 effective responses from the practitioners, ten critical strategies are identified, with the top five being "clearly defined plans and objectives for BIM implementation", "financial support", "capabilities and skills in BIM technology", "availability and interoperability of engineering information and data", and "the aligned objective of BIM implementation with the project goal". The study also investigates the possible discrepancy in the different actors' assessments on the criticality of the strategies to valid the survey. The further principal component analysis groups the strategies and finds five latent factors of the strategies, including *institutional governance*, *change accommodation, technical environment*, *cooperation*, and *resources*. This finding reveals that systematic BIM implementation is inevitably associated with the AEC project context and indicates the enhancement of current BIM implementation in projects covers the strategies of the technical, institutional, and managerial aspects to accommodate changes brought by BIM. The international comparison of the top drivers with the found peer studies from Nigeria, Singapore, and Turkey classifies leadership as a driving force to incorporate BIM into the AEC projects. The results provide implications for enhancing BIM implementation in AEC projects and may improve the efficiency of the industry.

Author Keywords: Architecture, engineering, and construction; information and communication technology; Building information modeling (BIM); BIM implementation; Project.

Introduction

The architecture, engineering, and construction (AEC) industry is commonly regarded as being fragmented and low-efficiency with poor productivity (Fulford and Standing 2014; Segerstedt et al. 2010). Due to this fact, the production of AEC is organized by projects to encompass various procedures, disciplines, and teams. However, with increasing scale, uncertainty, and complexity of AEC works, limitations of traditional project management practice keep appearing in large complex projects (Chan et al. 2004; Lu et al. 2014). The information and communication technologies (ICTs) helps to deal with the miscellaneous information of the various project activities and enhance the communications among the project organizations (Ahuja et al. 2010; Martínez-Rojas et al. 2015). As an initiative to organize the simulation and visualization of building information, building information modeling (BIM) is widespread in the AEC industry and projects.

Recent years have viewed the rapid expanding of BIM implementation worldwide. According to McGraw-Hill Construction (2014), the compulsory BIM adoption on some projects had become active in Denmark, Finland, Norway, Singapore, Sweden, the UK, and the US. In addition, the Australian government had a three-year plan to adopt BIM in its public AEC projects and encouraged BIM use throughout the industry of the country (BuildingSMART Australasia 2012). The National Economic and Social Development Plans of China also specified BIM as a key initiative to promote the adoption of BIM in the AEC industry

(Bernstein 2015).

BIM also has a couple of observed values in the industry. The recent survey of Dodge Data & Analytics (2017) showed 25%, 48%, 37%, 35% participants from the US, the UK, France, and Germany reported there was 25% more return on investment in their projects that had adopted BIM. Moreover, one recent case study showed that the use of BIM in a construction project could clarify and address issues equal to 15.92% the total expense of the project (Kim et al. 2017).

However, the adoption of BIM in AEC requires frameworks to accommodate the systematic implementation of BIM and realize its potential values. Many studies dedicated to this issue. For example, Howard and Björk (2008) indicated BIM encompassed both technical and organizational aspects. Succar (2009) pointed out the integration of BIM in the AEC project involves process, technology, and policy. Similarly, Gu and London (2010) suggested the adoption of BIM concerning people, products, and process. Jung and Joo (2011) integrated the viewpoints and proposed a framework for BIM practice. Moreover, Rezgui et al. (2013) referred to different aspects, process, and levels of BIM to classify a set of categories to BIM deployment. Furthermore, Alwan et al. (2017) attached BIM with a framework to develop strategies for enhancing sustainable building. Yet, few frameworks dedicate to the enhancement of BIM implementation in projects, while the project context is a natural framework for AEC practice.

Moreover, much of the existing BIM research indicates the implementation of BIM in practice is a systematic and step-by-step effort. A few studies (Khosrowshahi and Arayici 2013; Porwal and Hewage 2013; Succar 2009) point out the advance of BIM implementation includes three stages, and the final is to achieve integrated collaboration. Also, Jin et al. (2017b) clarified the correlations of BIM benefits, value-realized factors, and barriers in BIM practice. The integration of BIM into IPD is of necessity to improve project performance (Miettinen and Paavola 2014; Rowlinson 2017). However, systematic BIM implementation in AEC projects staggers due to the complexity of the construction works (Mancini et al. 2017).

Although BIM practice involves industry deployment and organizational strategies, the cultural resistance embedded in the AEC projects has a substantial influence on the successful implementation of BIM (Eadie et al. 2013; Davies et al. 2017). Some studies such as Cao et al. (2016) and Liao and Teo (2017), have associated BIM with the project, but the strategies to advance the use of BIM in projects remain to be explicated. Thus, this study identifies the strategies and frames them in the AEC project context for enhancing BIM towards integrated collaboration, and thereby promoting BIM in the industry. Due to the sophisticated features of BIM, the strategies are in details and cover different aspects of BIM implementation in AEC projects. This study contributes to the better understanding and adoption of strategies for enhancing BIM implementation in project practices and escalating BIM use level in the AEC industry.

Literature review

The deployment of BIM in the industry involves different contexts (Poirier et al. 2015; Jung and Joo 2011). Further exploration is possible with a few studies to accommodate BIM implementation in the project context of the AEC industry regarding organizational change (e.g., Liao and Teo 2018); motivations (e.g., Cao et al. 2017); partnering (e.g., Porwal and Hewage 2013); process integration (e.g., Eadie et al. 2013); and collaboration (e.g., Liu et al. 2017).

Some studies refer to critical factors to develop strategies for BIM implementation. Ozorhon and Karahan (2016) identified five focuses encompassing people, projects, the industry, regulations, and resources that are of primary importance to implement BIM. Won et al. (2013) interviewed Korean BIM professionals to clarify the importance of investment and training in BIM execution. Abubakar et al. (2014) investigated contractors' opinions in the Nigerian construction context and identified a few driving factors for BIM adoption such as funding of BIM affairs, technical capability in BIM, organizational commitment, and BIM infrastructure. Eadie et al. (2015) examined BIM implementation in the UK from the views of different project participants to categorize a list of strategies to enhance BIM such as setting a collaborative work environment and providing sufficient codes and data. Additionally, Rogers et al. (2015) explored the Malaysian AEC industry and focused on the adoption of BIM into a few areas, for example, financial and technical support. Jin et al. (2017a) explored the Chinese construction context to identify the risks of BIM implementation. Furthermore, the international study by Dainty et al. (2017) emphasized the technical infrastructure of BIM and training of the BIM personnel as key factors in the implementation of BIM. Considering the fact BIM has been deployed on an industry level but implemented in projects, this study aims to identify the strategies from the project perspective to enhance BIM implementation. The possible verbs (e.g., achieve/provide/set) in the strategies are omitted to be concise and result-oriented. The strategies drawn from the review of literature are listed in Table 1.

<Please insert Table 1 here>

Research method

Factor studies are widely applied in many academic areas. For example, the research on critical success factors (CSFs) prevails in strategic management and project management (Amberg et al. 2005). The CSF approach can be used to evaluate and develop strategies (Leidecker and Bruno 1984). In project management, CSFs are built on existing theoretical foundation referring to multiple aspects of the project context and contribute to the systematic implementation of projects (Müller and Jugdev 2012). CSFs also applies to AEC to ensure the overall success of projects (Sanvido et al. 1992; Chan et al. 2004). However, the CSF approach has some weaknesses, such as bias assessments and possible inaccuracy (Boynton and Zmud, 1984).

Factor studies in construction management cover key performance indicators (e.g., Chan and Chan 2004; Cox et al. 2003), risks (e.g., Ke et al. 2010; Zou et al. 2009), and strategies (e.g., Darko and Chan 2018; Manley et al. 2009). Some factor studies adopt an empirical approach with common procedures including the identification of factors, empirical questionnaire survey, and statistical analysis of data (e.g., Cao et al. 2016; Chang et al. 2017; Eadie et al. 2015).

"Strategy is the creation of a unique and valuable position, involving a set of activities" (Porter 1996). Strategies developed from CSFs help organizations adapt to complex business environment and response to changes (Leidecker and Bruno 1984). Strategies can be used to enhance the adoption of ICT through aligning objectives and managing cultural changes in AEC (Henderson and Ruikar 2010). According to Mintzberg et al. (2005), strategy can be interpreted as a position shaped by factors to achieve specific goals. Such interpretation applies to construction management research (e.g., Darko and Chan, 2018; Oyedele et al. 2014, Hallowell and Calhoun 2011). Regarding the research purpose, this study focuses on the strategies to enhance BIM implementation in projects and explore the latent factors behind them. As an empirical factor study adopting the CSF approach, this research encompasses several procedures, including identification of strategies through literature review, execution of the questionnaire survey, data collection, and data analysis, which are detailed followingly in this section. To avoid possible weaknesses of the CSF approach including biased opinions and inaccurate empirical assessments, this study employs a comprehensive review of relevant literature to gain a broad view of the strategies, pilot study to verify their applicability and validity, and comparisons of subgroups' assessments in projects to test possible biases and inaccuracy.

Identification of the strategies through literature review

The comprehensive review of BIM implementation studies helps to identify the strategies. Firstly, the initial literature review referred to the factor studies, such as Eadie et al. (2015); Rogers et al. (2015); and Jin et al. (2017a), to provide an overview on BIM implementation. The following examination focused on qualitative research on BIM practice such as Ahn et al. (2015); Liu et al. (2017); Dainty et al. (2017). Strategies were synthesized from the two types of studies. However, as strategies shall be practical and contribute to enhancing BIM implementation in projects, the strategies are based on qualitative studies that directly research on BIM practice rather than empirical factor studies, and they have at least one source of qualitative BIM practice studies. Through the review, 17 strategies related to BIM implementation in projects were identified as presented in Table 1.

Execution of the questionnaire survey

The execution of the survey had gained help from China BIM Union (CBU). It is a country-wise organization that provides high-level seminars to experienced BIM professionals and promotes the integration of research and practice. A pilot survey with 12 BIM experts from CBU improved the solidarity and practicability of this questionnaire. Hence, a few changes had been done to the questionnaires. For example, more academic word "leadership" had been specified and replaced by "the aligned objective of BIM implementation with the project goal" and "requirement and support from the client and management". Followingly, the formal questionnaire survey investigated the opinions of BIM professionals from the BIM seminar groups of CBU to rate the importance of the identified strategies with a five-point Likert scale (1 = not critical, 2 = not quite critical, 3 = fairly critical, 4 = quite critical, and 5 = extremely critical). The participants are BIM professionals with rich work experience in AEC and BIM.

Data collection

The questionnaire survey had been implemented via a web-based survey system that automatically generates data from the answers and records the time cost for each response. The link to the questionnaire was sent to the seminar groups of CBU, and the BIM professionals were invited to complete it. Initially, 202 out of 477 responses were collected. A following data screen process improved the quality of this survey. Through the process, some responses were eliminated due to several reasons, such as non-targeted respondents and invalid answers. A final of 116 responses were obtained, and the valid response rate is 23.48%. According to Hair et al. (2010), factor analysis requires a sample size at least five times of the variables (strategies in this study). The ratio of this survey is 116/17=6.82, which is satisfactory.

Demographic descriptions of respondents

The demographic background of the 116 BIM professionals regarding their experience in the industry and BIM use is illustrated in Fig. 1 and Fig. 2. As this study targets at the experienced practitioners, the responses of participants who have less than five years of work experience in the AEC industry or less than three years' BIM use experience are screened out. Among all the respondents, 29 consisting of 25.0% have 6-10 years' experience; 33.6%, 19.8%; and 21.6% have 11-15 years' experience, 16-20 years' experience, over 20 years' experience, respectively. Regarding BIM use, 60.3 % of the respondents have three to five years' experience; and 39.7% have more than five years. Since BIM is a relatively recent initiative in the industry, the background of the respondents satisfies this survey.

Data analysis

The analysis of the collected data relies on the aid of the SPSS (Statistical Product and Service Solutions) software and uses a few techniques introduced below.

Normalization of criticality assessments on variables

The normalization of criticality assessments on variables helps to identify the critical strategies and compare them. According to previous studies (Zhao et al. 2014; Chan et al. 2017; Liao and Teo 2017), the normalization of variables by Equation (1) can realize the benchmark of criticality, and a variable with a nominalization value no less than 0.5 is supposed to be a critical factor. This technique applies in further to identify the critical strategies.

$$\textit{Normalization value} = (\textit{mean} - \textit{minimum mean})/(\textit{maximum mean} - \textit{minimum mean}) \qquad (1)$$

Non-parametric test: the Kruskal-Wallis

Considering different roles of project actors in BIM use (Liu et al. 2016), the possible discrepancies of their assessments are compared. As the assessed values on strategies by all the actors were found to distribute non-normally, a non-parametric test, the Kruskal-Wallis was adopted to analyze the data. The Kruskal-Wallis test examines the rank of a specific variable among the variables by values and uses their mean ranks to identify the difference in different groups of variables (Salkind 2010). In this study, the Kruskal-Wallis test ranks each strategy by the assessed values and compares their mean ranks in the 116 assessments to identify the possible significant discrepancy in the opinions of different actors.

Principal component analysis

Principal component analysis (PCA) is employed in this study to investigate the relations of the strategies and interpret the latent factors. Among the statistical techniques to explore the relations of variables, principal component analysis (PCA) gathers variables by the intrinsic nature of the data (Field 2009). Also, PCA is a common technique used in construction management to group factors (e.g., Chan et al. 2017; Liao and Teo 2017). The threshold value of factor loading for identifying a component factor is 0.5 (Field 2009; Norusis 2008).

The cross-context comparison of cases

Yin(2003) suggests a case study should relate a practical one-time situation to its broad context and gain general implications from the investigated facts. In the international context, case studies can benefit from diverse approaches such as quantitative data collection, multiple tracks and comparisons of the findings (Piekkari et al. 2009). In construction management, an in-depth interpretation of one or two cases and the cross-context comparative analysis can leverage the validity of a case study (Fellows and Liu 2003; Taylor et al. 2009). Thus, this study focuses on the projects in the Chinese construction context but also refers to cases in multiple contexts to obtain general implications.

Findings and analysis

Rankings of strategies

The ranking of the strategies refers to the mean values of their criticality as perceived by the respondents. The nominalization values of all the strategies are calculated to identify critical ones. As Table 2 presents, S6, S1, S2, S8, S16, S14, S3, S15, S11, S7 with normalization values over 0.5 are identified as critical strategies. "Clearly defined plans and objectives for BIM implementation" with a mean value of 4.56 ranks as the most critical strategy, followed by "financial support for BIM implementation" with a mean of 4.52. "Capabilities and skills in BIM technology", which has a mean value of 4.51, is the third critical strategy. "Availability and interoperability of engineering information"(4.44) is the fourth critical. The fifth critical strategy, "the aligned objective of BIM implementation with the project goal", has the same mean value (4.28) but a smaller deviation (0.830) than the sixth, "requirement and support from the client and management". The other critical strategies are "appropriate choice of delivery systems and contract types"(4.22), "sufficient codes and standards to refer to"(4.19), and "clear roles and responsibility in BIM affairs"(4.19).

The survey has gained a comprehensive project perspective with the respondents from the major actors including designers, contractors, consultants, and owners. All the Cronbach α values are above the threshold 0.7 (Field 2009), which demonstrates good reliability of the survey. The following Kruskal-Wallis test finds no significant discrepancies of the actors' assessments on the strategies at a significant level of 0.05 (Table 3); all the mean ranks and the values of $\chi 2$ are also provided.

The cross-country comparison of top drivers for BIM implementation

<Please insert Table 4 here>

The most critical strategies as top drivers identified by this study have been compared with the results of studies from three countries, including Nigeria, Singapore, and Turkey, as presented in Table 4. Firstly, two drivers including "clearly defined plans and objectives for BIM implementation" and "financial support" are distinct for China, where BIM implementation is viewed as an effort requiring clarification of particulars and financial support. Meanwhile, some similar drivers emerge in the cases of other countries such as "BIM implementation environment" of the Nigerian (Abubakar et al. 2014), "early adoption of BIM regulation" of the Singaporean for organizing BIM implementation (Liao and Teo 2018), and "leadership and support" of the study in the Turkish context to facilitate the BIM effort (Ozorhon and Karahan 2016). Second, "capability and skills" and "availability and interoperability of engineering information and data" of Chinese context are rather consistent with the drivers in the Turkish case, such as "capable personnel" and "access to information and technical conditions", and also the Nigerian case, such as "training and consultancy" and "BIM infrastructure". The most common driver identified in projects across all the countries is on leadership regarding goal alignment. However, it only ranks the fifth driver in the Chinese construction context, followed by the other leadership-based strategy with an equal mean value.

PCA findings

The PCA of strategies proceeds in two rounds with varimax rotation. In the first trial of PCA, S5 only had the highest factor loading of 0.477 and was eliminated. The second round of PCA has demonstrated a satisfactory result, as shown in Table 5. A few indicators suggest the fitness of PCA. As Table 5 presents, the KMO is 0.847, which is acceptable according to Field (2009). The significance of Bartlett's test is 0.000 with $\chi(120) = 828.979$, implying the independence of the variances.

The capture of the components through PCA refers to the initial Eigenvalues (Table 6) and scree plot (Fig. 3), and only 4.683% more variances can be explained by the sixth component. According to Field (2009), 69.616% of the total variance explained is acceptable for five components. They group the strategies by the original assessed values. As Table 7 shows, the components reveal five latent factors that point to *institutional governance*, *change accommodation*, *technical environment*, *cooperation*, and *resources*.

The first factor is identified as *institutional governance*. The strategies related to this factor are "the aligned objective of BIM implementation with the project goal", "requirement and support from the client and management", "appropriate choice of delivery systems and contract types", "government policy and incentives to promote BIM implementation", and "organizational and delivery measures to ensure BIM implementation". As the strategies are associated with goal alignment and organizational commitment of BIM implementation in projects, the factor is summarized as *institutional governance*.

Change accommodation is the second factor. The strategies include "clear roles and responsibility in BIM affairs", "managing changes and risks in projects brought by BIM", and "collaborative working environment and culture". These strategies concern the arrangements and measures to offset changes in projects brought by BIM. Thus, this factor is classified as *change accommodation*.

The third factor points to *technical environment*. It involves three strategies, including “sufficient technical support”, “sufficient training and consultancy”, and “sufficient and appropriate IT infrastructure”. All the strategies contribute to the technical aspects and form an environment to implement BIM in projects. Therefore, the factor is defined as *technical environment*.

The fourth factor concerns *cooperation*. The ad hoc strategies are “clearly defined plans and objectives for BIM implementation”, “availability and interoperability of engineering information and data” and “sufficient codes and standards to refer to”. Those three are linked to the capability to implement BIM in projects, thereby shaping the factor *cooperation*.

The fifth factor relates to *resources*. As “financial support for BIM implementation” and “capabilities and skills in BIM technology” represent the financial and personnel resources invested respectively, the factor is concluded as *resources*.

Among the strategies, S7 has cross-loadings over 0.5 for two components, *technical environment*, and *cooperation*. The higher loading value of S7, 0.533, indicates “sufficient codes and standards to refer to” is more of a strategy for *cooperation.* However, its factor loading 0.513 implies S7 is unneglectable for *technical environment*. To conclude, the BIM codes and standards serve as part of the technical environment to facilitate BIM-based cooperative efforts. This finding develops the understanding of the possible correlation of the strategies and factors.

Discussion

The results focus on the criticality and latent factors of strategies. Thus, the discussion covers the implications of both the criticality analysis and PCA of the strategies.

Implications of the criticality analysis

This study identifies a set of critical strategies in the Chinese AEC projects that may help the practitioners prioritize efforts to enhance BIM implementation. As the list with all the strategies and the research methodology were developed from the international academic works, they apply worldwide. Such data from other countries can enrich the comparison and develop the understanding of project-based BIM implementation across national contexts.

However, strategies are somewhat implicit and rely on activities to implement (Porter 1996; Mintzberg et al. 2005). Even in the AEC project, the implementation of BIM enhancing strategies involves different levels. For example, the stakeholders shall provide resources and technical support; the project management help develop the strategies; and the project team execute the according activities. Such an effort can also spread across different project stages. Thus, it is part of the project planning and management.

Implications of the PCA

Some implications are obtained from the PCA. From the identified latent factors, the implementation of BIM in projects is not limited to the technical aspect but also about organizations, regulations, and managerial affairs. The PCA also explains BIM, in the project context, is not only a modeling technology but also a process to handle building information and related conditions with digital modeling. Thus, there is a potential need to rethink the terminology to describe systematic BIM implementation in the AEC project as it is inevitably associated with the project context, and "BIM" may lack specification as it can also mean the computational modeling in simple disciplinary works and lead to multiple interpretations (Chan et al. 2018). The more specific terminology may benefit the advanced implementation of BIM, especially in project practices.

In addition, the result of PCA confirms a few conclusions such as enhancing BIM in AEC projects needs push-pull strategies (Chang et al. 2017); implementing BIM in projects also faces the resistance of organizational culture (Lee and Yu 2015); and the adoption of BIM brings institutional changes to projects (Akintola et al. 2017). Interpreted from the latent factors, the enhancement of current BIM implementation in projects requires the accommodation of changes in project context by institutional governance. It can be triggered by leadership (Thamhain, 2004), and sustained by ad hoc settings in project context regarding technical, organizational, financial conditions. This analysis provides a systemic insight into the enhancement of BIM implementation in AEC projects.

Conclusion

Although BIM has wide application in the industry and attracts great attention in academia, its systematic implementation in AEC projects experiences challenges. This case study summarizes BIM implementation drivers from the international research community and ranks their criticality in AEC projects based on the empirical assessments from the Chinese practitioners, and compares the findings with the Nigerian, Singaporean and Turkish cases. In addition, the assessments of the different project actors have been compared to examine the discrepancy of their opinions. Furthermore, the exploration of the principal components that accommodate the strategies finds five latent factors, including *institutional governance, change accommodation, technical environment, cooperation,* and *resources*. From the project perspective, the factors explain the relations and functions of the strategies and clarify the major areas in the context of the AEC project to contribute to BIM body of knowledge (Wu et al. 2018). The PCA result also indicates the adoption of strategies to accommodate the changes brought by BIM is of necessity to sustain the BIM use in AEC projects. This finding suggests that the advanced use of BIM should be part of the implementation of AEC projects. Through the cross-country comparison of the top drivers for Nigeria, Singapore, and Turkey, leadership is classified as a key driving force to incorporate BIM into the AEC projects, which is also confirmed in the interpretation of the result of PCA. This finding rationalizes "push initiatives" adopted in many countries for enhancing BIM implementation in their AEC projects.

This study contributes to enhancing the systematic implementation of BIM in AEC projects. The strategy list provides a category of possible strategies to improve the implementation of BIM, and the identified ranking of strategies helps to prioritize the efforts for BIM implementation in projects. It also offers a systematic approach for enhancing BIM implementation in the AEC project.

Several features differentiate this study from the existing research. First, this study associates BIM to the AEC project practice and explains the factors underlying strategies for enhancing BIM implementation in projects; very few studies have a likewise angle of view. Second, this study bases the strategies on the improvement of the status quo, as the recent implementation of BIM is inevitably associated with the project practices but staggers on its systematic development (He et al. 2017; Mancini et al. 2017; Whyte and Hartmann 2017). Lastly, the cross-country comparison indicates that BIM implementation in AEC projects is context-based. This analysis identifies the country-wise practice or culture as another factor for the diffusion of BIM.

This study also has some limitations. In this study, the generalized concept of the AEC project is used as a framework to accommodate the systematic implementation of BIM. Such interpretation is common in BIM factor studies (e.g., Eadie 2013; Teo and Liao 2017; Badrinath and Hsieh 2018). However, the strategies may differ regarding the different types of AEC facilities such as the residential or industrial. In the survey, the practitioners are requested to refer to their rich experience of BIM-based AEC projects to decide the criticality of the strategies. The influence of the facility type is alleviated. Meanwhile, the empirical assessments on the criticality of the strategies by the practitioners could be biased and inaccurate. Accordingly, the investigation probes into the opinions of different actors and finds no significant difference. A large number of responses by the practitioners also help to reduce the possible inaccuracy. In addition, as BIM implementation in projects is a systematic effort, the enhancement of BIM implementation should refer to the strategies as well as the barriers and obstacles. Although the priority of critical strategies provides a reference list to project practices, the clarification of barriers finds room to improve. Future research can devote to match BIM implementation and AEC project practice and tackle related barriers.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request.

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Table 1. The strategies for BIM implementation from the literature review

Code	Strategy	Sources
S1	Financial support for BIM implementation	Abubakar et al. (2014); Rogers et al. (2015); Dainty et al. (2017); Won et al. (2013); Jin et al. (2017a)
S2	Capabilities and skills in BIM technology	Abubakar et al. (2014); Ding et al. (2015); Gu and London (2010)
S3	Government policy and incentives to promote BIM implementation	Porwal and Hewage (2013); Ding et al. (2015); Abubakar et al. (2014); Linderoth (2010)
S4	Collaborative working environment and culture	Linderoth (2010); Eadie et al. (2013); Eadie et al. (2015); Abubakar et al. (2014); Liu et al. (2017)
S5	Teamwork to BIM execution	Porwal and Hewage (2013); Abubakar et al. (2014); Ding et al. (2015); Linderoth (2010); Liu et al. (2017)
S6	Clearly defined plans and objectives for BIM implementation	Dainty et al. (2017); Ding et al. (2015); Rogers et al. (2015); Liu et al. (2017)
S7	Sufficient codes and standards to refer to	Alreshidi et al. (2017); Eadie et al. (2015); Gu and London (2010)
S8	Availability and interoperability of engineering information and data	Abubakar et al. (2014); Eadie et al. (2015); Rogers et al. (2015); Gu and London (2010)
S9	Sufficient and appropriate IT infrastructure (hardware, software, and information system, etc.)	Porwal and Hewage (2013); Abubakar et al. (2014); Rogers et al. (2015); Dainty et al. (2017)
S10	Sufficient technical support	Porwal and Hewage (2013); Liu et al. (2017); Ding et al. (2015)
S11	Clear roles and responsibility in BIM affairs	Abubakar et al. (2014); Liu et al. (2017); Gu and London (2010)
S12	Managing changes and risks in projects brought by BIM	Porwal and Hewage (2013); Abubakar et al. (2014); Ding et al. (2015); Jin et al. (2017a)
S13	Sufficient training and consultancy	Won et al. (2013); Porwal and Hewage (2013); Rogers et al. (2015); Dainty et al. (2017)
S14	Requirement and support from the client and management	Eadie et al. (2013); Linderoth (2010); Al Ahbabi and Alshawi (2015)
S15	Appropriate choice of delivery systems and contract types	Eadie et al. (2015); Linderoth (2010); Cavka et al. (2017); Lee et al. (2017); Liu et al. (2017)
S16	The aligned objective of BIM implementation with the project goal	Sackey et al. (2014); Ahn et al. (2015); Hartmann et al. (2012)
S17	Organizational and delivery measures to ensure BIM implementation	Sackey et al. (2014); Porwal and Hewage (2013); Liu et al. (2017)

Table 2. Ranking of BIM implementation strategies in AEC projects

Strategy	Total（N=116）				Designer (n=27)			Contractor (n=42)			Consultant (n=37)			Owner (n=10)		
	Mean	SD[a]	Rank	NV[b]	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
S6	4.56	0.608	1	1.000[c]	4.59	0.636	1	4.64	0.577	1	4.51	0.607	2	4.30	0.675	5
S1	4.52	0.728	2	0.951[c]	4.44	0.801	4	4.55	0.670	4	4.57	0.728	1	4.40	0.843	2
S2	4.51	0.567	3	0.939[c]	4.56	0.577	2	4.55	0.550	3	4.46	0.558	3	4.40	0.699	1
S8	4.44	0.676	4	0.854[c]	4.48	0.700	3	4.57	0.630	2	4.30	0.740	4	4.30	0.483	3
S16	4.28	0.830	5	0.659[c]	4.30	0.823	9	4.40	0.857	5	4.22	0.787	6	3.90	0.876	16
S14	4.28	0.842	6	0.659[c]	4.41	0.797	5	4.31	0.869	7	4.16	0.898	7	4.30	0.675	5
S3	4.25	0.874	7	0.622[c]	4.41	0.844	6	4.29	0.774	8	4.08	0.983	11	4.30	0.949	9
S15	4.22	0.803	8	0.585[c]	4.30	0.869	10	4.24	0.790	9	4.24	0.760	5	3.90	0.876	15
S11	4.19	0.801	9	0.549[c]	4.37	0.967	7	4.12	0.803	14	4.11	0.699	8	4.30	0.675	5
S7	4.19	0.874	10	0.549[c]	4.30	0.912	11	4.38	0.764	6	3.89	0.936	16	4.20	0.789	10
S17	4.14	0.756	11	0.488	4.26	0.859	12	4.14	0.783	12	4.08	0.682	9	4.00	0.667	13
S12	4.10	0.828	12	0.439	4.30	0.775	8	3.95	0.909	16	4.08	0.829	10	4.30	0.483	3
S4	4.10	0.908	13	0.439	4.22	1.013	14	4.19	0.969	11	3.97	0.763	13	3.90	0.876	17
S9	4.09	0.823	14	0.427	4.07	0.917	16	4.19	0.890	10	3.95	0.664	14	4.30	0.823	8
S10	4.09	0.850	15	0.427	4.22	0.801	13	4.07	0.947	15	4.00	0.782	12	4.10	0.876	12
S5	4.07	0.862	16	0.402	4.19	0.921	15	4.14	0.843	13	3.89	0.875	15	4.10	0.738	11
S13	3.74	0.896	17	0.000	4.07	0.781	17	3.57	0.941	17	3.62	0.893	17	4.00	0.816	14
	Cronbach α= 0.912				Cronbach α= 0.931			Cronbach α= 0.903			Cronbach α= 0.897			Cronbach α= 0.936		

Note: a. SD-Standard deviation; b. NV- Normalization value; c. Critical strategies.

Table 3. The result of the Kruskal-Wallis test

Strategy	Mean ranks[a]				$\chi2$	Asymp. sig.
	Designer (n=27)	Contractor (n=42)	Consultant (n=37)	Owner (n=10)		
S1	55.87	59.02	60.85	54.70	0.670	0.880
S2	61.20	60.37	55.53	54.35	0.975	0.807
S3	64.69	58.54	53.22	61.20	2.230	0.526
S4	64.20	62.62	51.97	49.95	3.898	0.273
S5	63.44	61.12	51.96	58.35	2.517	0.472
S6	60.70	62.58	55.74	45.60	3.371	0.338
S7	63.35	65.19	47.69	57.30	7.000	0.072
S8	60.87	64.54	52.59	48.60	4.398	0.222
S9	58.39	63.13	51.19	66.40	3.518	0.318
S10	63.61	59.05	54.19	58.35	1.423	0.700
S11	68.70	55.44	53.69	61.60	4.284	0.232
S12	66.09	53.26	57.53	63.60	3.105	0.376
S13	70.69	52.30	54.43	66.70	6.906	0.075
S14	63.09	59.95	54.12	56.20	1.497	0.683
S15	62.46	58.81	58.65	45.95	2.080	0.556
S16	59.20	64.51	55.22	43.50	4.383	0.223
S17	64.87	58.98	55.20	51.50	2.070	0.558

Note: [a]This rank refers to the mean rank of a strategy by the assessed values of each subgroup in the 116 assessments.

Table 4. The top BIM implementation drivers for different countries

Rank	China	Nigeria (Abubakar et al. 2014)	Singapore (Liao and Teo 2018)	Turkey (Ozorhon and Karahan 2016)
1	Clearly defined plans and objectives for BIM implementation	Training and consultancy	Leadership and support from the management	Capable personnel
2	Financial support	BIM infrastructure	Collaborative design	Leadership and support
3	Capabilities and skills	BIM implementation environment	Training and change of practices	Access to information and technical conditions
4	Availability and interoperability of engineering information and data	Clients' advocation	Clients' advocation	Collaboration of teams
5	The aligned objective of BIM implementation with the project goal	The attention of actors for the use of BIM	Early adoption of BIM regulation	Training

Table 5. KMO and Bartlett's test

Test	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.847
Bartlett's Test of Sphericity	
Approx. Chi-Square	828.979
df	120
Sig.	0.000

Table 6. Total variance explained by different components

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.575	41.092	41.092	2.661	16.634	16.634
2	1.401	8.753	49.845	2.457	15.355	31.989
3	1.145	7.156	57.001	2.318	14.485	46.474
4	1.033	6.453	63.455	1.927	12.041	58.515
5	0.986	6.161	69.616	1.776	11.101	69.616
6	0.749	4.683	74.298			

Table 7. Rotated component matrix

Strategies	Components[a]				
	Institutional governance	Change accommodation	Technical environment	Cooperation	Resources
S16: The aligned objective of BIM implementation with the project goal	**0.859**	0.248	-0.012	0.089	0.078
S14: Requirement and support from the client and management	**0.691**	0.107	0.300	0.140	0.199
S15: Appropriate choice of delivery systems and contract types	**0.650**	0.321	0.288	0.098	0.010
S3: Government policy and incentives to promote BIM implementation	**0.572**	-0.043	0.276	0.308	0.391
S17: Organizational and delivery measures to ensure BIM implementation	**0.558**	0.483	0.009	0.157	0.215
S11: Clear roles and responsibility in BIM affairs	0.175	**0.775**	0.111	0.288	0.046
S12: Managing changes and risks in projects brought by BIM	0.302	**0.742**	0.174	0.025	0.260
S4: Collaborative working environment and culture	0.187	**0.565**	0.333	0.168	0.092
S10: Sufficient technical support	0.089	0.381	**0.778**	0.071	-0.002
S13: Sufficient training and consultancy	0.295	0.050	**0.775**	0.092	0.176
S9: Sufficient and appropriate IT infrastructure	0.070	0.484	**0.526**	0.284	0.317
S6: Clearly defined plans and objectives for BIM implementation	0.187	0.146	-0.048	**0.796**	0.169
S8: Availability and interoperability of engineering information and data	0.110	0.300	0.333	**0.767**	-0.034
S7: Sufficient codes and standards to refer to	0.181	0.111	**0.513**	**0.533**	0.216
S1: Financial support for BIM implementation	0.177	0.121	0.037	0.004	**0.880**
S2: Capabilities and skills in BIM technology	0.137	0.234	0.233	0.239	**0.686**

Note: a. Rotated with varimax