

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

2 **Industries**

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4 **Abstract**

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

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

33 **CE Database subject headings:**

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

36

37 **Introduction**

38 Building Information Modeling (BIM), as defined by Eastman et al (2011), is one of the
39 most promising developments in the architectural, engineering, and construction (AEC)
40 industries with the digital construction of accurate virtual models. China, the country
41 accounting for nearly half of Asia-Pacific AEC industry revenue as reported by Marketline
42 (2014), is experiencing the increasing demand on BIM usage in the years to come. Starting in
43 2011, China's national BIM policy was announced by the State Ministry of Housing and
44 Urban-Rural Construction (SMHURC, 2011) aiming to establish relevant standards in the

45 follow-up years. A more detailed strategic plan was released from State Ministry of Housing
46 and Urban-Rural Construction (SMHURC, 2013) in another proposal on BIM application that
47 by 2016, government-invested projects over 20,000 square meters (215,278 square feet) and
48 green building in the provincial level should adopt BIM in both design and construction. By
49 2020, the industry guidelines for BIM application and public standards should be well-
50 established. The effects of isomorphic pressures from governmental bodies, regulatory
51 agencies, or industry associations on project-level BIM adoption in China were studied by Cao
52 et al. (2014). However, there is still limited research on Chinese BIM practitioners' perceptions
53 on how the BIM adoption would affect the whole AEC market crossing fields.

54 Along with the public authorities' movement on demanding BIM applications, AEC
55 professionals' status of BIM implementation in mainland China was also investigated in earlier
56 studies including China Construction Industry Association (CCIA, 2013), Shenzhen
57 Exploration & Design Association (SZEDA, 2013), and Jin et al. (2015). Although there are
58 still limited regions in China with developed BIM standards, and BIM applications during the
59 project delivery process may still be limited to the design stage, the trend of AEC firms in
60 China towards BIM-equipped digitalization can be foreseen from the state-of-the-art policies
61 and visions released from public authorities and the spreading involvement of BIM in China's
62 construction projects. For example, Shanghai Municipal People's Government (2014)
63 announced the strategic objectives of BIM implementation highlighting that industry standards
64 enabling the BIM implementation in Shanghai's AEC projects should be available by the end
65 of 2016, and government-invested projects must adopt BIM starting from 2017. Internationally,
66 a review of previous research on BIM benefits, practice status, policy development, and
67 challenges revealed that these studies mostly focused on BIM application in specialty areas
68 (e.g., electrical construction in Hanna et al., 2014), with research-involved participants from
69 certain technical fields (e.g., consultants and researchers in Won et al., 2013), or targeting on

70 project construction stage (e.g., Cao et al., 2014; Francom et al. 2015). So far, relevant
71 empirical studies (e.g., Eadie et al., 2013) that recruited survey participants from multiple AEC
72 disciplines are still not sufficient for the purpose of gaining a more holistic picture of BIM
73 implementation-associated issues such as risks, returns from investments, and strategies.

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

88 Extending from previous BIM-implementation-related studies in developed countries (e.g.,
89 Eadie et al., 2013; Hanna et al., 2014; Francom and El Asmar, 2015), this questionnaire-based
90 study focuses on investigating the perceptions of BIM practitioners towards the BIM
91 investment, returns from BIM investment, ways to improve the return from BIM applications,
92 and risks in implementing BIM in China. Returns are defined in this study as added-values or
93 benefits gained from adopting BIM, including both tangible benefits (e.g., direct financial
94 incentives) and intangible values (e.g., enhanced multi-party communication in the project

95 delivery process and improved efficiency). The survey pool is divided into subgroups
96 according to their profession and BIM proficiency level as defined by Jin et al. (2017). Potential
97 subgroup differences are explored to analyze whether the perceptions towards returns and risks
98 of BIM would be affected by participants' profession and BIM experience level. The results of
99 this questionnaire survey provide suggestions on how to enhance returns from BIM usage for
100 AEC industry professionals or stakeholders who are investing in BIM or planning to adopt
101 BIM in their projects.

102

103 **Literature Review**

104 *BIM movement in developing countries*

105 BIM implementation is accelerating worldwide, and this is being driven by government
106 mandates, as well as clients and contractors as they realize the possible benefits of BIM in the
107 long and short term (Smith, 2014). McGraw Hill (2014) conducted a survey from ten of the
108 largest construction markets in the world including India and China. The survey found that
109 BIM implementation in all these countries was significantly increasing and was predicted to
110 continue increasing over the next few years. Many other countries, such as Pakistan (Masood
111 et al., 2013) and Poland (Juszczak et al., 2015), have been accelerating their use of BIM, and
112 the trend of BIM usage growth can be expected in the near future (McGraw-Hill Construction,
113 2014). However, there have been limited empirical studies of BIM implementation in these
114 developing countries with large AEC markets including India (e.g., Mahalingam et al., 2015)
115 and China (e.g., Cao et al., 2016).

116 Earlier questionnaire-based surveys from CCIA (2013), SZEDA (2013), and Jin et al.
117 (2015) showed that large-sized and highly-qualified contractors nationwide in China mostly
118 stayed in the "heard-of" stage with limited adoption of BIM, design firms mostly used BIM in
119 the experimental stage for small-size projects, and BIM was a new concept in China with the

120 majority of employees starting to learn BIM after 2010. It was also found that in China BIM
121 implementation faced challenges such as lack of well-developed standards and legislation,
122 insufficient interoperability and collaboration among different disciplines, as well as
123 difficulties in implementing BIM during the whole lifecycle of a building project (He et al.,
124 2012; Ding et al., 2015; Liu et al; 2017).

125 *Returns from BIM Application*

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

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

145 ***BIM implementation risks***

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

150 It was suggested by Ghosh (2004) that risks could be defined by some factors that can
151 jeopardize the successful completion of a project. Wang et al (2004) listed three main stages
152 within risk management: identification of the risk, analysis and evaluation, as well as responses
153 to the risk. Identification of potential risks is the first step in the BIM implementation process.
154 Chien et al (2014) studied the risk factors in BIM and concluded that assessing risks and
155 countering them required an understanding of the characteristics of the risks. Inadequate project
156 experience and a lack of training have the most effect on other risk factors (Chien et al., 2014).
157 Other challenges that could affect risk factors within BIM practice included practitioners'
158 knowledge on cross disciplinary nature of BIM, cultural resistance to BIM, clients' knowledge
159 and supports on BIM, higher initial cost, difficulties of applying BIM through the full building
160 cycle, the interoperability issues between companies, and legal issues as identified by multiple
161 studies (e.g., Denzer and Hedges, 2008; Birkeland, 2009; Breetzke and Hawkins, 2009; Bender,
162 2010; Dawood and Iqbal, 2010; Azhar, 2011; He et al. 2012; NFB Business & Skills; 2013;
163 Cao et al., 2014; Suwal et al., 2014; Mahalingam et al., 2015;).

164

165 **Methodology**

166 The questionnaire survey-based research method was adopted to collect information on
167 perceptions towards BIM investment focus, returns by adopting BIM, ways to enhance returns,
168 and risks associated with BIM implementation from AEC industry professionals in mainland
169 China, with targeted survey participants from various professions and different BIM experience

170 levels. The questionnaire was developed by the research team from the University of
171 Nottingham Ningbo China (UNNC) between August 2014 and May 2015 and peer-reviewed
172 by professionals from the Shanghai BIM Engineering Centre (SBEC), the first BIM
173 organization in mainland China focusing on technological communication and information
174 exchange. The questionnaire was updated according to the feedback provided by SBEC.
175 Finally, the approval from the Research Ethics Office was obtained in June 2015 to ensure that
176 relevant ethics requirements were met (e.g., no personal information of participants were
177 included) when delivering the questionnaire survey.

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

189 The questionnaire was divided into two parts. The first part collected the background
190 information of respondents, including their working location in mainland China, their
191 profession (e.g., architects, engineer, contractor, etc.), their BIM experience level (i.e., expert,
192 advanced level, intermediate level, entry-level, and little BIM experience), and the software
193 tools adopted in their work. The second part of the questionnaire consisted of four sections,
194 targeted at BIM investment focuses, returns from BIM usage, ways to improve relevant BIM

195 returns, and risks encountered in BIM implementation. The Likert scale and multiple-choice
196 were the two types of questions designed in the survey. For the Likert scale questions related
197 to BIM investment and return, four major statistical methods were involved:

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

203

204

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

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

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

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

222 (3) Analysis of Variance (ANOVA) was applied as a parametric method to test the subgroup
223 (i.e., survey sample divided according to the profession and BIM experience level in this
224 study) consistencies of their perceptions towards BIM investment and return related
225 sections. ANOVA has been used in the data analysis of Likert scale questions in
226 construction engineering studies such as Aksorn and Hadikusumo (2008), Meliá et al.
227 (2008), and Tam (2009). Following the procedure described by Johnson (2005), the F
228 statistics was computed based on *degrees of freedom, sum of squares, and mean square*
229 in the ANOVA analysis. The values of these terms were calculated with the assistance
230 of Minitab, the statistical analysis software. Based on a 5% level of significance and the
231 null hypothesis that there were no significantly different mean values among subgroups
232 of BIM professionals towards the given Likert-scale question, a p value was obtained
233 according to the computed F value. The p value lower than 0.05 would indicate that
234 subgroups of survey participants have inconsistent views towards the given item.

235 (4) For multiple-choice questions related to risks encountered in BIM implementation,
236 based on the null hypothesis that all subgroups have consistent percentages of selecting
237 the same proposed risk, the Chi-Square test of independence described in Johnson (2005)
238 at the 5% level of significance was performed to analyze the subgroup variations in
239 identifying these BIM risks. The Chi-Square value was calculated according to
240 differences between observed and expected cell frequencies in each question related to
241 BIM implementation risks following the computation procedure guided by Johnson
242 (2005). A p value lower than 0.05 would reject the null hypothesis and suggest the
243 significantly different percentages of subgroups in identifying the given BIM risk.

244

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

246 Finally 81 responses were received with survey participants from different professions
247 including architects, engineers, owners, BIM consultants, and other AEC practitioners. In total
248 13 responses were received from the on-line survey. The 81 on-site responses collected and the
249 13 on-line responses received were tested using the two-tailed statistical test (i.e., two-sample
250 *t*-tests for inferences concerning two means or two proportions) recommended by Johnson
251 (2005) based on the 5% level of significance. The two-tailed tests revealed no significantly
252 different mean values or proportions between site and on-line responses for the four major
253 sections related to BIM investment areas, BIM returns, ways to enhance BIM return, and BIM
254 risks. Therefore, by combing the responses from the forum site and on-line surveys, 94
255 questionnaires were collected as the whole survey sample. The discussion on findings of this
256 questionnaire were divided into survey participants' background, BIM investment areas,
257 recognized BIM returns, suggested ways to enhance BIM return, and risks in BIM
258 implementation.

259 ***Regional coverage of the survey in China***

260 BIM implementation in projects remains relatively rare in mainland China (Cao et al.,
261 2016). According to Jin et al. (2015), Beijing, Shanghai, and Canton were the major regional
262 centers in China that had actively adopted BIM in AEC practices. Survey population from or
263 nearby these three regional centers occurred to constitute 84% of the whole sample. This was
264 consistent with Jin et al. (2015)'s findings regarding China's BIM-leading regions in that
265 surrounding municipalities or provinces had been following these three key regional centers'
266 BIM regulatory and standard movements.

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

268 It is shown in Fig.1 that over 60% of respondents came from Shanghai or nearby locations
269 (including provinces of Zhejiang and Jiangsu). The other 16% of survey participants were from

270 the inland part of China or overseas. Detailed geographic distribution of this survey sample can
271 be found from Jin et al. (2017). Although majority of survey participants came from Beijing,
272 Shanghai, and Canton, or their nearby locations representing the major BIM-active and more
273 economically developed regions in China, the findings from this empirical study provide
274 insights to other less-BIM-active regions (e.g., inland part of China) and those regions with
275 limited BIM movement but likely to start BIM implementation in the near future, for example,
276 Liaoning Province in north-eastern part of China mentioned in Jin et al. (2015).

277 *Survey participants' background*

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

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

295 experts or advanced practitioners tended to have more frequent BIM adoptions in their AEC
296 projects.

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

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

304 ***Focuses in BIM investment***

305 Survey participants were asked their perceptions on the importance of BIM investment
306 areas based on the Likert-scale question format. Multiple areas of BIM investment were
307 provided. For example, the BIM software investment, BIM training, and BIM library update,
308 etc. Based on the numerical value ranking, with “1” being least important, “3” indicating
309 neutral, and “5” standing for most important, the statistical analysis is summarized in Table 1.

310 Survey participants were also provided with the extra option of “N/A” if unable to answer the
311 given item due to lack of knowledge. Eight items following the *RII* score ranking are listed in
312 Table 1.

313 The Cronbach’s alpha at 0.921 indicated a relatively high internal consistency of
314 participants’ view on these BIM investment areas. The item-total correlation value displayed
315 in Table 1 measured the correlation between the target item and the aggregate score of the
316 remaining items. For example, the item-total correlation value at 0.701 for I1 in Table 1
317 indicated fairly positive and strong relationship between item I1 and the rest seven items. All
318 these relatively high item-total correlation values in Table 1 suggested that each item’s Likert
319 scale score was somewhat internally consistent with that of other items. The internal

320 consistency could be further tested by the individual Cronbach's alpha value in Table 1, which
321 showed the changed Cronbach's alpha value if the given item was removed from this section.
322 All values lower than the original one at 0.921 indicated that each of the eight items positively
323 contributed to the internal consistency.

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

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

338 The overall mean value above or close to 4.0 indicated that the six areas (i.e., I1 to I6 in
339 Table 1 and Table 2) were considered more important in BIM investment. All *p* values above
340 0.05 suggested that all survey participants, regardless of job profession or BIM experience level,
341 shared the consistent views on all the eight identified BIM investment areas.

342 ***Returns from BIM Application***

343 Survey participants were asked of their recognitions of returns from BIM investment and
344 application. Various potential or achieved returns from BIM investment were evaluated by

345 survey participants, with “1” being strongly disagree, “3” being neutral, “5” being strongly
346 agree, and the extra option of “N/A” was given to those with little knowledge on it. The internal
347 consistency analysis is summarized in Table 3.

348 It is seen in Table 3 that improving multiparty communication and understanding from 3D
349 visualization was the top-ranked recognized return from BIM investment, followed by the
350 positive impact on sustainability. Survey participants had strongly positive perceptions that
351 BIM would enhance the communication among multiple project parties through detailed
352 visualization. This could be due to the fact that BIM implementation may be limited to 3D
353 visualization for some Chinese engineering firms identified by Jin et al. (2015). He et al. (2012)
354 stated that the usage of BIM in China was still limited to design firms. The gap that lies between
355 proposed BIM application and its current implementation in China, as defined by Jin et al.
356 (2015), was from using BIM solely as a 3D visualization tool to adopting BIM as the platform
357 for project delivery and business management. The second ranked BIM value in light of BIM’s
358 positive impact on sustainability could be due to the fact that 50% of the survey sample had
359 either high or moderate adoption of BIM in their green building projects. In another multiple-
360 choice question asking respondents’ expectation of BIM application in green buildings, around
361 94% of survey participants believed that BIM would have an increased application in China’s
362 future green building projects, with 0% of them choosing decreased application or remaining
363 the same, and the other 6% claimed no knowledge on this subject. Among those who expected
364 an increased BIM application in green buildings, nearly half (49%) of the survey sample
365 selected “high increase”, with the remaining choosing a moderate increase (22%) or a slow
366 increase (5%).

367 Besides the improved communication from visualization and sustainability, there were
368 another five BIM return related items perceived with *RII* scores above 0.800 (i.e., equivalent
369 to an average Likert scale score at 4.0). Though returns from BIM usages in reducing project

370 cost and decreasing project duration had been identified in multiple previous studies
371 internationally (Furieux and Kivvits, 2008; Khanzode and Fischer, 2008; Yan and Damian,
372 2008; Becerik-Gerber and Rice, 2010; Both et al., 2012; Cheung et al., 2012; Crotty, 2012;
373 Migilinskas et al., 2013), the recognitions of BIM returns relevant to lowered project cost and
374 duration were ranked below the *RII* scores at 0.800 (equivalent to Likert scale score at 4.0
375 indicating “agree” among respondents). The relative lower ranking and score obtained related
376 to project cost and duration could be due to the limited work that had been performed to
377 compare project cost and time of project with and without BIM adoptions among Chinese
378 practitioners. Instead, returns related to other BIM assistances in construction and operation
379 were recognized with higher *RII* scores, such as fewer RFIs and more accurate shop drawings.
380 It is worth mentioning the increased applications of BIM in prefabrication construction, which
381 has become one of the mainstream movements in China’s AEC industries. The enhancement
382 of prefabrication design codes, technical standards, and construction methods was clearly
383 specified in the recently released China State Council announcement (2016). It had been
384 foreseen from participants in this survey pool regarding BIM’s application in the emerged
385 prefabrication construction market.

386 Similar to items within BIM investment areas, the high Cronbach’s alpha value at 0.927
387 showed a generally high consistency among these 13 identified recognitions of returns from
388 BIM usage. The Cronbach’s alpha values in Table 3 are lower than the original value indicated
389 that all the 13 items contributed to the internal consistency. Though overall survey participants
390 who chose a score for one item in Table 4 tended to assign a similar score to another one, the
391 item-total correlation coefficients suggested that R1, R12, and R13 had relatively weaker
392 correlation with the remaining items. It could be inferred that a respondent who scored these
393 remaining items was more likely to provide a different score on R1, R12, and R13. Generally,
394 the return of BIM in enhancing multiparty communication was more likely to be assigned with

395 a higher Likert scale score than other items related to returns from BIM application. A
396 respondent was prone to score lower in BIM's impacts on project planning and recruiting
397 /retaining employees compared to other items.

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

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

403 Those with little BIM experience tended to have a more conservative view on improved
404 communication and understanding from BIM-driven visualization, with a mean Likert score at
405 3.889 which is between "neutral" and "agree". In contrast, all other respondents with some
406 BIM experience (from entry level to expert level) all had wider recognition of BIM-enhanced
407 communication and understanding, with Likert scale score above 4.500 or close to "strongly
408 agree." That would infer that gaining BIM practical experience would provide AEC
409 professionals with higher recognition in returns from BIM in terms of enhancing
410 communication.

411 The p value lower than 0.05 suggested significant differences among subgroups'
412 recognitions towards BIM's impact on marketing their professional work. Specifically,
413 architects had less positive perceptions on BIM's positive impact on marketing, with a mean
414 Likert scale score at 3.222 (i.e., close to the neutral score at 3), while all other subgroups had
415 mean scores from 4.167 to 4.750, all above the score at 4.0 representing "agree" to the
416 statement that BIM could positively market their professional work. The majority of architects
417 from this survey sample had BIM usage experience ranging from one to seven years, with an
418 average usage around two years. The lower mean score assigned from architects was therefore
419 unlikely due to their lack of BIM experience or lower BIM proficiency level. Instead, it could

420 result from their job nature, in which BIM-driven 3D visualization is more frequently
421 implemented. Architects, which usually lead the project delivery in the early planning and
422 design stage through more visualized work, might perceive less impact of BIM on marketing
423 their work since architectural work tends to have more BIM elements such as 3D visualization
424 and dynamic walkthrough. In contrast, software developer, academics, and owner, with a mean
425 score at 4.750, 4.667 and 4.667 respectively, are prone to perceive more BIM in positively
426 marketing their work or product, followed by BIM consultant (4.375), engineers (4.320), and
427 general contractors (4.167).

428 Besides the recognition of BIM's positive impact on marketing, architects also tended to
429 have lower recognition of BIM in reducing project planning time and recruiting/retaining staff.
430 While other professions held the view of "agree" or "strongly agree". The mean Likert scale
431 scores from architects in R12 and R13 were 2.667 and 2.625 respectively, indicating architects'
432 perceptions between "disagree" and "neutral" towards BIM's positive influences on project
433 planning duration and employee recruitment/retention. When looking into previous studies of
434 how BIM affected architects' role in the project, it was claimed that BIM platform changed the
435 role in the project design phase and added risks to architects of being replaced by a more
436 computer skilled designer or engineer (Thomsen, 2010). Sometimes mainstream BIM tools
437 such as Revit as identified in this study may not be as effective as more traditional tools (e.g.,
438 Sketchup or Rhinoceros) according to the pedagogical study of Jin et al. (2016). Thomsen
439 (2010) further stated that BIM technical platforms limited the options of possible solutions and
440 provided extra requirements than traditional projects. These previous studies could serve as the
441 rationale of architects' lower recognitions of BIM's positive impact on project planning and
442 employees, as architects may experience more negative effects from BIM usage including but
443 not limited to role change and extra work as identified by Thomsen (2010) and Jin et al. (2016).

444 ***Ways to improve BIM returns***

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

450 The overall Cronbach’s alpha value at 0.943 indicated a high degree of internal consistency
451 of respondents on all these 15 items related to suggested ways to enhance BIM returns. All
452 these Cronbach’s alpha values lower than 0.943 after removing any one of these items in Table
453 5 suggested that every item contributed to the overall internal consistency. The comparatively
454 high item-total correlation in Table 5 also indicated that respondents tended to assign similar
455 scores to these 15 suggested ways. The item showing lowest item-total correlation was W15
456 regarding the availability of subcontracted modeling service, suggesting that respondents were
457 more likely to score differently to W15. The top two ranked items, with *RII* scores above 0.900,
458 both addressed the issues of interoperability. Although Autodesk was identified as the most
459 widely used BIM authoring tool in this survey pool according to Fig.3, other BIM software
460 suppliers, including domestic Chinese vendors (e.g., Glondon and Luban) were also being used
461 by AEC professionals. There is ongoing work of software developers in localizing international
462 BIM tools (e.g., Autodesk) in China practice by including Chinese industry standards (e.g.,
463 establishment of new building element families). The interchange of digital information among
464 multiple BIM tools using file formats such as Industry Foundation Class (IFC) and gbXML is
465 one of the major issues in BIM interoperability to be solved in the future. Clearly defined BIM
466 deliverable among different parties, including the level of development (LOD) at different
467 stages of project design and procurement, was listed as the second most urgent approach in
468 enhancing BIM returns. Since one major return value from BIM is the improvement of
469 multiparty communication, clearly specified BIM deliverables are a prerequisite to enable the

470 collaboration among architects, engineers, contractors, and other project parties. The third
471 ranked item in Table 5 was also related to collaboration within the BIM context. Survey
472 participants held the view that contract language supporting BIM implementation and
473 collaboration would enhance BIM returns. All the three interoperability and collaboration
474 related items were ranked as top priorities in pursuing BIM returns. In contrast, BIM related
475 services including BIM consulting and subcontracted modeling were not considered as
476 important as other ways in enhancing BIM returns (e.g., authorities' policy on BIM practice,
477 BIM-skilled employees, and owners' demands on BIM usage) according to survey responses,
478 indicating that most survey participants believed that AEC firms should develop their own BIM
479 capacity rather than solely rely on external BIM services. Actually it might be more efficient
480 in the work flow if architects and engineers have their own BIM capacity incorporated with
481 their own fields of expertise and design, compared to asking for external BIM services to assist
482 their own design.

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

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

488 ***BIM Risks***

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

495 The major risks identified by survey participants included T1 (i.e., incapability of BIM
496 software tools), H2 (i.e. lack of BIM-skilled employees), F3 (i.e., high-cost of short-term
497 investment), M2 and M3 (i.e., adjustments in business procedure and management pattern), as
498 well as O4 (i.e., lack of industry standards), as selected by the majority (from 63% to 73%) of
499 respondents. The issues in BIM tool usage, for example, the data exchange among various
500 software tools in China's AEC practice and the necessity of incorporating the internal BIM tool
501 (e.g., Autodesk Revit) with domestic Chinese industry standards as previously discussed in this
502 study, is one of the major concerns in BIM implementation. The lack of sufficient BIM-skilled
503 employees in China's current AEC industries indicate the importance of BIM training
504 including the college level education. High cost of short-term investment in BIM turned out a
505 major risk. Besides the top-ranked BIM investment areas suggested in Table 1, college
506 graduates equipped with BIM knowledge could reduce the investment from BIM training as
507 mentioned by Tang et al. (2015). The implementation of BIM may also affect the management
508 platform and the project delivery process, as indicated from previous international studies such
509 as Thomsen (2010), SmartMarket Report (2015), and Liu et al. (2017). How to optimize BIM's
510 influence on project management and work flow was a concern from this survey sample.
511 Finally, it was believed that a well-established standard would be a key issue for successful
512 BIM implementation.

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

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

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

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

534

535 **Summary and Discussion**

536 Review of previous BIM implementation related studies crossing countries revealed
537 insufficient investigations conducted in developing AEC markets (e.g., China and India)
538 compared to more developed counterparts (e.g., U.S and U.K). There was also a need on
539 adopting a holistic approach to gain BIM-application-based perceptions. To address these
540 concerns, this study adopted the questionnaire survey based approach to perform the statistical
541 analysis of Chinese BIM practitioners' perceptions on BIM investment, return, and risk related
542 issues. Active BIM practitioners or those who plan to implement BIM in China's AEC

543 industries were targeted as the survey sample. The respondents from the survey were mostly
544 from or nearby Shanghai, Beijing, and Canton as these were China's major regions identified
545 with leading BIM practices. Feedback on survey respondents' perceptions focusing on BIM
546 investment areas, returns from BIM investment, ways to enhance BIM returns, and existing
547 risks in BIM implementation was collected and analyzed. The survey sample recruited
548 participants from multiple job professions and different BIM proficiency levels to study
549 whether BIM practitioners' perceptions would depend on profession and level of BIM usage
550 experience.

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

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

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

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

586 Major risks in BIM implementation were identified with the most frequently selected risks
587 being the lack of BIM industry standards and the AEC firms' transition of management pattern,
588 followed by the lack of BIM-skilled employees, high cost of short-term investment,
589 adjustments in business procedure, and incapacity of BIM software. Analysis of subgroup
590 difference released that perceptions of survey sample towards these risks were independent of

591 their job profession. However, those without previous BIM experience were more likely to
592 underestimate the problems within BIM software capacity.

593

594 **Conclusions**

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

- 603 • Some commonly encountered risks such as the lack of authority standardization and
604 multiparty collaboration in BIM-involved projects should be recognized based on
605 multiple investigations of BIM implementation crossing countries and regions;
- 606 • Countries or regions like China, larger regional variations in terms of economic
607 development, geographic location, and culture would cause some regional differences
608 in BIM movements. In this study, the questionnaire survey sample was limited to
609 AEC practitioners from China's major BIM-active regions (i.e., Shanghai, Beijing,
610 and Canton). The lessons or experience learned from these BIM-leading regions could
611 provide guides for other less BIM-developed regions (e.g., inland part of China) when
612 moving forward with the adoption of information technology in the AEC practice;
- 613 • It is recommended that empirical studies related to BIM practice and application be set
614 in the interdisciplinary context by considering perspectives from different AEC fields

615 as BIM, by its nature, aims to enhance cross-disciplinary collaboration and
616 communication.

617

618 **Recommendations for future research**

619 Future empirical studies of China's BIM adoption could expand from BIM-active regions
620 to other less developed areas to allow the regional comparison of BIM implementation crossing
621 the country. Future research would be extended to in-depth study of architects' perceptions on
622 returns from BIM investments, through interview and case studies in China's AEC industries.
623 How BIM implementation would affect architects' role in the project delivery process would
624 be explored. Case studies of BIM impacts on project duration and cost will be conducted.
625 Projects in similar sizes with and without BIM adoption in China's high-rise complex building
626 would be targeted to measure BIM effects on project budget expenditure and scheduling.

627

628 **Data Availability Statement**

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

631

632

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634

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641

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852 Appendix: Questionnaire of BIM Investment Areas, Returns, Strategies, and 853 Risks

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855 Part A: BIM Users Information

- 856 1. Where are you working?
857 2. Your current position () A. Architect; B. Engineer (e.g., Structural Engineer); C. Contractor; D. Owner; E. BIM consultant; F.
858 Others, please specify _____.
859 3. How long have you been using BIM software? _____
860 4. What BIM software tools are you using or have you ever used before (multi-choice)? A. Autodesk (e.g., Revit); B. Bentley; C.
861 Nemetschek (e.g., ArchiCAD); D. Dassault (e.g., Digital Project); E. Others, please specify _____; F. Have never used any BIM
862 software.

- 863 5. How would you define your proficiency level in applying BIM tools? A. Experts; B. Advanced level; C. Moderate level; D. Beginner.

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

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

924 **Table 1.** Survey results of importance of BIM investment areas (Cronbach's alpha =
925 0.921)

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

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

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

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934 **Table 5.** Survey results of perceptions on ways enhance returns from BIM application
935 (Cronbach's alpha = 0.943)

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

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

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

| Item | N* | <i>RII</i> | Item-total correlation | Cronbach’s Alpha |
|--|-----------|-------------------|-------------------------------|-------------------------|
| 11: Developing internal collaboration according to BIM standards | 71 | 0.876 | 0.701 | 0.913 |
| 12: Developing collaborative BIM processes with external parties | 69 | 0.872 | 0.732 | 0.911 |
| 13: Software customization and interoperability solutions | 71 | 0.865 | 0.799 | 0.905 |
| 14: Marketing your BIM capability | 71 | 0.814 | 0.673 | 0.916 |
| 15: BIM software | 69 | 0.809 | 0.767 | 0.908 |
| 16: BIM training | 71 | 0.808 | 0.715 | 0.912 |
| 17: Developing custom 3D libraries. | 66 | 0.785 | 0.752 | 0.909 |
| 18: New or upgraded hardware | 68 | 0.768 | 0.752 | 0.909 |

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

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

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988 **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 | |
|------|--------------|--------------------|---|----------------|---|----------------|
| | | | <i>F</i> value | <i>p</i> value | <i>F</i> value | <i>p</i> 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 |

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1010 **Table 3.** Survey results of recognitions on returns from BIM investment (Cronbach’s alpha =
 1011 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 |

1012 *:The total number of responses for each given item.
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1029 **Table 4.** ANOVA analysis of subgroup differences towards recognitions on BIM return-related
 1030 items.

| Item | Overall Mean | Standard deviation | ANOVA analysis for subgroups according to professions | | ANOVA analysis for subgroups according to BIM proficiency level | |
|------|--------------|--------------------|---|----------------|---|----------------|
| | | | <i>F</i> value | <i>p</i> value | <i>F</i> value | <i>p</i> 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 |

1031 *: *p* values lower than 0.05 indicate significant subgroup differences towards the given item in BIM return values

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1049 **Table 5.** Survey results of perceptions on ways to improve returns from BIM application
 1050 (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 |

1051 *:The total number of responses for each given item.

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1067 **Table 6.** ANOVA analysis of subgroup differences on ways to enhance returns from BIM
 1068 application

| Item | Overall Mean | Standard deviation | ANOVA analysis for subgroups according to professions | | ANOVA analysis for subgroups according to BIM proficiency level | |
|------|--------------|--------------------|---|----------------|---|----------------|
| | | | <i>F</i> value | <i>p</i> value | <i>F</i> value | <i>p</i> 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 |

1069 *: *p* values lower than 0.05 indicate significant subgroup differences towards the given item in BIM return values

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1085 **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 | <i>p</i> value | Chi-Square value | <i>p</i> 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 |

1086 ^{*}*p*value lower than 0.05 indicates significant subgroup differences

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