Building Information Modelling Education for Quantity Surveyors in Hong Kong: Current States, Education Gaps, and Challenges

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Rapid developments in building information modelling (BIM) are escalating the architecture, engineering, and construction (AEC) industry towards digital transformation. However, the lack of skilled BIM professionals is a critical issue slowing this transformation. Currently, few educational institutions include BIM topics in their curricula, especially those developed for quantity surveying (QS) programs. Moreover, the learning outcomes of BIM curricula may not meet the current industrial requirements. Thus, this study investigated the current states, gaps, and challenges of BIM education for QS practices in Hong Kong. This study conducted surveys to determine industrial requirements and a case study to examine the BIM curricula currently offered at Hong Kong educational institutions. The results suggest that the current BIM education for QS practices is in line with the pace of BIM development in the AEC industry. However, some advanced topics are not covered in BIM education. Additionally, the non-standardized BIM competencies to be attained by students lead to uncertainty and challenges in BIM education for quantity surveyors.

Key Words: BIM education; quantity surveying; industry demand; multi-institution

Introduction

Information and communication technologies have been advancing rapidly. With these technologies, the construction industry is improving its productivity and efficiency in the case of communication, coordination, and collaboration among project stakeholders (Sawhney, Riley & Irizarry, 2020). Among the advanced technologies, building information modelling (BIM) is emerging in the architecture, engineering, and construction (AEC) industry, with its increasing applications across the world (McGraw Hill Construction, 2014). Given the increasing popularity of BIM, it becomes urgent for industry professionals to equip themselves with relevant knowledge and skills to keep pace with emerging technologies (Liao & Teo, 2019).

The AEC industry demands competent BIM professionals (Ma, Darko, Chan, Wang & Zhang, 2020; Wu & Issa, 2014). One of the major suppliers of BIM professionals is educational institutions producing graduates to support BIM implementation (Ali, Mustaffa, Keat & Enegbuma, 2016). However, the current supply of BIM-equipped graduates cannot meet the industry demands (Casasayas, Reza Hosseini, Edwards, Shuchi & Chowdhury, 2020; Shelbourn, Macdonald, McCuen & Lee, 2017; Yusuf, Embi & Ali, 2017). In addition, educational institutions face challenges in incorporating BIM education and practices into their curricula (Abbas, Din & Farooqui, 2016; Casasayas et al., 2020; Yusuf et al., 2017). Regarding BIM education for quantity surveying (QS) practices, a critical concern involves whether BIM drives the entire QS curriculum as an intrinsic part (Ali et al., 2016; Babatunde & Ekundayo, 2019). Furthermore, considerable resources are required to support BIM education, for instance, teaching staff (Ali et al., 2016), computer software and hardware (Barison & Santos, 2010), and supports from government and professional bodies (Abdirad & Dossick, 2016). With the rapid evolvement and implementation of BIM in QS practices, it is unclear whether the current BIM education for QS practices can sufficiently meet the current industrial demands. Thus, this study aimed to fill this knowledge gap by achieving the following research objectives: 1. understand the current industrial BIM adoption and demands in QS practices, 2. understand the current education provided on BIM for QS practices in educational institutions, and 3. compare the current education on BIM for QS practices against the current industrial adoption and demands in QS practices.

Background

BIM education and curriculum design

Education programs and courses from educational institutions should align with real-world industry practices. However, the AEC industry is dynamic, and the associated technology is changing rapidly. Therefore, it is highly challenging for any educational institution to ensure that its BIM curriculum meets the industry demands (Becerik-Gerber, Gerber & Ku, 2011; Lee & Hollar, 2013). The AEC industry demands professional training via a long-established curriculum (Charef, Emmitt, Alaka & Fouchal, 2019; Govender et al., 2019). Thus, substantial efforts are necessary to incorporate BIM contents and practices into the current curricula of educational institutions. Table 1 shows the essential elements of BIM education based on a comprehensive literature review. Eight essential elements have been identified from thirteen studies, including interdisciplinary student projects, BIM classes, software, industrial support, research projects, student learning activities, hardware, and cross-institutional cooperation. Most of the studies highlighted the significance of interdisciplinary student projects and BIM classes. Abdirad and Dossick (2016) suggested three strategies for educational institutions. First, standalone BIM courses can cover general BIM applications (Lee & Hollar, 2013; Taylor, Liu & Hein, 2008; Wong, Wong & Nadeem, 2011). Second, specialized BIM applications can be introduced in existing courses focusing on specific subjects, such as structural design, cost estimation, and scheduling and planning (Abdirad & Dossick, 2016; Taylor et al., 2008). Third, with the combination of the above two strategies, BIM-focused capstone projects can be developed in which students can apply their BIM skills and knowledge to practice or research projects (Badrinath, Chang & Hsieh, 2016; Lee & Hollar, 2013; Sacks & Pikas, 2013). With regard to standalone BIM courses, one of the limitations is that long-term BIM learning is not supported because of the lack of follow-up courses. Students cannot apply their newly acquired BIM skills to future courses; therefore, it is challenging to maintain these skills (Abdirad & Dossick, 2016). Wong et al. (2011) suggested that students gradually need to learn BIM knowledge and skills over different curriculum levels. In their first year, students can learn the development of models, whereas, over later years, they can learn the use and management of models, such as clash detection, costing, and scheduling and planning. By doing this, the delivery of BIM knowledge and skills can be aligned with the existing curriculum.

Weak ties between the industry and academia have slowed the adoption of BIM education (Badrinath et al., 2016). Abdirad and Dossick (2016) argued that collaboration with industries is essential to accelerate BIM adoption at educational institutions by enabling industry financial, technological, and educational support. The involvement of external collaboration is beneficial to improving learning outcomes. Students will receive BIM education which is well-aligned with up-to-date industrial practices. There are several recommendations to support this type of collaboration. For instance, teaching staff can involve professional bodies in curriculum design to reflect industry practices in BIM courses (Lee & Hollar, 2013). Badrinath et al. (2016) proposed workshops and short courses for the general community to be engaged with BIM. This can be an effective strategy to build engagement between industry and academia. Molavi and Shapoorian (2013) suggested that student internships can be facilitated by collaboration with industry partners.

The previous studies provided the essential elements of BIM education (see Table 1). The essential elements form the educational framework that contributes to the design, development, and delivery of the BIM curriculum, supporting educational institutions offering comprehensive BIM education.

BIM in QS education

There is an increasing need for quantity surveyors equipped with the appropriate knowledge and skills to participate in BIM-based QS practices (Chamikara, Perera, B. A. K. S. & Rodrigo, 2020; Wao & Flood, 2016). Traditionally, quantity surveyors adopt a paper-based approach that is inefficient and error-prone (Monteiro & Martins, 2013). BIM has been introduced to facilitate several QS tasks. Table 2 summarizes the BIM-enable QS tasks that can significantly improve the productivity and accuracy of QS practices. A total of fourteen BIM-enabled QS tasks have been reported in the literature, including both pre-contract and post-contract QS tasks. For instance, most studies argued that BIM had enabled preliminary cost advice, cost planning, and bill of quantities measurement in the early stage of a project. BIM can also assist in valuating variations, cost control, and life cycle costing. Quantity take-off (QTO) and cost estimation can be prepared efficiently by quantity surveyors if BIM models are used instead of paper drawings (Lu, Lai & Tse, 2018; Smith, 2014; Stanley & Thurnell, 2014; Wu & Issa, 2014). Besides, when a change is made in designs, the change ripples automatically to all the related construction documentation and quantity schedules used by quantity surveyors in a BIM environment (Lu et al., 2018). BIM can also reduce quantity surveyors' errors and improve the quality of their deliverables. For example, the feature of automated QTO is one of the critical benefits for quantity surveyors (Fung, Salleh & Rahim, 2014; Monteiro & Martins, 2013; Nagalingam, Jayasena & Ranadewa, 2013). Moreover, BIM software applications offer an alternative approach to accelerating the preparation of post-contract cost management tasks (Vigneault, Boton, Chong & Cooper-Cooke, 2019). BIM models can link with construction cost databases. This model-cost integration allows efficient valuations and accurate cost advice for post-contract cost control and management (Fung et al., 2014; Nagalingam et al., 2013; Stanley & Thurnell, 2014). In particular, five-dimensional (5D) BIM models offer efficient time-related cost management such as cash flow forecasting and interim valuations. This 5D BIM approach integrates construction costs into scheduling and planning data, enhancing quantity surveyors' job performance (Lu et al., 2018; Yeung & Keung, 2012). In addition, the BIM technology facilitates quantity surveyors to delve more deeply into cost management processes than would have been achievable with conventional approaches (Vigneault et al., 2019). For instance, the available lifecycle data in the BIM environment can contribute to further analyses at project inception stages. Quantity surveyors can be involved more in project feasibility studies, supporting the economic decision-making on material selections (Kim & Park, 2016; Pittard & Sell, 2016). Furthermore, the visualized 3D models can facilitate faster and more accurate preparation for construction claims than traditional approaches (Koc & Skaik, 2014). With the use of BIM models and common data platforms, organizations can systematically keep sufficient site records for substantiations in case disputes arise (Dougherty, 2015; Koc & Skaik, 2014). BIM is a rich information model that offers a powerful visualization and communication tool for forensic engineering and dispute resolution purposes (Dougherty, 2015; Lu et al., 2018).

To meet the demand for BIM professionals, educational institutions have been integrating BIM knowledge into their curricula, including QS subjects. Ali et al. (2016) proposed a BIM education framework for QS subjects, which includes four major learning objectives: i) visualization, ii) quantification, iii) planning and scheduling, and iv) management. Students studying QS subjects need a range of BIM knowledge and skills to achieve the learning objectives. BIM skills are BIM capabilities regarding different BIM applications in QS practices. Quantity surveyors who possess BIM capabilities can enhance their job performance through BIM adoption (Fung et al., 2014). For instance, 3D visualization can be made with BIM authoring software, a design tool with additional functions such as scheduling for quantification. Therefore, modelling skills are beneficial for quantity surveyors to enhance their 3D visualization skills and verify the integrity of models before QTO (Gurmu, Kamardeen & Mahmood, 2021). QTO skills can help QS students efficiently extract quantities and information from BIM by using BIM software. Post-contact cost management skills can help QS students to integrate construction schedules and costs with 3D models, performing 5D BIM applications such as valuations of variations, interim valuations, and cash flow forecasting. BIM management skills are also essential for QS students to understand the process of BIM project planning and execution, and the key responsibilities of the BIM management team throughout all stages of the project lifecycle.

A structured BIM curriculum can equip QS graduates with appropriate BIM skills in project delivery through BIM adoption (Ali et al., 2016). These skills represent the achievements of students after the completion of BIM courses. Several global educational institutions that offer QS degree programs have begun teaching BIM and have developed curricula incorporating BIM into their existing courses. Based on the course information available from university websites and the data obtained through academic networks, the BIM courses were examined to identify the basic course outlines and the particular learning outcomes that delineate the abilities and performances of the students under BIM learning. A thorough syllabus search and examination revealed that individual BIM learning outcomes of some courses were not apparent because BIM elements only constitute a small part of the entire course. Some common BIM elements were identified across different courses at different levels. Thus, an alternative approach was adopted to determine the collective learning objectives, defined as the goals to be achieved by the students as a result of a collective learning process (Mittendorff, Geijsel, Hoeve, de Laat & Nieuwenhuis, 2006). Based on similar classifications of BIM education levels in construction and engineering programs from previous studies (Ali et al., 2016; Lee & Hollar, 2013; Sacks & Pikas, 2013; Wong et al., 2011), the collective learning objectives that reflect the students' holistic BIM learning experience are represented by three broad levels of BIM education: development, application, and integration. According to the BIM education framework for QS students (Ali et al., 2016) and the BIM capabilities in respect of different BIM applications in QS practices (Fung et al., 2014), four essential BIM skills acquired by QS students at the selected universities were determined based on the collective learning objectives identified from the BIM courses. They are named as modelling, QTO and estimation, post-contract cost management, and BIM management.

Research methods

This study employed two research methods: the survey and case study (Keung, 2019). The two research methods were designed to collect and analyze data to achieve the research objectives designed in this study. Surveys were conducted to collect information about the industrial requirements and BIM adoption in QS practices, thus fulfilling the first research objective. Regarding the second objective, case studies were conducted to examine the current state of BIM education for QS at educational institutions in Hong Kong. To investigate the extent of BIM education to meet the industrial requirements in QS practices, a gap analysis was conducted by mapping BIM skills derived from the collective learning objectives of BIM courses against the industrial requirements, thus achieving the third research objective.

Data collection

Surveys

An initial draft of the survey questionnaire was developed based on a comprehensive literature review that examined BIM-enabled QS tasks. It was sent to 15 BIM professionals and QS professionals for review and comments. Then, the final version of the questionnaire was updated based on the received feedback and suggestions (Liu & Gambatese, 2018; Shan, Chan, Le, Hu & Xia, 2017). The target respondents of the surveys comprised QS professionals from client organizations, consultant firms, and contractor companies (Kim & Park, 2016). Quantity surveyors who manage BIM applications in BIM projects were invited to participate in the surveys. The research team of this study used two steps to recruit survey respondents. Firstly, the research team selected research samples randomly from the name lists of major organizations and associations in the AEC industry in Hong Kong, for instance, the list of Approved Contractors for Public Works under the Development Bureau of Hong Kong, the QS company list maintained by the Hong Kong Institute of Surveyors (HKIS), and the member list of the Real Estate Developers Association of Hong Kong. The research team also contacted government departments involved in public works to offer research samples as client organizations. Secondly, with the help of professional institutions, the research team distributed survey questionnaires throughout the industry. Out of 150 questionnaires, 60 questionnaires were returned, reaching a response rate of 40%. Fellows and Liu (2015) pointed out that a useable response rate for questionnaires should lie between 25% and 35%. Thus, the questionnaire survey obtained a reasonable response rate. All the 60 questionnaires were appropriate for data analysis.

Case studies

Regarding BIM education in QS practices, exploratory case studies were conducted. The case studies investigated the academic departments of educational institutions in Hong Kong that offer BIM education to QS students, including their academic backgrounds and BIM curricula. Also, this approach aimed to collect data across different educational institutions and map the data with the essential elements of BIM education developed from the literature review. In addition, the BIM skills derived from the collective learning objectives of BIM courses were mapped against the industrial requirements identified through the surveys. According to the BIM education framework for QS students (Ali et al., 2016) and the BIM capabilities in respect of different BIM applications in QS practices (Fung et al., 2014), the four essential BIM skills acquired by QS students were determined based on the collective learning objectives identified from the BIM courses, namely: (i) modelling, (ii) QTO and estimation, (iii) post-contract cost management, and (iv) BIM management. Based on the nature of each QS practice and its required skillset for performing the corresponding BIM application, the BIM skills were mapped with the identified BIM applications in consultant firms and contractor companies. The case studies also collected information on BIM education from scholars teaching in educational institutions. The collected data include the perception of BIM education, the challenges of BIM curriculum design, and the recommendations to enhance BIM education for quantity surveyors in Hong Kong. Generally, the modes of study and the type of student admission influence the curriculum design of a degree program. In addition, some private institutions in Hong Kong offer self-financed top-up bachelor's degree programs in cooperation with overseas universities. To compare degree programs at the same level, four educational institutions that offer full-time four-year Bachelor of Science degrees in surveying were selected as the research samples. The degree programs offered by these four institutions are accredited by professional bodies such as the HKIS and Royal Institute of Chartered Surveyors (RICS).

Data analysis and results

Industrial requirements

This section outlines the current adoption of and expectations for BIM in QS practices. Survey respondents provided answers regarding BIM adoption in QS practices via the questionnaire survey. In this study, BIM adoption means quantity surveyors who apply BIM skills to accomplish various QS practices required under the contract (i.e., mandatory BIM adoption) or voluntarily (i.e., voluntary BIM adoption). Hence, the data give insights into the variety of BIM applications in QS practices compared with the BIM skills derived from the collective learning objectives of BIM courses. Table 3 lists the proportions of BIM-engaged organizations that have adopted BIM in each QS practice. Percentages were derived from the survey respondents' multiple selections of their BIM adoption in QS practices. According to the results, the most popular BIM-enabled QS task in consultant firms is bills of quantities (BQ)/schedules of rates (SOR) measurement. Financial reports, lifecycle costing, assessment of financial claims, and procurement advice are examples of low-level adoption in QS practices. On the other hand, the most attractive BIM-enabled QS tasks in contractor companies are variation and claims. On the contrary, lifecycle costing, project cash flow, sub-contractor's payment preparation, and financial report are examples of non-BIM adoption in contractor QS practices. Further statistics regarding mandatory and voluntary BIM adoption are presented for comparison. The results show a trend toward voluntary BIM adoption in QS practices, even without contractual requirements.

Current states of BIM education for QS in Hong Kong

The case studies involved the analysis of BIM education at the four educational institutions in Hong Kong. First, the academic departments of these educational institutions that offer bachelor's degree programs in surveying were identified. Their programs were analyzed to determine the composition of construction disciplines. The academic department of *Institution A* covers the most significant construction disciplines, including architecture, civil engineering, building services, surveying, and construction management. This department covers the significant disciplines of construction projects. In contrast, the academic departments of institutions B and D comprise the fewest construction disciplines.

Second, the details of BIM education from these academic departments were investigated. Results were mapped to the essential elements of BIM education presented in Table 1. The four educational institutions offer various BIM-related taught courses to their QS students. The academic department of *Institution A* offers the maximum number of BIM courses, whereas that of *Institution B* offers the fewest. Only the academic departments of institutions A and C provide BIM projects for students to collaborate in an interdisciplinary setting. All the academic departments set up computer laboratories or centers where students can access BIM software applications regarding the hardware and software supports. Various BIM learning activities are available from the four academic departments, for instance, workshops, internships, conferences, seminars, and study tours. In addition, a memorandum of understanding (MoU) was signed between these academic departments and the Hong Kong Construction Industry Council (HK CIC), which aims to enhance industrial collaborations in BIM education. However, academic collaborations among these departments regarding BIM education are absent.

Third, the BIM skills for QS practices were categorized based on the collective learning objectives of the BIM courses offered by each educational institution. The BIM courses were examined to identify the particular learning outcomes that delineate the abilities and performances of the students under BIM learning. To achieve this, a thorough syllabus search and examination are necessary to collect the relevant data. First, a complete list of courses offered to QS students by the four institutions in Hong Kong is obtainable. As course titles may not reflect the contents of BIM-related teaching, course outlines can be referred to filter non-BIM-related courses. Course outlines offer basic information such as course aims and objectives to give a general representation of the course contents. Second, intended learning outcomes can provide the measurable learning achievements for students after completing BIM courses. The learning outcomes give clear and specific information about what students need to learn to succeed in a course. Initial searches from the institution websites can sweep the basic information of the BIM courses offered by the four institutions. Information unavailable from the websites was obtained from scholars teaching in the four institutions. The results revealed that some courses' individual BIM learning outcomes were not apparent because BIM elements only constitute a small part of the entire course. Additionally, some common BIM elements were identified across different courses at different levels. Thus, based on the available course information, an alternative approach was adopted to determine the collective learning objectives that reflect the students' holistic BIM learning experience represented by three broad levels of BIM education: development, application, and integration. For instance, the collective learning objectives of the BIM courses offered by the academic department of *Institution A* indicated that their students are expected to acquire the following four BIM skills: modelling, QTO and estimation, post-contract management, and BIM management. Similarly, the BIM skills acquired by students at the remaining educational institutions can be categorized using the same approach.

Fourth, the training of BIM skills offered by each bachelor's degree program in surveying was further mapped to the industrial requirements as shown in Table 3. These industrial requirements are expected to be met with appropriate BIM skills. The industrial requirements demonstrate the major BIM applications in QS practices representing the most demanding practices related to industrial BIM adoption. The corresponding BIM skills can be identified based on each BIM application's nature and technical skills in QS practices. According to the four BIM skills derived from collective learning objectives from the four educational institutions, Table 4 demonstrates the mapping results of the BIM skills with the major BIM applications in QS practices in consultant firms and contractor companies. This analysis gives insights into the coverage of the current BIM education provided by the four educational institutions in Hong Kong. The results show that the four educational institutions offer fundamental BIM courses. QS students can acquire essential modelling and QTO skills to accomplish most BIM-enabled QS tasks in consultant firms or contractor companies. However, advanced BIM courses are absent in some educational institutions, such as BIM management and post-contract cost management.

Discussion

This section discusses the BIM curriculum design in QS programs offered by the educational institutions in Hong Kong and their approaches toward BIM teaching for QS students. The results further highlight how the non-standardized BIM competencies to be attained by QS students lead to uncertainties and challenges in the current BIM education.

First, the composition of construction disciplines in an academic department was identified as a determinant of the BIM curriculum design in the educational institution in Hong Kong. The academic department of *Institution A* provides five undergraduate programs and three postgraduate programs with a combination of academic staff in multidisciplinary fields, including construction management, surveying, structural engineering, architecture, and building services engineering. This comprehensive composition enables the academic department to deliver BIM courses across different construction disciplines, facilitating student project collaboration and design coordination training in the BIM environment. However, this interdisciplinary approach was not observed in other academic departments with only a few construction disciplines. Additionally, the lack of variety in BIM software installed in educational institutions narrows QS students' learning opportunities. The four academic departments were also keen to collaborate with the industry to enhance BIM education. This point is solidly supported by the invitation of practitioners from the industry to offer BIM workshops or talks and establish an MoU with the HK CIC. Under this MoU, the HK CIC works with educational institutions to develop educational materials incorporated into the BIM curriculum. According to the case studies, an overwhelming number of applications to the HK CIC BIM competition proves that educational institutions treasure this opportunity to facilitate BIM learning via competitive and collaborative approaches for their students. However, the case studies did not discover cross-institutional cooperation between the sampled educational institutions regarding BIM education. The educational institutions can build academic networks with each other and launch joint institution activities for interdisciplinary BIM activities. For instance, collaborative student projects across multiple construction disciplines can be organized for QS students to learn BIM in a team-based approach.

Second, the educational institutions currently provide various BIM courses, learning activities, and final-year research projects to QS students. In particular, they offer courses to train QS students with essential BIM modelling and QTO skills. Modelling skills can facilitate students to validate model integrity, while QTO skills effectively support students to extract quantities and information from BIM models. These two skills enable students to conduct the major BIM applications in QS practices identified from the surveys in this study, including cost planning, BQ/SOR preparation, preliminary cost advice, tender preparation, and quantification of works. However, some educational institutions do not offer advanced BIM courses related to BIM management and post-contract cost management. As a result, some students cannot equip with the necessary skills for the alternative BIM-enabled QS practices such as value engineering, contractual advice, and dispute resolution. As no consensus has been reached regarding the specific BIM skills and capabilities to be acquired by QS students in Hong Kong, this uncertainty makes academic departments challenging to plan teaching contents and so causes such differences in their BIM curriculum design. The incapability of academic staff and other limited resources (i.e., technical, financial, or administrative support) also hinder some educational institutions from offering advanced BIM courses. Government-led training courses and programs may fill this gap (Chan, Olawumi & Ho, 2019; Lu, Chen, Zetkulic & Liang, 2021). Additionally, the expansion of BIM education is further constrained by the university graduation and QS profession accreditation requirements. Thus, the educational institutions can engage with professional bodies such as the HKIS and RICS to identify a set of standard BIM skills and capability levels to be attained by QS students. Following that, the existing curriculum can be reviewed holistically to examine any room for enhancing BIM education to meet the industry demands and future needs.

Limitations and future research areas

This study has three limitations. Firstly, the detailed course information about some BIM courses is restricted from inspection. As a result, part of the data analysis was based on the supplementary information supplied by the interviewees or collected through academic networks. Secondly, the case study about BIM education for QS practices was carried out with the educational institutions in Hong Kong only. However, the findings align with other international studies where the educational gap regarding advanced BIM skills and competencies exists in the current QS education (Babatunde & Ekundayo, 2019; Kwong, 2019). Further research is recommended to extend the investigation on BIM education for QS practices in other countries to capture global trends. Thirdly, the research samples consisted of a large portion of professional quantity surveyors practicing in client organizations, contractor companies, and consultant firms in Hong Kong. Nonetheless, the sample did not capture a large number of surveyors from specialist sub-contractors in the AEC industry. In addition to this, regarding the case study, the research samples were limited to bachelor’s degree programs in surveying with 4-year full-time terms in Hong Kong. Although these programs are the significant sources supplying QS students to the industry, graduates from other programs, such as part-time distance learning or top-up bachelor’s degree programs, can be investigated in future studies. As a result, further studies can consider larger sample sizes and broader research samples.

Conclusions

Based on the surveys and case studies, this study can conclude that the current BIM education for quantity surveyors in Hong Kong aligns with BIM development in the AEC industry. The educational institutions provide comprehensive BIM education to their QS students. Fundamental BIM courses are also offered to meet the industrial requirements of major BIM applications in QS practices. However, some educational institutions do not offer courses for advanced BIM skills. The absence of such courses is due to limited teaching resources and uncertainties regarding BIM capabilities and competency levels to be acquired by QS students. On the other hand, the existing university graduation and QS profession accreditation requirements further inhibit the curriculum change to keep up with the rapid BIM advancement. Results also indicate that the BIM education collaboration among local educational institutions in Hong Kong is absent. As the results revealed that an interdisciplinary approach gives a teaching edge to an academic department over others, the educational institutions with only a few construction disciplines were recommended to establish collaborative ties with other institutions, offering interdisciplinary learning opportunities to enhance their QS students' BIM learning.

The results highlight two salient points about the design and planning of BIM education for the AEC industry. First, educational institutions should realize industrial expectations regarding the BIM-equipped competencies of graduates. To ensure proper planning and integration of BIM into existing curricula, the accreditation criteria must be reviewed by exploring the desired BIM competencies with the appropriate breadth and depth required by a particular AEC profession. Second, the AEC industry is heading into a more collaborative working environment. After graduation, students should be competent to work collaboratively with different project stakeholders in a BIM environment. Thus, in addition to BIM courses focusing on individual disciplines, an interdisciplinary approach to BIM education is critical for addressing complex engineering and construction problems in the current industry.

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Table 1

Essential elements of building information modelling (BIM) education

Essential elements	**Barison and Santos (2010)**	**Taylor et al. (2008)**	**Molavi and Shapoorian (2013)**	**Kymmell (2008)**	**Lee and Hollar (2013)**	**Badrinath et al. (2016)**	**Wong et al. (2011)**	**Abdirad and Dossick (2016)**	**MacDonald and Mills (2013)**	**Sacks and Pikas (2013)**	**Becerik-Gerber et al. (2011)**	**Suwal and Singh (2018)**	**Olowa et al. (2020)**	**Total counts**
Interdisciplinary student projects	x	x	x	x	x	x	x	x	x		x	x	x	12
BIM classes	x	x			x	x	x	x		x	x	x	x	10
Software	x	x				x	x	x			x		x	7
Industrial support			x		x	x		x			x		x	6
Research projects	x				x			x		x	x			5
Student learning activities	x		x							x		x	x	5
Hardware						x		x					x	3
Cross-institutional cooperation	x								x				x	3

Table 2

Building information modelling (BIM)-enabled QS tasks

BIM-enabled QS tasks	**BIM Industry Working Group (2011)**	**Dougherty (2015)**	**Monteiro and Martins (2013)**	**Lu et al. (2018)**	**Smith (2014)**	**Stanley and Thurnell (2014)**	**Nagalingam et al. (2013)**	**Fung et al. (2014)**	**Pittard and Sell (2016)**	**Yeung and Keung (2012)**	**Kim and Park (2016)**	**Chan et al, (2019)**	**Total counts**
Preliminary cost advice	x		x	x	x	x	x	x	x	x	x	x	11
Cost planning	x			x	x	x	x	x	x	x	x	x	10
BQ measurement/quantification	x		x	x		x	x	x	x	x	x		9
Valuation of variations				x		x	x	x	x	x			6
Procurement advice	x			x			x		x			x	5
Financial report/cost control			x	x			x			x		x	5
Life cycle costing	x								x		x	x	4
Value engineering	x								x	x		x	4
Contractual advice		x		x					x				3
Re-measurement of provisional items				x				x		x			3
Cash flow forecast	x			x						x			3
Assessment of financial claims		x		x						x			3
Interim valuation/payment application				x						x			2
Arbitration/dispute resolution		x							x				2

Note: BQ - bill of quantities

Table 3

Building information modelling (BIM) adoption in quantity surveying (QS) practices in consultant firms and contractor companies

	Proportion of BIM-engaged organizations	
Consultant firms' QS practices	**Mandatory BIM adoption**	**Voluntary BIM adoption**
Bill of quantities/Schedules of rates measurement	41.7%	75%
Cost planning	25%	66.7%
Preliminary cost advice	25%	50%
Valuation of variations	25%	50%
Cash flow forecast	16.7%	50%
Interim valuation	16.7%	41.7%
Re-measurement of provisional items	16.7%	41.7%
Value engineering	-	41.7%
Contractual advice	-	41.7%
Dispute resolution	-	41.7%
Financial report	-	33.3%
Lifecycle costing	-	33.3%
Assessment of financial claims	-	33.3%
Procurement advice	-	25%
Contractor companies' QS practices		
Variations and claims	40%	40%
Tender preparation	-	33%
Payment application	33%	-
Progress report	20%	33%
Cost monitoring and control	-	20%
Value engineering	-	20%
Quantification of works for sub-letting/purchasing	-	20%
Arbitration and dispute resolution	-	13%
Risk management	-	13%
Lifecycle costing	-	-
Project cash flow	-	-
Sub-contractor's payment preparation	-	-
Financial report	-	-

Table 4

Mapping of building information modelling (BIM) skills with the major BIM applications in quantity surveying (QS) practices in consultant firms and contractor companies

Educational institutions: BIM skills derived from collective learning objectives	***Institution A***: Modelling	***Institution A***: QTO & estimation	***Institution A***: Post-contract cost management	***Institution A***: BIM management	***Institution B***: Modelling	***Institution B***: QTO & estimation	***Institution C***: Modelling	***Institution C***: QTO & estimation	***Institution C***: Post-contract cost management	***Institution D***: Modelling	***Institution D***: QTO & estimation	***Institution D***: Post-contract cost management
Major BIM applications in QS practices in consultant firms												
BQ/SOR preparation	x	x			x	x	x	x		x	x	
Cost planning	x	x			x	x	x	x		x	x	
Preliminary cost advice	x	x			x	x	x	x		x	x	
Valuations of variations			x						x			x
Cash flow forecast			x						x			x
Interim valuation			x									x
Re-measurement	x	x			x	x	x	x		x	x	
Value engineering				x								
Contractual advice				x								
Dispute resolution				x								
Major BIM applications in QS practices in contractor companies												
Variations and claims			x						x			x
Tender preparation	x	x			x	x	x	x		x	x	
Payment application			x						x			x
Progress report				x								
Cost monitoring and control			x						x			x
Value engineering				x								
Quantification of works for sub-letting/purchasing	x	x			x	x	x	x		x	x	
Arbitration and dispute				x								
Risk management				x								

Note: BQ/SOR - bill of quantities/schedules of rates, QTO – Quantity take-off

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