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6 **Comparisons of Students’ Perceptions on BIM Practice among Australia,**

7 **China and U.K.**

8 **Abstract**

9 **Purpose** –University students are the future driving forces in and leaders of the AEC industry  
10 advancement. Although BIM pedagogical studies have been performed in different  
11 institutions, there has not been sufficient research providing a global perspective of BIM  
12 education and students’ perceptions towards BIM practice and application following their  
13 learning progress. This study adopted student samples from Swinburne University of  
14 Technology (SUT, Australia), Wenzhou University (WZU, China), and University of  
15 Brighton (UoB, U.K.) as three case studies to investigate the BIM practice and application-  
16 related perceptions and motivations.

17 **Design/Methodology/Approach** – Based on the thorough understanding of the BIM  
18 pedagogical delivery including teaching contents and assessment methods among the three  
19 institutions, a questionnaire survey approach was adopted to collect AEC students’  
20 perceptions of BIM. Within each selected case, statistical analysis was conducted to  
21 investigate both the overall sample and subgroup differences regarding students’ opinions on  
22 BIM’s functions (e.g. as a 3D visualization tool) and BIM usefulness in various industry  
23 professions, their motivation in BIM-related jobs, and their perceptions of challenges  
24 encountered in BIM practice and application. Multiple factors influencing BIM learners’  
25 perceptions were discussed, such as pedagogical assessment approach, and individual factors  
26 (e.g. disciplines).

27 **Findings** –The results showed that students were able to discern the latest industry practices  
28 and critical thinking in BIM movements. For example, SUT students perceived more  
29 challenges from the government legislation or incentive policies, which was consistent with  
30 Australia’s BIM policy movement. WZU students tended to have less positive views on BIM  
31 usefulness. The results also indicated fewer differences regarding perceived challenges  
32 among students from these three institutions.

33 **Originality/value** –This study contributed to the body of knowledge in managerial BIM by  
34 focusing on learners’ perceptions from the perspective of students’ understanding, motivation,  
35 and individual views of BIM, which were insightful to both BIM educators and employers.  
36 By initiating the framework of BIM learning process and its influence factors, the current  
37 study serves as a point of reference to continue the future work in strengthening the  
38 connection between institutional BIM education and industry practical needs worldwide.

39 **Keywords:**Building InformationModelling (BIM); Pedagogy; Education;Comparative  
40 Analysis;Subgroup analysis; Individual perceptions

## 41 **1. Introduction**

42 BIM, or Building Information Modelling, which is the digital technology that enables  
43 creations of accurate virtual models and supports the project delivery process, was viewed by  
44 Eastman et al. (2011) as one of the most promising developments in the architectural,  
45 engineering, and construction (AEC) industry. The movement of BIM in the global AEC  
46 market has driven practical, academic research, and educational activities worldwide. Much  
47 academic research of BIM has focused on technical aspects referring to BIM application and  
48 implementation (Yalcinkaya and Singh, 2015), but less on the managerial part of BIM which  
49 is also a key critical factor for successful BIM practice (Oraee et al., 2017). One important  
50 aspect within managerial BIM is the collaboration among project team members (Eadie et al.,  
51 2013; Tang et al., 2015). It was further indicated by Jin et al. (2016) that there could be a

52 complementary relationship between new college graduates with BIM skillsets and senior  
53 professionals with more industry experience. The study of perceptions towards BIM practice  
54 between AEC students and industry professionals is needed because: 1) perceptions would  
55 have a direct impact on individual behavior(Dijksterhuis and Bargh, 2001); and 2) BIM-  
56 based projects would involve team members from different background and experience levels  
57 (e.g., entry-level and senior employees), and their shared perceptions towards BIM could be a  
58 driver towards multi-disciplinary and cross-experience-levelcollaboration in the BIM  
59 environment (Jin et al., 2017a).

60 A review of existing literature revealed the following knowledge gaps: 1) most existing  
61 managerial BIM studies focused on the industry, company, or project levels, without  
62 sufficiently addressing the individual level (Howard et al., 2017); 2) most existing BIM  
63 studies of individual perceptions (e.g., Eadie et al., 2013; Ding et al., 2015; Howard et al,  
64 2017;) targeted industry professionals, without sufficiently addressing perceptions from AEC  
65 students or graduates; 3) compared to other BIM-related studies (e.g., interoperability), the  
66 education, training, and pedagogy of BIM have not been sufficiently studied (Santos et al.,  
67 2017); 4) existing BIM-pedagogy-based studies focus mainly on case studies of individual  
68 institutions or a single discipline (e.g., Sacks and Barak, 2010; Nawari, 2015; Jin et al. 2017c).  
69 There have been various BIM pedagogical delivery and assessment methods  
70 acrossinstitutions which could lead to different student perceptions and behaviors in BIM  
71 practice, and there have been limited comparative studies of BIM education focusing on AEC  
72 students' perceptions across differentinstitutions worldwide.

73 Addressing these gaps is important due to the following facts: 1) the global BIM  
74 movement (Jin et al., 2017b) has driven educational institutions to establish or promote their  
75 BIM programs in order to update themselves in the AEC education; 2) AEC students or  
76 college graduates are the future employees of the industry and they play a significant role in

77 the AEC market (Zou et al., 2018). There is a need to study their perceptions towards BIM  
78 practice following their BIM learning; 3) the knowledge gap identified between industry  
79 needs and BIM institutional education (Wu and Issa, 2014) requires more effective coping  
80 strategies from the perspective of BIM pedagogy; and 4) there is a need to bridge BIM  
81 educators, learners, and industry practitioners to enhance college graduates' readiness in the  
82 job market, and to reduce AEC employers' investment in training BIM competent employees  
83 (Sacks and Pikas, 2013;;Solnosky and Parfitt, 2015).

84 By adopting student survey samples from three universities located in different  
85 continents (i.e., Swinburne University of Technology (SUT) Australia, Wenzhou University  
86 (WZU) China, and the University of Brighton (UoB ) UK, this study aims to achieve the  
87 following objectives: 1) to study the overall perception of students towards BIM practice; 2)  
88 to analyze the sub-sample perceptions of students from the three selected case study  
89 universities; and 3) to discuss potential factors that lead to different perceptions among  
90 students (e.g., local BIM practice and BIM assessment methods). **Students' perceptions**  
91 **towards BIM were categorized into their opinions of BIM functions (e.g., as a digital**  
92 **platform for cross-disciplinary collaboration), BIM's usefulness in various AEC professions**  
93 **(e.g., architectural design), their desire for BIM-related industry jobs (e.g., BIM engineer),**  
94 **and challenges encountered in BIM practice. The sampling strategy for choosing these three**  
95 **universities was Simple Random Sampling (SRS) and the only criteria used were that chosen**  
96 **samples should represent the mainstream higher education institutions in their country of**  
97 **origin and should not be considered as leading universities, or belong in the bottom of the**  
98 **academic league table in their respected countries. It was believed that following these simple**  
99 **inclusion/exclusion criteria within the SRS strategy, will increase the validity, reliability and**  
100 **in return the generalisability of the knowledge claim of this study.** The findings from this case  
101 study further address the connection between institutional education and industry practice in

102 BIM. The study provides insights to BIM educators in a global perspective of how students  
103 from different institutions perceive BIM after a certain period of BIM learning and practice.  
104 AEC employers could also gain information from this study on how students (i.e., their  
105 potential future employees) view BIM practice and students' motivation in BIM-related jobs.  
106 The study also leads to future studies to evaluate the perceptions between BIM learners and  
107 BIM industry practitioners.

108

## 109 **2. Background**

### 110 *2.1. BIM movement in Australia, China, and U.K.*

111 BIM has enjoyed fast growth in the AEC global market, such as Australia (Hong et al.,  
112 2018), China (Zhao et al., 2018), UK (Khosrowshahi and Arayici, 2012), USA (Oraee et al.,  
113 2018), Canada (Poirier et al., 2017), and Scandinavia (Jensen and Jóhannesson, 2013). The  
114 UK Government Construction Strategy Board (2011) required the U.K. AEC industry to  
115 achieve BIM Level 2 (i.e. three-dimensional environment with interdisciplinary data sharing)  
116 by 2016. The BIM Task Group (2011), funded by the UK government, was founded in 2011  
117 aiming to strengthen the public sectors' capacity in BIM implementation towards  
118 collaborative BIM and to establish British Standards for BIM Level 2. **More recently, the UK**  
119 **Government's Department for Business, Innovation and Skills (DBIS, 2016) has launched the**  
120 **Digital Built Britain programme focusing on the development of BIM Level 3.** According  
121 to Innovate UK and Infrastructure and Projects Authority (2017), Level 3 of BIM has  
122 commenced its development and is expected to come to practice by mid-2020s.

123 Following the UK's BIM movement, a number of Australian government agencies (e.g.,  
124 Transport for New South Wales, Transport and Infrastructure, and the Northern Territory  
125 Department of Infrastructure) have started moving towards using BIM (Consult Australia,  
126 2016). The Report from Australia's Standing Committee on Infrastructure, Transport and

127 Cities (SCITC, 2016) recommended that the Australian government should form a smart  
128 infrastructure task force (modelled on the UK BIM Task Group) to promote the BIM policy  
129 nationwide, including the development of standards, training, and education on BIM. The  
130 Report further suggested that Australian government require BIM implementation at the LOD  
131 (i.e., Level of Detail) 500 on all infrastructure projects over \$50 million in funding provided  
132 by the government.

133 Somewhat similar to Australia, China's BIM movement was also guided by government  
134 from both federal and state levels. From the federal government side, China's BIM policy has  
135 moved forward fast in recent years, from announcing the digitalization visions in 2011 to  
136 proposing the BIM application across the entire project lifecycle in 2014 (Jin et al., 2015). In  
137 the state or provincial level, Shanghai Municipal People's Government (2014) announced the  
138 strategic objective of promoting BIM implementation in Shanghai, requiring that  
139 government-funded projects must adopt BIM starting from 2017.

140 Alongside the fast BIM movement in these three countries, challenges in implementing  
141 BIM have been studied in Australia (Aibinu and Venkatesh, 2014), China (Ding et al., 2015),  
142 and U.K. (Eadie et al., 2013). Commonly encountered challenges in BIM implementation  
143 included but not limited to cost of implementing BIM features within the existing practice,  
144 reluctance of moving from a 2D (i.e., two-dimensional) to a 3D working environment, lack of  
145 client demands, collaboration issues among project team members, and lack of industry  
146 standards or guidelines (He et al., 2012; Sackey et al., 2014; Tang et al., 2015; Çıdık et al.,  
147 2017). Among these challenges, lack of sufficient education resources and university  
148 restrictions were identified by multiple studies (Trine, 2008; Gier, 2015; Puolitaival and  
149 Forsythe, 2016) as another key barrier in meeting the industry demand for BIM-capable  
150 employees.

151 *2.2. BIM pedagogy and learning*

152 BIM education and training was identified by Khosrowshahi and Arayici (2012) as one  
153 of the key strategies on UK's roadmap of BIM implementation. Institutional education is of  
154 key importance in BIM transition (Solnosky and Parfitt, 2015; Jäväjä and Salin, 2016). BIM-  
155 pedagogy-based studies have been adopted in multiple AEC disciplines, such as architecture  
156 (Mathews, 2013), construction engineering (Kim, 2011), and civil engineering (Ma et al.,  
157 2015). More recent BIM education-based studies (e.g., Zhang et al., 2018) have adopted  
158 team-based and project-based learning approach stressing the project delivery process. BIM  
159 has also been linked to other AEC subjects in pedagogical work, such as energy modeling  
160 (Lewis et al., 2015). Interdisciplinary BIM pedagogy (e.g., Solnosky et al., 2014) was further  
161 adopted aiming to expose students to multiple AEC disciplines in the BIM-based project  
162 teamwork.

163 Researchers (e.g., Gerber et al., 2013; Sacks and Pikas, 2013) suggested that BIM  
164 education should be improved to address the industry needs. Efforts (e.g., Solnosky et al.,  
165 2014; Wu et al., 2015; Lucas, 2017) have been made in addressing the gap between BIM  
166 education and industry requirements, such as inviting industry partners to evaluate student  
167 BIM work. The study of Wu and Issa (2014) revealed that a more proactive partnership  
168 would enhance the institutional education and help the industry partners recruit BIM talents.  
169 It was further suggested by Pikas et al. (2013) that BIM education should be practiced at the  
170 program level instead of an isolated course. Upon the completion of BIM pedagogical work,  
171 Zou et al. (2018) suggested that BIM learners' perceptions could be further compared to that  
172 of industry professionals in order to identify the gap.

### 173 **3. Research Methodology**

174 This study utilizes a multiple-case, single-unit of analysis (Gustafsson, 2017) case study  
175 method to investigate university students' perceptions of BIM practices among three cases  
176 which have been chosen using Simple Random Sampling (SRS) strategy (Berger and Zhang,

177 2005) in UK, Australia, and China. Although the main research instrument used for the  
178 single-unit analysis of this study is purely statistical – hence the choice of questionnaire  
179 survey as the main data collection means for this study, it is crucially important to note that  
180 the knowledge claim of this study does not follow that of a pure quantitative methodology.  
181 The case study method at the heart of this study, like experiments, bounds the findings of this  
182 study to be generalizable to theoretical propositions and not to the populations or universes  
183 the samples may seemingly represent. In this sense, the case study, does not represent a  
184 ‘sample’, and the investigators’ goal is to expand and generalize theories (analytic  
185 generalization) and not to enumerate frequencies (statistical generalization) (Yin, 1989). The  
186 choice of questionnaire as a main instrument for the single unit of analysis of this study was  
187 made to meet multiple purposes. Firstly, it would have made it possible to conduct a pure  
188 statistical analysis between the cases which represented mainstream institutions in their  
189 country of origin. Furthermore, a statistical (pure and interpretative) analysis also made an  
190 internal comparison of perceptions of different aspects of this study within each of those  
191 selected cases internally. Last but not least, the other advantage of using questionnaire was  
192 that not only it could have used and did use the data collection methods as suggested by  
193 precedent studies (e.g., Eadie et al., 2013; Ding et al., 2015), but it will also provide a  
194 standardized tool for future studies on which identical or similar studies can be built that in  
195 return offers higher degree of validity and reliability of the current study. **The validity and  
196 reliability of data collected through questionnaire survey were checked following the rules  
197 suggested by Heale and Twycross (2015). For example, (1) the same questionnaire was  
198 reviewed and agreed by BIM instructors from all the three institutions in this study to ensure  
199 that the same variables (e.g., students’ motivations in BIM-related jobs) were measured; (2)  
200 theory evidence was applied by linking students’ BIM perceptions to their learning behaviors;**



201 and (3) homogeneity (i.e., internal consistency) of BIM categories in the questionnaire was  
202 analyzed using Cronbach's Alpha value (Cronbach, 1951).

203 Three institutions including Swinburne University of Technology (SUT) from Australia,  
204 Wenzhou University (WZU) from China, and University of Brighton (UoB) from UK were  
205 selected as three cases for the continental comparison of students' perceptions towards BIM-  
206 practice related questions. They were selected using simple random sampling method and the  
207 rationale behind selection of these three institutions was based on the fact that:

- 208 1. They all are representatives of mainstream universities in their country of origin.  
209 They do not represent the top-ranked or bottom of the league table universities.
- 210 2. They had all been actively implementing BIM undergraduate education in recent  
211 years (i.e. after 2012).
- 212 3. BIM educators from all these three institutions had been keen to carry out pedagogy  
213 research to evaluate their students' learning and perceptions of BIM practice and they  
214 all expressed strong interests in viewing their BIM education from a global  
215 perspective through institutional comparisons.

216 To make this study materialise and prior to its launch, BIM educators from all of the three  
217 institutions discussed, and confirmed that BIM pedagogy in their respective institutions  
218 represents the average level of BIM education in their home countries, in terms of the year  
219 BIM course was launched, and assessment of learning outcomes (e.g. teamwork and digital  
220 skills, as well as addressing the AEC industry needs in their countries).Fig.1 describes the  
221 research methods associated with the three pre-defined research objectives.

222 <Insert Fig.1 here>

223 As indicated in Fig.1, this study started with case studies method using multiple-cases  
224 comprising three institutions where a single-unit of analysis were utilised through a  
225 questionnaire survey as the data collection instrument within each institution. Since August

226 2017, researchers and educators from SUT, WZU, and UoB have communicated the teaching  
227 and learning experience of BIM and decided to conduct a comparative study by collecting  
228 their own students' perceptions of BIM. The shared questionnaire was initiated during  
229 August and September 2017 by BIM educators from the three institutions. BIM course  
230 instructors from these three institutions discussed and finalized the questionnaire in the end of  
231 September. Afterwards, the questionnaire was peer reviewed externally by BIM educators  
232 from other institutions and further modified during October 2017. Following the pilot study  
233 procedure described by Xu et al. (2018) when delivering questionnaires in different  
234 geographic regions, the initiated questionnaire was sent out to smaller groups of final year  
235 AEC students from the three institutions to ensure that: 1) these questions were clear and  
236 easily understood by students; and 2) the questionnaires were delivered by instructors in a  
237 consistent approach (e.g. students were provided with proper explanation of the research  
238 purpose). The formal questionnaire was then sent to AEC students in SUT, WZU, and UoB  
239 between November and December in 2017.

240 The questionnaire consisted of two major sections. The first section focused on  
241 collecting the background information of the students, including their age, AEC discipline  
242 (e.g. civil engineering or architectural technology etc.), and their prior learning experience of  
243 BIM. The second part of the questionnaire adopted five-point Likert-scale questions  
244 targeting students' perceptions of BIM's functions, BIM's usefulness to multiple AEC  
245 professions (e.g. structural design), desired BIM-related industry jobs (e.g., BIM coordinator),  
246 and challenges encountered in BIM practice. Likert scale, as suggested by Vagias (2006), can  
247 be adopted to collect responses on the sample population's level of agreement, level of  
248 desirability, level of concern, or level of problem. Students were evaluated of their level of  
249 agreement on different BIM functions following their learning process, such as whether BIM  
250 was just another software tool like CAD. AEC professions were defined by IMSCAD (2013)

251 that covered various players (e.g. construction management) who worked together to achieve  
252 project completion. Students were also asked to rank their level of agreement on BIM's  
253 applicability in multiple AEC professions. In the section related to BIM industry jobs, brief  
254 job descriptions were provided to students following the definitions provided by Joseph  
255 (2011). For example, BIM coordinators were defined as professionals who coordinated the  
256 multiple digital models from different disciplines (e.g. structural and mechanical models)  
257 involving clash-detection; BIM manager would develop BIM materials for marketing purpose,  
258 establish documented procedures and workflows, as well as adopting pro-active approaches  
259 in practicing new BIM software packages. In comparison, BIM director would work in the  
260 higher management position (e.g. executive) at the organization level and are responsible for  
261 visioning, planning, and strategizing BIM implementation. **Students were asked to rank their  
262 level of desirability in the pre-defined BIM-related jobs. Finally, they were also guided to  
263 select a Likert-scale related to their level of concern in challenges encountered in BIM  
264 practice.**

265 Statistical analyses were performed following the data collection of student responses  
266 from SUT, WZU, and UoB. Besides the basic statistical values (i.e., the mean value and the  
267 standard deviation for each Likert-scale item), main analysis methods included: 1) the  
268 relative importance index (*RII*) to rank students' perceptions towards items within each  
269 Likert-scale question; 2) the internal consistency analysis incorporating Cronbach's Alpha  
270 value, and analysis of variance (ANOVA) to studying the subgroup differences of students  
271 from SUT, WZU, and UoB. More detailed descriptions of these three methods are provided  
272 below:

- 273 • The *RII* has been widely applied in empirical studies in the field of construction  
274 engineering and management (CEM), such as Tam (2009) and Eadie et al. (2013), and Xu  
275 et al. (2018). Its value ranges from 0 to 1. A higher *RII* value means that the

276 corresponding item was perceived by students with more significance or importance. It  
277 was calculated following Equation (1) proposed by Kometa et al. (1994) and Tam et al.  
278 (2000):

$$279 \quad RII = \frac{\sum w}{A \times N} \quad (1)$$

280 where  $w$  represents the Likert-scale score from 1 to 5;  $A$  denotes the highest numerical  
281 score which was 5 in this study, and  $N$  meant the number of valid responses from  
282 students.

- 283 • Cronbach's Alpha value, initiated by Cronbach (1951), was adopted to measure the  
284 internal consistency among Likert-scale items within each question regarding students'  
285 perceptions of BIM practice. Ranging from 0 to 1, the value between 0.70 and 0.95 would  
286 be considered acceptable with high internal consistency (Nunnally and Bernstein, 1994;  
287 Bland and Altman, 1997). A higher Cronbach's Alpha value means that a student who  
288 selected one numerical score in one item is more likely to assign a similar score to other  
289 items within the same question. For the overall student sample, an internal consistency  
290 analysis table was provided in each of the four sections corresponding to students'  
291 perceptions of BIM applicability, BIM usefulness, desired BIM-related jobs, and BIM-  
292 practice-related challenges respectively. An individual Cronbach's Alpha value and an  
293 item-total correlation coefficient were also computed corresponding to each item within  
294 every section. An individual Cronbach's Alpha value higher than the overall value would  
295 mean that the given Likert-scale item does not contribute to the internal  
296 consistency (Hanover College Psychology Department, 2018). In other words, it indicates  
297 that students tend to perceive differently of this given item than they would do to others.
- 298 • Within each section or Liket-scale question, ANOVA, as one of the parametric methods,  
299 was adopted to analyze the subgroup consistencies and differences for students from SUT,

300 WZU, and UoB. The parametric method was adopted in this study over non-parametric  
301 approach due to the facts (The Minitab Blog, 2015) that: (1) parametric tests perform well  
302 with skewed and non-normal distributions, especially for One-Way ANOVA in this study  
303 with each subgroup sample size over 15; and (2) parametric tests have more statistical  
304 power than non-parametric methods. The advantage of parametric over non-parametric  
305 methods is also stated by Sullivan and Artino (2013) in terms of the robustness. Parametric  
306 methods including ANOVA have been adopted in some earlier studies in the field of  
307 construction engineering and management (CEM), such as Aksorn and Hadikusumo  
308 (2008); Meliá et al. (2008); and Tam (2009). The robustness of parametric methods in  
309 being applied in questionnaire survey samples have been proved by Carifio and Perla  
310 (2008) and Norman (2010), including samples that were small-sized or skewed  
311 (e.g., Pearson, 1931; Tam, 2009). Based on the null hypothesis that there were no  
312 significant differences of perceptions for students among SUT, WZU, and UoB using the  
313 level of significance at 5%, the  $F$  value and its corresponding  $p$  value were computed for  
314 each item. A  $p$  value lower than 0.05 would reject the null hypothesis and suggest that  
315 students from these three institutions held different perceptions towards the given item.  
316 Following ANOVA, a post-hoc analysis was conducted to further confirm which pair of  
317 subgroups held significantly different perceptions. Based on 95% Confidence Intervals,  
318 two types of post-hoc methods were adopted in this study, including Tukey Simultaneous  
319 and Fisher Individual.

320 Following the questionnaire survey accompanied with statistical analysis, a qualitative  
321 discussion was adopted to analyze potential internal and external factors that could affect  
322 students' perceptions towards BIM practice, for example, the teaching and learning strategy  
323 of BIM (Wu and Issa, 2014), and local BIM climate (Xu et al., 2018), etc.

#### 324 **4. Results**

325 *4.1. Background of survey participants*

326 At the end of December 2017, excluding those who had no prior learning experience of  
327 BIM, 117, 35, and 40 valid responses were received from SUT, WZU, and  
328 UoB respectively. More information of the survey results (e.g., total number of questionnaire  
329 delivered at each institution) can be found in Table 1.

330 <Insert Table 1 here>

331 The number of total population within each institution referred to the total sample of  
332 students who could have BIM learning experience. The number of questionnaires distributed  
333 in each institution was counted as students who were willing to participate in the survey after  
334 being explained with the purpose of this study in the end of the BIM course. Following the  
335 anonymous site questionnaire survey procedure described by Chen and Jin (2013), as well as  
336 Han et al. (2018), potential survey participants could either decide to participate or decline  
337 the survey request. They could also withdraw the survey in the middle of filling the  
338 questionnaire. The returned questionnaire number was counted as those who completed and  
339 submitted the questionnaire. The valid questionnaire number was counted by excluding those  
340 incomplete questionnaires from the returned sample, as well as following the screening  
341 procedure described by Smits et al. (2017). For example, those who chose the same Likert-  
342 scale score for all items within one section would be considered invalid.

343 Based on the valid questionnaires returned, the background information (i.e. student age,  
344 AEC disciplines, learning experience of BIM) of student survey participants from these three  
345 universities are also summarized in Table 1.

346

347 *4.2. Student perceptions towards BIM function*

348 Students were asked of their opinions on BIM functions which reflected their  
349 understanding of BIM. Using the five-point Likert-scale format with 1 being “strongly

350 disagree”, 3 indicating a neutral attitude, and 5 meaning “strongly agree”, totally eight  
351 different functions listed in Table 2 were ranked according to their *RII* scores. Excluding  
352 those choosing 6 indicating that they were unsure of the answer, the statistical information  
353 including mean value, standard deviation, item-total correlation (ITC), and Cronbach’s Alpha  
354 value for the overall student sample are presented in Table 2.

355 <Insert Table 2 here>

356 The overall Cronbach’s Alpha value at *0.8245* suggests a fair internal consistency among  
357 students from these three universities, meaning that a student assigning a numerical score to  
358 one BIM function is likely to select a close score to the remaining items. According to Table  
359 2, the two BIM functions (i.e. BIM as a management tool and as a digital platform) were  
360 ranked top based on their higher *RII* scores with lowest variations among students. These two  
361 functions were also the only two items with *RII* scores over *0.800*, or mean scores over *4.000*,  
362 indicating that students held the view between “strongly agree” and “agree” towards F5 and  
363 F6. In contrast, F1 (i.e. BIM as another software tool) was ranked lowest by students.  
364 Students also had the highest variations on F1. F1 was also the only BIM function that was  
365 perceived by students differently as they did to other functions, due to its significantly lower  
366 ITC with higher Cronbach’s Alpha value than the overall value. The overall sample was then  
367 divided into the three institutions and their internal consistency within their own institution  
368 were analyzed. Table 3 shows the comparison among them.

369 <Insert Table 3 here>

370 The overall Cronbach’s Alpha values for all the three sub-samples were relatively strong,  
371 indicating good internal consistencies within each of them. WZU students were found having  
372 significantly higher individual Cronbach’s Alpha values in F1 and F2 than their overall value,  
373 indicating that WZU students had highly differed perceptions of BIM as a software tool and  
374 as a 3D visualization tool. In investigate the subgroup differences, students from these three

375 subgroups were compared of their perceptions using ANOVA. Table 4 displays the results of  
376 statistical comparison.

377 <Insert Table 4 here>

378 Table 4 reveals that there were significant differences of students' opinions on BIM  
379 functions. Although there was no significant difference regarding the overall perception of  
380 BIM functions among students from the three institutions, a few subgroup differences in  
381 individual items were found (i.e., F5, F6, and F8). It was suggested that SUT students had  
382 higher positive perception of BIM as management tool, digital platform, and environmental  
383 assessment tool compared to their peers from WZU and UoB. Fig.2 showcases the post-hoc  
384 analysis identifying SUT students' more confirmative perceptions towards F5 (i.e. BIM as a  
385 project management tool).

386 <Insert Fig.2 here>

#### 387 4.3. Student perceptions towards BIM's usefulness in different AEC professions

388 Students were asked to rank the usefulness of BIM in various AEC professions listed in  
389 Table 5. Using the Likert-scale format, they were guided to choose a numerical score from 1  
390 being "least useful" to 5 suggesting "most useful". Excluding those unsure of the answer, the  
391 overall sample analysis is summarized in Table 5.

392 <Insert Table 5 here>

393 The overall Cronbach's Alpha value at *0.9051* shows a fairly high internal consistency  
394 among items. Students generally held similar views on BIM's usefulness in multiple  
395 professions except architectural design, which was also one of the top-ranked items. The  
396 individual Cronbach's Alpha value higher than the overall value meant that students were  
397 likely to have different perceptions on BIM's usefulness in architectural design as they did to  
398 other professions. Three AEC professions (i.e. architectural design, structural design, and  
399 building services design) received the mean scores over *4.000*, indicating that students



400 perceived BIM to be more useful in them. These three items were all related to project design  
401 stages. The overall student sample was then divided into three institutions and the subgroup  
402 analysis is summarized in Table 6 and Table 7.

403 <Insert Table 6 here>

404 It can be seen in Table 6 that all the three institutions had generally high internal  
405 consistency in their perceptions of these AEC professions however, exceptions can be found  
406 within these subgroups. Basically, UoB students had every item in Table 6 contributing to the  
407 internal consistency, meaning that UoB students who selected one numerical score to one  
408 item would be likely to assign a close score to all other items. WZU students had the largest  
409 variation of perceptions over these items. Specifically, they had more diverged opinions of  
410 BIM's usefulness in structural design, building services design, and building energy  
411 assessment. The architectural design was perceived by SUT students differently. Similar to  
412 the finding in Table 5, these three top-ranked items were viewed by students with more  
413 differences. Further subgroup analysis was conducted using ANOVA. Table 7 displays the  
414 outcomes of comparisons of students' perceptions towards each individual AEC profession as  
415 well as the overall view of these professions.

416 <Insert Table 7 here>

417 Similar to Table 4, significant differences were found in Table 7 regarding students'  
418 perceptions in most individual items and the overall perception. Students from SUT and UoB  
419 perceived BIM with significantly more usefulness in the overall and most individual AEC  
420 professions compared to WZU students. Fig.3 showcases the post-hoc analysis demonstrating  
421 that compared to peers from SUT and UoB, WZU students generally held significantly less  
422 confirmative views towards BIM's overall usefulness in all these listed AEC professions. The  
423 same factors that affected WZU students' less positive perceptions on BIM's applicability

424 might also be applied in BIM's usefulness (i.e., local BIM practice and teaching delivery of  
425 BIM).

426 <Insert Fig.3 here>

#### 427 4.4. Students' desired BIM-related AEC jobs

428 Following the studies of Wu and Issa (2014), and Uhm et al. (2017), this study asked for  
429 students' motivations in multiple BIM-related AEC industry jobs listed in Table 8 and Table  
430 9. Students were asked to select a five-point Likert-scale score to show their interests in  
431 these BIM-related jobs. Based on the numerical score options with 1 meaning "least desired",  
432 2 being "not very interested", 3 indicating neutral, 4 denoting "interested", 5 inferring "most  
433 desired", the statistical analysis for the overall sample is provided in Table 8.

434 <Insert Table 8 here>

435 High internal consistency was found in the overall sample according to Table 8, with all  
436 BIM-related jobs contributing to the internal inter-correlation. No jobs received mean scores  
437 over 4.000 which indicated higher level of motivation of students. However, two BIM-related  
438 jobs (BIM software developer and BIM facility manager) received mean scores below 3.000.  
439 The BIM jobs ranked top by students included BIM project manager, BIM engineer, and BIM  
440 leader/director. It was indicated that students generally were more interested in management  
441 or engineering related jobs. By further dividing the overall sample into three subgroups  
442 according to their institutions, internal consistency analysis was re-performed and is shown in  
443 Table 9.

444 <Insert Table 9 here>

445 Though all three subgroups had high overall Cronbach's Alpha values, the internal  
446 consistencies for WZU and UoB students were even higher compared to that of SUT. Each  
447 subgroup has one item with its individual Cronbach's Alpha value higher than its overall  
448 value. Similar to the findings shown in Table 8, students from SUT and WZU were more

449 interested in jobs related to manager, leader, or director. UoB students had less interests in  
450 being a BIM quantity surveyor. Further, subgroup analysis in Table 10 enables the cross-  
451 institutional comparison of student motivations in BIM-related industry jobs.

452 <Insert Table 10 here>

453 Similar to Table 4 and Table 7, significant differences among subgroups were found in  
454 majority of these individual items in Table 10. However, differing from Table 4 and Table 7  
455 where WZU students showed less positive perceptions in BIM applicability and usefulness,  
456 the overall mean values showed that SUT and WZU students had significantly more  
457 motivation in obtaining a BIM-related AEC job compared to their peers from UoB. The  
458 reason of UoB students' less interests in BIM jobs remain to be discussed.

#### 459 *4.5. Student perceptions on challenges in BIM practice and implementation*

460 The last section of the questionnaire targeted student opinions of challenges encountered  
461 in BIM practice. These challenges listed in Table 11 were adapted from Jin et al. (2017a).  
462 Students were asked to rank the level of challenges, from 1 being "least challenging" to 5  
463 indicating "most challenging". Excluding those who selected 6 inferring that they were  
464 unsure of the given challenges, the overall sample analysis is provided in Table 11.

465 <Insert Table 11 here>

466 Relative weaker internal consistency was found in challenge-related items, compared to  
467 that in other sections. Respondents tended to have a more varied opinions on the challenge  
468 related to the high cost of BIM software, which was the top-ranked difficulty together with  
469 lack of governmental legislation/incentive. Overall, all challenges in Table 11 received the  
470 mean scores between 3.000 and 4.000, indicating that students generally held the perception  
471 between neutral and "challenging". The lack of client demand, which was identified by  
472 Aibinu and Venkatesh (2014) as one of these main barriers in Australia's AEC market, was

473 ranked bottom by the overall student sample. Table 12 summarized the subgroups' internal  
474 consistencies.

475 <Insert Table 12 here>

476 It is found in Table 12 that SUT students had much lower internal consistency compared  
477 to that in WZU and UoB. The overall lower internal consistency was caused by the sample  
478 from SUT, where students had different opinions on high cost of BIM software as well as  
479 upgrading of existing hardware. UoB students also held different views on upgrading existing  
480 hardware as they did to other potential challenges. The more diverged views of SUT students  
481 on challenges could be explained by the higher diversity of the SUT student sample in terms  
482 of their age range, AEC disciplinary background, and learning experience. The subgroup  
483 comparison for students among the three institutions is continued in Table 13.

484 <Insert Table 13 here>

485 Unlike three previous sections where significant differences were identified among the  
486 three subgroups, students from SUT, WZU, and UoB were found with fewer differences  
487 regarding their opinions on challenges encountered in BIM implementation. Though in most  
488 cases, they were found with consistent opinions on these challenges listed in Table 13, SUT  
489 students were more concerned on the government legislation and incentive policy on  
490 promoting BIM usage. Post-hoc analysis further suggested that SUT students perceived  
491 higher degrees of challenges in the items related to hardware upgrading and evaluation of the  
492 BIM value. Overall, SUT students also held more conservative views on BIM-  
493 implementation-related challenges.

## 494 **5. Discussion of findings**

495 Two of the BIM functions (i.e. as a project management tool and as a digital platform for  
496 interdisciplinary collaboration) were perceived most positive by the overall student sample.  
497 This was consistent with findings from industry-based surveys (e.g. Eadie et al., 2013) that

498 collaboration was a key issue in successful BIM practice. BIM as an interdisciplinary digital  
499 platform had also been emphasized in the institutional education (e.g. Jin et al., 2017c). The  
500 survey question reflecting students' perceptions of BIM functions indicated that students  
501 from the three selected institutions had gained certain understanding of BIM, especially  
502 compared to some AEC industry professionals, who might still consider BIM mainly as a  
503 visualization tool (Zhang et al., 2018). Nevertheless, subgroup differences should be noticed  
504 among students from these different institutions. For example, compared to students from  
505 SUT and UoB, WZU students agreed more on the view that BIM was a software tool similar  
506 to CAD and as a 3D visualization tool. SUT students held more positive views of BIM as a  
507 project management tool, digital platform, as well as an environmental assessment tool.  
508 These differences among subgroups could be due to both external and internal factors.  
509 External factors include the local BIM climate defined by Xu et al. (2018) related to the local  
510 BIM industry culture. Internal factors include students' teaching and learning experience,  
511 which is not only related to students' time of learning, but also how the BIM course was  
512 delivered and assessed. For example, in SUT, the BIM education had focused on not only 3D  
513 visualisation and engineering drawings, but also management-based BIM and environmental  
514 sustainability. In comparison, WZU's BIM education had highlighted more on training  
515 students with BIM software skills. WZU's BIM pedagogical method could reflect the local  
516 industry culture, as BIM had been largely applied as a 3D visualization skill (Jin et al., 2015)  
517 and there was a large need of BIM technicians. These different pedagogical delivery and  
518 assessment methods could result in students' differed perceptions towards BIM, as reflected  
519 in the questionnaire survey results summarized in Tables 2, 3, and 4. Furthermore, the  
520 continental comparison of BIM education indicate the pedagogical and practical needs  
521 between technical and managerial skills in BIM. Both technical skill and management

522 capability are needed in BIM practice, and the educational focus between techniques and  
523 management could be emphasized accordingly in institutional education.

524 Students seemed to perceive that BIM offers more usefulness when applied in early  
525 design stages involving architectural, structural, and building services design. In contrast,  
526 AEC professions perceived less use at later project stages (e.g. facility management and  
527 quantity surveying). Facility management or quantity surveying related BIM jobs also  
528 received the least interests from students. As found by Zou et al. (2018), students generally  
529 perceived more usefulness and showed more interest in BIM at the early stages of a project.  
530 This could be due to the fact that BIM has been more widely applied in AEC design-related  
531 practice. The application of BIM in follow-up project work such as facility management  
532 remain relatively rare (Carreira et al., 2018) and needs more academic research.

533 Compared to those from SUT, Australia and UoB,UK, students from WZU, China  
534 consistently held significantly less positive views on BIM's usefulness in various AEC  
535 professions. Factors causing the significant differences in WZU students remain to be  
536 explored, although it could be due to the local BIM climate in China as defined by Xu et al.  
537 (2017) where WZU is located, and how the BIM teaching was designed, delivered, and  
538 assessed. Some other internal factors that caused WZU student's different perceptions could  
539 be further investigated. For example, in this case study, WZU students all came from the  
540 same discipline (i.e., CE), with little age variation, and similar learning experience of BIM.  
541 These internal factors could lead to WZU students' more consistent views on BIM practice  
542 with smaller variation of opinions. Compared to their peers from WZU, SUT and UoB  
543 students came from different AEC disciplines with larger variations of age, and possibly with  
544 a larger variation of practical experience. As a result, students from SUT and UoB could have  
545 larger variations of their opinions compared to their WZU counterparts (e.g., Table 10 and

546 Table 13). Further studies are needed to investigate these internal or personal factors affecting  
547 individual students' perceptions, such as AEC discipline, age, and prior industry experience.

548 When it came to students' motivation in obtaining BIM-related industry jobs, WZU and  
549 SUT students had similar levels of motivation, significantly higher than the motivation of  
550 UoB students. It was inferred that students' perceptions of BIM's applicability and usefulness  
551 might not necessarily lead to their motivation in finding a relevant BIM job. The current  
552 case studies can lead to further research on the comparison among BIM pedagogical activities  
553 crossing institutions, and how the pedagogical approach would affect students' perceptions.

554 Finally, when asked about their opinions on the challenges encountered in BIM  
555 implementation, fewer subgroup differences were found among students across the three  
556 institutions, except for the concern on governmental legislation and incentive policy to  
557 promote BIM practice. SUT students expressed their concern over the perceived the  
558 challenges in Australia's BIM policy movement. According to multiple Australian industry  
559 and governmental reports (e.g., Consult Australia, 2016; Gelic et al., 2016; SCITC, 2016),  
560 although Australian governmental authorities have been intensifying the BIM usage and  
561 research, the adoption of BIM has not been mandated so therefore needs to undergo further  
562 development (Gelic et al., 2016). SCITC (2016) recommended the Australian government  
563 follow the strategy of UK's BIM Task Group (2011) to implement BIM policy nationwide. In  
564 comparison, internationally, multiple countries including U.K. and China have mandated the  
565 use of BIM (Consult Australia, 2016). Therefore, it is inferred that Australia might have a  
566 longer way to undergo before reaching mandatory BIM adoption. Correspondingly, Students  
567 at SUT Australia also perceived more challenges in the legislation and policy. It has also been  
568 previously identified by Zou et al. (2018) that students held some similar perceptions to AEC  
569 professionals towards BIM implementation. The differing views among SUT students  
570 towards these challenges (i.e., BIM software costs and hardware upgrading) could be due to

571 the higher diversity of SUT student sample in terms of their age groups, BIM learning  
572 experience, and AEC disciplinary background.

573 Based on this comparative study, a framework is initiated in Fig.4 to illustrate students'  
574 BIM learning and practical process.

575 <Insert Fig.4 here>

576 As can be seen in Fig.4, there is a starting phase corresponding to BIM learning when  
577 students started their college BIM courses. In the middle of their BIM learning (e.g., the end  
578 of one BIM course), students could have developed their perceptions towards BIM practice.  
579 It should be noticed that their perceptions, as shown in Fig.4, are affected by multiple factors,  
580 including both internal factors such as students' own disciplines and prior industry experience  
581 (Zou et al., 2018), as well as external factors (e.g., the teaching delivery of BIM courses). The  
582 perceptions would drive their continuous learning and practice by adopting BIM in their  
583 academic or professional work. It should be noticed that the learning process does not  
584 necessarily end but continues after students become industry practitioners who would then be  
585 involved in the local industry culture and industry guidelines. It is also noticed that there is a  
586 starting phase of BIM learning, but not necessarily a last phase due to the loop described in  
587 Fig.4. Industry practitioners with BIM experience, could also return to university to  
588 redevelop their BIM learning skills and perceptions. According to Fig.4, multiple factors  
589 affect the learning process consisting of learning, post-learning perceptions, and behaviors to  
590 transform a learner to an industry practitioner. These influencing factors, as indicated in this  
591 study, include but are not limited to: students' disciplines (e.g., construction management);  
592 learning resource affected by the pedagogical delivery and assessment method determined by  
593 BIM educators; industry guideline and policy influenced by governmental authorities; local  
594 industry culture formed by project owners, AEC employers, and industry practitioners. The  
595 interconnections among these multiple roles (i.e., authority, employer, educator, owner, and  
596



597 learner/practitioner) can be seen in Fig.4. More demographic factors can be studied in the  
598 future for their impacts on BIM learning, such as age, gender, and prior industry experience.

## 599 **6. Conclusions**

600 This study aimed to address the issue of limited research that had been conducted to  
601 investigate the individual perceptions of AEC students towards BIM practice and the lack of  
602 cross-institutional comparison of students' perceptions following their BIM learning. The  
603 questionnaire-survey approach was adopted to gauge students' perceptions from three  
604 different case study universities located in Australia, China, and UK. The statistical  
605 evaluation was carried out to study the overall sample and subgroup differences in terms of  
606 students' perceptions towards BIM functions, BIM's usefulness in different AEC professions,  
607 their motivation in multiple BIM-related jobs, and their opinions on challenges encountered  
608 in BIM practice. However, as the main underlying method used for this research remains to  
609 be case study method, the generalisation of the findings does not use the statistical discourse  
610 at its core. By contrast the discourse for making the generalisation of the findings of this  
611 study lays its foundation on analytical discourse.

612 The overall analysis revealed that students generally held more positive views on BIM  
613 functions as a project management tool and as an interdisciplinary digital platform rather than  
614 as a 3D visualization tool. Students generally perceived more usefulness of BIM in early  
615 project stages or design-related work, but less at later stages of project work such as on  
616 facilities management. Facilities management related jobs were also ranked by students as  
617 one of the least desired BIM jobs. Students' perceptions on BIM function, usefulness, and  
618 their motivations in BIM-related jobs showed to some degree their discernment on the latest  
619 industry practice as well as their understanding of BIM. Cross-institutional comparisons of  
620 student perceptions and motivations in BIM revealed that students from WZU China held  
621 significantly less positive view on BIM usefulness. However, those from UoB U.K. showed

622 significantly less motivation in obtaining a BIM-related industry job. Students from SUT  
623 Australia held more varied views among these challenges, and they were more concerned  
624 about government legislation or incentive policies. This could be linked to the BIM policy  
625 movement in Australia, which might be behind the U.K. and China. Compared to peers from  
626 two other institutions, SUT students also perceived higher degrees of challenges in hardware  
627 upgrading and sufficient evaluation of BIM value.

628 The qualitative discussion following the questionnaire survey and statistical analysis led  
629 to a framework describing the loop from an individual's start of BIM learning into an industry  
630 practitioner. Multiple stakeholders (e.g., employer) and influence factors to individuals'  
631 perceptions of BIM were discussed within the context of the BIM learning loop. Based on the  
632 findings from the comparative study including the proposed framework, the following  
633 suggestions are provided for both BIM educators and industry practitioners: 1) students'  
634 perceptions on BIM practice are affected by both external and internal factors, such as  
635 demographic factors (e.g., gender), professional experience, learning experience of BIM,  
636 pedagogical delivery of BIM, students' discipline (e.g., architectural technology), and the  
637 social, cultural, and economic background of their country of study or work (e.g., Australia,  
638 China, and U.K. in this case study). It is recommended that future research address these  
639 factors' impacts on BIM learners' perceptions and behaviors; 2) Corresponding to industry  
640 practice, both managerial and technical skills of BIM should be emphasized in BIM  
641 education. A comprehensive education program or curriculum covering different aspects of  
642 BIM would be needed for students from various disciplines; 3) with proper education, college  
643 graduates could develop consistent perceptions as industry practitioners do. Therefore,  
644 institutional education plays an important role in preparing students for their future career.  
645 Overall, both educator and employers should be aware of these aforementioned individual  
646 factors that may affect the perceptions of BIM learners and practitioners. A closer connection

647 between educators and employers would be helpful in establishing a stronger joint vision of  
648 BIM education areas such as BIM in life cycle assessment.

649 By proposing the framework that described multiple influencing factors to BIM learning  
650 and that linked multiple professional roles in BIM learning and practice, this BIM  
651 comparative study contributes to the body of knowledge in managerial BIM in terms that: 1)  
652 the continental comparison provides insights for peer BIM educators based on students'  
653 perceptions following their learning activities. Educators could then reflect and react towards  
654 their own BIM pedagogical work accordingly based on students' feedback; 2) it allows the  
655 further comparison between BIM learners and industry practitioners by addressing the  
656 connection between industry needs and education visions, such as the needs between  
657 technical and managerial BIM skills; 3) it contributes to the body of knowledge in BIM  
658 pedagogy and education by extending managerial BIM research from previously limited to  
659 industry practitioners to learners and college graduates, by proposing multiple factors (e.g.  
660 student demographic factors) affecting learners' perceptions of BIM.

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Table 1. Comparison of student background among SUT, WZU, and UoB

Description		SUT (Australia)	WZU (China)	UoB (U.K.)
Summary of survey results	Total student population for BIM survey	428	38	98
	Total questionnaire distributed	387	38	76
	Total questionnaire returned	257	36	44
	Return rate	66%	95%	58%
	Valid questionnaire number for this study	117	35	40
Student age (years)	Minimum	19	21	19
	Maximum	41	23	38
	Median	22	22	20.5
	Mean	22.9	22.0	21.8
	Standard deviation	3.5	0.8	4.1
Disciplines		Around 66% of students came from CE (excluding CEM*), 25% enrolled in CEM, and 9% from other disciplines (e.g., building services engineering).	All from CE	CE (45%), Building Surveying (25%), Architectural Technology (20%), and CEM (9%)
Learning experience of BIM		Minimum learning experience of BIM at 1 month, maximum learning and practical experience at 84 months, median, mean, and standard deviation at 12, 19, and 13.7 months respectively	One semester in Fall 2017	One semester in Fall 2017

887 \*: CEM stands for construction engineering and management.

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Table 2. Overall sample analysis of BIM functions (Overall Cronbach's Alpha = 0.8245)

BIM Function	Mean	Std*	<i>RII</i>	Ranking	Item-total Correlation	Cronbach's Alpha
F1: BIM can be used as another computer software tool like CAD	3.459	1.471	0.692	8	<b>0.394</b>	<b>0.8290</b>
F2: BIM can be used as a 3D modelling tool for visualization	3.908	1.228	0.782	3	0.535	0.8058
F3: BIM can be used as an energy assessment tool	3.792	1.305	0.758	6	0.665	0.7871
F4: BIM can be used as a quantity surveying tool	3.603	1.296	0.721	7	0.598	0.7969
F5: BIM can be used as a management tool in project design, construction, and asset management.	4.127	1.152	0.825	1	0.547	0.8045
F6: BIM is can be used as a digital platform for interdisciplinary collaboration.	4.078	1.140	0.816	2	0.591	0.7992
F7: BIM can be used as a data exchange platform.	3.876	1.251	0.775	5	0.475	0.8137
F8: BIM can be used as an environmental impact assessment tool for managing building performance throughout its life cycle.	3.886	1.248	0.777	4	0.604	0.7963

904 \*: Std stands for standard deviation. The same rule applies to all other tables.

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Table 3. Comparison of internal consistency among SUT, WZU, and UoB regarding the question of BIM functions

BIM functions	SUT (Australia) Overall CA=0.8311		WZU (China) Overall CA=0.8503		UoB (U.K.) Overall CA=0.8051	
	ITC	CA	ITC	CA	ITC	CA
F1	0.477	0.824	<b>-0.021</b>	<b>0.8975</b>	0.423	0.8045
F2	0.611	0.804	<b>0.101</b>	<b>0.8734</b>	0.493	0.7877
F3	0.629	0.801	0.879	0.7953	0.720	0.7506
F4	0.596	0.806	0.700	0.8177	0.542	0.7798
F5	0.477	0.821	0.815	0.8055	0.701	0.7561
F6	0.616	0.805	0.719	0.8171	0.422	0.7964
F7	0.447	0.826	0.801	0.8032	0.461	0.7919
F8	0.631	0.802	0.736	0.8127	0.448	0.7939

\*: 1. The definitions from F1 to F8 are provided in Table 2. The same rule applies to Table 4. 2. ITC stands for Item-total Correlation, and CA means Cronbach's Alpha.

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Table 4. ANOVA results for subgroup analysis of students from the three different universities to the question of BIM functions

BIM Function	SUT (Australia)		WZU (China)		UoB (U.K.)		Statistical comparison		Post-hoc analysis results
	Mean	Std	Mean	Std	Mean	Std	F value	p value	
F1	3.308	1.551	3.943	0.725	3.524	1.565	2.65	0.073	WZU Students held somewhat more confirmatory views compared to SZU peers.
F2	3.855	1.308	4.171	0.514	3.905	1.322	0.93	0.396	No significant subgroup differences
F3	3.880	1.409	3.719	0.888	3.663	1.258	0.50	0.605	No significant subgroup differences
F4	3.701	1.410	3.455	1.003	3.402	1.168	1.03	0.358	No significant subgroup differences
F5	4.336	1.179	3.656	0.745	3.890	1.148	<b>5.85</b>	<b>0.003</b> *	SUT students held more confirmative views than two other subgroups
F6	4.282	1.224	3.600	0.770	3.841	0.925	<b>5.76</b>	<b>0.004</b> *	SUT students held more confirmative views than two other subgroups
F7	3.923	1.421	3.563	0.878	3.902	0.944	1.07	0.344	No significant subgroup differences
F8	4.051	1.286	3.744	1.272	3.485	0.870	<b>3.12</b>	<b>0.047</b> *	SUT Students held somewhat more confirmatory views compared to WZU peers.
Overall	3.916	0.916	3.735	0.569	3.749	0.780	1.01	0.368	No significant subgroup differences

972 \*: A *p* value lower than 0.05 indicates significant differences among respondents from the three different  
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Table 5. Overall sample analysis in the question of BIM's usefulness in different AEC professions (overall Cronbach's Alpha = 0.9051)

AEC profession	Mean	Std	<i>RII</i>	Ranking	Item-total Correlation	Cronbach's Alpha
Architectural design	4.278	0.840	0.856	2	<b>0.4533</b>	<b>0.9085</b>
Structural design	4.306	0.895	0.861	1	0.5699	0.9019
Building services design	4.069	0.973	0.814	3	0.6733	0.8951
Construction project management	3.903	1.092	0.781	4	0.7824	0.8866
Cost estimate/Bills of quantities	3.875	1.170	0.775	5	0.6961	0.8934
Quality control/quality assurance	3.667	1.177	0.733	8	0.7892	0.8857
Quantity surveying	3.708	1.090	0.742	7	0.7447	0.8895
Facility management	3.417	1.232	0.683	9	0.7629	0.8880
Building energy assessment	3.819	1.095	0.764	6	0.6265	0.8984

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Table 6. Comparison of internal consistency among SUT, WZU, and UoB regarding the question of BIM's usefulness in different AEC professions

AEC profession	SUT (Australia) Overall CA=0.8937		WZU (China) Overall CA=0.8676		UoB (U.K.) Overall CA=0.9189	
	ITC	CA	ITC	CA	ITC	CA
Architectural design	<b>0.3543</b>	<b>0.9011</b>	0.5463	0.8583	0.6465	0.9138
Structural design	0.5559	0.8891	<b>0.2603</b>	<b>0.8810</b>	0.7426	0.9090
Building services design	0.7144	0.8780	<b>0.4011</b>	<b>0.8704</b>	0.7552	0.9070
Construction project management	0.7372	0.8760	0.8290	0.8305	0.7333	0.9082
Cost estimate/Bills of quantities	0.6544	0.8821	0.7066	0.8426	0.5866	0.9173
Quality control/quality assurance	0.7464	0.8740	0.8028	0.8327	0.8194	0.9020
Quantity surveying	0.6879	0.8794	0.8288	0.8320	0.6493	0.9147
Facility management	0.7657	0.8727	0.7858	0.8338	0.8136	0.9027
Building energy assessment	0.6672	0.8810	<b>0.2354</b>	<b>0.8829</b>	0.6938	0.9108

1036 \*: ITC stands for Item-total Correlation, and CA means Cronbach's Alpha.

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Table 7. ANOVA results for students from SUT, WZU, and UoB responding to the question of BIM usefulness in different AEC professions

AEC profession	SUT (Australia)		WZU (China)		UoB (U.K.)		Statistical comparison		Post-hoc analysis results
	Mean	Std	Mean	Std		Std	F value	p value	
Architectural design	4.336	0.812	4.029	0.785	4.561	0.743	<b>4.28</b>	<b>0.015</b> *	WZU students held significantly less confirmative views than peers from two other institutions.
Structural design	4.455	0.864	3.576	1.173	4.500	0.679	<b>13.52</b>	<b>0.000</b> *	Same as above
Building services design	4.160	0.951	3.781	0.906	4.079	0.969	1.94	0.147	No significant differences
Construction project management	4.211	1.010	2.871	1.118	3.902	0.860	<b>21.77</b>	<b>0.000</b> *	WZU students held significantly less confirmative views than peers from two other institutions.
Cost estimate/Bills of quantities	4.152	1.133	2.966	1.117	3.895	0.924	<b>13.52</b>	<b>0.000</b> *	Same as above
Quality control/quality assurance	3.848	1.292	2.933	1.112	3.474	1.033	<b>6.96</b>	<b>0.001</b> *	WZU students held significantly less confirmative views than peers from SUT.
Quantity surveying	3.856	1.136	2.793	1.013	3.737	1.032	<b>10.86</b>	<b>0.000</b> *	WZU students held significantly less confirmative views than peers from two other institutions.
Facility management	3.480	1.283	2.833	1.206	3.588	0.892	<b>3.98</b>	<b>0.021</b> *	Same as above
Building energy assessment	3.881	1.235	3.387	0.882	3.875	0.871	2.46	0.088	WZU students held somewhat less confirmative views than peers from SUT.
Overall	4.043	0.766	3.266	0.702	3.992	0.659	<b>15.51</b>	<b>0.000</b> *	WZU students held significantly less confirmative views than peers from two other institutions.

1072 \* A *p* value lower than 0.05 indicates the significant differences of perceptions for students from different  
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Table 8. Overall sample analysis in the question of desired BIM-related AEC jobs (Overall Cronbach's Alpha = 0.9045)

<b>BIM-related job titles</b>	<b>Mean</b>	<b>Std*</b>	<b>R/I</b>	<b>Ranking</b>	<b>Item-total Correlation</b>	<b>Cronbach's Alpha</b>
BIM manager	3.521	1.159	0.704	4	0.6180	0.8973
BIM engineer	3.799	1.094	0.760	2	0.5905	0.8988
BIM coordinator	3.201	1.144	0.640	6	0.7949	0.8878
BIM technician	3.042	1.256	0.608	8	0.7693	0.8886
BIM modeler/operator/draughtsman	3.313	1.220	0.663	5	0.6404	0.8962
BIM quantity surveyor	3.076	1.212	0.615	7	0.6127	0.8977
BIM project manager	3.806	1.136	0.761	1	0.5375	0.9015
BIM leader/director	3.632	1.133	0.726	3	0.6184	0.8973
BIM software developer	2.646	1.287	0.529	11	0.6043	0.8985
BIM consultant	3.042	1.251	0.608	8	0.6423	0.8961
BIM facility manager	2.840	1.120	0.568	10	0.6671	0.8948

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Table 9. Comparison of internal consistency among SUT, WZU, and UoB regarding students' motivation in different BIM-related industry jobs

BIM-related job titles	SUT (Australia) Overall CA=0.8535		WZU (China) Overall CA=0.9537		UoB (U.K.) Overall CA=0.9454	
	ITC	CA	ITC	CA	ITC	CA
BIM manager	0.4505	0.8477	0.7405	0.9513	0.8164	0.9380
BIM engineer	0.3508	0.8535	0.8662	0.9463	0.7520	0.9407
BIM coordinator	0.7179	0.8269	0.8721	0.9464	0.9132	0.9355
BIM technician	0.7479	0.8230	0.8434	0.9472	0.8836	0.9355
BIM modeler/operator/draughtsman	0.5123	0.8437	0.8395	0.9474	0.8097	0.9383
BIM quantity surveyor	0.6505	0.8318	0.8294	0.9482	<b>0.4118</b>	<b>0.9530</b>
BIM project manager	<b>0.2715</b>	<b>0.8583</b>	0.7726	0.9500	0.8139	0.9381
BIM leader/director	0.5002	0.8442	<b>0.5952</b>	<b>0.9557</b>	0.7607	0.9404
BIM software developer	0.5928	0.8369	0.7575	0.9514	0.6942	0.9428
BIM consultant	0.5194	0.8433	0.8122	0.9486	0.8029	0.9386
BIM facility manager	0.5832	0.8379	0.8010	0.9491	0.7400	0.9411

1118 \*: ITC stands for Item-total Correlation, and CA means Cronbach's Alpha.

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Table 10. ANOVA results for subgroup analysis of students divided by institutions responding to the question of desired BIM-related AEC jobs

BIM-related job titles	SUT (Australia)		WZU (China)		UoB (U.K.)		Statistical comparison		Post-hoc analysis
	Mean	Std	Mean	Std	Mean	Std	F value	p value	
BIM manager	3.818	1.128	3.394	0.747	2.586	1.268	<b>14.57</b>	<b>0.000</b> *	UoB students had significantly less motivations compared to peers from two other institutions.
BIM engineer	4.061	0.895	3.545	1.063	3.313	1.401	<b>7.52</b>	<b>0.001</b> *	SUT students had more motivations than peers from two other institutions.
BIM coordinator	3.388	1.240	3.375	0.907	2.567	1.104	<b>6.09</b>	<b>0.003</b> *	UoB students had significantly less motivations compared to peers from two other institutions.
BIM technician	3.000	1.331	3.500	1.047	2.710	1.189	<b>3.28</b>	<b>0.040</b> *	UoB students had significantly less motivations compared to peers from WZU.
BIM modeler / operator / draughtsman	3.304	1.332	3.375	0.976	2.933	1.311	1.18	0.309	No significant differences
BIM quantity surveyor	3.140	1.290	3.406	0.837	2.625	1.212	<b>3.62</b>	<b>0.029</b> *	UoB students had significantly less motivations compared to peers from two other institutions.
BIM project manager	4.227	0.930	3.469	0.842	3.118	1.365	<b>17.61</b>	<b>0.000</b> *	SUT students had more motivations than peers from two other institutions.
BIM leader/director	3.863	1.017	3.594	0.911	3.125	1.385	<b>5.65</b>	<b>0.004</b> *	UoB students had significantly less motivations compared to peers from SUT.
BIM software developer	2.396	1.326	3.250	1.164	2.500	1.270	<b>5.40</b>	<b>0.005</b> *	WZU students had more motivations than peers from two other institutions.
BIM consultant	2.990	1.403	3.281	1.085	2.727	1.180	1.47	0.234	No significant differences
BIM facility manager	2.806	1.191	3.219	0.832	2.273	1.098	<b>5.99</b>	<b>0.003</b> *	UoB students had significantly less motivations compared to peers from two other institutions.
Overall	3.345	0.804	3.404	0.779	2.830	1.052	<b>5.25</b>	<b>0.006</b> *	Same as above

1153 \* A p value lower than 0.05 indicates the significant differences of perceptions among students from different  
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Table 11. Overall sample analysis in the question of challenges encountered in BIM implementation (Overall Cronbach's Alpha = 0.7904)

Challenges	Mean	Std*	<i>RII</i>	Ranking	Item-total Correlation	Cronbach's Alpha
Insufficient BIM education resource or training	3.204	0.994	0.641	5	0.5425	0.7599
High cost of BIM software tools	3.307	1.068	0.661	1	<b>0.3584</b>	<b>0.7907</b>
Upgrading of existing hardware	3.277	0.929	0.655	4	0.3478	0.7891
Attitudes of AEC companies towards BIM adoption	3.175	0.984	0.635	7	0.5371	0.7608
Lack of client demand for using BIM	3.029	0.947	0.606	8	0.5563	0.7582
Lack of sufficient time to evaluating the ratio of BIM inputs and outputs	3.182	0.949	0.636	6	0.5574	0.7580
Lack of legislation or incentives from government or authority	3.307	1.054	0.661	1	0.5529	0.7579
Lack of industry standards in BIM applications	3.292	0.986	0.658	3	0.5344	0.7613

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1189 Table 12. Comparison of internal consistency among SUT, WZU, and UoB regarding  
 1190 students' perceptions of challenges encountered in BIM implementation

Challenges	SUT (Australia) Overall CA=0.7266		WZU (China) Overall CA=0.8876		UoB (U.K.) Overall CA=0.8376	
	ITC	CA	ITC	CA	ITC	CA
Insufficient BIM education resource or training	0.5619	0.6690	0.5449	0.8845	0.5693	0.8183
High cost of BIM software tools	<b>0.2200</b>	<b>0.7413</b>	0.7420	0.8652	0.5003	0.8273
Upgrading of existing hardware	<b>0.2137</b>	<b>0.7345</b>	0.5975	0.8799	<b>0.4018</b>	<b>0.8424</b>
Attitudes of AEC companies towards BIM adoption	0.4244	0.6980	0.6600	0.8735	0.7392	0.7939
Lack of client demand for using BIM	0.4688	0.6899	0.6519	0.8743	0.7119	0.7980
Lack of sufficient time to evaluating the ratio of BIM inputs and outputs	0.4762	0.6871	0.6944	0.8707	0.7317	0.8054
Lack of legislation or incentives from government or authority	0.5030	0.6804	0.7384	0.8658	0.4857	0.8285
Lack of industry standards in BIM applications	0.4960	0.6827	0.6609	0.8735	0.4769	0.8292

1191 \*: ITC stands for Item-total Correlation, and CA means Cronbach's Alpha.

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1219 Table 13. ANOVA results for subgroup analysis of students among SUT, WZU, and UoB  
 1220 responding to the question of challenges encountered in BIM practice

Challenges	SUT (Australia)		WZU (China)		UoB (U.K.)		Statistical comparison		Post-hoc analysis
	Mean	Std	Mean	Std	Mean	Std	F value	p value	
Insufficient BIM education resource or training	3.240	1.066	3.406	0.946	2.912	0.933	2.09	0.126	No significant differences
High cost of BIM software tools	3.411	1.149	3.094	1.027	3.294	1.031	1.04	0.356	No significant differences
Upgrading of existing hardware	3.385	1.055	2.969	0.861	3.171	1.071	2.19	0.115	SUT students perceived a higher degree of challenge compared to their WZU peers
Attitudes of AEC companies towards BIM adoption	3.313	1.113	2.969	0.822	3.031	0.933	1.83	0.164	No significant differences
Lack of client demand for using BIM	3.113	0.934	2.806	0.792	2.971	0.904	1.44	0.241	No significant differences
Lack of sufficient time to evaluating the ratio of BIM inputs and outputs	3.319	1.063	3.167	0.747	2.839	0.688	3.02	0.052	SUT students perceived a higher degree of challenge compared to their UoB peers
Lack of legislation or incentives from government or authority	3.495	1.139	3.103	0.817	3.033	0.850	<b>3.10</b>	<b>0.048</b> *	Same as above
Lack of industry standards in BIM applications	3.387	1.152	3.241	0.786	2.938	0.801	2.29	0.105	Same as above
Overall	3.329	0.632	3.079	0.620	3.082	0.700	3.06	0.050	No significant differences

\* A *p* value lower than 0.05 indicates the significantly different opinions of students from different institutions

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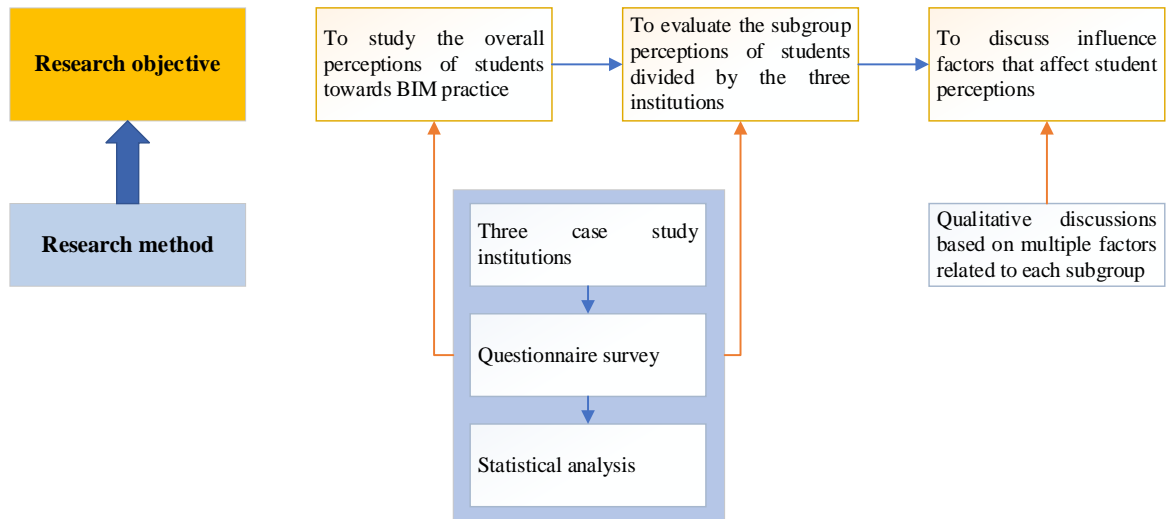
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1232 **Fig.1.** Description of research methods to achieve research objectives

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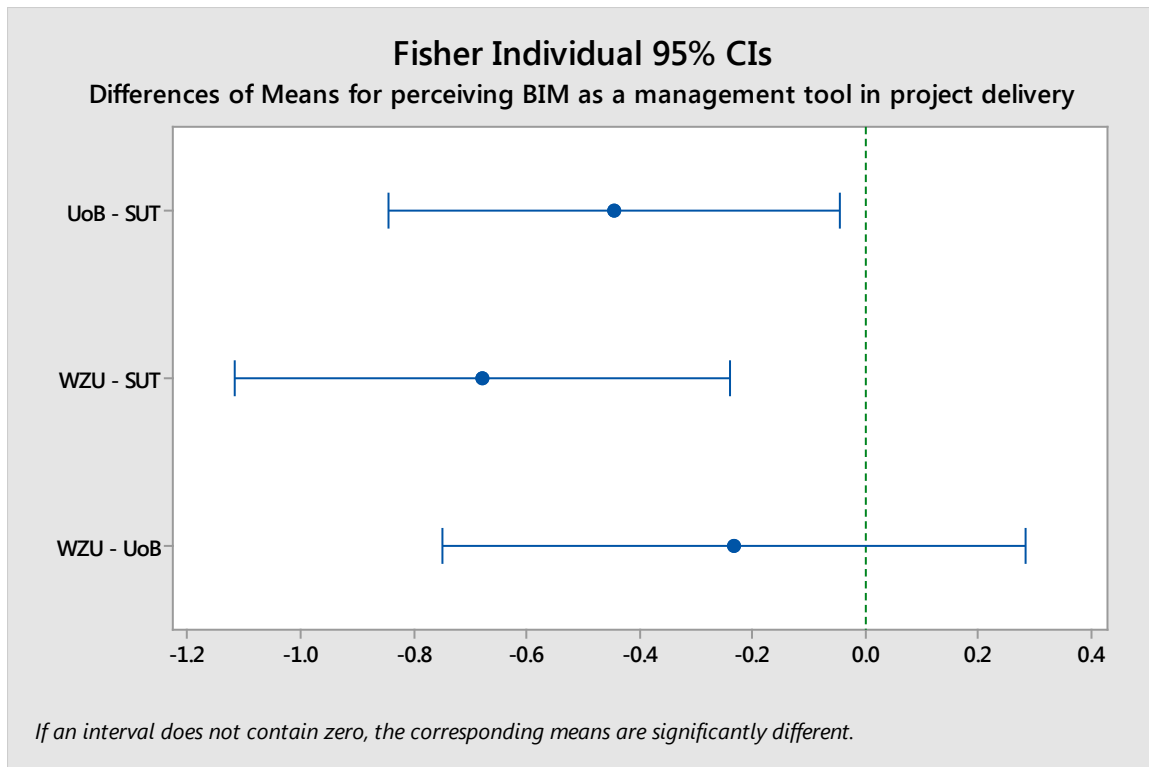
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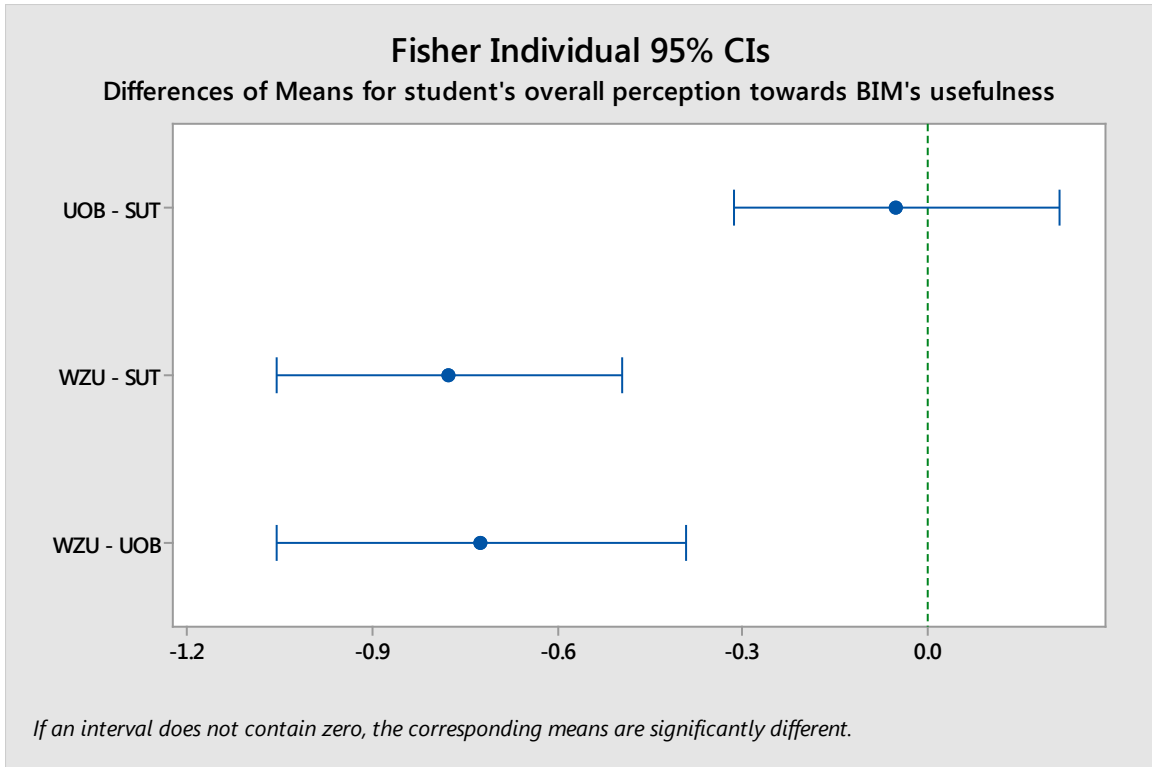
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1242 **Fig.2.** Post-hoc analysis of subgroup differences towards perceiving BIM as a management  
 1243 tool in project management

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1248 **Fig.3.** Post-hoc analysis of subgroup differences towards perceiving BIM's overall usefulness  
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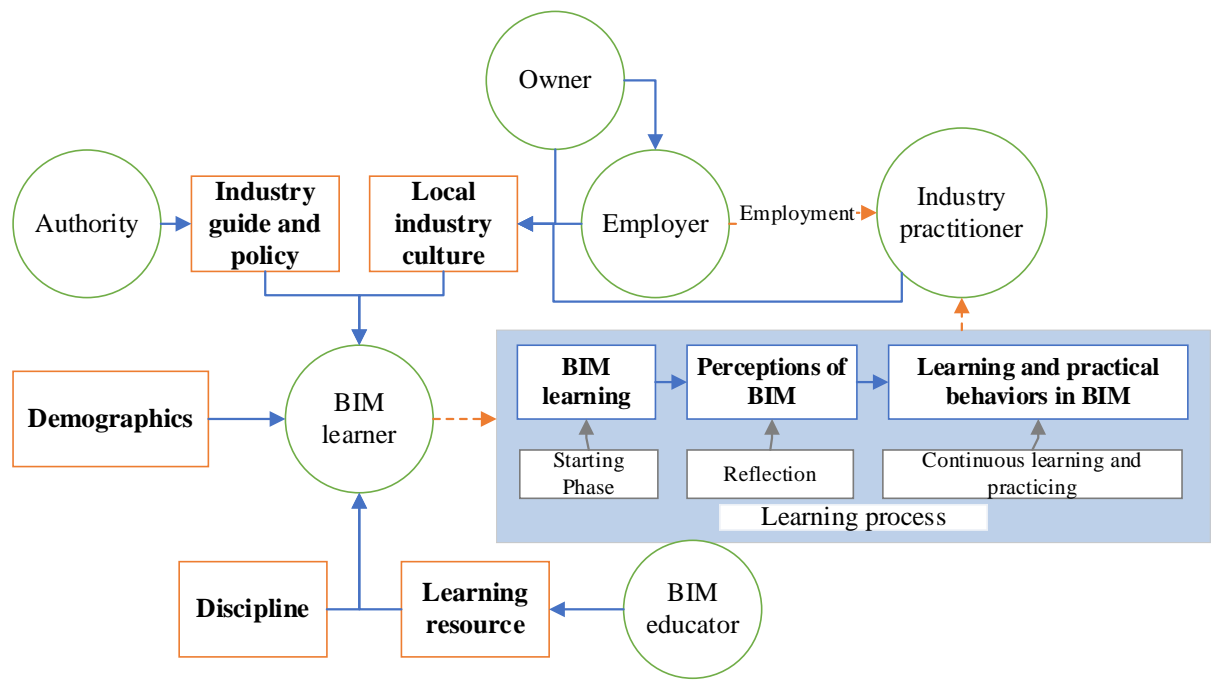
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**Fig.4.** Framework describing the BIM learning process