Investigation of BIM Investment, Returns, and Risks in China's AEC Industries

Ruoyu Jin[1], Craig Matthew Hancock[2], Llewellyn Tang[3], Dariusz Wanatowski[4]

Abstract

Building Information Modeling, or BIM, the emerging digital technology, is undergoing increasing application in developing countries including China. Both the governmental policy and industry motivation have indicated that BIM is becoming the mainstream innovation in China's construction industry. Nevertheless, one major concern lies in the uncertainty of BIM investment for AEC firms. Specifically, AEC firms should have the knowledge of what areas BIM investment could focus on (e.g., BIM software), what are the expected returns from BIM investment, how to enhance the returns from BIM usage, and what are the risks in implementing BIM. This study adopts a questionnaire survey-based approach to address these BIM application and risk related concerns in China. BIM practitioners from multiple AEC fields and different experience levels were recruited as the survey sample. It was found from the questionnaire survey that both internal and external collaboration should be the BIM investment priority, together with the interoperability among multiple BIM software tools. Improved multiparty communication and understanding was the highest recognized return from BIM investment. Survey participants had a high expectation of BIM application in green building projects. Subgroup analysis conveyed the information that gaining BIM practical

[1] Assistant Professor, Department of Architecture and Built Environment, University of Nottingham Ningbo China, 199 Taikang East Rd., Ningbo China. Email: jinruoyu@yahoo.com
[2] Assistant Professor, Department of Civil Engineering, University of Nottingham Ningbo China, 199 Taikang East Rd., Ningbo China. Email: Craig.Hancock@nottingham.edu.cn
[3] Associate Professor, Department of Architecture and Built Environment, University of Nottingham Ningbo China, 199 Taikang East Rd., Ningbo China. Email: Llewellyn.Tang@nottingham.edu.cn
[4] Professor and Pro-Dean of the SWJTU-Leeds Joint School, University of Leeds, United Kingdom. Email: d.wan@leeds.ac.uk

experience would provide professionals with more confidence on returns from BIM adoption in enhancing communication and understanding. Compared to survey participants from other professions, architects tended to have more conservative views on BIM's impact on marketing their work, project planning, and recruiting/retaining employees. The findings from this empirical study provide an overview of BIM investment, return, and implementation-related risks for AEC professionals at different stages or levels of BIM practice, as well as suggestions for relevant public authorities when developing BIM guidelines (e.g., BIM applications in prefabrication construction). As an extension of existing BIM implementation related studies in developed countries, this study provides insights of BIM practical experience and associated risks in China adopting a holistic approach by summarizing the perceptions from AEC professionals across disciplines and experience levels. The knowledge gained from this study could be further applied in other developing countries where the application of information technology is gaining the growth in AEC projects.

CE Database subject headings:

Author Keywords: Building information modeling; Collaboration; Interoperability; Returns; Risks; Green building; AEC Industries; China.

Introduction

Building Information Modeling (BIM), as defined by Eastman et al (2011), is one of the most promising developments in the architectural, engineering, and construction (AEC) industries with the digital construction of accurate virtual models. China, the country accounting for nearly half of Asia-Pacific AEC industry revenue as reported by Marketline (2014), is experiencing the increasing demand on BIM usage in the years to come. Starting in 2011, China's national BIM policy was announced by the State Ministry of Housing and Urban-Rural Construction (SMHURC, 2011) aiming to establish relevant standards in the follow-up years. A more detailed strategic plan was released from SMHURC(2013) in another proposal on BIM application that by 2016, government-invested projects over 20,000 square meters (215,278 square feet) and green building in the provincial level should adopt BIM in both design and construction. By 2020, the industry guidelines for BIM application and public standards should be well-established. The effects of isomorphic pressures from governmental bodies, regulatory agencies, or industry associations on project-level BIM adoption in China was studied by Cao et al. (2014). However, there is still limited research on Chinese BIM practitioners' perceptions on how the BIM adoption would affect the whole AEC market crossing fields.

Along with the public authorities' movement on demanding BIM applications, AEC professionals' status of BIM implementation in mainland China was also investigated in earlier studies including China Construction Industry Association (CCIA, 2013), Shenzhen Exploration & Design Association (SZEDA, 2013), and Jin et al. (2015). Although there are still limited regions in China with developed BIM standards, and BIM applications during the project delivery process may still be limited to the design stage, the trend of AEC firms in China towards BIM-equipped digitalization can be foreseen from the state-of-the-art policies and visions released from public authorities and the spreading involvement of BIM in China's construction projects. For example, Shanghai Municipal People's Government (2014) announced the strategic objectives of BIM implementation highlighting that industry standards to enable the BIM implementation in Shanghai's AEC projects should be available by the end of 2016, and government-invested projects must adopt BIM starting from 2017. Internationally, a review of previous research on BIM benefits, practice status, policy development, and challenges revealed that these studies mostly focused on BIM application in specialty areas (e.g., electrical construction in Hanna et al., 2014), with research-involved participants from certain technical fields (e.g., consultants and researchers in Won et al., 2013), or targeting on project construction stage (e.g., Cao et al., 2014; Francom et al. 2015). So far relevant empirical studies (e.g., Eadie et al., 2013) that recruited survey participants from multiple AEC disciplines are still not sufficient for the purpose of gaining a more holistic picture of BIM implementation-associated issues such as risks, returns from investments, and strategies.

In order to keep self-competitiveness in the bidding market, AEC firms in China have started or planned to start BIM applications in their projects. The start and update of BIM-involved work would require initial cost and effort in not only relevant software and hardware, but also in technical, management, human resources, and other aspects. For those industry practitioners, either currently adopting BIM, or planning to invest in BIM for their future projects, there is a need to understand what are the key investment priorities in BIM, what could be the associated risks once starting BIM usage, and how to enhance the returns from BIM, as these issues would affect the decision making in BIM investment. AEC firms and professionals from different fields, such as architecture, multiple engineering fields, consultants, and others may work in a collaborative environment once BIM is adopted as the communication platform in the project delivery process. AEC professionals working on the same project may be at different levels of BIM proficiency. It is not clear whether the perceptions of BIM investment and return related issues would vary depending on job profession or BIM proficiency level.

Extending from previous BIM-implementation-related studies in developed countries (e.g., Eadie et al., 2013; Hanna et al., 2014; Francom and El Asmar, 2015), this questionnaire-based study focuses on investigating the perceptions of BIM practitioners towards the BIM investment, returns from BIM investment, ways to improve the return from BIM applications, and risks in implementing BIM in China. The survey pool is divided into subgroups according to their profession and BIM proficiency level as defined by Jin et al. (2017). Potential subgroup differences are explored to analyze whether the perceptions towards returns and risks of BIM would be affected by participants' profession and BIM experience level. The results of this questionnaire survey provide suggestions on how to enhance returns from BIM usage for AEC industry professionals or stakeholders who are investing in BIM or planning to adopt BIM in their projects.

Literature Review

BIM movement in developing countries

BIM implementation is accelerating worldwide, and this is being driven by government mandates, as well as clients and contractors as they realize the possible benefits of BIM in the long and short term (Smith, 2014). McGraw Hill (2014) conducted a survey from ten of the largest construction markets in the world as well as India and China. The survey found that BIM implementation in all these countries was significantly increasing and was predicted to continue increasing over the next few years. Many other countries have been accelerating their use of BIM such as Pakistan (Masood et al., 2013) and Poland (Juszczyk et al., 2015), and the trend of BIM usage growth can be expected in the near future (McGraw-Hill Construction, 2014). However, there have been limited empirical studies of BIM implementation in these developing countries with large AEC markets including India (e.g., Mahalingam et al., 2015) and China (e.g., Cao et al., 2016).

Earlier questionnaire-based surveys from CCIA (2013), SZEDA (2013), and Jin et al. (2015) showed that large-sized and highly-qualified contractors nationwide in China mostly stayed in the "heard-of" stage with limited adoption of BIM, design firms mostly used BIM in the experimental stage for small-size projects, and BIM was a new concept in China with the majority of employees starting to learn BIM after 2010. It was also found that in China BIM implementation faced difficulties due to lack of well-developed standards and legislation, insufficient interoperability among different building trades, as well as difficulties in implementing BIM during the whole lifecycle of a building project (He et al., 2012).

Returns from BIM Application

AEC companies and professionals desire to know whether the time and money invested in implementing BIM, such as four-dimensional BIM software studied by Lopez et al. (2016) for usage in construction projects, will deliver worthwhile returns. This is one of the factors that is slowing the wider implementation of BIM within the AEC industries as BIM is seen by many as expensive to implement (Azhar, 2011). Return on investment (ROI) has been defined and quantified in multiple BIM-application-based empirical studies (e.g., Gilligan and Kunz, 2007; MaGraw Hill Construction, 2009; Geil and Issa; 2011) to measure the returns against BIM investment in terms of savings.

Nevertheless, ROI must be used with caution when looking at the potentially financial benefits of BIM as some research (e.g., Neelamkavil and Ahamed, 2012; Love et al., 2013) have indicated that it does not accurately reflect the real benefits and costs coming with the implementation of BIM. Intangible benefits and indirect costs such as improved productivity and potential revenue growth associated with BIM are difficult to estimate (Love et al., 2013). Other returns from BIM implementation included improved project performance and reduced design changes (Lopez and Love, 2012; Francom and El Asmar, 2015), improved visualization and better coordination (Bynum et al., 2013; Ahn et al., 2015), improvement of project performance through better information sharing (Francom and El Asmar, 2015; Mahalingam et al., 2015), and working as the multidisciplinary platform for facility management (Becerik-Gerber et al., 2016).

BIM implementation risks

Understanding, identifying, and assessing potential risk factors for BIM enrollments in AEC projects is an important part of the BIM implementation process. Identifying risks early can allow users to plan ahead and respond quickly to potential problems. This can aid the successful implementation of BIM.

It was suggested by Ghosh (2004) that risks could be defined by some factors that can jeopardize the successful completion of a project. Wang et al (2004) listed three main stages within risk management: identification of the risk, analysis and evaluation, as well as responses to the risk. Identification of potential risks is the first step in the BIM implementation process. Chien et al (2014) studied the risk factors in BIM and concluded that assessing risks and countering them required an understanding of the characteristics of the risks. Inadequate project experience and a lack of training have the most effect on other risk factors (Chien et al., 2014). Other challenges that could affect risk factors within BIM practice included practitioners' knowledge on cross disciplinary nature of BIM, cultural resistance to BIM, clients' knowledge and supports on BIM, higher initial cost, difficulties of applying BIM through the full building cycle, the interoperability issues between companies, and legal issues as identified by multiple studies (e.g., Denzer and Hedges, 2008; Birkeland, 2009; Breetzke and Hawkins, 2009; Bender, 2010; Dawood and Iqbal, 2010; Azhar, 2011; He et al. 2012; NFB Business & Skills; 2013; Cao et al., 2014; Suwal et al., 2014; Mahalingam et al., 2015;).

Methodology

The questionnaire survey-based research method was adopted to collect information on perceptions towards BIM investment focus, returns by adopting BIM, ways to enhance returns, and risks associated with BIM implementation from AEC industry professionals in mainland China, with targeted survey participants from various professions and different BIM experience levels. The questionnaire was developed by the research team from the University of Nottingham Ningbo China (UNNC) between August 2014 and May 2015 and peer-reviewed by professionals from the Shanghai BIM Engineering Centre (SBEC), the first BIM organization in mainland China focusing on technological communication and information exchange. The questionnaire was updated according to the feedback provided by SBEC. Finally, the approval from the Research Ethics Office was obtained in June 2015 to ensure that relevant ethics requirements were met (e.g., no personal information of participants were included) when delivering the questionnaire survey.

The survey was targeted towards AEC professionals from China's national network of Digital Design and Construction (DDC). These professionals include active BIM practitioners as defined by Eadie et al. (2013), professional individuals involved in BIM implementation activities defined by Cao et al. (2016), and those beginning BIM practice in China's AEC industries defined by Jin et al. (2017). In July 2015, SBEC invited 200 members from the network of DDC to attend the First Forum of BIM Technology and Lean Construction. In collaboration with SBEC, the UNNC research team delivered 200 questionnaires during the forum. Besides the site collection of questionnaires, an extra 97 questionnaires were sent on-line through SOJUMP, the Chinese on-line survey platform (www.sojump.com) to reach more AEC professionals either with BIM practical experience or professionals planning to implement BIM.

The questionnaire was divided into two parts. The first part collected the background information of respondents, including their working location in mainland China, their profession (e.g., architects, engineer, contractor, etc.), their BIM experience level(i.e., expert, advanced level, intermediate level, entry-level, and little BIM experience), and the software tools adopted in their work. The second part of the questionnaire consisted of four sections, targeted at BIM investment focuses, returns from BIM usage, ways to improve relevant BIM returns, and risks encountered in BIM implementation. The Likert scale and multiple-choice were the two types of questions designed in the survey. For the Likert scale questions related to BIM investment and return, four major statistical methods were involved:

(1) Relative Importance Index (*RII*) was used to rank multiple items within each BIM return and investment related section. Ranging from *0* to *1*, the *RII* value is calculated by Eq.2, which is the same equation adopted by previous or ongoing studies from Kometa and Olomolaive (1994), Tam et al. (2000), Tam et al. (2009), Eadie et al.(2013), and Jin et al. (2017).

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

In Eq.1, *w* is the Likert score (numerical values from *1* to *5* in integer) selected by each respondent in the questionnaire, *A* denotes the highest score in each given item (*A* equals to 5 in this survey), and *N* represents the number of responses. An item with a higher *RII* value would indicate a higher significance or importance.

(2) Cronbach's alpha was adopted as the tool to measure the internal consistency of items (Cronbach, 1951) within each section of BIM investment and return. Cronbach's alpha ranges from *0* to *1*, a larger value suggesting a higher degree of consistency among these items within one section. In other words, a higher calculated Cronbach's alpha would indicate that a survey participant selecting a Likert score for one item is more likely to choose a similar score to the rest items within the same section. In this study, the Cronbach's alpha value was computed in each of these three sections related to BIM investment areas, recognized returns from BIM implementation, and ways to enhance BIM returns. The Cronbach's alpha value would measure the internal consistency among items within each of these sections. Generally Cronbach's alpha value from 0.70 to 0.95 would be considered high internal inter-relatedness (Nunnally and Bernstein, 1994 and

DeVellis, 2003). In contrast, a lower value of Cronbach's alpha shows poor correlation among items (Tavakol and Dennick, 2011).

(3) Analysis of Variance (ANOVA) was applied as a parametric method to test the subgroup (i.e., survey sample divided according to the profession and BIM experience level in this study) consistencies of their perceptions towards BIM investment and return related sections. ANOVA has been used in the data analysis of Likert scale questions in construction engineering studies such as Aksorn and Hadikusumo(2008), Meliá et al. (2008), and Tam (2009). Following the procedure described by Johnson (2005), the *F* statistics was computed based on *degrees of freedom, sum of squares, and mean square* in the ANOVA analysis. The values of these terms were calculated with the assistance of Minitab, the statistical analysis software. Based on a *5%* level of significance and the null hypothesis that there were no significantly different mean values among subgroups of BIM professionals towards the given Likert-scale question, a *p* value was obtained according to the computed *F* value. The *p* value lower than *0.05* would indicate that subgroups of survey participants have inconsistent views towards the given item.

(4) For multiple-choice questions related to risks encountered in BIM implementation, based on the null hypothesis that all subgroups have consistent percentages of selecting the same proposed risk, the Chi-Square test of independence described in Johnson (2005) at the 5% level of significance was performed to analyze the subgroup variations in identifying these BIM risks. The Chi-Square value was calculated according to differences between observed and expected cell frequencies in each question related to BIM implementation risks following the computation procedure guided by Johnson (2005). A *p* value lower than *0.05* would reject the null hypothesis and suggest the significantly different percentages of subgroups in identifying the given BIM risk.

Findings on the status of BIM Practice in China's AEC industries

Finally 81 responses were received with survey participants from different professions including architects, engineers, owners, BIM consultants, and other AEC practitioners. In total 13 responses were received from the on-line survey. The 81 on-site responses collected and the 13 on-line responses received were tested using the two-tailed statistical test (i.e., two-sample *t*-tests for inferences concerning two means or two proportions) recommended by Johnson (2005) based on the 5% level of significance. The two-tailed tests revealed no significantly different mean values or proportions between site and on-line responses for the four major sections related to BIM investment areas, BIM returns, ways to enhance BIM return, and BIM risks. . Therefore, by combing the responses from the forum site and on-line surveys, 94 questionnaires were collected as the whole survey sample. The discussion on findings of this questionnaire were divided into survey participants' background, BIM investment areas, recognized BIM returns, suggested ways to enhance BIM return, and risks in BIM implementation.

Regional coverage of the survey in China

BIM implementation in projects remain relatively rare in mainland China (Cao et al., 2016). According to Jin et al. (2015), Bejing, Shanghai, and Canton were the major regional centers in China that had actively adopted BIM in AEC practices. Survey population from or nearby these three regional centers occurred to constitute 84% of the whole sample This was consistent with Jin et al. (2015)'s findings regarding China's BIM-leading regions in that surrounding municipalities or provinces had been following these three key regional centers' BIM regulatory and standard movements.

Survey participants' working locations are summarized in Fig.1.

It is shown in Fig.1 that over 60% of respondents came from Shanghai or nearby locations (including provinces of Zhejiang and Jiangsu). The other 16% of survey participants were from the inland part of China or overseas. Detailed geographic distribution of this survey sample can be found from Jin et al. (2017). Although majority of survey participants came from Beijing, Shanghai, and Canton, or their nearby locations representing the major BIM-active and more economically developed regions in China, the findings from this empirical study provide insights to other less-BIM-active regions (e.g., inland part of China) and those regions with limited BIM movement but likely to start BIM implementation in the near future, for example, Liaoning Province in north-eastern part of China mentioned in Jin et al. (2015).

Survey participants' background

The subgroup categories according to survey participants' professions and self-identified BIM experience levels are summarized in Fig.2.

The survey sample covers various professions, including architects, engineers in the fields of civil engineering, building services engineering, and structural engineering, contractors, owners, engineering consultants, academics, software developers, and others. Examples of other professions include company administration directors, material supplier, etc. The majority of the sample pool had BIM usage experience from one year to five years. When divided by subsamples according to their self-perceived BIM proficiency levels, the expert and advanced BIM users, moderate level users, and beginners or those with limited experience had median values of five years, two years, and half a year respectively. The overall sample had a mean, median, and standard deviation at 3.0 years, 2.0 years, and 2.57 years respectively. Detailed data analysis in box plots of subsamples' years of BIM experience can be found in Jin et al. (2017). Considering the nature of the survey population representing fore-runners of BIM practice in China's AEC industries, the data that 75% of participants in this survey sample had BIM experience of less than five years could convey the information that BIM is still a relative new technology applied in China. This is also consistent with the study in Jin et al. (2015). The self-identified BIM proficiency level was further tested by Jin et al. (2017) that experts or advanced practitioners tended to have more frequent BIM adoptions in their AEC projects.

Survey participants were also asked of the major BIM software tools adopted in their professional work. The multiple-choice question is summarized in Fig. 3.

It is indicated from Fig.3 that Autodesk (e.g., Revit) was the dominating BIM authoring tool adopted. Close to 90% of respondents claimed having used Autodesk, much higher than the adoption rate of Bentley or other BIM software developers. Respondents that selected "others" specified tools used, mainly including software tools from domestic developers, such as Glondon and Luban. Around 10% of respondents reported having never adopted BIM tools.

Focuses in BIM investment

Survey participants were asked their perceptions on the importance of BIM investment areas based on the Likert-scale question format. Multiple areas of BIM investment were provided. For example, the BIM software investment, BIM training, and BIM library update, etc. Based on the numerical value ranking, with "*1*" being least important, "*3*" indicating neutral, and "*5*" standing for most important, the statistical analysis is summarized in Table 1. Survey participants were also provided with the extra option of "N/A" if unable to answer the given item due to lack of knowledge. Eight items following the *RII* score ranking are listed in Table 1.

The Cronbach's alpha at 0.921 indicated a relatively high internal consistency of participants' view on these BIM investment areas. The item-total correlation value displayed in Table 1 measured the correlation between the target item and the aggregate score of the remaining items. For example, the item-total correlation value at 0.701 for I1 in Table 1 indicated fairly positive and strong relationship between item I1 and the rest seven items. All these relatively high item-total correlation values in Table 1 suggested that each item's Likert scale score was somewhat internally consistent with that of other items. The internal consistency could be further tested by the individual Cronbach's alpha value in Table 1, which showed the changed Cronbach's alpha value if the given item was removed from this section. All values lower than the original one at 0.921 indicated that each of the eight items positively contributed to the internal consistency.

Developing internal collaboration according to BIM standards was considered the top priority in BIM investment according to the *RII* score calculated. This was consistent with the findings from He et al. (2012), CCIA (2013), SZEDA (2013), and Eadie et al. (2013) that collaboration was considered the key of successful BIM implementation. On the other hand, lack of well-established standards and legislation was identified by He et al. (2012) as one major challenge for implementing BIM in China's AEC market. Top three important BIM investment areas perceived by respondents in Table 1 were all related to collaboration. This conveyed the information to stake holders that investing on solving BIM collaboration issues within the context of existing BIM standards, with project partners, and technical support to enhance the software interoperability would be the priority. In contrast, BIM training, development of BIM digital libraries, and updates of hardware were ranked lower in Table 1.

The overall sample was also divided into subgroups according to the profession and BIM experience levels defined in Fig.2. Table 2 demonstrated the ANOVA analysis on these eight BIM investment area related items among subgroups.

The overall mean value above or close to 4.0 indicated that the six areas (i.e., I1 to I6 in Table 1 and Table 2) were considered more important in BIM investment. All p values above 0.05 suggested that all survey participants, regardless of job profession or BIM experience level, shared the consistent views on all of the eight identified BIM investment areas.

Returns from BIM Application

Survey participants were asked of their recognitions of returns from BIM investment and application. Various potential or achieved returns from BIM investment were evaluated by survey participants, with “1” being strongly disagree, “3” being neutral, “5” being strongly agree, and the extra option of “N/A” was given to those with little knowledge on it. The internal consistency analysis is summarized in Table 3.

It is seen in Table 3 that improving multiparty communication and understanding from 3D visualization was the top-ranked recognized return from BIM investment, followed by the positive impact on sustainability. Survey participants had strongly positive perceptions that BIM would enhance the communication among multiple project parties through detailed visualization. This could be due to the fact that BIM implementation may be limited to 3D visualization for some Chinese engineering firms identified by Jin et al. (2015). He et al. (2012) stated that the usage of BIM in China was still limited to design firms. The gap that lies between proposed BIM application and its current implementation in China, as defined by Jin et al. (2015), was from using BIM solely as a 3D visualization tool to adopting BIM as the platform for project delivery and business management. The second ranked BIM value in light of BIM’s positive impact on sustainability could be due to the fact that 50% of the survey sample had either high or moderate adoption of BIM in their green building projects. In another multiple-choice question asking respondents’ expectation of BIM application in green buildings, around 94% of survey participants believed that BIM would have an increased application in China’s future green building projects, with 0% of them choosing decreased application or remaining the same, and the other 6% claimed no knowledge on this subject. Among those who expected an increased BIM application in green buildings, nearly half (49%) of the survey sample selected “high increase”, with the remaining choosing a moderate increase (22%) or a slow increase (5%).

Besides the improved communication from visualization and sustainability, there were another five BIM return related itemss perceived with *RII* scores above 0.800 (i.e., equivalent to an average Likert scale score at 4.0). Though returns from BIM usages in reducing project cost and decreasing project duration had been identified in multiple previous studies internationally (Furneaux and Kivvits, 2008; Khanzode and Fischer, 2008; Yan and Damian, 2008; Becerik-Gerber and Rice, 2010; Both et al., 2012; Cheung et al., 2012; Crotty, 2012; Migilinskas et al., 2013), the recognitions of BIM returns relevant to lowered project cost and duration were ranked below the *RII* scores at 0.800 (equivalent to Likert scale score at 4.0 indicating "agree" among respondents). The relative lower ranking and score obtained related to project cost and duration could be due to the limited work that had been performed to compare project cost and time of project with and without BIM adoptions among Chinese practitioners. Instead, returns related to other BIM assistances in construction and operation were recognized with higher *RII* scores, such as fewer RFIs and more accurate shop drawings. It is worth mentioning the increased applications of BIM in prefabrication construction, which has become one of the mainstream movements in China's AEC industries. The enhancement of prefabrication design codes, technical standards, and construction methods was clearly specified in the recently released China State Council announcement (2016). It had been foreseen from participants in this survey pool regarding BIM's application in the emerged prefabrication construction market.

Similar to items within BIM investment areas, the high Cronbach's alpha value at 0.927 showed a generally high consistency among these 13 identified recognitions of returns from BIM usage. The Cronbach's alpha values in Table 3 are lower than the original value indicated that all the 13 items contributed to the internal consistency. Though overall survey participants who chose a score for one item in Table 4 tended to assign a similar score to another one, the item-total correlation coefficients suggested that R1, R12, and R13 had relatively weaker correlation with the remaining items. It could be inferred that a respondent who scored these remaining items was more likely to provide a different score on R1, R12, and R13. Generally, the return of BIM in enhancing multiparty communication was more likely to be assigned with a higher Likert scale score than other items related to returns from BIM application. A respondent was prone to score lower in BIM's impacts on project planning and recruiting /retaining employees compared to other items.

Subgroup differences are analyzed and summarized in Table 4 in terms of survey participants' recognition of returns from BIM investment.

Significant subgroup differences regarding the recognition of BIM return values in R1, R5, R12, and R13 from Table 4 can be found among either different professions or BIM proficiency levels.

Those with little BIM experience tended to have a more conservative view on improved communication and understanding from BIM-driven visualization, with a mean Likert score at 3.889 which is between "neutral" and "agree". In contrast, all other respondents with some BIM experience (from entry level to expert level) all had wider recognition of BIM-enhanced communication and understanding, with Likert scale score above 4.500 or close to "strongly agree." That would infer that gaining BIM practical experience would provide AEC professionals with higher recognition in returns from BIM in terms of enhancing communication.

The p value lower than 0.05 suggested significant differences among subgroups' recognitions towards BIM's impact on marketing their professional work. Specifically, architects had less positive perceptions on BIM's positive impact on marketing, with a mean Likert scale score at 3.222 (i.e., close to the neutral score at 3), while all other subgroups had mean scores from 4.167 to 4.750, all above the score at 4.0 representing "agree" to the statement that BIM could positively market their professional work. The lower mean score assigned from architects could result from their job nature, in which BIM-driven 3D visualization is more frequently implemented. Architects, which usually lead the project delivery in the early planning and design stage through more visualized work, might perceive less impact of BIM on marketing their work since architectural work tends to have more BIM elements such as 3D visualization and dynamic walkthrough. In contrast, software developer, academics, and owner, with a mean score at 4.750, 4.667 and 4.667 respectively, are prone to perceive more BIM in positively marketing their work or product, followed by BIM consultant (4.375), engineers (4.320), and general contractors (4.167).

Besides the recognition of BIM's positive impact on marketing, architects also tended to have lower recognition of BIM in reducing project planning time and recruiting/retaining staff. While other professions held the view of "agree" or "strongly agree". The mean Likert scale scores from architects in R12 and R13 were 2.667 and 2.625 respectively, indicating architects' perceptions between "disagree" and "neutral" towards BIM's positive influences on project planning duration and employee recruitment/retention. When looking into previous studies of how BIM affected architects' role in the project, it was claimed that BIM platform changed the role in the project design phase and added risks to architects of being replaced by a more computer skilled designer or engineer (Thomsen, 2010). Sometimes mainstream BIM tools such as Revit as identified in this study may not be as effective as more traditional tools (e.g., Sketchup or Rhinoceros) according to the pedagogical study of Jin et al. (2016). Thomsen (2010) further stated that BIM technical platforms limited the options of possible solutions and provided extra requirements than traditional projects. These previous studies could serve as the rationale of architects' lower recognitions of BIM's positive impact on project planning and employees, as architects may experience more negative effects from BIM usage including but not limited to role change and extra work as identified by Thomsen (2010) and Jin et al. (2016).

Ways to improve BIM returns

Based on these recognitions of returns brought from BIM as listed in Table 4, a further Likert-scale question was carried to gain perceptions of survey participants on how to optimize BIM returns, with "*1*" being least important, "*3*" standing for neutral, and "*5*" representing most important. Table 5 summarizes the statistical analysis of totally 15 listed potential ways to improve BIM returns.

The overall Cronbach's alpha value at 0.943 indicated a high degree of internal consistency of respondents on all these 15 items related to suggested ways to enhance BIM returns. All these Cronbach's alpha values lower than 0.943 after removing any one of these items in Table 5 suggested that every item contributed to the overall internal consistency. The comparatively high item-total correlation in Table 5 also indicated that respondents tended to assign similar scores to these 15 suggested ways. The item showing lowest item-total correlation was W15 regarding the availability of subcontracted modeling service, suggesting that respondents were more likely to score differently to W15.The top two ranked items, with *RII* scores above 0.900, both addressed the issues of interoperability. Although Autodesk was identified as the most widely used BIM authoring tool in this survey pool according to Fig.3, other BIM software suppliers, including domestic Chinese vendors (e.g., Glondon and Luban) were also being used by AEC professionals. There is ongoing work of software developers in localizing international BIM tools (e.g., Autodesk) in China practice by including Chinese industry standards (e.g., establishment of new building element families). The interchange of digital information among multiple BIM tools using file formats such as Industry Foundation Class (IFC) and gbXML is one of the major issues in BIM interoperability to be solved in the future. Clearly defined BIM deliverable among different parties, including the level of development (LOD) at different stages of project design and procurement, was listed as the second most urgent approach in enhancing BIM returns. Since one major return value from BIM is the improvement of multiparty communication, clearly specified BIM deliverables are a prerequisite to enable the collaboration among architects, engineers, contractors, and other project parties. The third ranked item in Table 5 was also related to collaboration within the BIM context. Survey participants held the view that contract language supporting BIM implementation and collaboration would enhance BIM returns. All the three interoperability and collaboration related items were ranked as top priorities in pursuing BIM returns. In contrast, BIM related services including BIM consulting and subcontracted modeling were not considered as important as other ways in enhancing BIM returns (e.g., authorities' policy on BIM practice, BIM-skilled employees, and owners' demands on BIM usage) according to survey responses, indicating that most survey participants believed that AEC firms should develop their own BIM capacity rather than solely rely on external BIM services. Actually it might be more efficient in the work flow if architects and engineers have their own BIM capacity incorporated with their own fields of expertise and design, compared to asking for external BIM services to assist their own design.

A further ANOVA approach was adopted to explore potential subgroup differences in perceptions towards ways to enhance BIM returns. Table 6 lists the results from ANOVA.

All p values higher than 0.05 in Table 6 demonstrated that survey participants had consistent views on ways to enhance BIM returns regardless of job professions or BIM experience levels.

BIM Risks

Survey participants were asked of their identified risks in implementing BIM within the given categories including technical, human resource, financial, management, and others. In these semi-open multiple-choice questions, participants were allowed to select any of the given options within each risk category and to list additional risks according to their own experience. The percentages of survey participants that selected each risk within these defined categories are presented in Fig.4.

The major risks identified by survey participants included T1 (i.e., incapability of BIM software tools), H2 (i.e. lack of BIM-skilled employees), F3 (i.e., high-cost of short-term investment), M2 and M3 (i.e., adjustments in business procedure and management pattern), as well as O4 (i.e., lack of industry standards), as selected by the majority (from 63% to 73%) of respondents. The issues in BIM tool usage, for example, the data exchange among various software tools in China's AEC practice and the necessity of incorporating the internal BIM tool (e.g., Autodesk Revit) with domestic Chinese industry standards as previously discussed in this study, is one of the major concerns in BIM implementation. The lack of sufficient BIM-skilled employees in China's current AEC industries indicate the importance of BIM training including the college level education. High cost of short-term investment in BIM turned out a major risk. Besides the top-ranked BIM investment areas suggested in Table 1, college graduates equipped with BIM knowledge could reduce the investment from BIM training as mentioned by Tang et al. (2015). The implementation of BIM may also affect the management platform and the project delivery process, as indicated from previous international studies such as Thomsen (2010), SmartMarket Report (2015), and Liu et al. (2016). How to optimize BIM's influence on project management and work flow was a concern from this survey sample. Finally, it was believed that a well-established standard would be a key issue for successful BIM implementation.

When encouraged to list further risks encountered in BIM implementation, respondents' feedback mainly focused on the insufficient collaboration among project parties, lack of BIM culture, interoperability among BIM tools, and lack of profit sharing agreement among multiple parties. Among these further identified risks from survey participants, lack of collaboration among project participants was again the most frequently mentioned fact.

Subgroup perceptions towards BIM risks were analyzed adopting Chi-Square analysis. Table 7 lists the Chi-Square values with corresponding p values to study the views of subgroups by profession and BIM experience level on each of these identified risks in Fig.4.

No significant differences in perceiving BIM implementation risks were found among subgroups divided by job professions. Among subgroups from different BIM proficiency levels, these significant differences were identified:

- None of the respondents with limited BIM experience considered imperfect software a major risk, while the majority from other subgroups from entry level to expert level all perceived risk within BIM software. Compared to survey participants with a certain level of BIM usage experience, those with limited previous BIM experience tended to underestimate the potential risk from BIM software problems.
- Though H1 (i.e., tight schedule in the current business) was not identified as a major risk in BIM implementation with only 29% of respondents choosing it, significantly different percentages among subgroups were found. Specifically, 45% of advanced level and 44% of entry-level BIM users identified H1 as a major risk, compared to 17% from expert level, 10% from moderate level, and 0% from those with little experience.

Summary and Discussion

Review of previous BIM implementation related studies crossing countries revealed insufficient investigations conducted in developing AEC markets (e.g., China and India) compared to more developed counterparts (e.g., U.S and U.K). There was also a need on adopting a holistic approach to gain BIM-application-based perceptions. To address these concerns, this study adopted the questionnaire survey based approach to perform the statistical analysis of Chinese BIM practitioners' perceptions on BIM investment, return, and risk related issues. Active BIM practitioners or those plan to implement BIM in China's AEC industries were targeted as the survey sample. Feedback on survey respondents' perceptions focusing on BIM investment areas, returns from BIM investment, ways to enhance BIM returns, and existing risks in BIM implementation was collected and analyzed. The survey sample recruited participants from multiple job professions and different BIM proficiency levels to study whether BIM practitioners' perceptions would depend on profession and level of BIM usage experience.

The collaboration related issues were unanimously ranked as a priority in BIM investment focuses. Insufficient collaboration among project parties was mentioned as a risk encountered in BIM implementation. This could be partly due to the insufficient standardization of BIM execution plan in Chinese AEC industries. It was suggested that both the investors and the implementers should not only develop BIM-based internal collaboration procedure, but also a coordination process with external parties. The interoperability problem among various BIM software tools in China's AEC market is one of the main challenges. Enhancing the software interoperability within one company or among collaboration partners is one suggested BIM investment area and also the top priority in the suggested ways to enhance BIM returns.

When asked of their recognitions of BIM return values, respondents ranked the improved multiparty communication and understanding from visualization as the most widely realized added value of BIM. Other widely recognized BIM returns included positive impacts on sustainability, better site coordination and building operation, and more applications in prefabrication. However, lowered project cost and shortened duration were not as positively perceived. This could be due to the fact that limited measurement work in the comparison of project cost and duration had been performed.

Subgroup differences were identified that those with little BIM experience tended to have a less positive view on BIM's enhancement to multiparty communication, indicating that gaining BIM experience would also change practitioners' views towards more positive perceptions on BIM's impact on project-based communication and understanding. Compared to other professions in the BIM practice, architects were found more likely to have more reserved or even negative views on BIM's impacts on marketing their own project or professional work, project planning duration, and recruiting/retaining employees. Architects' significantly diverged perceptions towards certain BIM returns from other professions could be inferred from the architecture nature of planning and design associated with visualization-assisted aesthetics, as well as potentially restricted solutions, role change, and extra requirements from BIM platforms.

Besides the top-ranked BIM software interoperability, more clearly defined BIM deliverables and contract language to support BIM-driven collaboration were another two highly recommended ways to enhance BIM returns. High internal consistency among items within these recommended ways on BIM returns enhancement suggested that multiple other ways were also important, for example, authorities' acceptance to BIM-created document submission, improved software capacity, more owners demanding BIM usage, and BIM-skilled staff, etc. Nevertheless, it was believed that AEC firms should have their own BIM capacities rather than solely rely on subcontracted BIM services such as modeling.

Major risks in BIM implementation were identified, the most frequently selected risks being lack of BIM industry standards and the AEC firms' transition of management pattern, followed by lack of BIM-skilled employees, high cost of short-term investment, adjustments in business procedure, and incapacity of BIM software. Analysis of subgroup difference released that perceptions of survey sample towards these risks were independent of their job profession. However, those without previous BIM experience were more likely to underestimate the problems within BIM software capacity.

Conclusion

This empirical study of BIM investment areas, return from BIM, ways to enhance BIM returns, and risks in BIM implementation provides suggestions for AEC professional and business owners regarding focuses within BIM investment, what could be expected from BIM adoption, suggestions to enhance returns from BIM implementation, and potentially associated risks. Public authorities may also learn from this study for further development of industry guidelines, such as standards motivating BIM-based multiparty collaboration and software interoperability. Findings from this empirical study can be interpreted and applied in other developing AEC countries in that:

- Some commonly encountered risks such as lack of authority standardization and multiparty collaboration in BIM-involved projects should be recognized based on multiple investigations of BIM implementation crossing countries and regions;
- Countries or regions like China, larger regional variations in terms of economic development, geographic location, and culture would cause some regional differences in BIM movements. Some more BIM-active regional centers (e.g., Shanghai in this study) could be identified and focused for the initial empirical studies. The lessons or experience learned from these BIM-leading regions could provide guides for other less BIM-developed regions (e.g., inland part of China) when moving forward with the adoption of information technology in the AEC practice;
- It is recommended that empirical studies related to BIM practice and application be set in the interdisciplinary context by considering perspectives from different AEC fields as BIM, by its nature, aims to enhance cross-disciplinary collaboration and communication.

Recommendations for future research

Future research would be extended to in-depth study of architects' perceptions on returns from BIM investments, through interview and case studies in China's AEC industries. How BIM implementation would affect architects' role in the project delivery process would be explored. Case studies of BIM impacts on project duration and cost will be conducted. Projects in similar sizes with and without BIM adoption in China's high-rise complex building would be targeted to measure BIM effects on project budget expenditure and scheduling.

Data Availability Statement

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

Acknowledgement

The authors would like to acknowledge the peer-review and feedback of the questionnaire provided from BIM professionals in Shanghai BIM Centre.

The work presented herein was undertaken under the aegis of BIM-GIS Application in Green Built Environment Project, funded primarily by Ningbo Bureau of Science and Technology (Grant No. 2015B11011) through the Innovation Team at the University of Nottingham Ningbo China.

References

Ahn, A.H., Kwak, Y.H., and Suk, S.J. (2015). "Contractors' transformation strategies for adopting building information modelling." *J. Manage. Eng.*, 32(1), DOI: 10.1061/ (ASCE)ME.1943-5479.0000390.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). "Technology adoption in the BIM implementation for lean architectural practice." *Autom. Constr., 20*(2), 189-195.doi: http://dx.doi.org/10.1016/j.autcon.2010.09.016

Aksorn, T. and Hadikusumo, B. H. W. (2008). "Critical success factors influencing safety program performance in Thai construction projects." *Safety Sci.,* 46 (4),709-727.

Azhar. S. (2011). "Building Information Modelling (BIM): trends, Benefits, Risks and Challenges for the AEC Industry." *Leadersh.Manag. Eng.* 11 (3), 241–252.

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Calis, G. (2016). "Application areas and data requirements for BIM-enabled facilities." *J. Constr. Eng. Manage.*, 138 (3), DOI: 10.1061/(ASCE)CO.1943-7862.0000433.

Becerik-Gerber, B., and Rice, S. (2010). "The perceived value of building information modeling in the U.S. building industry." *J. Inf. Technol. Constr. (ITcon)*, 15, 185–201.

Bender, D. (2010). "Implementing building information modeling in the top 100 architecture firms." *J. Build. Inf. Model.*, (Spring 2010) 23–24.

Birkeland, J. (2009). "Eco-retrofitting with building integrated living systems." Proceedings of the 3rd CIB International Conference on Smart and Sustainable Built Environment: SASBE09, Delft University of Technology,1–9.

Both, P., Koch, V.,andKindsvater, A. (2012). "Potentials and barriers for implementing BIM in the German AEC market."

Breetzke, K., and Hawkins, M. (2009). "Project extranets and e-procurement: user perspectives." RICS, London, UK.

Bynum, P., Issa, R.R.A., Olbina, S. (2013). "Building Information Modeling in support of sustainable design and construction." *J. Constr. Eng. Manage.*, 139 (1), DOI: 10.1061/(ASCE)CO.1943-7862.0000560.

Cao, D., Li, H., and Wang, G. (2014). "Impacts of isomorphic pressures on BIM adoption in construction projects." *J. Constr. Eng. Manage.*, 140 (12), DOI: 10.1061/(ASCE)CO.1943-7862.0000903.

Cao, D., Li, H., Wang, G., and Huang, T. (2016). "Identifying and contextualising the motivations for BIMimplementation in construction projects: An empirical study in China." *Int. J. Proj.Manage.*, In Press,doi:10.1016/j.ijproman.2016.02.002.

Chien, K.F., Wu, Z.H. and Huang, S.C. (2014). "Identifying and assessing critical risk factors for BIM projects: Empirical study." *Autom. Constr.*, *45*, 1-15.

Cheung, F.,Rihan, J., Tah, J., Duce, D., andKurul, E. (2012). “Early stage multi-level cost estimation for schematic BIM models.”*Autom. Constr.* 27, 67–77.

China Construction Industry Association (CCIA, 2013), Research of BIM application in construction firms (1), Beijing: China Architecture & Building Press (in Chinese).

China State Council (2016).“The 13th Five-Year Plan of State Technology Innovation.”Released on August 8th 2016 (in Chinese).

Cronbach, L. J. (1951). “Coefficient alpha and the internal structure of tests.”*Psychometrika.,*16 (3), 297-334.

Crotty, R. (2012). “The impact of building information modelling transforming construction.”1st ed. Taylor and Francis, London, UK.

Dawood, N., and Iqbal N. (2010). “Building information modelling (BIM): a visual & whole life cycle approach.” CONVR2010, Sendai, Japan, November 4–5, 2010, in: K. Makanae, N. Yabuki, K. Kashiyama (Eds.), Proceedings of the 10th International Conference on Construction Applications of Virtual Reality, CONVR2010 Organizing Committee, 2010, 7–14.

Denzer, A. , and Hedges, K. (2008). “From CAD to BIM: educational strategies for the coming paradigm shift.” AEI, available on-line at http://ascelibrary.org/doi/abs/10.1061/41002(328)6 (accessed February 2016).

DeVellis, R. F. (2003). “Scale development: theory and applications.”2nd Ed., SAGE Publications, Inc., Thousand Oaks, CA.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., and McNiff, S. (2013). “BIM implementation throughout the UK construction project lifecycle: An analysis.” *Autom. Constr.*, 36, 145–151.

Eastman, C., Teicholz, P., Sacks, R. &Liston, K. (2011). “BIM Handbook, A Guide to Building Information Modeling For Owners, Managers, Designers, Engineers, and Contractors.” John Wiley & Sons, Inc., Hoboken, New Jersey.

Francom, T.C., and El Asmar, M. (2015). “Project quality and change performance differences associated with the use of Building Information Modeling in design and construction projects: univariate and multivariate analyses.” *J. Constr. Eng. Manage.*, 141(9), DOI: 10.1061/(ASCE)CO.1943-7862.0000992.

Furneaux, C.,andKivvits, R. (2008). “BIM — Implications for government, CRC for construction innovation.” Brisbane, 2008, available on-line at http://eprints.qut.edu.au/26997/ (accessed February 2016).

Ghosh, S. and Jintanapakanont, J., 2004. "Identifying and assessing the critical risk factors in an underground rail project in Thailand: a factor analysis approach." *Int. J. Proj. Manage.*, *22*(8), 633-643.

Giel, B.K. and Issa, R.R. (2011). "Return on investment analysis of using building information modeling in construction". *J. Comput. Civil Eng.*, *27*(5), 511-521.

Gilligan, B., and Kunz, J. (2007). "VDC use in 2007: Significant value, dramatic growth, and apparent business opportunity." CIFE TechnicalReports, http://www.stanford.edu/group/CIFE/online.publications/TR171.pdf⟩ (Dec. 4, 2010).

Hanna, A.S., Yeutter, M., and Aoun, D.G. (2014). "State of practice of Building Information Modeling in the electrical construction industry." *J. Constr. Eng. Manage.*, 140(12), DOI: 10.1061/(ASCE)CO.1943-7862.0000893.

He, Q., Qian, Li., Duan, Y., and Li, Y. (2012). "Current Situation and Barriers of BIM Implementation." Journal of Engineering Management, 26 (1), 12-16.

Jin, R., Hancock C.M., Tang, L., Chen, C., Wanatowski, D., and Yang, L. (2017). "An empirical study of BIM-implementation-based perceptions among Chinese practitioners." *J. Manage. Eng.*, in Press, DOI: 10.1061/(ASCE)ME.1943-5479.0000538.

Jin, R., Tang, L., Hancock, C.M., and Allan, L. (2016). "BIM-based Multidisciplinary Building Design Practice-A Case Study."7th International Energy and Environment of Residential Buildings Conference.20-24 November, 2016, Brisbane, Australia.

Jin, R., L. Tang, and K. Fang.(2015). "Investigation into the current stage of BIM application in China's AEC industries." *WIT Transactions on The Built Environment*, 149, 493-503.

Johnson, R. A. (2005). Miller & Freund's probability and statistics for engineers, 7th Ed., Pearson prentice Hall, Upper Saddle River, NJ, 292-307; 397-413.

Juszczyk, M., Výskala, M., and Zima, K. (2015). "Prospects for the use of BIM in Poland and the Czech Republic –Preliminary research results." Creative Construction Conference, *Procedia Eng.*, 123, 250 – 259.

Khanzode,A., Fischer, M.,andReedD. (2008)."Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project."*J. Inf. Technol. Constr. (ITcon)* 13, 324–342(Special Issue Case studies of BIM use).

Kometa, S.T. ,Olomolaiye, P.O., and Harris, F.C. (1994). "Attribute of UK construction clients influencing project consultants' performance."*Constr. Manag. Econ.*, 12 (5), 433-443.

Liu, Y., Nederveen, S.V., and Hertogh, M. (2016). "Understanding effects of BIM on collaborative design and construction: An empirical study in China." *Int. J. Pro. Manage.*, In press, accepted June 21, 2016.

Lopez, R., Chong, H.Y., Wang, X., and Graham, J. (2016). "Technical review: analysis and appraisal of four-dimensional Building Information Modeling usability in construction and engineering projects." *J. Constr. Eng. Manage.*,142 (5), DOI: 10.1061/(ASCE)CO.1943-7862.0001094.

Lopez, R., and Love, P.E.D. (2012). "Design error costs in construction projects." *J. Constr. Eng. Manage.,*138 (5), DOI: 10.1061/(ASCE)CO.1943-7862.0000454.

Love, P.E.D., Simpson, I., Hill, A., and Standing, C. (2013). "From justification to evaluation: Building information modeling for asset owners." *Autom.Constr*., 35, 208-216.

Mahalingam, A., Yadav, A.K., and Varaprasad, J. (2015). "Investigating the role of lean practices in enabling BIM adoption: evidence from two Indian cases." *J. Constr. Eng. Manage.*,142 (5), DOI: 10.1061/(ASCE)CO.1943-7862.0000982.

MarketLine Industry Profile (2014), Construction in China, Reference Code: 0099-2801.

Masood, R., Kharal, M.K.N., and Nasir, A.R. (2013). "Is BIM adoption advantageous for construction industry of Pakistan?" Fourth International Symposium on Infrastructure Engineering in Developing Countries, IEDC 2013, *Procedia Eng.* 77, 229 – 238.

McGraw-Hill Construction. (2009). "The business value of BIM: Getting building information modeling to the bottom line." McGraw-Hill Construction SmartMarket Rep., McGraw Hill, New York.

McGraw Hill Construction (2014). "The business value of BIM for construction in Global Markets." McGraw Hill Construction, Bedford MA, United States.

Meliá, J. L.,Mearns, K., Silva, S. A., and Lima, M. L. (2008)."Safety climate responses and the perceived risk of accidents in the construction industry." *Safety Sci.*, 46 (6), 949-958.

Migilinskas, D., Popov, V.,Juocevicius, V., and Ustinovichius, L. (2013). "The benefits, obstacles and problems of practical BIM implementation." *Procedia Eng.* 57, 767–774.

Neelamkavil, J. and Ahamed, S.S. (2012). "The Return on Investment from BIM Driven Projects in Construction." National Research Council, Canada. (IRC-RR-324 9 (Available at www.nrc.cnrc.gc.ca/irc).

NFB Business & Skills (2013). "BIM shaping the future of construction." Report.

Nunnally, L. and Bernstein, L. (1994)."Psychometric theory."McGraw-Hill, Inc., New York.

Shanghai Municipal People's Government (2014). "Guidelines on BIM Applications in Shanghai." Shanghai, China.

Shenzhen Exploration & Design Association (SZEDA, 2013), Guide for BIM application and development in the engineering & design industry of Shenzhen, *Tianjin Science & Technology Press*, Tianjin (in Chinese).

SmartMarket Report (2015). “Measuring the impact of BIM on complex buildings.” Dodge Data & Analytics, Bedford, MA.

Smith, P. (2014). “BIM implementation–global strategies.” *Procedia Eng.*, *85*, pp.482-492.

State Ministry of Housing and Urban-Rural Construction (SMHURC, 2011). “The 2011-2015 Development Guideline for the Construction Industry Digitalization.” Beijing, China (in Chinese).

State Ministry of Housing and Urban-Rural Construction (SMHURC, 2013). “Request for Proposal on BIM Application in the Construction Industry.” Beijing, China (in Chinese).

Suwal, S., Jäväjä, P., & Salin, J. (2014). “BIM Education: Implementing and Reviewing" OpeBIM"—BIM for Teachers.” *Computing in Civil and Building Engineering*, 2151-2158.

Tam, C. M.,Deng, Z. M.,Zeng, S. X. , and Ho, C. S. (2000). “Quest for continuous quality improvement for public housing construction in Hong Kong.”*Constr. Manage. Econ.*, 18 (4), 437-446.

Tam, V.W.Y. (2009). “Comparing the implementation of concrete recycling in the Australian and Japanese construction industries.”*Constr. Manage. Econ.*, 17(7), 688-702.

Tang, L., Jin, R. and Fang, K. (2015). “Launching the innovative BIM module for the architecture and built environment programme in China.”*Building Information Modelling (BIM) in Design, Construction and Operations*, 149, 145.

Tavakol, M. and Dennick, R. (2011). “Making sense of Cronbach’s alpha.” *Int. J. Med. Edu.* 2, 53-55.

Thomsen, A. (2010). “The role and influence of the Architect in industrialized building.”

Wang, S.Q., Dulaimi, M.F. and Aguria, M.Y. (2004). “Risk management framework for construction projects in developing countries.” *Constr. Manage. Econ.*, *22*(3), 237-252.

Won, J., Lee, G., Dossick C., Messner, J. (2013). “Where to focus for successful adoption of building information modeling within organization.” *J. Constr. Eng. Manage.*,139(11), DOI: 10.1061/(ASCE)CO.1943-7862.0000731.

Yan, H. andDamianP.(2008). “Benefits and barriers of building information modelling.”

Zahir, I and Love P.E.D. (2008) *Evaluating information systems: public and private sector*. Routledge, 2008.

Appendix: Questionnaire of BIM Investment Areas, Returns, Strategies, and Risks

Part A: BIM Users Information

1. Where are you working?
2. Your current position ( ) A. Architect; B. Engineer (e.g., Structural Engineer); C. Contractor; D. Owner; E. BIM consultant; F. Others, please specify________________.
3. How long have you been using BIM software? _________________
4. What BIM software tools are you using or have you ever used before (multi-choice)? A. Autodesk (e.g., Revit); B. Bentley; C. Nemetschek (e.g., ArchiCAD); D. Dassault (e.g., Digital Project); E. Others, please specify _________; F. Have never used any BIM software.
5. How would you define your proficiency level in applying BIM tools? A. Experts; B. Advanced level; C. Moderate level; D. Beginner.

Part B: Perceptions on BIM investment focuses, returns, ways to enhance BIM returns, and risks

6. How would you evaluate the importance of following areas of BIM investments? Choose one from the following five numerical scales. 1. Least important; 2.Not very important; 3. Neutral; 4. Important; 5. Very important.
   - BIM software
   - Developing internal collaboration according to BIM procedures
   - Marketing your BIM capability
   - BIM training
   - New or upgraded hardware
   - Developing collaborative BIM processes with external parties
   - Software customization and interoperability solutions
   - Developing custom 3D libraries
7. How would you perceive these following recognized returns from BIM investment? Choose one from the following five numerical scales. 1. Strongly disagree; 2.Disagree; 3. Neutral; 4. Agree; 5. Strongly agree.
   - Better multiparty communication and understanding from 3D visualization
   - Improved project process outcomes, such as fewer RFIs (request for information) and field coordination problems
   - Improved productivity
   - Increased application of prefabrication
   - Positive impact on marketing
   - Reduced cycle time for project activities and delivery
   - Lower project cost
   - Improved jobsite safety
   - Positive impact on sustainability
   - Positive impact on recruiting/retaining staff
   - Faster plan approval and permits
   - More accurate construction documents
   - Improved operations, maintenance and facility management
8. The adoption of BIM in your organization's greening building practical or research projects. A. Frequent adoption; B. Moderate adoption; C. Little adoption.
9. What is your expected change of BIM use in green building projects in the future? A. Decrease; B. Stay unchanged; C. Low increase; D. Moderate increase; E. High increase; F. Incredible increase
10. How would you perceive the importance of these following suggested ways to enhance returns from BIM application? Choose one from the following five numerical scales. 1. Least important; 2.Not very important; 3. Neutral; 4. Important; 5. Very important.
    - Improved interoperability between software applications
    - Improved functionality of BIM software
    - More clearly defined BIM deliverables between parties
    - More internal staff with BIM skills
    - More owners consulting for BIM
    - More external firms with BIM skills
    - More 3D building product manufacturer to employ more prefabrication
    - More use of contract language to support BIM and collaboration
    - More incoming entry-level staffs with BIM skills
    - Willingness of AHJs (Authorities Having Jurisdiction) to accept models
    - Reduced cost of BIM software
    - More hard data demonstrating the business value of BIM
    - More readily available training on BIM
    - Integration of BIM data with mobile devices/applications
    - More readily available outsourced modeling service
11. Please identify these key risks in BIM implementation (multi-choice)
    - Technical risks: 1). Imperfect BIM software; 2). Rapid update of BIM technologies; 3). The difficulty of BIM technologies; 4). Poor adoption of BIM technologies
    - Human resource risks: 1). Tight schedule of current business; 2). Lack of BIM technicians; 3). Reluctance to accept new BIM technologies; 4). Lack of knowledge and capabilities among current employees
    - Financial risks: 1). Long period of return on investment; 2). Uncertainty of profit; 3). High cost of short-term investment
    - Management risks: 1). Reluctance to adopt BIM from the management level; 2). The difficult transition of business procedures; 3). The difficult transition of management pattern
    - Other risks: 1). Low recognition of society; 2). Unclear legal liability; 3). Unknown intellectual property; 4). Lack of industry standards

Table List

Table 1. Survey results of importance of BIM investment areas (Cronbach's alpha = 0.921)

Item	**N***	***RII***	**Item-total correlation**	**Cronbach's Alpha**
I1: Developing internal collaboration according to BIM standards	71	0.876	0.701	0.913
I2: Developing collaborative BIM processes with external parties	69	0.872	0.732	0.911
I3: Software customization and interoperability solutions	71	0.865	0.799	0.905
I4: Marketing your BIM capability	71	0.814	0.673	0.916
I5: BIM software	69	0.809	0.767	0.908
I6: BIM training	71	0.808	0.715	0.912
I7: Developing custom 3D libraries.	66	0.785	0.752	0.909
I8: New or upgraded hardware	68	0.768	0.752	0.909

*:The total number of responses for each given item.

Note: The sample forming data analysis of this Likert-scale question excludes those who selected "N/A" within each given item. The same rule applies to the data analysis of other Likert-scale questions.

Table 2. ANOVA analysis of subgroup differences towards BIM investment-related items.

Item	Overall Mean	Standard deviation	ANOVA analysis for subgroups according to professions		ANOVA analysis for subgroups according to BIM proficiency level	
			F value	*p* value	*F* value	*p* value
I1	4.380	0.811	0.92	0.496	2.35	0.064
I2	4.362	0.816	0.97	0.459	1.29	0.284
I3	4.324	0.835	1.01	0.434	0.66	0.620
I4	4.070	1.025	1.19	0.320	0.94	0.448
I5	4.057	0.860	0.58	0.769	0.55	0.698
I6	4.042	0.895	1.54	0.171	1.05	0.389
I7	3.924	0.910	0.12	0.997	0.32	0.862
I8	3.838	0.933	0.99	0.445	0.68	0.609

Table 3. Survey results of recognitions on returns from BIM investment (Cronbach's alpha = 0.927)

Item	**N***	**RII**	**Item-total correlation**	**Cronbach's Alpha**
R1:Improved multiparty communication and understanding from 3D visualization	82	0.920	0.581	0.925
R2: Positive impact on sustainability	83	0.855	0.623	0.924
R3: Improved operations, maintenance and facility management	85	0.849	0.731	0.920
R4: Improved project process outcomes, such as fewer RFIs (request for information) and field coordination problems	83	0.848	0.710	0.921
R5: Positive impact on marketing	84	0.845	0.614	0.924
R6: Increased application of prefabrication	80	0.845	0.693	0.921
R7: More accurate shop drawings	85	0.828	0.723	0.920
R8: Lower project cost	84	0.795	0.660	0.923
R9: Shortened construction duration	83	0.790	0.780	0.918
R10: Improved productivity	85	0.788	0.816	0.916
R11: Improved jobsite safety	84	0.767	0.732	0.920
R12:Shortened duration in the project planning stage	78	0.744	0.597	0.925
R13: Positive impact on recruiting/retaining staff	79	0.732	0.522	0.927

*:The total number of responses for each given item.

Table 4. ANOVA analysis of subgroup differences towards recognitions on BIM return-related items.

Item	**Overall Mean**	**Standard deviation**	**ANOVA analysis for subgroups according to professions**		**ANOVA analysis for subgroups according to BIM proficiency level**	
			F value	*p* value	*F* value	*p* value
R1	4.598	0.814	0.58	0.767	**2.58**	**0.044**[*]
R2	4.277	0.790	1.98	0.069	0.87	0.484
R3	4.247	0.831	1.63	0.140	0.74	0.565
R4	4.241	0.839	0.34	0.931	1.37	0.253
R5	4.226	0.892	**2.84**	**0.011**[*]	2.23	0.073
R6	4.225	0.830	0.87	0.536	0.06	0.994
R7	4.141	0.824	0.77	0.616	0.26	0.905
R8	3.976	0.923	0.46	0.861	0.47	0.755
R9	3.952	1.029	0.69	0.681	0.32	0.861
R10	3.941	0.980	1.20	0.311	0.57	0.687
R11	3.833	1.018	1.75	0.111	0.95	0.441
R12	3.718	0.998	**3.57**	**0.003**[*]	1.24	0.303
R13	3.658	0.875	**2.64**	**0.018**[*]	1.84	0.131

[*]: *p* values lower than 0.05 indicate significant subgroup differences towards the given item in BIM return values

Table 5. Survey results of perceptions on ways to improve returns from BIM application (Cronbach's alpha = 0.943)

Item	N*	RII	Item-total correlation	Cronbach's Alpha
W1:Improvement of interoperability among software applications	76	0.908	0.622	0.941
W2:More clearly defined BIM deliverables among project parties	76	0.903	0.672	0.940
W3: More use of contract language to support BIM and BIM-based collaboration	78	0.869	0.753	0.938
W4:Willingness of AHJs (Authorities Having Jurisdiction) to accept models	75	0.864	0.628	0.941
W5: Improved capacities of BIM software	78	0.859	0.784	0.937
W6: More demands from clients on BIM usage	77	0.855	0.721	0.938
W7: More internal staff with BIM skills	77	0.855	0.731	0.938
W8: More data demonstrating the business value of BIM	79	0.848	0.696	0.939
W9: More BIM applications in the manufacturing and construction of prefabrication members	79	0.825	0.837	0.935
W10:Integration of BIM data with mobile devices/applications	77	0.823	0.765	0.937
W11:Reduced cost of BIM software	78	0.821	0.700	0.939
W12:More BIM training provided to AEC professionals	79	0.795	0.658	0.940
W13:More hired entry-level staffs with BIM skills	74	0.781	0.727	0.938
W14:More consulting firms with BIM expertise	73	0.710	0.711	0.939
W15:More subcontracted modeling service available	70	0.671	0.601	0.942

*:The total number of responses for each given item.

Table 6. ANOVA analysis of subgroup differences on ways to enhance returns from BIM application

Item	**Overall Mean**	**Standard deviation**	**ANOVA analysis for subgroups according to professions**		**ANOVA analysis for subgroups according to BIM proficiency level**	
			F value	*p* value	*F* value	*p* value
W1	4.539	0.886	0.87	0.535	0.98	0.424
W2	4.513	0.757	1.26	0.287	0.65	0.626
W3	4.346	0.819	0.23	0.977	0.16	0.960
W4	4.320	1.029	0.40	0.902	0.29	0.886
W5	4.295	0.808	0.31	0.948	0.41	0.801
W6	4.273	0.883	0.34	0.933	0.27	0.894
W7	4.273	0.821	0.86	0.546	0.20	0.938
W8	4.241	1.003	0.99	0.444	0.48	0.747
W9	4.127	0.952	0.34	0.933	0.67	0.618
W10	4.117	1.038	0.67	0.699	0.97	0.427
W11	4.103	1.076	1.12	0.361	0.89	0.474
W12	3.975	1.012	1.83	0.095	1.03	0.397
W13	3.905	0.939	0.57	0.779	0.94	0.447
W14	3.548	1.106	0.65	0.714	0.21	0.933
W15	3.357	1.258	0.42	0.884	0.84	0.504

[*]: *p* values lower than 0.05 indicate significant subgroup differences towards the given item in BIM return values

Table 7. Chi-Square test of subgroup differences on BIM implementation related risks

	Subgroups divided by job profession (degree of freedom = 7)		**Subgroups divided by BIM proficiency level (degree of freedom = 4)**	
	Chi-Square value	*p* value	Chi-Square value	*p* value
T1	2.00	0.960	**13.8**	**0.008***
T2	8.23	0.312	0.693	0.952
T3	3.23	0.863	0.791	0.940
T4	7.29	0.399	2.56	0.635
H1	8.58	0.284	**11.1**	**0.026***
H2	3.59	0.825	3.97	0.411
H3	5.03	0.656	7.89	0.096
H4	8.99	0.253	1.38	0.847
F1	8.32	0.305	2.32	0.677
F2	7.56	0.373	2.58	0.630
F3	4.34	0.740	0.354	0.986
M1	12.0	0.100	3.31	0.508
M2	3.44	0.842	1.35	0.853
M3	12.5	0.085	5.58	0.233
O1	7.50	0.379	4.41	0.354
O2	11.6	0.113	4.19	0.381
O3	6.77	0.453	0.326	0.988
O4	5.31	0.623	2.52	0.641

*: *p* value lower than 0.05 indicates significant subgroup differences