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Research Article

Critical Challenges for BIM Adoption in Small and Medium-Sized Enterprises: Evidence from China

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Building information modelling (BIM) is a set of technologies that aim to increase interorganisational and cross-disciplinary collaboration in the architecture, engineering, and construction (AEC) industries to promote productivity and the quality of design, construction, and maintenance stages of a building. Studies on BIM adoption in small and medium-sized enterprises (SMEs) have remained an under-represented area. It is necessary to understand the main challenges hindering the adoption of BIM in SMEs and to consider corresponding strategies that can be applied in order to obtain further understanding of BIM in SMEs. On the basis of literature review and interview, stakeholder-associated factors were identified from a network perspective, and the social network analysis (SNA) method was applied to determine the interconnections between the influencing factors and links in BIM adoption in SMEs. Eventually, 10 critical factors and 10 crucial links were selected and divided into six challenges. Corresponding strategies, including cultivating the BIM perception of SMEs, integrated project delivery, strengthening the legal environment for BIM adoption in SMEs, and developing native software and standards and cloud-based technology, were proposed to mitigate these challenges. The strategies may help practitioners gain an in-depth understanding of BIM adoption in SMEs from a stakeholder-oriented perspective.

1. Introduction

Building information modelling (BIM) has been increasingly used by the architecture, engineering, and construction (AEC) industries to address performance problems that have long plagued the construction industry [1, 2]. Using BIM methods, compared with the traditional working model, can help us achieve coordination, cooperation, and integration whilst improving information flow and processing [3]. Recognising the aforementioned advantages, most AEC enterprises have started to use BIM in their projects and attempted not to perform traditional methods again, as BIM increases their productivity and greatly decreases the requests for information and rework [4], and even extend to the management of demolition waste [5]. Although the potential benefits of the technologies may seem evident, the industry adoption rate of BIM varies [6]. Kouide et al. found through an investigation on the Heathrow Airport Terminal 5 Project in London that although the latest software tools are available, major hidden technology constraints hinder their wide adoption in small and medium-sized enterprises (SMEs) [7]. Such constraints also exist in China, and we must admit that BIM adoption in SEMs in China is at an infant stage [8]. The Chinese central government has emerged as a major force for promoting BIM adoption [9]; the Ministry of Housing and Urban-Rural Development has mandated a guideline that aimed at a national BIM adoption rate of 90% by the year 2020 in large- and medium-sized buildings [10]. The main objectives of this guideline are to improve the digitisation of buildings. However, buildings are limited to large- and medium-sized buildings, which are mainly constructed by large enterprises. To some degree, BIM adoption in SMEs in China is largely overlooked. SMEs have greatly contributed to the economic development of existing regions or countries [11], and relying on large enterprises to improve the digitisation of buildings is insufficient. The problem that must be solved is how to achieve BIM adoption in SMEs in China.

Quantitative studies have investigated the influencing factors associated with BIM adoption for SMEs. Scholars, such as Gu, have confirmed that the factors affecting BIM adoption can mainly be grouped into technical tool functional requirements and needs and nontechnical strategic issues [6]. A case study conducted by Kouide et al. demonstrated that in terms of the time, cost, and effort required to implement the technology, the current investment means that BIM is unlikely to be used in small, simple projects where a traditional computer-aided design (CAD) remains sufficient [7]. Goodridge et al. pointed out that SMEs' innovation capability is extraordinarily low due to fragmentation, limited collaboration, and risk-averse attitude [12]. According to a research on the BIM adoption state of UK construction industry SMEs, the challenges faced by SMEs include the short of investments, the lack of BIM skills and capabilities, the slow return on investment, the security of the model, and the necessity to establish a mechanism for BIM implementation plan [13]. In fact, the reasons for BIM adoption in SMEs are not simply a single issue but a combination of several issues [14]. Previous studies have insufficiently considered the linkages that underlie the critical stakeholders and influencing factors. Therefore, critical factors that challenge BIM adoption in SMEs must be reidentified and must consider what strategies can be adopted from a stakeholder network perspective.

In consideration of the objectives of this study, two aspects are mainly discussed. Firstly, the critical factors that affect or impede BIM adoption in SMEs are investigated from the stakeholder perspective. Secondly, strategies for handling the challenges during the process of BIM adoption in SMEs are proposed. For these objectives, we propose the social network analysis (SNA) to evaluate the stakeholder-related factors in the adoption stage of BIM. This study contributes to local governments and SMEs in mitigating the existing challenges and promoting BIM adoption in SMEs through provided strategies. A new frontier for BIM adoption in SMEs is also opened via a network analysis, which integrates the critical factors with related stakeholders.

The remainder of this paper is organised as follows. Section 2 outlines the literature review of BIM adoption in SMEs. Section 3 demonstrates the research methodology, data collection and data processing. The results including node, link, and network levels are displayed in Section 4. Section 5 discusses the critical factors and corresponding strategies, and Section 6 summarises this paper.

2. Literature Review

2.1. The Development Process of BIM. The concept of BIM first appeared in 1992, published by the Automation in Construction journal in an article entitled "Modelling multiple views on buildings" [15]. Since then, studies on BIM have gradually emerged, and it has been defined in several ways. Paavola et al. described BIM from three aspects: (1) BIM is an object-based 3D model that can achieve visualisation and simulation of the building. (2) BIM can be perceived as a new way of working collaboratively through the entire life cycle of the building. (3) BIM can be considered a central way for promoting productivity and business results [14]. Succar et al. held the point that BIM can be perceived both as a technology and process [16]. In the early stages of BIM research, most articles regarded BIM as a technical means [17]. Gradually, Both et al. found that it is not enough to set the goal only on a technical level. The combination of technical and methodological aspects particularly contributes to the enhancement of understanding economic issues [18]. Gradually, a further comprehensive view on BIM emerged, which describes it as the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way [19].

The project-based nature and fragmentation of the construction industry lead its productivity development to lag behind that of other industries [2, 20]; the emergence of BIM aims to solve this problem [21]. However, Porwal pointed out that potential conflicts and risks will exist due to the change in work practices by the adoption of BIM [22]. On the basis of Chang et al.'s benefit-cost theory of BIM, we divided the development stage of BIM into three levels. In level 1, only a small group of AEC firms use BIM in daily production activities because the extra cost arising from BIM is high. As the application broadens (considerable life cycle phases), deepens (BIM levels), and diversifies (the benefits of various analyses), industry players acquire additional potential benefits from BIM [23]. Figure 1 shows the benefit-cost curve of BIM (the red curve represents the benefits of using BIM and the black curve represents the cost of using BIM). Numerous studies have recently been published to support that BIM is beneficial, since it presents an accurate cost estimation, is time saving, exhibits few design coordination errors, and presents energy-efficient design solutions [24–26]. Wang et al. found that early adoption of facility management in design stage with BIM can obviously reduce life cycle costs [27]. Paavola and Miettinen proposed a novel concept of "virtual materiality"; that is, BIM models provide dynamic but tangible ways for collaboration [14]. However, Arayici et al. found that stakeholder collaboration expands organisational boundaries [28]. When using BIM models in the construction industry, more stakeholders than ever will be involved in the entire phases of a project. As a result, critical factors that profoundly affect BIM adoption must be determined from the stakeholder perspective.

2.2. Factors and Stakeholders Related to BIM Adoption in SMEs. With respect to BIM adoption in AEC industries, researchers have identified sufficient influencing factors. Johnson et al. partly conceived the lack of initiative and training, the fragmented nature of AEC industries, the varying market readiness across geographies, and the industry's reluctance to change existing work practices as the reasons why BIM is at a relatively low level in AEC industries [29]. In addition, scholars found that collaborative environment and management process [30], motivation and BIM capability [23], a clear division of roles and responsibilities, and benefits allocation [31] also play important roles in the adoption of BIM in SMEs. On the basis of an empirical study of the motivations for BIM adoption in China, Cao et al. stressed

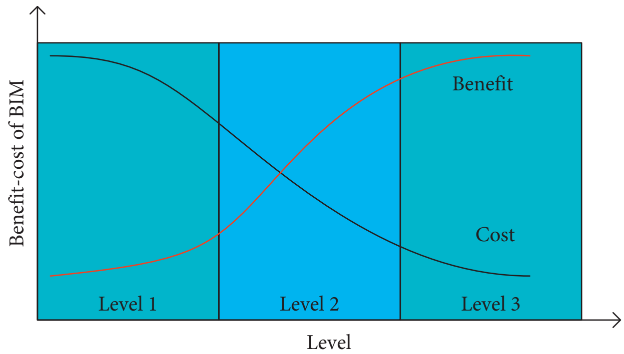

Figure 1: Benefit-cost curve of BIM.

that a robust understanding of how stakeholders implement a BIM adoption decision and which factor will affect it should be established [8]. As previously mentioned, these studies have helped us understand the factors that limit BIM adoption in AEC industries. However, Poirier described BIM as a technological innovation for construction organisations [32]. In terms of this respect, evidence suggested that SMEs treat innovation differently compared to large firms [33]. It is vital to find out the influencing factors to gain further insight into the BIM adoption for SMEs.

SMEs are usually defined by its characteristics including number of employees, enterprise turnover, asset size, and capital requirement [34]. The Ministry of Industry and Information Technology of the People's Republic of China (MOIIT) defined SMEs as companies that use approximately 10–300 employees [35]. With respect to BIM in SMEs, Jayasena first emphasized the terminology as these terms have yet to start their journey towards BIM transformation [36]. Rodgers et al. revealed that the level of understanding of BIM in Australia was much lower in SMEs, and there is prejudice to the requirements and challenges of implementing BIM in SMEs [37]. Based on Lam's study, he pointed out that guidance and frameworks in the UK to help SMEs to make an informed decision on BIM adoption are currently lacking [38]. Compared with developed countries, this situation also exists in China. China Construction Industry BIM Application Analysis report (2017) shows that only 10.4% of Chinese enterprises began to promote the deployment of BIM on a large scale [39]. Almost all of these enterprises are large enterprises, which means no SMEs. It widened the gap between SMEs and large firms in the market [40], despite the fact that research has confirmed the increase of using BIM by SMEs is a key condition for achieving the transformation of construction industry [38]. The above-mentioned influencing factors include diverse stakeholders, who are directly or indirectly involved in the process of BIM adoption in SMEs. The stakeholders mainly comprise the government, contractors, designers, software developers, owners, BIM consultants, and so forth.

Studies have also highlighted the factors that impeded BIM adoption in SMEs. Kouide et al. indicated that the BIM environment requires training, timing, and costing software, but SMEs would not pay additional fund where a normal traditional 2D method is adequate [7]. Resources limitation, competition, and functional structure were also influential barriers to BIM adoption in SMEs [38]. Grounded in a quantitative study performed on more than 200 manufacturing plants, Belvedere et al. found that SMEs cannot invest in the latest manufacturing practices and technologies that can improve their performance [41]. Meanwhile, Goodridge et al. revealed that fragmentation, limited collaboration, and risk-averse attitude are partly the reasons why SMEs are in low levels of innovation capability [12]. In fact, SMEs are naturally inclined to adopt reliable methods to ensure the return on investment (ROI) [32]. In the absence of sufficient evidence, the use of BIM is considered to be too risky due to the limited resources in SMEs [42]. Despite the lack of sufficient resources and key assets [38], Rosenbusch et al. deemed that SMEs are usually more flexible in their organisational structure and can quickly exploit new business opportunities in the market compared with large firms [43]. On the basis of an experiment with two SMEs, Hochscheid et al. brought to light that when actors are satisfied with the experiment results in their usual practices, they will take the initiative to invest in BIM and integrate more advanced BIM uses [44]. Project size was also investigated in Both and Petra's study, indicating that the use of BIM increases as the project grows in size [18], but they did not mention why the BIM adoption rate in SMEs is low. As discussed above, in this study, we considered the critical challenges that impede BIM adoption in SMEs from a stakeholder's perspective and proposed strategies to mitigate the challenges.

3. Research Methodology and Processes

3.1. Methodology

3.1.1. SNA. The concept of SNA was proposed by Moreno in 1934 [45]; since then, it has become an effective tool for researchers and practitioners who cover construction project management [46], information science [47], and risk management [48]. SNA is grounded on graph theory, sociology, and anthropology [49], which assumes that network members can interact with one another and their behaviours are largely influenced by the relationship pattern embodied in the network [50]. Accordingly, SNA is defined as a set of connections among stakeholders with additional attributes, which can be used to explain the social behaviours of the stakeholders involved [51]. Mok et al. applied SNA to solve the problems related to stakeholders in construction project management and other research fields and found that this is an effective means [52]. In order to identify critical factors for BIM adoption in SMEs, we applied SNA as it can link factors with associated stakeholders and quantify the interrelationships among different network nodes [48].

All nodes are encoded as SmFn in SNA, where m denotes the stakeholders and n represents the associated factors. For instance, S2F5 indicates the second stakeholder associated with the fifth influencing factor. Each node has a unique colour that represents corresponding stakeholder groups and factor categories. An arrow from node SxFy to node SwFz in the network indicates the relationship between SxFy and SwFz, and the thickness represents the influence degree of the relationship. Nodes with multiple links will be located at the centre of the network, while nodes with fewer connections will be on the edge of the graph. Density, node degree, status centrality, brokerage, and betweenness centrality are also the indicators for analysing the nodes and network [50]. These indicators provide a holistic understanding on the factor network.

3.1.2. Research Framework. Shi et al. adopted the SNA method to determine the critical factors to achieve dockless bike-sharing sustainability, which followed a classical framework, including factor identification, factor evaluation, key factor analysis and stakeholder analysis, and challenges mitigation [53]. Previous studies have shown that combining traditional frameworks with SNA can effectively manage stakeholder-related factors [46, 54]. Inspired by the above-named scholars, we (1) identified the factors that and the corresponding stakeholders who affect BIM adoption in SMEs, (2) estimated the relationships among factors, (3) analysed critical factors and stakeholders, and (4) conducted responding strategies. Figure 2 shows the main framework processes.

3.2. Processes

3.2.1. Data Collection. Interviews were conducted to collect data, which provided considerable information and a face-to-face interaction between investigators and interviewees. According to Brinkmann, open discussion and information sharing with different participants can mitigate ambiguities whilst improving data reliability [55]. In Section 2.2, government (S1), contractors (S2), designers (S3), software developers (S4), owners (S5), and BIM consultants (S6) were recognised as key stakeholder groups in BIM adoption in SMEs. We interviewed all six stakeholder groups to avoid a biased judgement and ensure data representativeness. S1 interviewees must come from a building department and involve in the management of BIM adoption. All interviewees from S2, S3, and S5 worked in SMEs (the number of employees is between 10 and 300) and have more than six years working experience. S2, S3, and S5 interviewees must also be knowledgeable about BIM or experienced related projects. S4 interviewees mainly came from Glodon (a native Chinese software developer, which has 10 years of BIM experience) and PMSbim (a local BIM developer in China, which is established in 2011). To find the appropriate people, interviewees from S6 were primarily introduced by S5 due to their close relationship. We do not pay particular attention to the natures of S5 and S6, because this paper discusses the BIM adoption by SMEs. However, S5 and S6 are mainly service providers. Initially, we contacted several familiar interviewees from corresponding stakeholder groups, and then a snowball sampling was used to encourage additional potential respondents to participate in our survey. We contacted 76 stakeholders via telephone, email, or face-to-face talk; 26 of them did not have sufficient knowledge or were not interested in our study topic, and 19 claimed that they were ineligible for the investigation. Thus, 31 participants were identified as eligible interviewees (with the exception of seven members in group S2, the number of members in the other groups was six). The sample met the requirements of previous studies [48, 53, 54].

Prior to the formal interview, we email all interviewees with background information and content to help them prepare for follow-up questions. On the basis of the questions proposed by Li et al. [48], we asked the interviewees to answer the following: (1) what factors do you think may affect BIM adoption in SMEs? (2) provide other factors that are not included in the above list (a reference list of stakeholder factors compiled by literature review), and (3) how are these identified factors relevant to the corresponding stakeholders? On the basis of their reply and combined with our literature review, we recompiled our influencing factors and the corresponding stakeholder list, delivered the manuscripts to respondents for feedback, and finally formed our list, as shown in Table 1.

Face-to-face interviews with semistructured attributes were conducted to find out the potential interconnections among the influencing factors. A detailed verbal explanation was provided to each interviewee when they were confused on the questions to minimise ambiguities. In SNA, nodes refer to the factors identified before, and links are defined as the influence of a stakeholder-related factor over another factor. Interviewees were asked to determine the direction of the potential effect clearly, as the interaction may be mutual. In other words, if a link exists between SxFy and SwFz, then SxFy can affect SwFz, and the corresponding stakeholder groups Sx and Sw will be asked to assess the linkage between SxFy and SwFz. Three types of questions were asked: (a) Can factor SxFy affect SwFz when using BIM method in a project (the link direction)? (b) What is the likelihood of this potential link? (c) If SxFy affects SwFz, then to what degree is the influence? On the basis of similar studies conducted by former scholar, we followed a five-level Likert scale, where "1" and "5" denote the lowest and highest levels, respectively [48, 53]. The overall effect of a link (P) can be represented by multiplying the likelihood of this link with the degree of influence.

3.2.2. Data Processing. In some cases, the associated stakeholders cannot agree on the final outcome of a linkage evaluation ($0 \le P \le 25$). Different stakeholders typically have different criteria for certain links. When this phenomenon happens, we calculate the degree of variation ($V = (P_{\max} - P_{\min})/25$, where $P_{\max}$ = the maximal effect of the link and $P_{\min}$ = the minimal effect of the link). If $V \le 0.2$, which indicates that the result is acceptable, then the weight of the link will be reflected by the median of the evaluation [66]. If $V > 0.2$, which means that the result is unacceptable, then a re-evaluation with related stakeholders must be performed until an acceptable result is generated. Given this situation, we organised an online meeting via WeChat (a social software in China) and obtained the ultimate data. We imported the collected data into NetMiner 4 for factor network visualisation and analysis. Critical factors, links and corresponding stakeholders were identified further.

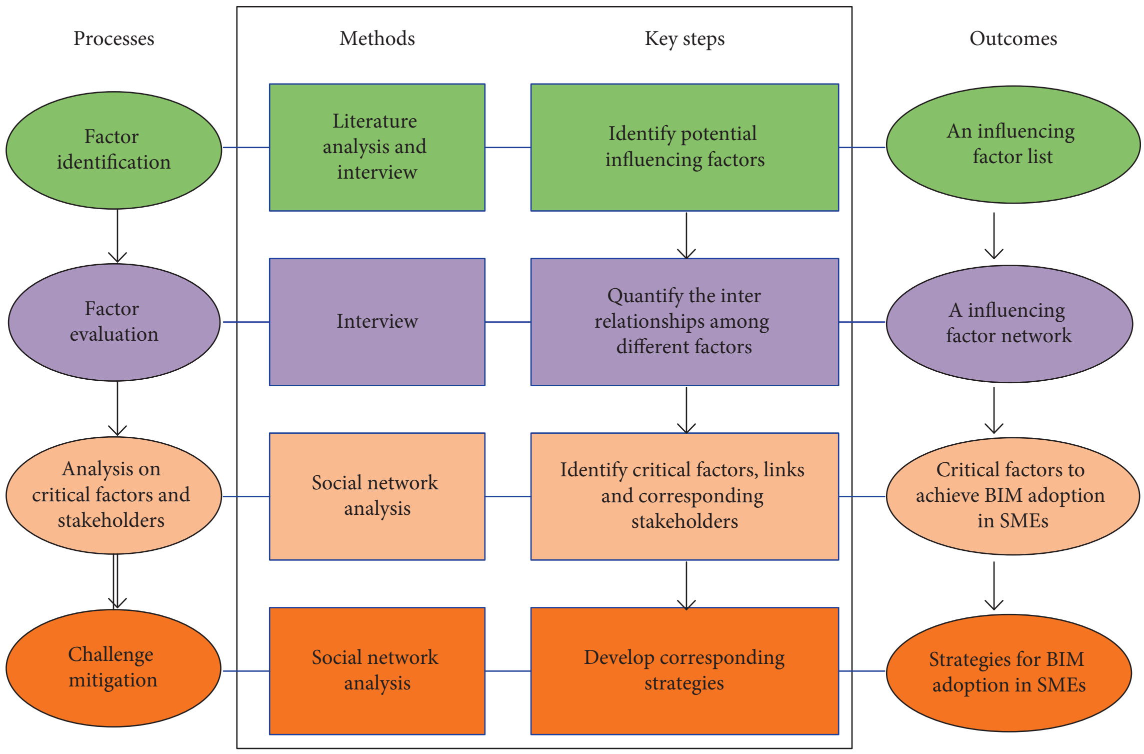

Figure 2: Research framework.

4. Results

On the basis of the literature analysis and semistructured interviews, 33 factors and 54 network nodes were identified, as shown in Table 1. On the basis of the different characteristics of these factors, we classified the 33 factors into 8 categories, namely, data (C1), cost (C2), technology (C3), perception (C4), contract (C5), collaboration (C6), legal (C7), and organisation (C8).

4.1. Network-Level Results. The factor network consists of 54 influencing factor nodes connected by 336 links, as shown in Figure 2. An arrow from nodes SxFy to SwFz indicates that SxFy can affect SwFz. The thickness of this arrow represents the influence level. Influencing factors with numerous links are at the centre of the network, while the less connected nodes are close to the graph boundary, as shown in Figure 3. A large number of interconnected relationships mean that the promotion of BIM adoption in SMEs is complex. The network density is 0.113, which indicates that the network is intensive and each factor has a close relation. S1 (governments), S3 (contractors), and S5 (owners) are at the network centre, which implies that governments, contractors, and owners are dominant in BIM adoption in SMEs.

4.2. Node and Link-Level Results. We explored the direct and indirect propagation effects of individual nodes to identify the key factors that influence BIM adoption in SMEs. Figure 4 shows the status centrality map, including all factors. Factors at the map centre play important roles in the network. Nodes S1 (governments), S3 (contractors), and S5 (owners) assume the central position, thereby implying the important role they play in BIM adoption in SMEs.

Out degree, degree difference, and ego size were used on the basis of previous studies to measure the roles of nodes in the network [48, 67]. The out degree reflects the range of direct influence, whereas a high degree of factor directly affects several neighbours in the network. The degree difference is equal to the gap between the out and in degrees [68]. A stakeholder issue with a large degree difference can be interpreted as exerting more influence on their neighbours than on acceptance [48]. If a factor has a large ego network size, numerous factors will be closely related to this factor [54]. In terms of the three indicators, we list the top 10 nodes in Table 2. A node with a high value often plays an important role in the network.

Brokerage is considered a valuable network index that demonstrates the different functions and capabilities of factor nodes in connection subgroups. These nodes play an important role in connecting various stakeholder groups; they are also crucial to BIM adoption in SMEs. We selected the top 10 nodes in the brokerage analysis, and they are shown in Table 3.

On the basis of betweenness centrality analysis, Table 4 displayed top 10 factors and links to show the capability of a factor or link to control the influence on other factors. Removing these factor nodes or links can considerably promote BIM adoption rates in SMEs.

5. Discussion

5.1. Critical Factors and Challenges Identified. On the basis of a previous study, the critical factors and links we selected will

Table 1: Influencing factors and relevant stakeholders.

Factor ID	Stakeholder node	Factor node	Factor name	Source	Category
S2F1	S2	F1	Security of confidential data	[56]	C1
S5F1	S5				
S2F2	S2	F2	Inserting, extracting, updating, or modifying the data in the BIM model	[57]	C1
S3F2	S3				
S4F2	S4				
S5F2	S5				
S6F2	S6				
S2F3	S2	F3	Accuracy of data transmission	Interview	C1
S3F3	S3				
S4F3	S4				
S2F4	S2	F4	Limited budget	[42, 44, 58]	C2
S2F5	S2	F5	High costs to educate people	[42, 59]	C2
S3F5	S3				
S5F5	S5				
S2F6	S2	F6	High-economic investment in the facilities	[40, 60]	C2
S5F6	S5				
S1F7	S1	F7	Inadequate funding	[38]	C2
S5F7	S5				
S5F8	S5	F8	Downstream beneficiaries do not pay compensation to upstream for additional cost and effort	Interview	C2
S4F9	S4	F9	Standards and protocols with a common language	[42]	C3
S5F10	S5	F10	Difficulties in measuring the effects of BIM	[42, 61]	C3
S4F11	S4	F11	Interoperability among different software	Interview	C3
S5F12	S5	F12	Unlikely to find BIM that matches SMEs' specific practice	[42, 61]	C3
S4F13	S4	F13	Lack of subcontractors who can use BIM technology	[42]	C3
S2F14	S2	F14	Lack of case studies and samples	[42]	C3
S3F14	S3				
S5F14	S5				
S4F15	S4	F15	Scalability to handle small simple and large complex projects	[38, 62]	C3
S2F16	S2	F16	Reluctance to change	[13]	C4
S3F16	S3				
S2F17	S2	F17	New roles and responsibilities	[22]	C5
S5F17	S5				
S5F18	S5	F18	Awareness about BIM	Interview	C4
S5F19	S5	F19	Client interest or request for BIM	[42]	C4
S2F20	S2	F20	Habits of 2D-based work	[18]	C3
S5F21	S5	F21	New contractual relationships	[63]	C5
S2F22	S2	F22	New project delivery methods	[7]	C5
S5F22	S5				
S2F23	S2	F23	Contractual responsibilities for inaccuracies in the BIM model are unclear	[57]	C5
S3F23	S3				
S5F23	S5				
S2F24	S2	F24	Distribution of benefits	[21]	C5
S5F25	S5	F25	Lack of BIM-ready samples for contractual documents	[18]	C5
S3F26	S3	F26	Several people are concerned in the planning and design phases	[13]	C6
S3F27	S3	F27	Interoperability among different project teams	[6]	C6
S2F28	S2	F28	Substantial adjustment to the current process/practice change	Interview	C6
S5F28	S5				
S3F29	S3	F29	Ownership and intellectual property rights over BIM models	[2, 6]	C7
S5F29	S5				
S2F30	S2	F30	New responsibilities among projects participants	[64]	C7
S1F31	S1	F31	No specific law to address BIM-related disputes	Interview	C7
S5F32	S5	F32	Organisational restructure to support BIM	[42, 60]	C8
S2F33	S2	F33	Changing well-established non-BIM procedures	[42, 65]	C8
S5F33	S5				

vary slightly in accordance with different ranking criteria; we followed a principle that selects the top factors from each ranking list in Section 4 as critical factors, often selecting three to five factors [48]. These factors play an important role in the network. Removing these nodes and links reduces the overall complexity of the factor network [46, 67]. Factors that appear many times in different ranking lists are identified as critical because they have multiple functions that support factor networks [53, 54]. Following these principles, 10 influencing factors and 10 links were identified as critical for BIM

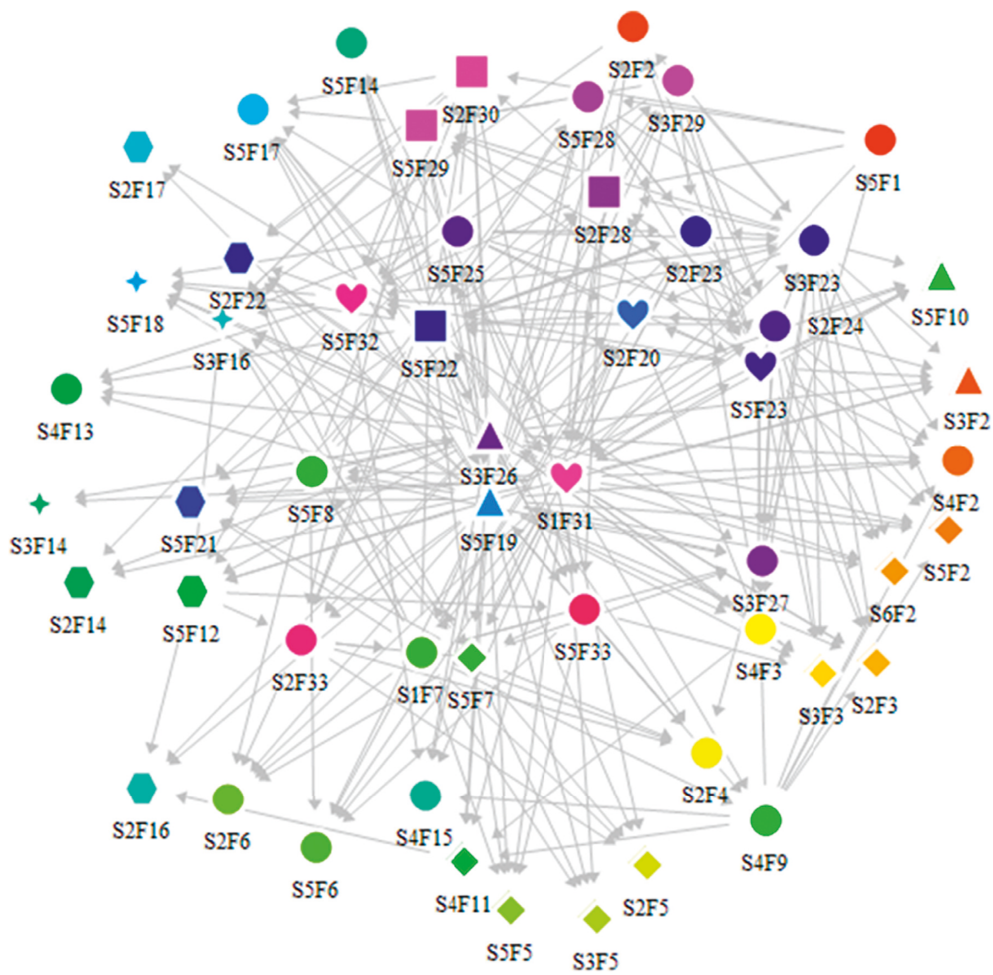

Figure 3: Stakeholder-related influencing factor network.

adoption in SMEs, as shown in Table 5. We divided them into six categories and explained them briefly to show the basic principles of this classification for understanding the meaning of key factors and links. The basic rationale of this classification is that if one of the 10 key factor nodes and the selected 10 key links exist in multiple links at the same time, which may lead to multiple problems, then that is a key challenge.

5.2. Strategies to Challenges Mitigation. From these analyses, we proposed five strategies to mitigate challenges in BIM adoption in SMEs. These strategies, including cultivating the BIM perception of SMEs, integrated project delivery (IPD), strengthening the legal environment for BIM adoption in SMEs, and developing native software and standards and cloud-based technology. These strategies are mainly based on the view of governments, software developers, owners, and contractors who are the main stakeholders in the adoption of BIM by SMEs. Following these management strategies, we constructed a governance framework, as shown in Figure 5.

5.2.1. Strategy 1: Cultivating the BIM Perception of SMEs. Incentives are major drivers of new technologies, whilst great efficiency is not enough to change business behaviour. Governments must play a positive role at the early stages of BIM adoption in SMEs. Issues, such as high education cost and high-economic investment in the facilities, must be solved through mandatory legislation and supervision. Clear compensation institutions must be provided to mitigate apprehensions, for instance, implementation and maintenance costs outweigh its usefulness. Apart from costs, the interest and willingness of project managers and engineers to use BIM also play important roles [73]. Following this principle, governments should strengthen BIM training. For example, they can force SMEs to set up a BIM department (with only 1–2 people required) and can train the BIM staff responsible for training within the enterprises and reporting on the result of the training. In this way, they are changing SMEs' attitude towards new technologies, formulating positive perceptions, and promoting BIM adoption in SMEs. As such, challenges 1 (SMEs are short on resources) and 3 (lack of BIM awareness) can be addressed.

5.2.2. Strategy 2: IPD. We introduced an IPD concept to address challenge 2 (collaboration challenges) identified in Table 5. The combination of BIM and IPD has been

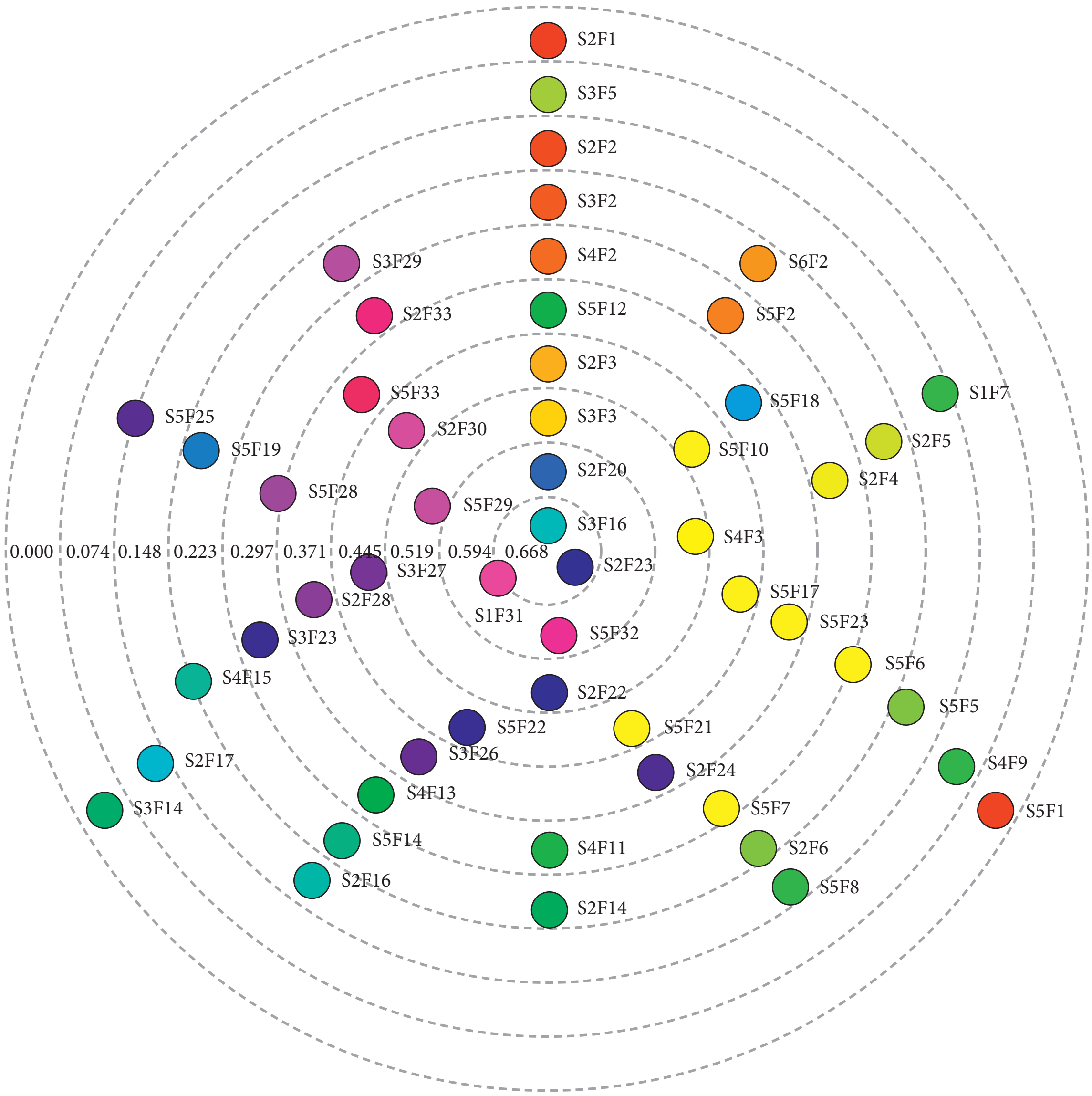

FIGURE 4: Status centrality map.

TABLE 2: Critical factors based on degree analysis, ego network, and status centrality.

Ranking	Factor ID	Ego size	Factor ID	Out status centrality	Factor ID	Out degree	Factor ID	Degree difference
1	S5F19	46	S5F19	3.15	S5F19	46	S5F19	39
2	S1F31	41	S5F22	1.696	S1F31	36	S3F26	28
3	S3F26	35	S1F31	1.675	F3F26	33	S1F31	24
4	S5F22	28	S3F26	1.627	S5F22	26	S5F22	15
5	S2F24	23	S3F23	1.247	S2F24	19	S5F25	14
6	S5F23	22	S2F24	1.132	S5F23	19	S1F7	14
7	S3F23	22	S5F23	0.973	S1F7	19	S2F24	11
8	S1F7	20	S1F7	0.968	S3F23	18	S5F23	11
9	S5F7	19	S5F25	0.762	S5F25	17	S3F23	11
10	S5F32	18	S5F7	0.643	S5F7	16	S5F7	10

widely supported in the literature as a method for solving the problem of limited collaboration in the construction industry [74, 75]. IPD is defined as the simultaneous development of a product and service during the planning stage. Using IPD increases the number of participants involved in the design, which leads to a good understanding among mean parties at the early stage. Therefore, a further detailed upstream analysis can be conducted on the product model, so that the product design process can be easily understood and the structure

Table 3: Critical factors for BIM adoption in SMEs based on brokerage analysis.

Ranking	Factor ID	Coordinator	Gatekeeper	Representative	Itinerant	Liaison	Total
1	S1F31	0	0	0	10	284	294
2	S5F19	0	7	0	13	163	183
3	S5F22	2	14	14	18	107	155
4	S3F26	0	3	0	7	81	91
5	S3F23	0	1	9	7	46	63
6	S5F23	0	1	11	7	44	63
7	S5F32	0	0	10	0	50	60
8	S2F24	0	1	11	6	33	51
9	S5F7	0	2	12	2	26	42
10	S5F33	0	0	6	0	28	34

Table 4: Critical factors and links for BIM adoption in SMEs based on betweenness centrality.

Ranking	Factor ID	Node betweenness centrality	Link ID	Link betweenness centrality
1	S1F31	0.1044	S2F33⟶S1F7	63.9
2	S5F19	0.0602	S4F11⟶S3F26	58.6
3	S5F22	0.0446	S5F33⟶S5F7	57.7
4	S1F7	0.0441	S2F33⟶S5F7	56.7
5	S5F7	0.0421	S5F32⟶S5F12	54.5
6	S5F33	0.0367	S5F12⟶S5F33	48.3
7	S3F26	0.0345	S5F12⟶S2F33	47.5
8	S2F33	0.0327	S5F7⟶S5F19	47.2
9	S5F1	0.0193	S2F30⟶S5F33	45.1
10	S5F12	0.0189	S5F29⟶S2F33	43.8

Table 5: Critical factors and challenges for BIM adoption in SMEs.

Critical factors and links	Associated critical stakeholder	Primary challenges and explanation
S1F7 S1F7⟶S2F4 S1F7⟶S5F5	Governments Governments Governments	1. SMEs are short on resources: SMEs are often extremely short on project resources [69]; as a result, they cannot afford extra overheads on infrastructure construction and training people to support new technology. SMEs' downstream beneficiaries also do not pay compensation to upstream for additional cost and effort. Thus, companies with limited human, time, and financial resources must focus on what they consider to be important criteria for success.
S3F26 S5F22 S2F30⟶S5F33 S5F22⟶S3F26	Designers Owners Contractors Owners	2. Collaboration challenges: The fragmented nature of construction industries leads to difficulties in sharing information and collaboration among different participants. Meanwhile, willingness to share information among project participants is considered the most critical [70]. The lack of cooperation consciousness and 2D-based work habits cause the production efficiency of the construction industry to be considerably lower than that of other industries, which is unconducive to the sustainable development of SMEs.
S5F19 S5F7⟶S5F19 S5F19⟶S3F16	Owners Contractors Owners	3. Lack of BIM awareness: As a new technology, BIM has been adopted and applied by large enterprises and has been gradually combined with project management and even enterprise management. However, SMEs lack the awareness of BIM and neither understand what BIM is nor how BIM is combined with the current working methods. Thus, the benefits of BIM to enterprises are difficult to determine.
S1F31 S2F24 S3F23 S1F31⟶S3F23 S5F29⟶S2F33	Governments Contractors Contractors Governments Owners	4. Legal disputes and uncertainties in policies: The construction industry is a complex process involving numerous people and information. When design information is generated in collaboration among several participants, identifying inaccurate responsibilities can be problematic [65]. No law explicitly addresses BIM disputes, and SMEs are worried about their own interests.

Table 5: Continued.

Critical factors and links	Associated critical stakeholder	Primary challenges and explanation
S5F12 S5F10 S4F11⟶S3F26	Owners Owners Software developers	5. Difficulties in meeting SMEs' needs: A 3D coordination and design review is considered the most effective and prevalent application of BIM today [71]. Projects in SMEs may be too simple to determine the benefits of BIM. Scalability to handle small, simple, and large, complex projects must be improved in an environment where conventional CAD remains adequate.
S5F1 S4F3⟶S4F11	Owners Designers	6. Concerns about data and information: The BIM model must store considerable data, involving input, output, and update. The accuracy of data transmission among different project teams must be ensured. Enterprises will not upload important data if data security cannot be guaranteed. Data security must be ensured through encryption or the use of secure file exchange servers during transmission [72].

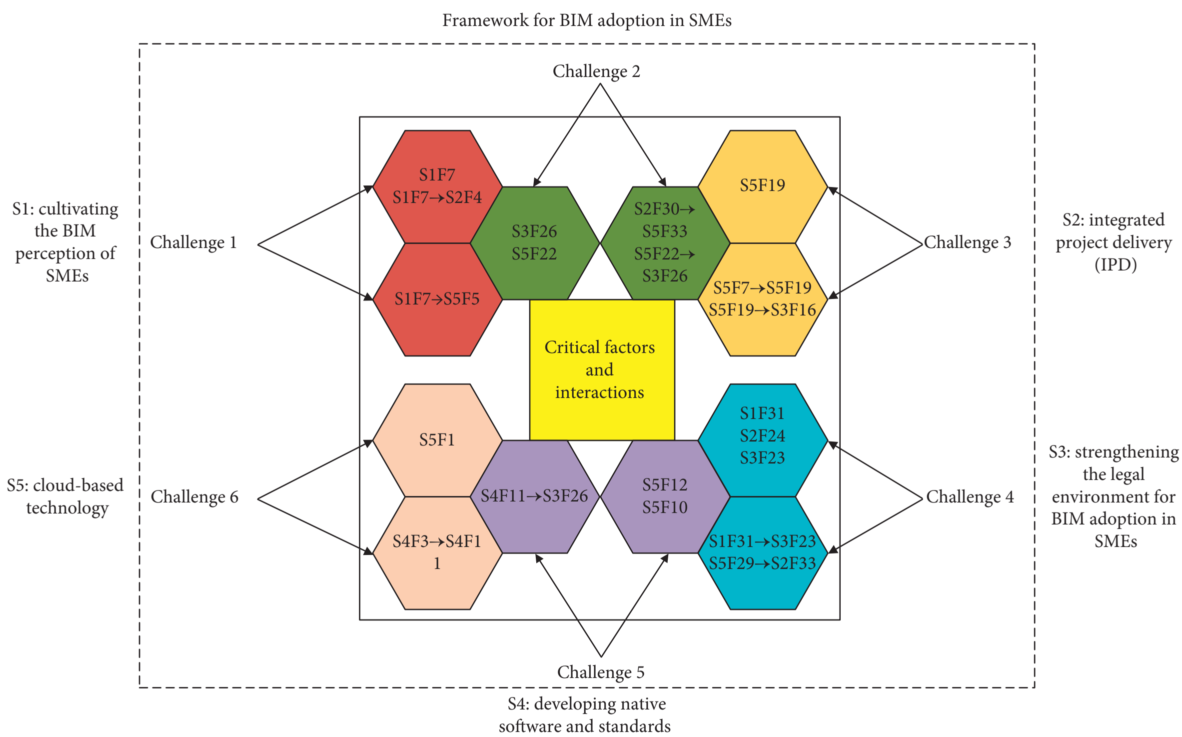

Figure 5: Framework for BIM adoption in SMEs.

can be adjusted in detail [76]. Besides, IPD also stimulates people to be involved in a project for the benefit of the entire project. BIM is more than a technical means with a social dimension, but it has no contractual authority to manage stakeholders. As a result, a formal infrastructure and a BIM manager are required to manage stakeholders across organisations.

5.2.3. Strategy 3: Strengthening the Legal Environment for BIM Adoption in SMEs. Resolving legal and contractual disputes is essential to SMEs. SMEs are more focused on immediate interests than large enterprises. When a potential risk exists, SMEs will select traditional project delivery over BIM to ensure the interests of the enterprises. BIM programmes are full of collaboration, in which individuals coordinate their work by using objects created or designed by others. Nevertheless, conventional legal instruments implemented to BIM project seldom accommodate the collaborative nature that is generated by BIM. When the design information is engaged in collaboration among numerous participants, identifying inaccurate responsibilities is vital. For instance, legislation can define the specific information that different actors are responsible for communicating. When the risk is equally shared through legislation, the return must be shared. Accordingly, part of the owner's savings must be shared with participating project members due to increased productivity. This aspect should be specified in the contract to facilitate BIM adoption by SMEs. As such, Challenge 4 (legal disputes and uncertainties in policies) can be governed.

5.2.4. Strategy 4: Developing Native Software and Standards. Software is a means for realising BIM application, but best results are only achieved when cross-disciplinary standards and platforms can be interoperable. The success of BIM adoption depends more on how a company combines BIM technology with their workflow than on how well prepared it is, thereby allowing teams to adapt to the technologies to suit their existing work practices [77]. From this point of view, without changing the existing building development approval process, a set of building code-related standards and software must be developed to assist SMEs to build the model correctly. If BIM-related software can automatically generate 2D drawings and related documents for building approval process, it will improve the adoption of BIM by SMEs. Establishing a BIM-based case library to fulfil local needs is also crucial. Well-documented experiences contribute to assessing achievements, problems, and challenges, thereby facilitating BIM adoption in SMEs. These strategies could play an important role in the mitigation of Challenge 5 (difficulties in meeting SMEs' needs).

5.2.5. Strategy 5: Cloud-Based Technology. Projects in construction industries often have a long life cycle, which involves quantitative data. Inserting, extracting, updating, and modifying data and ensuring the accuracy of data transmission in BIM model are important problems. Drawing on experience in other industries, software developers in BIM have moved towards cloud services to manage data. On the basis of the powerful computing and data-processing capability, embedding cloud technology in BIM can solve these problems. Interoperability issues can also be addressed as a cloud-based BIM solution will allow multiple BIM practitioners to work on the same version of BIM data [58]. Restricting password protection and assessing authority regulations can assure security and privacy that address users' concerns about security. Furthermore, cloud-based BIM enables users who have an Internet connection to synchronise their data on more than one device, such as personal computer and smart phone. In this way, infrastructure cost can be saved and bring convenience to SMEs. As a result, Challenge 6 (concerns about information and data) can be solved through this approach.

6. Conclusion

BIM adoption in SMEs is complicated, in which numerous stakeholders and various influencing factors are involved. In this paper, we list the factors that influence BIM adoption in SMEs on the basis of previous studies and interviews. We used SNA to investigate the underlying network of stakeholder-associated influencing factors and links and divided them into six challenges: (1) SMEs are short on resources, (2) collaboration challenges, (3) lack of BIM awareness, (4) legal disputes and uncertainties in policies, (5) difficulties in meeting SMEs' needs, and (6) concerns about data and information. We proposed five corresponding strategies, namely, cultivating the BIM perception of SMEs, IPD, strengthening the legal environment for BIM adoption, developing native software and standards, and cloud-based technology, to mitigate the challenges considering that removing these factors and links will greatly reduce network complexity.

The strategies provide a strong reference for building departments in China and software developers to apply appropriate approaches for increasing BIM adoption in SMEs. For example, related government departments can conduct training activities to improve BIM awareness in SMEs and mandate specific policies to address BIM disputes. For software developers, they can develop a local software to best suit China's current approval process.

The main limitations of this study are two. Firstly, a small-sample survey, which only covered 31 people, was used in this study due to the difficulty of researchers to find sufficient interviewees. The sample size may influence our results. Secondly, not all stakeholder groups involved in BIM adoption in SMEs were included in our study. Subcontractors, material suppliers, and mechanical, electrical, and plumbing workers are also stakeholder groups related to BIM adoption in SMEs. Therefore, a wider group of stakeholders should be invited to carry out follow-up studies.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

There are no conflicts of interest regarding the publication of this paper.

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