Constructing a BIM Climate-based Framework: Regional Case Study in China

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Abstract

BIM has been undergoing continuous growth in the global architecture, engineering, and construction (AEC) industry. However, knowledge development within BIM management is lagging behind its implementation. This study initiates a BIM management–based framework involving BIM climate, which is measured by individual BIM practitioners' perceptions. Subgroup comparison is highlighted in measuring perceptions. Regional variance in BIM climate is addressed in applying the framework by adopting an empirical case study within the context of China's AEC industry. The case study uses Shanghai and Wenzhou, which represent a BIM-leading metropolitan city and a BIM-developing counterpart, respectively, for the comparative analysis of BIM climate. Based on data collected from a questionnaire survey sent to BIM practitioners from these two cities, it is revealed that Shanghai, as the BIM-leading city in China, has somewhat significant differences in BIM climate compared with Wenzhou. For example, Shanghai BIM practitioners perceive fewer challenges in BIM training, but higher

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risk in adopting BIM technology. This study contributes to both academic work and practice in BIM based on its initiation of the concept of BIM climate and the case study of BIM-climate comparison. Academically, this holistic study proposes the BIM management–related knowledge framework aiming to fill the knowledge gap in BIM climate and culture, and it could be further applied in subclimates and subcultures within BIM. Practically, the case study provides insights to stakeholders regarding regional variations in BIM climate when promoting BIM practice or establishing BIM guidelines.

Keywords: Building Information Modelling (BIM); Analogical study; BIM climate; Digital technologies; BIM Culture; BIM management.

Introduction

Building information modelling (BIM), as the fast-growing digital technology worldwide, is undergoing increasing applications in the architecture, engineering, and construction (AEC) industry in developing countries such as China. Most influential studies in BIM have focused on its application and implementation (Yalcinkaya and Singh, 2015). Management-based research (e.g., collaboration) in BIM have not received the attention that it deserves (Oraee et al., 2017), although it has been emphasized as a core research area (He et al., 2017). Unlike other more traditional project management (PM) areas, such as safety, which has its well-established management system (MS) that is strongly related to safety climate and safety culture (Fernández-Muñiz et al., 2007), BIM has not been fully developed within its own knowledge system. There is still insufficient development of BIM-related MS, as well as BIM-based climate and culture within AEC individuals or organizations. Most existing management-based studies in BIM focused on the industry, company or project levels (e.g., Said and Reginato, 2018) while disregarding the impact of perceptions at the individual level

(Howard et al., 2017). Nevertheless, individuals' perceptions would build the climate in PM areas such as safety (National Occupational Research Agenda or NORA, 2008). Perceptions also have a direct effect on human behaviors (Dijksterhuis and Bargh 2001), which was identified by Lu et al. (2015) as a key issue in adopting information and communication technologies.

These two PM areas, safety and BIM, although at their different development stages of MSs, share some consistent contents within their knowledge bases. For example, individual perceptions (Cox and Flin, 2003; Howard et al., 2017) were both highlighted in the management of safety and BIM. Subgroup comparisons (Chen and Jin, 2015; Lee et al., 2015) were both indicated as key measurements for management within safety and BIM. Subgroup comparisons on perceptions of professionals from different regions has been tested by Chen et al. (2013) in safety management. Applied in BIM management, regional comparison has not yet been fully conducted, although it was considered important by Jin et al. (2017b). Although comparisons of BIM adoption among countries (e.g., Lee and Yu, 2016) have been performed, there have been limited studies addressing the regional differences within the same country's context (e.g., U.S., and China).

As the giant AEC market, China has its own regional differences in BIM practice due to its large geographic spread (Jin et al., 2017b). However, most previous empirical studies of BIM (e.g., Shenzhen Exploration & Design Association or SZEDA, 2013; Ding et al., 2015; Jin et al., 2017a) focused on BIM leading regions or cities in China. Insufficient work has been performed in investigating BIM climate in less developed counterparts. For example, Shanghai and Wenzhou, two metropolitan cities about 450 km apart from each other in south-eastern part of China, though not geographically distant, have not been studied or compared of their own BIM climate. It remains unclear whether different BIM user experience levels would cause significant regional variations in BIM climate. In recent years, policy-makers from less BIM-developed regions or metropolitan cities (e.g., Wenzhou) have been working on promoting BIM practice. Researchers believe that authorities from these less BIM developed metropolitan cities should have a better understanding of their home regions' BIM climate before establishing local BIM guidelines or standards. Since less BIM-developed regions represent the majority of China's population and its AEC market revenue, there is an urgent need to investigate how these regions practice BIM and how AEC individuals from these areas perceive BIM, compared to the few BIM-leading metropolitan cities or regions in China, such as Shanghai, Beijing, and Canton identified by Jin et al. (2015).

Through a holistic approach, this study aimed to fill the current knowledge gap in BIM by initiating the framework involving BIM climate defined by individual perceptions in BIM management. The initiated framework was then applied within the context of China's AEC market by adopting an empirical case study addressing the regional variation between two subgroup samples of BIM practitioners from two different metropolitan cities (i.e., Shanghai and Wenzhou). BIM climate was measured in this study based on how AEC practitioners perceived benefits, factors impacting BIM's successful application, challenges encountered in BIM implementation, as well as risks associated with BIM practice. The contribution of this study lies in that: 1) the knowledge framework involving BIM climate was initiated by proposing the new term (i.e., BIM climate); 2) the regional difference, as one of the subgroup categorization methods by extending the study of Jin et al. (2017a), was tested by an empirical case study; 3) practically, the comparative study between Shanghai and Wenzhou, representing the scenario of subgroup comparison between BIM-leading metropolitan cities and less BIM-developed counterparts within the same country, provides insights to policy-makers, AEC practitioners and other stakeholders when initiating new BIM standards or BIM-involved projects. Specifically, the BIM policy, guideline, or standards that have been adopted in China's BIM leading metropolitan cities may need to be adapted or adjusted before their implementation in less BIM-mature counterparts considering the local BIM climate; 4) this initial framework could be further expanded into future study from BIM climate to BIM culture within the organizational context.

Literature Review

Knowledge system within BIM management

A review of existing studies in both BIM and safety revealed that these two different PM areas are at different stages of knowledge system development. For example, these key terminologies within safety management, namely safety climate, safety culture, and safety management systems, have been widely applied in various studies (e.g., Fernández-Muñiz et al., 2007; Meliá et al., 2008; Jin and Chen, 2013). Safety climate was defined by Cox and Flin (1998) and NORA (2008) as workers' perceptions of the role of safety in the workplace and their attitudes towards safety. Safety culture is organizational principles, norms, commitments, and values related to the operation of safety and health (NORA, 2008), and is reflected in safety climate (Mearns et al., 2003). Similar terminologies within BIM management have not been fully developed or applied. However, comparing these two PM areas, highly similar measurement dimensions for both safety management and BIM management can be found, for example, individual perceptions in workplace (Cox and Flin, 1998; Lee et al., 2015;), perceptions of risks (Brown and Holmes, 1986; Jin et al., 2017b), and benefits or importance (Neal et al., 2000; Jin et al., 2017a). Besides, subgroup comparisons according to different categorization methods, such as professions (Zohar, 1980; Jin et al., 2017a), experience (Chen and Jin, 2013; Howard et al., 2017), and organization (Chen and Jin, 2015; Lee et al., 2015), can be found in both safety and BIM based management studies measuring individuals' perceptions. Perceptions of safety could be different depending on these aforementioned subgroup factors, such as in the study of Chen and Jin (2013). Similarly, the views of BIM may also depend on individuals' subgroup factors, such as job and perspective (Selçuk Çldlk et al., 2017). The management and coordination in both safety and BIM involve and require the multi-party coordination such as specialty contractors (Chen and Jin, 2015; Hanna et al., 2014). Education and training have been both implemented aiming to promote safe behaviors and BIM actions (Chen and Jin, 2012; Sacks and Pikas, 2013). These similarities between the two different PM areas infer that certain knowledge-based terminologies could be tailored from safety management to BIM-related management.

Perceptions towards BIM implementation

Perceptions towards BIM implementation can be generally categorized into benefits, factors influencing BIM practice, challenges, and risks in adopting BIM. It has been recognized from previous studies regarding benefits brought by BIM adoption, including financial savings, 3D visualization, reduction of design errors and rework, a better understanding of the project, improved collaboration among stakeholders, and decreased project duration (Migilinskas et al., 2013; Ahn et al., 2015; Poirier et al., 2017; Gholizadeh et al., 2018). To fully achieve these BIM benefits, several critical factors would play key roles in BIM implementation, including development of building information standards, planning and management, collaboration among project members, BIM expertise within project teams, legal issues relevant to BIM usage in the contract, project characteristics such as location, type and nature, budget (Race, 2012; Eadie et al., 2013; Cao et al., 2016; Papadonikolaki and Wamelink, 2017; Said and Reginato, 2018). During BIM implementation, multiple difficulties, challenges, and risks may be encountered, including but not limited to insufficient evaluation of BIM value, resistance at higher management levels due to cultural resistance, lack of demand from the client, lack of governmental policies or standards, high investment required; insufficient BIM training and education, organizational change and adjustment in management pattern, and insufficient understanding of BIM technology or practicability (He et al., 2012; Sackey et al., 2014; Tang et al., 2015; Lee and Yu, 2016; Çıdık et al., 2017). Perceptions of risks associated in implementing BIM due to these challenges were further investigated in multiple studies (e.g., Ahmad et al., 2018; Ham et al., 2018; Liao and Ai Lin Teo, 2018).

BIM movement in China

Although BIM movements in China has been facing problems such as the lack of well-developed standards and insufficient interoperability among project members (He et al., 2012), the governmental policies and industry standards announced in recent years would facilitate the increasing application of BIM in China's AEC industry (Jin et al., 2017a). According to Jin et al. (2015), China's BIM policy movement has undergone major steps since 2011, and more coherently since publishing the first BIM standard in 2012, then setting out the strategic objectives of BIM adoption in 2013, and proposing the BIM application crossing the whole project life cycle in 2014. As one of the few fore-runner metropolitan cities in BIM practice, Shanghai Municipal People's Government (2014) published the strategic objectives of promoting BIM application in Shanghai, mandating that government-funded projects must adopt BIM starting from 2017. Shanghai Housing and Urban-Rural Construction and Management Committee (SHURCMC, 2017) revealed that during 2016, 29% of new AEC projects in Shanghai had adopted BIM, and 32% of Shanghai-based AEC firms have achieved a higher maturity level of BIM implementation compared to the rest competitors in the local AEC market. The Committee further concluded that Shanghai had been in the leading level of BIM implementation in China. In contrast to Shanghai, other municipalities in China (e.g., Chongqing), was reported by Ministry of Housing and Urban-Rural Development (MHURD) of China (2017) as one of the three regions without any BIM-involved construction projects in the second quarter of 2017.

Research Design

A review of these existing studies related to BIM perceptions revealed that most of them have focused on the project or organizational level in perceiving BIM as both technological innovation and managerial challenge (e.g., Ahmed et al., 2018; Ham et al. 2018; Said and Reginato, 2018), but without addressing sufficiently the individual practitioners' perceptions. Although further studies have expanded from project or organization BIM perception to the individual level (e.g., Howard et al., 2017; Jin et al., 2017a), there are more influencing factors to be addressed in individual perceptions, such as regional difference proposed by Jin et al. (2017b). Overall, these earlier studies have not significantly contributed to the body of knowledge regarding the individual human factors in successful BIM implementation. The the design of this research was based on the individual perceptions of BIM practice by incorporating regional comparison. The rationale for addressing the regional comparison based on individual perceptions of BIM practice lie in: 1) contributing to the body of knowledge in managerial BIM by proposing BIM climate; 2) introducing the regional gap as an influencing BIM management stimulator (e.g., regional policy and guideline development); and 3) serving as the theoretical guide for future research by applying the developed BIM knowledge framework to other large construction markets (e.g., India and Vietnam). Both BIM and safety have relied on or refer to the concept of management as a substantial factor; BIM rather as a management tool and safety as an issue to be managed. More importantly both of them have the human factor (referred to as 'people' hereafter in the interest of better flow of argument and convenience) at their core with a major difference. While safety is determined (achieved or otherwise breached) due to people's behaviors/actions, its potential impact on people (and their personal and professional lives) is indisputable and probably far more substantial with more long-lasting effects. BIM by slight contrast is highly dependent on people and their attitudes towards it as to how seriously/fundamentally or otherwise they take it on board, commit to or comply with its preliminaries, processes, requirements and changes it entails in the working culture and working ethos in the AEC industry. It will of course have some reciprocal impact on people, their professional practice and other aspects overarching personal to interpersonal and organisational culture, in return.

When it comes to interrelationship between BIM and safety, this link is one way meaning that the research suggesting BIM can and/or will have an impact on safety is not few and far between (e.g., Park and Kim, 2013; Zhang, et. al, 2013; Riaz, et. al, 2014; Zhang, et. al, 2015a; Zhang, et. al, 2015b; Ding, et. al, 2016; Kim, et. al, 2016; Malekitabar, et. al, 2016; Martínez-Aires, et. al, 2018) among many others), but there is almost nothing to suggest the other way round. This research aims to lay the foundation for reciprocation of this one way interrelationship between BIM and safety by suggesting that what has been trialled (and to a very reasonable extent proven to be credible) in safety may be applicable to BIM to suggest a similar context (i.e. climate) for BIM, like what it is in safety. This has been the working hypothesis of this study building upon a ‘testing theory’ approach in this paper and is yet subject to further investigation in the future. However, in the meantime it remains to be a potentially valid theory under development. Fig.1 illustrates the rationale behind the research design for this study.

<Insert Fig.1.>

Methodology

Based on a thorough literature review of BIM management-based studies and tailoring the culture/climate theories from safety management into BIM management, the research first proposed a theoretical framework demonstrating how individual BIM practitioners’ perceptions would contribute to BIM climate, which would further reflect the BIM culture. The framework linking individual perceptions to climate and culture mapped the knowledge base from safety to BIM by aligning measurement dimensions (e.g., workplace perceptions) between these two management systems. The workflow of this study can be illustrated in Fig.2.

<Insert Fig.2.>

In the framework involving BIM climate illustrated in Fig.2, subgroup comparisons (e.g., employees from different professions or regions) were highlighted and formed the holistic picture of both safety and BIM management systems. The establishment of the initial framework in BIM management would hence be linked to testing subgroup variations. Continued from the subgroup tests conducted by Jin et al (2017a) and Jin et al (2017b), the follow-up research adopted an empirical case study by investigating regional variations of BIM-related individual perceptions. The case study was based on the regional comparison in terms of individual perceptions towards BIM implementation between two samples from Shanghai and Wenzhou, which were two metropolitan cities in China. Shanghai has been identified by multiple sources (e.g., Jin et al., 2015; SHURCMC, 2017) as one major BIM-leading metropolitan city. Wenzhou was chosen as the other sample in the case study to represent the less BIM developed metropolitan cities, based on the fact that BIM has been gaining some early-stage applications in a few pilot projects in Wenzhou in recent two years. A few large AEC firms in Wenzhou has been actively implementing BIM in their new projects. The research team's earlier pilot studies also indicated that both AEC practitioners and the governmental authority have been working on promoting BIM usage in order to enhance the adoption of digital technologies in Wenzhou's AEC market. However, the local BIM climate in less BIM-developed regions (e.g., Wenzhou) has not been studied. Therefore, the two samples (i.e., Shanghai and Wenzhou) were selected to represent a BIM-developed region and a BIM-developing region in this case study to fulfil the regional variation factor within the initiated framework in Fig.3. The researchers also believed that comparison between the two metropolitan cities would provide the big picture of the similarities and differences in the BIM climate between BIM leading regions and less mature counterparts.

According to Fig.2, a questionnaire survey based approach was adopted in the case study to collect information regarding individual perceptions towards BIM implementation among AEC practitioners from Shanghai and Wenzhou. Questionnaire survey has been adopted in

BIM perception-related studies (e.g., Ding et al., 2015; Cao et al., 2016). A follow-up comparative statistical analysis was conducted to investigate the consistencies and differences in BIM climate between Shanghai and Wenzhou.

Questionnaire survey

The questionnaire was used with two major types of questions (i.e., multiple-choice and Likert-scale). These questions were divided into two sections as can be seen in the Appendix. The first question in Part A was to ensure participants worked in Shanghai or Wenzhou metropolitan areas. Those who did not work in Shanghai or Wenzhou were excluded from the survey sample. The remaining questions in Part A focused on the professional background of survey participants, including their profession, years of using BIM, and types of BIM software tools being adopted by them. Part B of the questionnaire investigated perceptions of survey participants towards the benefits of adopting BIM, factors impacting BIM application, challenges encountered in BIM implementation, and risks associated with implementing BIM. The survey data collection approach was consistent as that in Cao et al. (2016). The questionnaire was peer-reviewed by AEC industry professionals in Shanghai and Wenzhou and finalized in mid-June 2017.

Sampling

Between July and August in 2017, the research team delivered the anonymous questionnaires in both Shanghai and Wenzhou through local BIM related networking events such as workshops and seminars. The research team also visited local major AEC firms that were known for actively implementing BIM to collect more questionnaires from these firms' employees. The sampling strategy in this research leaned towards purposive sampling, but did not intend to construct the sample size to ensure a more desirable outcome. Therefore, as the samples were picked up in specialized BIM communities and practices in both cities where BIM enthusiastic professionals were expected to attend, the sampling was not stratified any further. The fact of the matter was that Shanghai samples were significantly more experienced compared with Wenzhou samples and this was a fair representative of the population in corresponding cities. All BIM capable companies in Wenzhou were present in the sampling event, no further pool could be targeted for data collection. Manipulation of samples was strictly avoided because otherwise this would have potentially biased the construct of the sample, structuring an unrepresentative sample of the population which would have distorted the findings.

Statistical analysis

Three major types of statistical methods were adopted in the comparative study, namely Chi-squared test, *RII* analysis, and the two-sample *t*-test.

Chi-square test

For multi-choice questions, including those related to types of BIM software tools being used, perceptions towards project parties benefited from BIM, as well as risks associated with BIM implementation, the Chi-Square test of independence described in Johnson (2005) was adopted to study the consistency of survey participants between Shanghai and Wenzhou. The Chi-square values and corresponding *p* values were computed following the procedure recommended by Campbell (2007) and Richardson (2011). Based on a *5%* level of significance and the null hypothesis that Shanghai and Wenzhou participants had consistent percentages of choosing the given question item related to BIM, a *p* value lower than *0.05* would reject the null hypothesis and suggest statistically different percentages between Shanghai and Wenzhou participants in selecting the given item.

RII

For Likert scale questions related to BIM benefits, factors affecting BIM practice, and difficulties encountered in BIM implementation, the Relative Importance Index (*RII*) was adopted to rank multiple items within each question. The *RII* values were calculated based on

Eq.(1) which was previously used by other studies (e.g., Eadie et al., 2013; Jin et al., 2017c).

$$RII = \frac{\sum w}{A \times N} \qquad \text{Eq. (1)}$$

where *w* stands for the Likert score chosen by each survey participant for every item. It ranges numerically from 1 to 5. *A* is the maximum value that can be assigned to a Likert-scale item and it is equal to 5 in this study. *N* denotes the number of responses. The *RII* value ranges from 0 to 1. An item with a higher *RII* score would indicate that it ranks higher within the given section, meaning its relatively higher importance.

Cronbach's Alpha

The Cronbach's Alpha value (Cronbach, 1951) was adopted in this study to evaluate the internal consistency of Likert-scale items in each of the three sections within this study (i.e., BIM benefits, critical factors, and challenges). These internal consistency analyses were carried out for Shanghai, Wenzhou, and the combined samples. With the value ranging from 0 to 1, and a higher value would indicate a higher degree of internal consistency among items. According to George and Mallery (2003), the overall Cronbach's Alpha value over 0.700 would be considered acceptable, the value over 0.800 indicates a good internal consistency, and its value higher than 0.900 is deemed excellent. Besides the overall value within each Liker-scale section, an individual Cronbach's Alpha value with corresponding Item-total Correlation indicate the individual item's contribution to the overall consistency. An individual Cronbach's Alpha value lower than the overall value means that this item contributes positively to the overall consistency. Otherwise, an individual value higher than the overall value suggests that respondents are more likely to perceive differently towards this given item as they normally do to the remaining items.

Two-sample t-test

The two-sample *t*-test, as one type of parametric method, was adopted in this study to test the mean values between Shanghai and Wenzhou survey participants for each Likert-scale item.

Parametric methods have been previously applied in the field of construction engineering and management in studies including Aksorn and Hadikusumo (2008), Meliá et al. (2008), and Tam (2009). Carifio and Perla (2008) and Norman (2010) demonstrated the robustness of parametric methods in data samples that were either small or not normally distributed. The sample sizes of 47 for both Shanghai and Wenzhou survey pools were considered fair in this study. The two-sample *t*-test was based on the null hypothesis that Shanghai and Wenzhou survey samples had consistent views on the given Likert-scale item. Assisted by Minitab, the statistical software, a *t* value was computed for each item within the Likert-scale questions and the corresponding *p* value was obtained. A *p* value lower than 0.05 would decline the null hypothesis and indicate that the Shanghai and Wenzhou survey participants had different views on the given item within BIM climate.

BIM climate and culture framework

A thorough literature review of safety management and BIM management related studies is summarized in Table 1, in which measurement dimensions are listed to enable the comparison between safety and BIM.

<Insert Table 1>

Following Table 1, it could be indicated that these two independent PM areas (i.e., safety management and BIM management) share highly consistent dimensions, such as individual perception which is a key measurement for climate in safety management. The individual perceptions covered multiple categories such as importance or benefits, risks, and factors affecting the implementation in both safety management and BIM management. These individual perceptions have been studied by subgroup comparisons in both safety and BIM as showcased in Fig. 3.

<Insert Fig.3.>

It can be seen in Fig.3 that safety management and BIM management also share some consistent subgroup categorizations, for example, subgroups divided according to professions, experience, and organization, which constitute the individual perceptions to form the climate. The subgroup variation among BIM practitioners was studied by Jin et al. (2017a), who found out that generally BIM practitioners from different AEC professions held consistent perceptions towards benefits introduced by BIM and challenges faced within BIM practice. The only exception was that consultants, clients, and architects perceived more challenges for entry-level AEC employees to accept BIM practice compared to engineers, contractors, and software developers according to Jin et al. (2017). The framework was established from existing studies listed in Fig.3 in both safety and BIM.

Literature listed in Table 1 indicates that compared to BIM, safety has a better-established knowledge system with existing studies traced to 1980s or earlier. In contrast, BIM remains a relatively new area with most management related studies performed in recent years. There has not been well-established BIM-related knowledge in terms of climate or culture. Due to the similarities between safety and BIM in terms of measurement dimensions and subgroup comparison, researchers initiated the framework by tailoring safety related climate and culture into that in BIM. Specifically, BIM climate and BIM culture are proposed in Fig.3, following the concepts of safety climate and safety culture. Individual perceptions consisting of subgroup comparisons are also proposed to define BIM climate, which, together with BIM culture, can also be divided into sub-climate and sub-culture respectively.

BIM climate is defined based on individual perceptions on BIM implementation and relevant attitudes. In this study, four major categories are incorporated into individual perceptions, namely benefits, influencing factors, challenges, and risks following Jin et al. (2017a) and Jin et al. (2017b). According to Fig.3, subgroups categorized by profession, experience, and organization have been studied before, but not the regional difference as it has been in safety. To fill the gap of regional variation analysis in BIM climate, the follow-up empirical case study analyzes the individual perceptions between two different regions in China's AEC market.

Case study of regional difference in individual perceptions towards BIM

By the end of August 2017, 55 and 51 questionnaires in total were collected from Shanghai and Wenzhou respectively. The valid sample sizes were further reduced to 47 for Shanghai and 47 for Wenzhou, by excluding some respondents who chose the same answer for all Likert-scale items, following the procedure described by Smits et al. (2017). The comparative study was conducted consisting of these major sections, namely background information of survey participants, perceptions on BIM benefits, factors impacting BIM implementation, challenges in BIM practice, project parties that benefited the most and the least from BIM, and risks in implementing BIM.

Background information of survey participants

The background information of respondents includes their professions and experience of BIM usage. Table 2 summarizes the percentages of different AEC professions in Shanghai and Wenzhou samples.

<Insert Table 2>

Table 2 conveys the information that there was a wider distribution of professions among Shanghai respondents compared to Wenzhou participants, the majority of whom were architects and engineers. The average years of using BIM in the combined sample, Shanghai, and Wenzhou were 2 years, 3 years, and 9 months respectively. Both the average value and box plots Shown in Fig.4 convey the information that the survey participants in Shanghai had more BIM experience than Wenzhou respondents.

<Insert Fig.4>

It could be indicated that Shanghai, as one of China's BIM-leading metropolitan cities, had more BIM practical experience compared to Wenzhou, representing one of the less developed metropolitan cities in China. The majority of Wenzhou respondents were at the early stages of applying BIM in their AEC projects or at the stage of planning to adopt BIM in the near future. Table 3 lists the percentages of Shanghai and Wenzhou survey participants in using each BIM software tool. Some differences between Shanghai and Wenzhou respondents can be found according to the Chi-square test results.

<Insert Table 3>

The overall chi-square value computed at 28.080 with the corresponding *p* value at 0.000 indicate that Shanghai and Wenzhou had been using different BIM software tools. Specifically, although products of Autodesk (2017) such as Revit received the highest percentages among respondents from both Shanghai and Wenzhou indicating its dominance in China's AEC market, Shanghai had 91% of its respondents using Autodesk (2017), significantly higher than 49% in Wenzhou. Table 3 also revealed that compared to Shanghai, Wenzhou had significantly higher percentage of its participants using Glondon (2017), a domestic BIM software tool. Besides, Wenzhou also had a statistically higher percentage of respondents who had never used any BIM software before. Other software tools being used by Shanghai respondents included Dassualt (2017), whilst Wenzhou respondents specified "others" to be Hongye (2017) which were both domestic products. It could be inferred from Table 2 that Shanghai's BIM practitioners were more prone to use international BIM tools such as Autodesk (2017), Bentley (2017), and Dassualt (2017). Differing from Shanghai, Wenzhou BIM practitioners were more likely to adopt China's domestic BIM tools (e.g., Hongye, 2017).

Perceptions towards benefits in adopting BIM

In this section, survey participants were asked for their opinions on benefits of implementing BIM by choosing a numerical value from *1* to *6* for each Likert-scale item. With *1* indicating “strongly disagree”, *3* meaning “neutral”, *5* standing for “strongly agree”, and an extra option *6* given for those who were unsure of the answer, totally 13 Likert-scale items were included as shown in Table 4. Excluding the answers of *6*, the mean values and *t*-test results are presented in Table 4.

<Insert Table 4>

All *p* values higher than 0.05 in Table 4 indicate that Shanghai and Wenzhou respondents generally had consistent views on the benefits of adopting BIM. However, it seems that Wenzhou respondents had even more positive views on BIM benefits compared to Shanghai, because six out of 13 items (i.e., B1: reducing omissions and errors; B2: reducing rework; B3: better project quality; B4: offering new services; B5: marketing new business; and B6: increasing profits) received mean scores over 4.00, indicating Wenzhou respondents' perception between “agree” and “strongly agree” towards these six items. In comparison, only four items (i.e., B1, B2, B3, and B4) received mean scores higher than 4.00 among Shanghai respondents. The *RII* values, rankings, and internal consistency analysis listed in Table 5 would further indicate respondents' perceptions towards these 13 BIM benefit-related items.

<Insert Table 5>

According to Table 5, reducing omissions and errors in design and construction was ranked as the top benefit of using BIM among both Shanghai and Wenzhou respondents. Other highly ranked benefits from both Shanghai and Wenzhou groups included reducing rework, better project quality, and offering new services (e.g., BIM consultancy). Fewer claims/litigations and recruiting/maintaining employees were the two lowest ranked items marked by both Shanghai and Wenzhou respondents. The high overall Cronbach's Alpha values shown in Table 5 indicate that Shanghai, Wenzhou, and the combined sample had good or excellent internal consistencies, meaning that a survey participant who chose one numerical Likert scale score to one BIM benefit-related item would be more likely to have a similar opinion on other items in Table 5. All individual Cronbach's Alpha values lower than the overall value for both Shanghai and the combined groups indicate that Shanghai respondents and the overall sample tended to have high internal consistency in viewing these BIM-benefit-related items. Exception were found in the Wenzhou sample, who perceived differently towards B2 and B13. Wenzhou respondents generally perceived high benefits of BIM in reducing rework and lower benefits of BIM in recruiting and retaining employees.

Perceptions towards factors influencing BIM implementation

Following the empirical study of benefits that could be achieved through BIM usage, the question was also asked as to what factors play key roles for successful BIM implementation in AEC projects. Totally 14 factors were generated and listed in Table 5. Survey participants were asked to assign a numerical score to each factor. The numerical score ranges from *1* to *6*, with *1* indicating "least significant", *2* being "insignificant", *3* meaning "neutral", *4* indicating "significant", *5* referring to "most significant", and *6* given for those who were unsure of the answer. Excluding those who chose *6*, all the rest numerical answers were incorporated for the two-sample *t*-test as well as *RII* and internal consistency analysis as presented in Table 6 and Table 7.

<Insert Table 6 here>

It can be seen from Table 6 that Shanghai and Wenzhou survey participants generally held consistent views on these factors influencing BIM applications, except F4 (i.e., clients' knowledge of BIM). Shanghai respondents perceived F4 a more significant influencing factor for BIM implementation, with the mean score above 4.00. Wenzhou respondents had the mean score of 3.60, showing the opinion between "neutral" and "significant".

<Insert Table 7>

From Table 7, it can be further indicated that F1 (i.e., interoperability among BIM tools) was ranked as the top factor for successful BIM application in both Shanghai and Wenzhou respondents. Interoperability in BIM tools was also perceived as a major factor in BIM implementation in the earlier study of Jin et al. (2017a). Besides F1, F3 (i.e., project complexity) was another factor perceived with high priority by both Shanghai and Wenzhou respondents. Other factors ranked higher by Shanghai respondents with *RII* value 0.800 (equivalent to mean score of Likert-scale item higher than 4.00) included F2 (number of BIM knowledgeable professionals on the project team). Nevertheless, Wenzhou respondents perceived F9 (project schedule) with a higher priority. Some less significant factors perceived by both Shanghai and Wenzhou respondents included F12 (project size), F13 (project location), and F14 (whether different staff within the same project work in the same location). Overall Cronbach's Alpha values indicate good internal consistency among all the 14 items. There was only one item (i.e., F2) that was perceived differently in both Shanghai and Wenzhou respondents. The low Item-total Correlation value and higher Cronbach's Alpha value for F2 mean that survey participants' perceptions of number of BIM - knowledgeable professionals were not correlated to their views on other items.

Perceptions towards challenges encountered in BIM implementation

Besides identifying the factors that significantly affect BIM's successful application, the research team also investigated difficulties or challenges encountered in BIM implementation. Nine Likert-scale items were asked in this category, with *1* meaning "very easy to overcome the given challenge", *2* indicating "not hard to overcome", *3* being "neutral", *4* referring to "difficult to overcome", *5* being "most difficult to overcome", and the extra *6* meaning "not sure of the answer". The responses of *6* were excluded from the statistical analysis, and the remaining numerical options for each item were calculated and summarized in Table 8 and Table 9.

<Insert Table 8>

Table 8 revealed that although generally Shanghai and Wenzhou respondents had consistent views on the difficulties associated with practising BIM, they held different opinions on the challenges related to effective training of BIM. Specifically, Shanghai respondents did not perceive BIM training as a barrier in BIM practice, but Wenzhou respondents held somewhat "neutral" view on BIM training.

<Insert Table 9>

Table 8 and Table 9 indicated that none of these items were perceived difficult to overcome, as all items had Likert-scale mean scores below 4.00 and *RII* values below 0.800. The difficulty ranked highest by both Shanghai and Wenzhou respondents was D1, which referred to the sufficient evaluation of BIM value in AEC projects. Wenzhou respondents held the views between "neutral" and "difficult to overcome" for all the nine items. In contrast, Shanghai respondents perceived the following factors between "not difficult to overcome" and "neutral": D5 (lack of governmental regulation), D6 (cost upgrading hardware), D7 (cost of purchasing BIM software), D8 (cultural acceptance of BIM from entry-level staff), and D9 (effective BIM training), possibly due to the more established and longer history of BIM implementation in Shanghai compared to Wenzhou. All Cronbach's Alpha values over 0.800 infer that all the three samples in Table 9 had good internal consistencies. However, exceptions were found in all of these samples. Shanghai respondents and the combined sample perceived D5 (i.e., lack of government regulation) differently as they normally did to other items. Wenzhou respondents held different views on D4 and D9. Basically, Wenzhou respondents were more likely to perceive more difficulties of the lack of client requirements and less challenges in effective training as they typically did to other challenge-related items in Table 9.

Perceptions on the risks associated within BIM practice

Survey participants were also asked to rank their perceptions of risks associated with implementing BIM. These risks were categorised into technical risks from T1 to T4, human resource related risks from H1 to H4, financial risks from E1 to E3, management risks from M1 to M3, and other risks from O1 to O4. The description of each risk item is provided in Table 10.

<Insert Table 10>

Some risk items which received significantly different percentages between Shanghai and Wenzhou respondents include: 1) a significantly higher percentage (25%) of Wenzhou respondents considered applying BIM technology itself a major risk; 2) more Shanghai respondents (63%) considered the adoption of BIM technologies in their own AEC projects a major risk, compared to 36% for Wenzhou; 3) a significantly higher percentage (81%) of Shanghai respondents perceived the adaptation of management pattern due to BIM implementation a main risk.

Risks perceived with higher percentages of Shanghai and Wenzhou respondents included M3 (the transition of management pattern), H2 (lack of BIM knowledgeable employees), O4 (lack of industry standards), T1(problems within BIM software), and E2(uncertainty within profit brought by BIM). All these risks were perceived by more than half of respondents in both Shanghai and Wenzhou, across all categories related to technical, human resources, financial, management, and other risks. It is indicated that successful implementation of BIM in AEC project would require a multi-criteria risk assessment method.

Research Findings and Discussion

A thorough literature review suggested that compared to other PM areas such as safety, there had not been sufficient development of BIM management-based knowledge framework. Due to the highly consistent measurement dimensions and subgroup comparison between safety and BIM, researchers first initiated the framework within BIM management by mapping safety related knowledge into that in BIM. BIM climate and BIM culture were proposed in the framework. Individual perceptions which defined BIM climate were measured by subgroup consistency and variations. To apply the initiated framework, an empirical case study highlighting regional variations of individual perceptions of BIM implementation was conducted within the context of China's AEC industry. As suggested by Jin et al. (2017b), China has large regional variations in BIM implementation and lessons learned from BIM-leading regions (e.g., Shanghai) could provide guides for less BIM-developed regions. This study adopted the hypothesis that different metropolitan cities had inconsistent BIM climate defined by individual perceptions. Shanghai and Wenzhou were adopted as two samples for the comparative analysis of BIM climate in this research. Shanghai, due to its more developed BIM market in terms of both policy movement and AEC industry practice, had its BIM practitioners covering a wider range of different AEC professionals. Wenzhou, due to its less developed BIM market, had its BIM users limited to architects and engineers. It could also be inferred that Shanghai respondents were more likely to adopt international BIM software tools such as Autodesk (2017), Bentley (2017), and Dassualt (2017). In contrast, Wenzhou's BIM users had higher percentages in adopting domestic software tools (e.g., Glondon, 2017; Hongye, 2017). The reason could be due to the fact that Shanghai is a more international and a diverse metropolitan city, with more overseas AEC firms and BIM software developers (e.g., Autodesk, 2017) establishing their regional offices there.

Although Shanghai and Wenzhou respondents held consistent views on most Likert-scale items related to benefits offered by BIM, factors impacting BIM's successful application in AEC projects, and challenges encountered in BIM implementation, survey participants from Shanghai perceived clients' knowledge on BIM a more significant factor impacting BIM application. This could be due to the fact that compared to Wenzhou respondents, Shanghai BIM practitioners were more experienced and had a deeper understanding of what factors were important for BIM to be successfully implemented. Also it was found that Wenzhou respondents perceived BIM training more a challenge compared to Shanghai respondents. This could be because of less BIM experience that Wenzhou respondents had, as previously identified by Jin et al. (2017a) that gaining more BIM experience would change AEC practitioners' mindset regarding the significance of the challenge pertaining to BIM training. Moreover, as Shanghai is more BIM-developed with more training resources available, those BIM practitioners from Shanghai would tend to perceive less difficulty in BIM training and education. It was also understandable that Shanghai respondents perceived less difficulties of lacking governmental BIM regulation compared to Wenzhou counterparts, as Shanghai was one of the BIM active cities in China with better established government policy support.

The internal consistency analyses for Shanghai, Wenzhou, and the combined sample generally indicated satisfactory internal consistency for respondents' perceptions towards BIM benefits, critical factors, and challenges encountered in BIM practice. Nevertheless, Wenzhou respondents had relative lower internal consistency compared to their peers from Shanghai. Specifically, they were more likely to perceive: 1) more BIM benefits in reducing rework; 2) fewer benefits in recruiting and retaining AEC employees; 3) more challenges in lack of client requirements; and 4) a lower degree of challenge from lack of effective training as they would view other challenge-related items. It was inferred that Wenzhou had less developed BIM market with less sophisticated clients requiring BIM adoption. Shanghai respondents tended to perceive more crucial of BIM-knowledgeable professionals on project teams.

Significant differences between Shanghai and Wenzhou respondents were also found in perceiving risks associated with BIM implementation. Specifically, more Wenzhou respondents considered the understanding and application of BIM technology itself a major risk, while more Shanghai respondents perceived the adaptation of BIM technology in their own AEC projects, as well as the adjustment of PM pattern due to BIM application as major risks. The differences in perceiving these three risk items between Shanghai and Wenzhou respondents could also be explained by the different BIM maturity levels and experience between these two metropolitan cities. As Shanghai BIM users had more experience in adopting BIM in their AEC projects, they would tend to experience more risks from PM level and how BIM could better be adapted into their own AEC projects (e.g., interoperability among different BIM tools in one single project). As Wenzhou practitioners were mostly at beginning stages of learning and gradually applying BIM, they were more likely to view more risks in understanding and adopting the BIM technology. Although Shanghai represents regions with leading BIM practices in China, they still perceived, consistently with their Wenzhou counterparts, the lack of industry standard as one major risk in practicing BIM. It was also inferred that multiple risks covering technical, human resources, financial, management, and other aspects should be considered for successful implementation of BIM.

The established BIM climate-based framework was applied to comparison between subgroups from different regions. The regional variation in BIM experience levels in this empirical study was found correlated to certain degree of differences in BIM climate. Following the framework described in Fig.2, future studies of BIM implementation could expand the current individual perception-based BIM climate to organization-based BIM culture.

Conclusions

This study adopted a holistic approach by first initiating a BIM climate-involved framework aiming to fill the current knowledge gap in BIM-related management, followed by an empirical case study applying the framework. In the empirical study, BIM climate, which was measured by AEC practitioners' perceptions towards benefits, influencing factors, challenges, and risks related to BIM implementation, was studied addressing the subgroup comparisons for BIM users from different regions within the context of China's AEC industry. Individual perceptions were compared between Shanghai and Wenzhou, which represented a BIM-leading city and a less BIM-mature metropolitan area respectively. The questionnaire survey revealed that Shanghai respondents had more BIM experience in terms of years of BIM usage than their Wenzhou counterparts. Some significantly different perceptions of BIM, such as the difficulty of sufficient BIM training, the risk of adopting BIM technology, and the risk of properly adjusting project management pattern, could be explained by the fact that Shanghai, as one of the few BIM leading metropolitan cities in China, had a wider BIM application in its AEC projects. The comparative analysis between Shanghai and Wenzhou served as a case study of regional comparison in the established BIM climate related framework. It was concluded from this case study that regional variations caused by different BIM experience levels would result in different BIM climate. The empirical study could be further extended to investigate BIM climate in other countries with regional variations. The initiated BIM knowledge framework could be further developed by incorporating more subgroup comparisons and organization-based BIM culture.

The contribution of this study is two-fold, from both scholarly and practical perspectives. In the scholarly aspect, the study initiated the framework for linking BIM climate to BIM culture. The proposed BIM climate measured by individual perceptions addressing regional comparisons contributes to the existing knowledge within managerial BIM. The framework can be applied to the context of BIM climate in other countries; practically, the comparative study suggests that policy makers and other stakeholders that work on promoting BIM usage and establishing BIM standards/guidelines should consider the local BIM climate, as those metropolitan cities (e.g., Wenzhou) with less BIM experience may have different BIM climate.

This study would lead to future research in: 1) continuous development of BIM climate and BIM culture within BIM knowledge system; 2) the effects of AEC organization size in individual perceptions; 3) extension of BIM climate to BIM culture within the organizational context; and 4) sub-culture within BIM management considering social, economic, and environmental dynamics.

Data Availability Statement

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

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Supplemental Data

The questionnaire is available on-line in the ASCE Library (ascelibrary.org).

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Table 1. Measurement dimensions within safety and BIM

Safety culture/climate dimensions	BIM management related dimensions
Employees' perceptions of safety management and workplace safety (Cox and Flin, 1998)	Individual perceptions on BIM management and practice (Lee et al., 2015)
Safety procedure/policies/rules (Chen and Jin, 2012)	BIM standards/guidelines (Jin et al., 2015)
Perception of risk (Brown and Holmes, 1986)	Perception of risks in BIM implementation (Jin et al., 2017b)
Safety training (Zohar, 1980)	BIM training and education (Jin et al., 2017d)
Communication/collaboration (Loushine et al. 2006)	Communication/Collaboration in BIM (Oraee et al., 2015)
Employee involvement (Mearns et al., 2003)	Personal involvement (Ku and Taiebat, 2011)
Work environment (Varonen and Mattila, 2000)	Working environment (He et al., 2017)
Management attitudes/commitments (Dedobbeleer and Béland, 1991)	Attitudes/leadership (Liu et al., 2017)
Importance of safety (Neal et al., 2000)	BIM benefits and importance (Jin et al., 2017a)
Safety implementation (Cabrera et al., 1997)	BIM implementation (Zheng et al., 2017)

Note: Only one reference is included as an example to define each dimension for safety and BIM. More examples from previous studies could be found for each measurement dimension.

Table 2. Percentages of AEC professions in survey samples

	Architects	Engineers	Consultants	Contractors	SD[1]	Others[2]	Sum
Shanghai (N=47)	13%	28%	15%	13%	9%	23%	100%
Wenzhou (N=47)	34%	62%	2%	0%	0%	2%	100%
Overall (N=94)	23%	45%	9%	6%	4%	13%	100%

[1]: SD stands for Software developer

[2]: Other professions within the survey sample includes academics, material supplier, and AEC companies' administration and management staff.

Table 3. Comparison of percentages of respondents in adopting each BIM software tool between Shanghai and Wenzhou

	Shanghai (%)	Wenzhou (%)	Chi-squared value	*p* value
Nemetschek (e.g., ArchiCAD)	7	11	0.429	0.513
Autodesk (e.g., Revit)	91	49	18.395	**0.000***
Bentley	9	4	0.909	0.341
Glondon	0	31	15.994	**0.0001***
Others	20	13	0.784	0.376
Never used BIM	5	27	7.872	**0.005***

*: *p* value lower than 0.05 indicates significantly different percentages of Shanghai and Wenzhou respondents in using the certain type of BIM tool

Table 4. Survey results of perceptions on Benefits in BIM adoption

	Shanghai respondents		Wenzhou respondents		Statistical test results	
Benefits	Mean	Std	Mean	Std	*t*	*p*
B1. Reducing omissions and errors	4.57	0.90	4.68	0.47	0.74	0.461
B2. Reducing rework	4.25	1.14	4.61	0.62	1.80	0.076
B3. Better project quality	4.33	0.93	4.55	0.59	1.29	0.201
B4. Offering new services	4.27	1.01	4.29	0.65	0.12	0.902
B5. Marketing new business	3.84	1.15	4.22	0.85	1.68	0.097
B6. Easier for newly-hired staff to understand the ongoing project	3.93	1.04	3.95	0.91	0.10	0.923
B7. Reducing construction cost	3.88	1.00	3.83	0.91	0.24	0.809
B8. Increasing profits	3.80	1.00	4.05	0.78	1.30	0.196
B9. Maintaining business relationships	3.75	0.94	3.86	0.98	0.52	0.607
B10. Reducing overall project duration	3.73	1.16	3.90	0.80	0.79	0.429
B11. Reducing time of workflows	3.80	1.17	3.57	0.97	0.97	0.34
B12. Fewer claims/litigations	3.64	0.97	3.41	0.72	1.22	0.226
B13. Recruiting and retaining employees	3.30	0.94	3.38	0.63	0.42	0.676

Table 5. RII-based ranking of BIM benefit items

	Shanghai Respondents Overall CA* Value: 0.918				**Wenzhou Respondents Overall CA Value: 0.809**				**Overall sample Overall CA Value: 0.897**			
Item	*RII*	Rank	ITC*	CA	*RII*	Rank	ITC	CA	*RII*	Rank	ITC	CA
B1	0.914	1	0.610	0.913	0.936	1	0.332	0.805	0.925	1	0.567	0.890
B2	0.850	4	0.592	0.915	0.922	2	**0.200**	**0.813**	0.885	3	0.524	0.893
B3	0.866	2	0.683	0.911	0.910	3	0.361	0.802	0.887	2	0.625	0.888
B4	0.854	3	0.693	0.910	0.858	4	0.468	0.794	0.855	4	0.640	0.887
B5	0.768	7	0.554	0.915	0.844	5	0.416	0.798	0.802	5	0.532	0.892
B6	0.786	5	0.694	0.910	0.790	7	0.532	0.788	0.788	6	0.635	0.887
B7	0.776	6	0.657	0.911	0.766	10	0.716	0.770	0.772	8	0.662	0.886
B8	0.760	8	0.705	0.910	0.810	6	0.483	0.793	0.783	7	0.647	0.887
B9	0.750	10	0.643	0.912	0.772	9	0.613	0.779	0.760	10	0.612	0.888
B10	0.746	11	0.657	0.912	0.780	8	0.696	0.775	0.763	9	0.672	0.885
B11	0.760	8	0.689	0.910	0.714	11	0.467	0.796	0.737	11	0.604	0.889
B12	0.728	12	0.669	0.911	0.682	12	0.365	0.802	0.706	12	0.564	0.890
B13	0.660	13	0.641	0.912	0.676	13	**0.068**	**0.821**	0.668	13	0.503	0.893

*: ITC stands for Item-total Correlation, and CA means Cronbach's Alpha. The same abbreviations apply to follow-up tables.

Table 6. Survey results of perceptions towards factors impacting BIM implementation

	Shanghai respondents		Wenzhou respondents		Statistical test results	
Factors	Mean	Std	Mean	Std	*t*	*p*
F1. Interoperability of BIM software	4.24	0.83	4.33	0.61	0.54	0.589
F2. Number of BIM - knowledgeable professionals	4.19	0.74	3.95	0.88	1.30	0.198
F3. Project complexity	4.14	0.79	4.31	0.60	1.09	0.278
F4. Clients' knowledge on BIM	4.06	0.86	3.60	0.70	2.56	**0.013***
F5. Companies' collaboration experience with project partners	3.97	0.91	4.15	0.66	0.96	0.338
F6. contents or type of contract encouraging or mandating BIM usage (e.g., integrated design and construction)	3.89	0.97	3.93	0.66	0.17	0.862
F7. BIM technology consultants on the project team	3.92	0.83	3.81	0.89	0.57	0.574
F8. The project nature (e.g., frequency of design changes)	3.77	1.09	3.83	0.76	0.28	0.778
F9. Project schedule	3.71	1.03	4.00	0.73	1.40	0.166
F10. Number of BIM-knowledgeable companies in the project	3.67	0.99	3.78	0.83	0.51	0.608
F11. Project budget	3.57	1.04	3.93	0.78	1.68	0.098
F12. Project size	3.47	1.08	3.76	0.82	1.31	0.193
F13. Project geographic location	3.14	1.17	3.12	0.94	0.10	0.923
F14. Staff from different companies working in the same location	3.00	1.14	3.48	0.97	1.96	0.055

*: *p* value lower than 0.05 indicates significantly different perceptions between Shanghai and Wenzhou respondents towards the given item.

Table 7. RII-based ranking of factors impacting BIM practice

Item	Shanghai Respondents Overall CA Value: 0.897				Wenzhou Respondents Overall CA Value: 0.838				Overall sample Overall CA Value: 0.872			
	RII	Rank	ITL	CA	RII	Rank	ITL	CA	RII	Rank	ITL	CA
F1	0.848	1	0.502	0.893	0.866	1	0.293	0.837	0.858	1	0.418	0.869
F2	0.838	2	**0.286**	**0.900**	0.790	5	**0.060**	**0.852**	0.813	3	**0.169**	**0.880**
F3	0.828	3	0.676	0.887	0.862	2	0.292	0.837	0.846	2	0.525	0.864
F4	0.812	4	0.485	0.894	0.720	12	0.557	0.823	0.762	8	0.456	0.867
F5	0.794	5	0.675	0.886	0.830	3	0.305	0.837	0.813	3	0.526	0.864
F6	0.778	7	0.556	0.891	0.786	6	0.558	0.823	0.782	5	0.558	0.862
F7	0.784	6	0.689	0.886	0.762	8	0.511	0.825	0.772	7	0.592	0.861
F8	0.754	8	0.651	0.887	0.766	9	0.568	0.821	0.761	9	0.621	0.858
F9	0.742	9	0.585	0.890	0.800	4	0.574	0.821	0.774	6	0.584	0.861
F10	0.734	10	0.637	0.887	0.756	9	0.544	0.823	0.745	11	0.595	0.860
F11	0.714	11	0.665	0.886	0.786	6	0.764	0.807	0.753	10	0.705	0.854
F12	0.694	12	0.728	0.883	0.752	11	0.583	0.820	0.726	12	0.666	0.856
F13	0.628	13	0.610	0.889	0.624	14	0.540	0.823	0.626	14	0.568	0.862
F14	0.600	14	0.457	0.896	0.696	13	0.473	0.828	0.652	13	0.463	0.868

Table 8. Survey results of perceptions towards difficulties encountered in BIM implementation

	Shanghai respondents		Wenzhou respondents		Statistical test results	
Difficulties	Mean	Std	Mean	Std	*t*	*p*
D1. Lack of sufficient evaluation of BIM	3.50	0.82	3.85	0.91	1.71	0.091
D2. Acceptance of BIM from senior management	3.35	1.05	3.41	1.05	0.24	0.812
D3. Acceptance of BIM from middle management	3.45	1.12	3.29	1.05	0.61	0.543
D4. Lack of client requirements	3.32	1.11	3.43	0.84	0.49	0.627
D5. Lack of government regulation	2.90	1.19	3.25	0.90	1.35	0.183
D6. Cost of hardware upgrading	2.83	1.05	3.23	1.11	1.52	0.134
D7. Cost of purchasing BIM software	2.84	0.97	3.10	1.01	1.11	0.272
D8. Acceptance of BIM from the entry-level staff	2.84	1.37	3.22	1.17	1.24	0.219
D9. Effective training	2.58	1.23	3.17	1.10	2.10	**0.040***

*: *p* value lower than 0.05 indicates significantly different perceptions between Shanghai and Wenzhou respondents towards the given item.

Table 9. RII-based ranking of BIM challenge items

	Shanghai Respondents Overall CA* Value: 0.835				Wenzhou Respondents Overall CA* Value: 0.839				Overall sample Overall CA* Value: 0.839			
Item	RII	Rank	ITL	CA	RII	Rank	ITL	CA	RII	Rank	ITL	CA
D1	0.700	1	0.637	0.813	0.770	1	0.559	0.822	0.741	1	0.600	0.819
D2	0.670	3	0.616	0.811	0.682	3	0.708	0.804	0.678	2	0.656	0.810
D3	0.690	2	0.601	0.812	0.658	4	0.712	0.804	0.672	4	0.639	0.812
D4	0.664	4	0.589	0.814	0.686	2	**0.364**	**0.840**	0.678	2	0.460	0.831
D5	0.580	5	**0.248**	**0.852**	0.650	5	0.465	0.831	0.620	5	**0.363**	**0.841**
D6	0.566	8	0.398	0.834	0.646	6	0.651	0.810	0.612	6	0.548	0.822
D7	0.568	6	0.442	0.828	0.620	9	0.614	0.815	0.597	8	0.549	0.822
D8	0.568	6	0.802	0.783	0.644	7	0.608	0.816	0.611	7	0.703	0.803
D9	0.516	9	0.631	0.808	0.634	8	**0.295**	**0.852**	0.584	9	0.459	0.834

Table 10. Percentages of survey participants on perceiving different risks in BIM implementation

	Shanghai (%)	Wenzhou (%)	Chi-squared value	*p* value
T1: Insufficient capabilities of existing BIM software package	53%	57%	0.118	0.731
T2: Rapid update of BIM technologies	9%	23%	2.527	0.112
T3: The difficulty of understanding and applying BIM technologies	6%	25%	4.678	**0.031***
T4: Poor adaption of BIM technologies in specific AEC projects	63%	36%	5.346	**0.021***
H1: Tight schedule of current business	25%	34%	0.702	0.402
H2: Lack of BIM knowledgeable employees	72%	64%	0.532	0.466
H3: Reluctance to accept new BIM technologies	44%	50%	0.264	0.607
H4: Lack of knowledge and capabilities among current employees	38%	52%	1.442	0.230
E1: Long period of return on investment	47%	48%	0.007	0.932
E2: Uncertainty of profit	59%	55%	0.119	0.730
E3: High cost of Shanghaiort-term investment	63%	50%	1.251	0.263
M1: Reluctance to adopt BIM from the management level	28%	25%	0.085	0.771
M2: The difficult transition of business procedures	41%	57%	1.872	0.171
M3: The difficult transition of management pattern	81%	57%	4.771	**0.030***
O1: Low social recognition	25%	36%	1.028	0.311
O2: Unclear legal liability	31%	23%	0.603	0.438
O3: Unknown intellectual property	28%	34%	0.305	0.581
O4: Lack of industry standards	69%	64%	0.204	0.652

*: a *p* value lower than 0.05 indicates significantly different percentages between Shanghai and Wenzhou respondents on perceiving the given risk item in BIM implementation