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

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Abstract

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

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

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

Introduction

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

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

Literature review method

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

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

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

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

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

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

Review results

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

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

<Insert Table 1 here>

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

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

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

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

(4) Teaching and learning is a key focus in this review-based study, as indicated by these keywords including learning outcome, curriculum development, assessment, and other specific teaching methods (e.g., experiential learning, and project-based learning, etc.). Educational theories, e.g., Bloom's Taxonomy (1956), are being incorporated in BIM pedagogical activities (e.g., Govender et al., 2019); and

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

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

<Insert Table 2 here>

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

Discussion

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

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

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

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

Summary

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

Data Availability Statement

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

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

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

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

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.