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5 **A Review of BIM Adoption in the Higher Education of AEC Disciplines**

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7 **Abstract**

8 This Technical Note serves as one of the first review-based studies by analyzing existing
9 trends of incorporating Building Information Modeling (BIM) into the higher education of
10 architecture, engineering, and construction (AEC)-related disciplines. Assisted by a
11 scientometric review approach, this study identified mainstream journals and conference
12 proceedings publishing BIM educational research outputs, and analyzed existing research
13 keywords. It was found that *Journal of Professional Issues in Engineering Education and*
14 *Practice* was ranked as the top journal measured by number of publications and the total
15 citations received by all articles related to BIM education. However, *Journal of Construction*
16 *Engineering and Management* was the journal with the highest average influence per article
17 despite its small number of publications in BIM education. The keyword analysis through
18 visualized mapping and quantitative analysis revealed that existing BIM educational studies
19 had been focusing more on construction-related disciplines. Discipline-specific pedagogical
20 activities were reported (e.g., interactive display in construction education), also there had
21 been educational effort to bridge different AEC disciplines through integrated and

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22 collaborative approaches. Several research trends were identified following the keyword
23 analysis, such as the need of incorporating BIM at the program level by extending from a
24 single course (e.g., quantity surveying), and integrating BIM with other digital technologies
25 (e.g., drone). This study reports the state of BIM education literature by providing an
26 overview of the latest trends of adopting BIM in the AEC education. Based on the current
27 review, some continuous work in BIM education is foreseen, including educational
28 innovation addressing both technical and managerial aspects of BIM, and the
29 interdisciplinary collaboration to reduce the fragmentation among AEC disciplines.

30 **Keywords:** Literature review; higher education; Building Information Modeling (BIM);
31 architecture, engineering, and construction

32 **Introduction**

33 Building Information Modeling (BIM), as one of the main digital technologies being
34 applied in the architecture, engineering, and construction (AEC) industry, has also become
35 one of the main themes in the AEC higher education sector. Understanding the trends of BIM
36 education in the higher education is important based on the facts that: (1) BIM is one of the
37 key technologies in the global AEC industry movement towards digitalization to achieve
38 improved project efficiency; (2) educators or academia have the mission to update the AEC
39 curriculum to equip students with the latest digital skills and to nurture students' capabilities
40 of developing broader skills in the rapidly changing environment; (3) students are future
41 employees in the AEC professions and there is a need to address the gap between institutional
42 education and industry needs (Tang et al., 2015). Santos et al. (2017) reviewed 381 relevant
43 BIM-related articles and indicated that BIM educational themes had not received sufficient
44 attention in academic research. Recent review-based studies (e.g., Chen et al., 2019; Zheng et
45 al., 2019) in civil engineering education revealed the trend of adopting BIM in the curriculum
46 or other education activities. Jin et al. (2019c) also suggested that education or training

47 should become one of the main themes in BIM-related research for construction engineering
48 and management. Although some existing pedagogical examples (e.g., Jin et al., 2018a;
49 Zhang et al., 2018) of BIM could be found, so far there has not been a review-based work to
50 summarize the trend of incorporating BIM in the AEC higher education. This study reviews
51 BIM education-related publications aiming to uncover the trend of BIM-based institutional
52 education in the AEC sector. The study contributes to the body of knowledge in BIM
53 education in that: (1) it analyzes the existing research keywords extracted from the literature
54 sample related to BIM for higher education; and (2) it provides insights for scholars in the
55 global AEC academic community in understanding the trends of BIM education by proposing
56 near-future directions.

57 **Literature review method**

58 The overall workflow of the review consisted of three main steps, namely a bibliometric
59 search, scientometric analysis, and a further discussion. More detailed descriptions of the
60 review methodology can be found in Jin et al. (2019a). The bibliometric search was based on
61 key terms that were shown in either the title, abstract, or keyword lists of each reference. The
62 search format is displayed below.

63 TITLE-ABS-KEY (*BIM* OR "*Building Information Modelling*" OR "*Building*
64 *Information Modeling*") AND TITLE-ABS-
65 KEY (*education* OR *curriculum* OR *institution* OR *teaching* OR *pedagogy* OR *student*
66 *s*) AND TITLE-ABS-KEY (*architecture* OR *engineering* OR *construction*)

67 *Scopus* was used as the database for the literature search based on the fact that *Scopus*
68 covers more sources and more recent literature compared to other databases such as *Web of*
69 *Science* (AghaeiChadegani et al., 2013). BIM educational dissemination could be largely
70 found in conference proceedings (e.g., Huang, 2017). To have a wider coverage of literature
71 in this review-based study, papers published in English including both journal articles and

72 conference proceedings were included. After the initial literature sample was acquired
73 following the keyword search, researchers performed further screening to remove papers that
74 did not fall into the scope of the study. The scope was defined as AEC educational studies
75 incorporating BIM. The ways that BIM could be incorporated in the higher education sector
76 include but are not limited to teaching activities, curriculum development, pedagogical
77 strategies, and student feedback (e.g., student discussion or perceptions of BIM). Two types
78 of papers were excluded from the literature sample after further screening, i.e. (1) papers
79 focusing on BIM but not on the higher education sector; (2) papers based on AEC
80 educational research but not focusing on BIM.

81 After the literature sample was finalized, the scientometric analysis tool, *VOSViewer*
82 (van Eck and Waltman, 2010), was adopted to conduct the literature review. Based on the
83 text mining features, *VOSViewer* can be used to analyze research keywords assisted by
84 visualization (van Eck and Waltman, 2014). It also provides quantitative metrics (e.g.,
85 citation-based measurement) to evaluate the impact of research keywords, documents, or
86 literature sources. Some examples of utilizing these quantitative measurements can be found
87 in a few existing review-based studies (e.g., Jin et al., 2018b; Chen et al., 2019).

88 As the last step of this review, a further qualitative discussion was provided to unveil the
89 trends of BIM educational studies in AEC disciplines, and to propose the near-future
90 directions on continuing and enhancing BIM educational research and practice.

91 **Review results**

92 Initially, 683 documents including journal articles and conference proceedings were
93 found in *Scopus*. Five researchers in this study firstly performed independent screening of the
94 initial literature sample with the pre-agreed selection criteria, i.e., BIM in AEC higher
95 education sector. It was agreed by all researchers that the following types of documents
96 should be excluded: (1) studies focusing on BIM but not in the higher education sector, for

97 example, industry training to promote BIM. Therefore, studies investigating certain issues
98 (e.g., design collaboration) in utilizing BIM for professional implementation (e.g., Plume and
99 Mitchell, 2007) but not targeting teaching and learning were excluded; (2) studies based on
100 higher education in the AEC disciplines, but not focusing on BIM. These types of studies
101 were included in the literature sample: (1) educational studies linking BIM into other digital
102 technologies (e.g., virtual reality), for instance, the study of Kang et al. (2018) in developing
103 the broader concept of digitalization in construction engineering by incorporating BIM with
104 other digital technologies including BIM and virtual reality; (2) student perceptions or
105 feedback of BIM following their learning or practical activities related to BIM (e.g., Zou et
106 al., 2019); (3) studies without students directly involved but focusing on BIM educators’
107 training or digital upskilling for preparing BIM curriculum, e.g., Rahman and Ayer (2018)’s
108 investigation of how to adopt problem-based learning into the BIM education with the
109 feedback from industry professionals. After the individual screening of the initial literature
110 sample, the research team held two rounds of internal discussion according to these pre-
111 defined criteria until all researchers agreed on the finalized literature sample. By the mid-
112 January 2020, a total of 282 documents published up to the end of December 2019 were
113 selected for the literature review. Among these selected literature sample, 121 were journal
114 articles with the remaining sample from conference proceedings. The top ten sources of the
115 publications are summarized in Table 1.

116 <Insert Table 1 here>

117 Four major quantitative measurements are included in Table 1 to evaluate the
118 contributions of academic sources, including the number of publications and three citation-
119 related metrics. Two normalized citation-related metrics were used to prevent the impact of
120 misperception that earlier publications gain more time to receive citation compared to the
121 more recent publications (van Eck and Waltman, 2017). The normalized citation (NC) in

122 Table 1 is calculated by dividing the total citations of all publications from the given source
123 by the average number of citation of publications gained in the same year. It measures the
124 influence of the given source in publishing research outputs related to BIM education for
125 AEC. The average normalized citation (ANC) is calculated by further dividing NC by the
126 number of publications from the given source in one year. Differing from NC which
127 measures the influence of the given source without considering the number of publications
128 from the same source, ANC is the indicator of the average influence from the individual
129 publication perspective. More detailed descriptions of applying normalization in a given
130 literature sample can be found in Jin et al. (2018b). *Journal of Professional Issues in*
131 *Engineering Education and Practice* could be considered the top source in terms of all of the
132 above metrics. In terms of ANC, *Journal of Construction Engineering and Management*,
133 although with only three articles published related to BIM education in AEC, received high
134 citation numbers, inferring that these articles had been influential by guiding the BIM
135 educational research in the global AEC higher education. Specifically, Pikas et al. (2013) set
136 the guideline of BIM education in the construction engineering and management curriculum.
137 It was suggested that BIM should not be a topic itself, but a tool for performing a variety of
138 engineering tasks such as design and analysis (Pikas et al., 2013). Sacks and Pikas (2013)
139 compiled a framework for BIM education in AEC degree programs by outlining a series of
140 topics (e.g., design coordination) aiming to address the gap between institutional education
141 and industry requirements. The *ASEE Annual Conference and Exposition, Conference*
142 *Proceedings*, due to its nature of disseminating engineering educational work, could be
143 considered the most influential conference source in generating BIM education-related
144 outputs. Generally, it could be seen that journal articles receive more attention than
145 conference proceedings in BIM educational studies.

146 The visualization of research keywords is displayed in Fig.1.

147 <Insert Fig.1 here>

148 Author keywords extracted from the database of literature sample were analyzed based on
149 the text-mining feature of *VOSViewer*. The detailed procedure of conducting keyword
150 analysis in a text-mining approach can be found in Oraee et al. (2017) and Hosseini et al.
151 (2018). Keywords with the same semantic or contextual meanings were merged as seen in
152 Fig.1 and Table 2. For example, “construction” was used to merge “construction education”
153 and “construction engineering”. The keyword “construction” referred to educational activities
154 to construction-related subjects such as construction scheduling. General keywords such as
155 “BIM” or “higher education”, which were considered the review focus of this study, were
156 removed from the keyword mapping. The size of the circle and the keyword font indicate the
157 frequency of the noted keyword being studied in the literature sample. For example, BIM
158 educational studies had been frequently focusing on construction-related subjects (e.g.,
159 construction engineering). The distance and connection line between a pair of keywords
160 indicate the closeness of them, for example, using Revit to assist the traditional construction
161 estimating (Nassar, 2012).

162 The clusters shown in Fig.1 were determined based on a given group of keywords being
163 co-studied in the same publication or one being cited by another in different publications, e.g.,
164 co-occurrence of keywords as identified through the in-built algorithm in *VOSViewer* (van
165 Eck and Waltman, 2014). More details of how the algorithm was established to enable the
166 clustering can be seen in Yan et al. (2012). The relevance of a pair of keywords, i.e., being
167 co-studied within the same publication, can be detected in *VOSViewer* and visualized through
168 the connection line in Fig.1. For example, it was found that sustainability was closely linked
169 to learning outcome, as studies (e.g., Svennevig and Hjelseth, 2017) on adopting BIM for
170 sustainability-related course have been frequently emphasizing the learning outcome. The

171 visualized map of research keywords indicates separate clusters and the inter-connectedness
172 among the clusters, including:

173 (1) BIM has been taught in different disciplines, including construction, civil engineering,
174 architecture, architectural technology, management (e.g., project management), and MEP
175 (i.e., mechanical, electrical, plumbing), etc. These disciplines appear disaggregated as
176 indicated by the clusters and the distances among these keywords related to disciplines.
177 Specifically, the construction-related disciplines have been strongly connected to digital
178 platforms driven by BIM-supported virtual reality (VR). For example, Zolfagharian et al.
179 (2013) applied BIM to achieve interactive display during construction education; the civil
180 engineering subject has been concerned incorporating BIM to the more traditional graphic
181 tool (e.g., Computer-Aided Design or CAD); the architectural discipline has been more
182 involved with utilizing BIM for visualization; the management disciplines have addressed
183 more collaborative issues, e.g., teamwork and communication as part of students'
184 learning curve;

185 (2) Despite of the variation of BIM educational activities due to the discipline nature, efforts
186 have been made to connect these different disciplines through the interdisciplinary
187 approach and collaborative work (e.g., Jin et al., 2018a). As seen in Fig.1, collaboration is
188 directly connected to interdisciplinary work;

189 (3) BIM-related education can be categorized into managerial and technical activities, which
190 are consistent with the statement of He et al. (2017) that managerial aspect is the other
191 important part of BIM besides the technical development using BIM. The technical BIM
192 education involves BIM authoring tool (e.g., Revit) and the data format for information
193 exchange (e.g., IFC) as indicated in Fig.1. On other hand, communication, teamwork, and
194 integration are being addressed in the management-related BIM education. The

195 managerial and technical aspects of BIM could be integrated through BIM-assisted
196 technologies such as VR;

197 (4) Teaching and learning is a key focus in this review-based study, as indicated by these
198 keywords including learning outcome, curriculum development, assessment, and other
199 specific teaching methods (e.g., experiential learning, and project-based learning, etc.).

200 Educational theories, e.g., Bloom's Taxonomy (1956), are being incorporated in BIM
201 pedagogical activities (e.g., Govender et al., 2019); and

202 (5) Case studies are being adopted as the educational research methodology emphasizing
203 educators' or learners' perceptions of BIM. Perceptions or feedback of BIM learners
204 following educational activities form part of professional growth of AEC students as
205 demonstrated by Zou et al. (2019). The subgroup traits are considered influence factors of
206 learners' perceptions towards BIM usage and practice, e.g., disciplinary background (Jin
207 et al., 2019b).

208 More quantitative measurements of main research keywords are summarized in Table 2,
209 including the average normalized citation (ANC), which is calculated in the consistent
210 manner as demonstrated in Table 1. The ANC measures the influence of a given keyword
211 according to average citations received per year. For example, although *Revit* and *VR* have
212 the same occurrence, the ANC received by *Revit* is significantly lower than that by *VR* (i.e.,
213 *0.98* (compared to *3.34*), indicating that VR-related studies in BIM education are more likely
214 to receive higher attention in the academic community and to have a higher impact. It is seen
215 that 3D model and VR are among the most influential keyword involved in BIM education. It
216 is not uncommon that BIM is integrated with VR to provide experiential learning (e.g., Park
217 et al., 2016) for AEC students in a more immersive approach.

218 <Insert Table 2 here>

219 As seen in both Fig.1 and Table 2, construction-related subjects, such as construction
220 engineering and management, is the most frequently studied keywords in the literature
221 sample. It is seen that more BIM educational studies have been focusing on construction (e.g.,
222 construction engineering), management (e.g., project management), and architecture-related
223 subjects, compared to others such as civil engineering, and architectural engineering, etc.
224 Curriculum or course development is another frequently studied topic. Average publication
225 year is the metric to measure the recency or newness of the studied keyword. These keywords
226 are identified as being most recently studied: VR, AR, case study, civil engineering, and
227 experiential learning. Innovative teaching deliveries are being demonstrated as case studies
228 (e.g., Zhang et al., 2019) to be shared with BIM educators in the AEC academic community
229 worldwide.

230 **Discussion**

231 This Technical Note aims to provide an overview of global movements of BIM
232 education in AEC disciplines. Based on the scientometric review method, the quantitative
233 summary of publication sources indicated that *Journal of Professional Issues in Engineering*
234 *Education and Practice* was the top journal in publishing BIM educational research. Some
235 other non-education-based journals in the AEC disciplines (e.g., *Journal of Construction*
236 *Engineering and Management*) also had highly influential outputs in BIM education. *ASEE*
237 *Annual Conference and Exposition Conference Proceedings* was identified as the most
238 influential conference proceeding to disseminate BIM educational studies based on the
239 number of publications and citations received.

240 The visualization and quantitative analysis of research keywords revealed that existing
241 educational studies had focused more on construction-related subjects, followed by
242 architecture. It could be indicated of how BIM pedagogical activities varied among
243 disciplines. For example, visual and interactive displays were more involved in construction

244 education, while management subjects were involved more with communication, simulation,
245 and teamwork. BIM, as the digital platform, could be found being incorporated into other
246 educational themes or activities, as reflected from the keywords of sustainability and
247 curriculum development. Both the managerial (e.g., collaboration) and technical (e.g., IFC)
248 aspects of BIM education could be found in the literature sample, although these two seemed
249 distant in the visualized map (e.g., Fig.1). A sub-sample of the literature indicated that
250 perceptions from BIM learners following the educational activities could be considered part
251 of learning loop to transform the knowledge into practice in the career growth of AEC
252 students.

253 The keyword analysis further reveal several trends: (1) BIM adoption for a single course
254 (e.g., quantity surveying) can be found, but there is also a need to plan these individual
255 courses at the curriculum or program level by incorporating BIM as the digital platform to
256 reduce the fragmentations among courses; (2) further studies could be performed to evaluate
257 how BIM is taught among various AEC disciplines (e.g., civil engineering and architecture)
258 and to continue bridging different disciplines in an interdisciplinary approach; (3) more
259 incorporations of pedagogic strategies or education theories (e.g., project-based learning)
260 could be introduced in implementing BIM education. It will also be insightful to integrate
261 different teaching strategies, such as experiential learning and problem-based learning; (4)
262 BIM should not be viewed as a standalone digital technology itself, but could be extended in
263 the context of Industry 4.0 and Internet-of-Things for nurturing the next generation of AEC
264 professionals. More studies are needed to integrate BIM with other digital technologies or
265 platforms, such as 3D printing, drone, mixed reality, and laser scanning, which have not been
266 found in the existing literature sample of BIM education. Overall, these latest practices or
267 research movements in BIM (e.g., interoperability to enhance information exchange) could be
268 adopted in education to spark more research-informed teaching and practice-based teaching.

269 **Summary**

270 Based on the current review work, future educational studies could address: (1) viewing
271 BIM as the digital platform from the single course level to the program or curriculum level
272 involving BIM-standalone and BIM-embedded courses; (2) collaborative nature of BIM to
273 reduce the fragmentation among different AEC disciplines through new pedagogical
274 strategies (e.g., interdisciplinary project-based learning); (3) information sharing between
275 BIM and other digital technologies (e.g., laser scanning) to motivate the research-informed
276 teaching; and (4) continuous educational innovation to bridge the gap between higher
277 education and industrial needs on the technical and managerial digitalization capabilities of
278 AEC graduates. This study is limited to BIM education for higher education in the AEC
279 disciplines. More future review-based work could extend the current study to highlight BIM
280 education or training to industry professionals. Other sources of literature such as trade
281 magazine could be included to conduct the analysis of BIM professional training and
282 institutional education to meet the global needs of industrial transformation towards
283 digitalization.

284 **Data Availability Statement**

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

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Table 1. Distribution of top ten sources of the literature sample

Document Source	Number of documents	Total citations	Normalized citations	Average normalized citations
<i>Journal of Professional Issues in Engineering Education and Practice</i>	18	509	64.2	3.56
<i>Electronic Journal of Information Technology in Construction</i>	3	189	7.3	2.42
<i>Journal of Construction Engineering and Management</i>	3	150	12.5	4.18
<i>International Journal of Construction Education and Research</i>	10	114	20.1	2.01
<i>Journal of Information Technology In Construction</i>	14	84	12.8	0.91
<i>ASEE Annual Conference and Exposition, Conference Proceedings</i>	32	81	9.3	0.29
<i>International Journal of Engineering Education</i>	10	47	18.8	1.88
<i>Procedia Engineering</i>	5	37	6.9	1.38
<i>Practice Periodical on Structural Design and Construction</i>	2	23	2.6	1.32
<i>Proceedings - Winter Simulation Conference</i>	2	22	1.4	0.71
<i>Architectural Engineering and Design Management</i>	2	21	4.9	2.46
<i>Journal of Engineering, Design and Technology</i>	4	16	2.6	0.65
<i>Sustainability (Switzerland)</i>	4	15	3.6	0.90
<i>Engineering, Construction and Architectural Management</i>	4	14	10.8	2.70
<i>AEI 2013: Building Solutions for Architectural Engineering - Proceedings of the 2013 Architectural Engineering National Conference</i>	3	12	1.0	0.33
<i>Proceedings - Frontiers in Education Conference, FIE</i>	3	12	2.5	0.83

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Table 2. Quantitative summary of keywords from the literature sample focusing on BIM adoption in AEC education

Keyword	Occurrences	Average publication year	Average normalized citation
Construction	24	2015	2.55
Curriculum	21	2016	1.27
Management	17	2016	1.17
Architecture	15	2014	0.95
Collaboration	14	2016	1.34
Sustainability	10	2014	1.62
Integration	8	2015	0.94
Civil Eng	7	2018	0.26
Revit	6	2015	0.98
Visualization	6	2010	0.81
VR	6	2018	3.34
PBL	5	2017	1.02
CAD	4	2016	2.15
Case Study	4	2018	1.32
E-Learning	4	2014	0.88
Interdisciplinary	4	2014	2.62
Learning Outcome	4	2016	1.28
Problem-Based Learning	4	2016	1.73
QS	4	2017	0.92
Teamwork	4	2016	2.28
3D Model	3	2012	4.72
AR	3	2018	1.96
Architectural Engineering	3	2016	1.86
Assessment	3	2015	1.12
Barrier	3	2018	0.38
Capstone	3	2015	1.54
Experiential Learning	3	2018	2.17

IPD	3	2013	1.38
Malaysia	3	2018	0.59
Virtual	3	2012	2.20

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Note: Not all keywords from the literature sample are listed in Table 2. Only those top-ranked keywords are included according to the occurrence and citation-related metrics.