Bridging the gap between building information modelling education and practice: a competency-based education perspective

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Abstract

This study reports a case study that investigates the gap between BIM tertiary education and the building industry's needs in New Zealand (NZ). In specific, it aims to (1) identify the industry's requirements on BIM competencies, (2) examine the status quo of BIM tertiary education in NZ, and (3) identify and analyse the gaps between current BIM education and the industry's needs. Data were collected through BIM job advertisement to identify the industry's requirements of BIM competencies and top BIM uses. Data of thirty-three courses were also collected from nine tertiary institutions. Results indicated that there were discrepancies between the type and level (i.e., cognitive levels) of BIM competencies. It was indicated that missing links existed in almost all BIM uses that were taught, except 4D modelling. A large proportion of learning outcomes were focused on "understanding" for several BIM uses, while NZ BIM Handbook requires higher levels of application and evaluation. To bridge the gaps, core competence sets should be determined by disciplines. BIM competencies can also be classified based on BIM uses, BIM processes and phases, and project roles. This paper proposed a conceptual framework, which suggests the way ahead towards future competency-based BIM education.

Keywords: BIM, Tertiary education, Competency-based education, BIM competence, BIM job advertisement, Constructive alignment

1. Introduction

Building information modelling (BIM) is defined as “a modelling technology and associated set of processes to produce, communicate, and analyse building models (Sacks et al., 2018). The architecture, engineering, and construction (AEC) industry has long suffered from issues such as low productivity, cost overrun, delays, and accidents. BIM, seen as a game-changer, can be used in the whole lifecycle of construction projects, from design, via construction, to operation (Faisal Shehzad et al., 2020; Le et al., 2019). BIM digitalises construction project processes and offers promising solutions to these issues (Ahankoob et al., 2019; Azhar, 2011; Crowther and Ajayi, 2019; Mostafa et al., 2020).

The past decade has seen a steady increase in BIM adoption in tertiary education. An increasing number of tertiary education institutions either integrated BIM into existing courses or developed stand-alone BIM courses (Hu, 2019). The movement was motivated by the fact that more engineering graduates equipped with BIM knowledge and skills are needed to support the BIM-based automation and digitalisation within the AEC industry. Early research efforts were made to define BIM competencies (Gu and London, 2010; Succar et al., 2013), develop BIM education frameworks (Clevenger et al., 2010; Macdonald, 2012; Sacks and Pikas, 2013), and report case studies of BIM education implementation (Govender et al., 2019; Hu, 2019; Jin et al., 2018). Various pedagogical strategies were applied in BIM teaching and learning, such as project-based learning (Forsythe et al., 2013) and virtual environment based learning (Ozcan-Deniz, 2018). BIM was also applied as a pedagogy strategy to teach other relevant courses, such as Building Materials and Construction Methods (Hu, 2019).

BIM, as a technology and method, keeps evolving. The importance of aligning BIM knowledge and skills embedded in BIM courses with the industry needs has been emphasised. Researchers pointed out that the consistency between BIM education and industry BIM competency requirements is the key to the success of BIM tertiary education (Hu, 2019; Wu et al., 2018). Indeed, the evolution of BIM technologies and processes is rapid and noticeable. The tertiary education sector must be proactive and adaptable to fast-changing workplaces. It is vital for both instructors and students to understand the BIM knowledge and skills that are essential for BIM-based construction projects.

The gap between education and practice is a perennial issue in many domains, such as education (Cheng et al., 2010), engineering (Hanna and Sullivan, 2005; Yuen and Naidu, 2007), and nursing (Burns and Poster, 2008; Mckay and Narasimhan, 2012). In engineering education, the paradigm shift toward a system based on educational outcomes began in the early 1990s (Walther and Radcliffe, 2007). As a result, there were significant changes in underlying instructional principles and pedagogical processes. Instructors designed and delivered teaching and learning activities that were matched with industry and society needs. As Lemaitre et al. (2006) stated, it is the ultimate goal of engineering curricula that prepare students for professional competence. Nevertheless, the industry claimed that engineering graduates had deficiencies regarding key job competencies (Business Council of Australia, 2006; Volkwein et al., 2004; Wulf and Fisher, 2002). From the competency-based education perspective, the misalignment and disconnectedness between education and practice undermine the quality of education (Harris et al., 1995).

It is a fact that different industry positions require different BIM knowledge and skills. Industry professionals hold a view that knowledge of BIM concepts and processes, and technical skills in BIM software should be integrated into BIM education (Zhao et al., 2015). To the best knowledge of the authors, however, there is not a systematic investigation of BIM tertiary education regarding gaps between current BIM education and the industry's needs and expectations at the national level. Therefore, this study reports a case study investigating the gap between BIM tertiary education and the industry's needs in New Zealand. In specific, the objectives of this study are to (1) identify the industry's requirements on BIM competencies by examining BIM job advertisement, the industry's perceptions of important BIM uses and competencies, and the New Zealand BIM Handbook, (2) examine the status quo of BIM tertiary education in New Zealand, (3) identify and analyse the gaps between current BIM education and the industry's needs, and (4) discuss the gaps from a competency-based education perspective.

2. Literature review

2.1 BIM education

Efforts have been made to develop frameworks for BIM education. For example, Macdonald (2012) proposed an IMAC framework for collaborative BIM education across the AEC disciplines. The framework is composed of four stages: illustration, manipulation, application, and collaboration. Learning outcomes within each stage are described using the Bloom taxonomy (Bloom, 1956). Ahn et al. (2013) presented an approach to developing a BIM course suitable for undergraduate construction and engineering programs. The approach consists of three stages: (1) preparation, (2) development, and (3) improvement. Five main learning goals were established in the course: (1) have a general understanding of BIM knowledge and skills, (2) comprehend the concept of BIM as applied in construction, (3) understand and implement BIM in construction processes, (4) become familiar with BIM software, and (5) contemplating future directions and applications. More recently, Boton et al. (2018) developed a framework for BIM implementation in engineering education. The framework consists of three main components: (1) skills to be acquired, (2) teaching approach, and (3) implementation strategy. Huang (2018) proposed a three-level framework for BIM education in construction management programs. The framework consists of BIM components at three levels: fundamental, application, and advanced level. Courses at the fundamental level are mainly construction management core courses, such as Introduction to BIM. Courses at the application level are oriented towards solving real-world problems, while those at the advanced level are focused on the latest and advanced topics of BIM, such as Revit Energy Analysis. The three-level framework defines the hierarchy of learning objectives (i.e., remember, understand, apply, analyse, evaluate, and create) in the same order of the academic standings (i.e., freshman, sophomore, junior, and senior). It suggests that freshmen should be focused on the low-level cognitive process, such as remember and understand, while seniors should be able to demonstrate the ability of evaluation and creation. This practice may not be consistent with the industry's requirements, if the "object" of the "predicate" (i.e., remember, understand, apply, analyse, evaluate, and create) is the specified. Similarly, (Govender et al., 2019) analysed a BIM specialist training course based on the Bloom taxonomy and investigated its impacts on students' career development.

Researchers reported pedagogical strategies applied in developing BIM courses. For example, Pikas et al. (2013) reported a case study of integrating BIM into the entire construction-engineering and management curriculum. They highlighted the importance of soft skills of information sharing and knowledge management, professional roles, the commercial context within BIM education. Forsythe et al. (2013) proposed a programme-wide implementation strategy to integrate BIM in tertiary construction project management education. The strategy categorises the BIM subjects into three types: technical, analytical, and non-technical, which then are mapped to three implementation levels: instructive, illustrative, and immersive. The strategy is based on a mix of project-based learning, visually oriented multimedia learning, and networked learning, which facilitates collaborating among student-to-teacher and student-to-student groups. In addition, Sacks and Pikas (2013) defined a six-level BIM competency based on Bloom's Taxonomy, including know, understand, apply, analyse, synthesise, and evaluate. They measured the gap between current BIM teaching and the industry's requirements. They reviewed 18 syllabi and concluded that existing BIM courses are technology-oriented and multidisciplinary-collaboration-focused, while the management aspects of BIM are generally missing.

2.2 Competency-based education

Competency-based education (CBE) is an emerging concept in tertiary education (Foster and Jones, 2020). In its initial stage, CBE had appealed to both tertiary education and professional qualification programs. CBE has been applied in several education domains, such as health profession (Long, 2000), accounting (Boritz and Carnaghan, 2003), and engineering (Dowling, 2006; Walther and Radcliffe, 2007). Kelchen (2015) defined CBE as “a form of higher education in which credit is provided on the basis of student learning rather than credit or clock hours”. Anema (2009) defined CBE as a pedagogy that ensures graduates have the essential knowledge, skills, and attitudes to enter the workforce.

In the CBE literature, the terms ‘competence’ and ‘competency’ were used inconsistently (Chuenjitwongsa et al., 2018). The two terms were often used interchangeably (Pijl-Zieber et al., 2014). However, Khan and Ramachandran (2012) suggested that the term ‘competency’ should be used to represent the ‘skill’ per se, while ‘competence’ refers to a person’s ability to perform that skill.

CBE has two paramount features. Firstly, it applies a “utility-minded” philosophy, which promises efficient education by defining and aligning competencies with industry needs. It emphasises the development of well-defined competency and application of knowledge and skill in the real world and thus bridges the gap between education and practices (Johnstone and Soares, 2014). Therefore, CBE offers the potential of improving the ability of graduates to apply their skills and knowledge to work situations. Education researchers believed that CBE could lead to improved linkages between education and practice (Harris et al., 1995; Spady, 1994). Secondly, CBE adopts an individualised approach that allows students to demonstrate mastery of clearly defined learning outcomes (or competencies) at their own pace. With a focus on observable and measurable outcomes, CBE provides personalised and customised learning opportunities (Foster and Jones, 2020). From this perspective, CBE is similar to outcome-based education (Chuenjitwongsa et al., 2018).

Johnstone and Soares (2014) proposed principles for developing CBE programs: (1) the degree reflects robust and valid competencies, (2) students are able to learn at a variable pace and are supported in their learning, (3) effective learning resources are available anytime and are reusable, (4) the process for mapping competencies to courses, learning outcomes, and assessments is explicit, and (5) assessments are secure and reliable. Pichette and Watkins (2018) claimed that true CBE programs include all five the following qualities: (1) competencies embedded in the curriculum, (2) robust assessments, (3) recognition of prior learning, (4) fixed outcomes, variable timelines, and (5) credential signifying mastery.

Monat and Gannon (2018) reported a pilot study of converting graduate-level System Engineering courses into a CBE format. The pilot study indicated that student characteristics, course characteristics, and the university's business model are intimately tied together when deciding if CBE is suitable or not. The authors concluded that CBE could be a successful pedagogy. A significant benefit of CBE is that it fits with other pedagogical strategies such as outcome-based learning, self-paced learning and individualised e-learning (Johnstone and Soares, 2014). For example, Dowling (2006) also reported a case study of developing the Master of Engineering Practice, a distance education program, based on CBE pedagogical principles. The CBE program required students to be self-directed and self-disciplined learners and be responsible for their own learning pathways. Positive perceptions and feedback from students were also reported. For example, Wang (2015) reported that CBE students were positive about the assessment process and the employment outcomes.

3. Research Methods

To achieve the three objectives, the researchers collected data from both NZ AEC industry and tertiary institutions. First, in order to understand the industry's expectations regarding BIM competencies, the researchers collected and analysed BIM job advertisements. In addition, the NZ BIM Handbook (BIM Acceleration Committee, 2019b) and the BIM Benchmark surveys (BIM Acceleration Committee, 2019a) were used as secondary data. Data of BIM courses that have been implemented in NZ tertiary institutions were also collected to identify (1) BIM topics/uses taught, (2) learning outcomes, (3) teaching and learning activities, (4) assessment tasks, and (5) BIM software taught and used in class.

3.1 Data collection

3.1.1 BIM job advertisement

The goal of the content analysis of BIM job advertisement was to infer the BIM competence that industry employers seek. The use of job advertisements to identify the competencies sought by the industry is a proven approach in various research communities (Brooks et al., 2018). To ensure a representative sample, BIM job advertisements were collected from four main job-posting websites in NZ, including seek.co.nz, careers.govt.nz, nz.indeed.com, and trademe.co.nz/jobs, during the period between September 2019 and April 2020. In order to collect relevant BIM-related advertisements, this study used keywords, including "*BIM*", "*building information modelling*", "*digital engineering*", "*revit*", to search relevant advertisements. As a result, a total of 371 job advertisements were collected.

3.1.2 BIM course information

The purposive sampling method was used to collect the BIM course information. A survey was sent to the members of New Zealand BIM Education Working Group (NBEWG) to collect (1) course name and code, (2) course level (e.g., undergraduate, postgraduate, and master), (3) course type (e.g., BIM as a topic in the course, and BIM as a stand-alone course),

(4) BIM topics taught, (5) learning outcomes, (6) teaching and learning activities, (7) assessment tasks. NBEWG consists of ten organizational members, with five universities and five polytechnics. Nine members responded the survey and thirty-three courses were collected. The distribution of all BIM courses surveyed is presented by course level and type in Table 1. All BIM courses at Level 6 are compulsory. Some courses at Level 7 are fully elective, and some at Level 7 and 8 are either compulsory or elective, depending on which degree the enrolled students study towards.

[Table 1 near here]

3.2 Data analysis

The aims of the data analysis were to identify the following possible gaps:

- Discrepancies between the type of BIM competencies taught in the tertiary institutions and required by the industry.
- Discrepancies between the level of BIM competencies taught in the tertiary institutions and required by the industry.
- BIM teaching capacity against top ten BIM uses in the New Zealand AEC industry in 2019.

To enable meaningful comparisons between the industry needs and BIM teaching, consistent data analyses were conduct on two sides. As illustrated in Figure 1, types of BIM competence required by the industry were identified by analysing BIM job advertisement and NZ BIM Handbook. NZ BIM handbook specifies the cognitive level of BIM competence. This provides a basis for comparison with cognitive level of BIM competence taught in classroom. In addition, New Zealand BIM Acceleration Committee conducted a series BIM Benchmark surveys from 2014 to 2019 (BIM Acceleration Committee, 2019a). The results of the surveys were used a secondary data to identify top BIM uses in the industry. The top BIM uses in the industry were compared with those taught in NZ tertiary institutions. Details of the data analysis are provided as follows.

[Figure 1 near here]

3.2.1 Job advertisement analysis

The primary research question that was associated with job advertisement analysis was, “what are the BIM knowledge and skills that organisations are seeking when looking to hire BIM-related professionals?” The answer to this question can help the researchers identify core BIM competencies required by the industry and analyse the gaps between current BIM education and the industry needs. To answer this question, the researchers took the following steps to carry out the content analysis:

Step 1: data cleaning

The data cleaning process was performed to ensure the job advertisements were relevant, correct, consistent, useable, and non-repeated. Raw data were re-organised and re-structured by “employer”, “job title”, “requirement”, “location”, and “working attribute”. During the process, 20 advertisements were deleted. This resulted in a total of 351 advertisements for the next step.

Step 2: Categorising advertisements by job titles

There were a total of 98 different job titles identified. Seven main categories of BIM jobs were developed based on the nature of the job, as shown in Table 2. Other job titles, such as Prefabrication Designer, Software Engineer, BIM Enterprise Business Analyst, etc., were abandoned, due to a small sample size. As a result, 311 advertisements remained for the next step.

[Table 2 near here]

Step 3: Coding

A qualitative software package, Nvivo 12 (Nvivo, 2020), was utilised to code two main categories of BIM competencies: (1) domain-related technical knowledge and skills and (2) soft skills. Experience and qualification requirements were out of the scope of analysis. Two researchers extracted and coded knowledge and skills from all remaining 311 advertisements. Finally, the researchers reconciled any differences in the agreed-upon categories. A total of 61 technical competence with different levels of abstraction and 32 types of soft skills (i.e., individual and social skills) were coded.

Step 4: identifying skill set for groups

This step was focused on ranking both technical and soft competencies by group. Competencies were ranked based on document frequency (i.e., the number of advertisements that require a particular competency), rather than term frequency (i.e., how frequently a term occurs in an advertisement). Document frequency is a common feature selection and ranking methods in text analysis (Azam and Yao, 2012). The rationale behind the application of this method is that the more advertisements in which a particular competency is required, the more important the competency.

3.2.2 BIM course analysis

Data analysis of BIM courses was focused on (1) BIM topics taught, (2) BIM software taught and used, (3) learning outcomes, (4) teaching and learning activities, and (5) assessment tasks. The results of the analyses helped the researchers to identify the type of BIM competencies taught in the NZ tertiary institutions. Likewise, Bloom taxonomy was applied to measure the level of the BIM competencies taught in the tertiary institutions. Leaning outcomes defined in each BIM course were measured based on the six cognitive levels (i.e., remember, understand, apply, analyse, evaluate, and create).

4. Results

4.1 Industry's needs

Table 3 presents the top ten BIM-related technical competences of all seven groups. The rank was measured by the frequency of competences occurred per document and thus reflects the priority the group puts on a particular skill set. Across all 25 competence categories, the results indicated a large variation of the competences sought by groups. However, the results suggest that "revit", as a software skill, is ranked first for all seven groups. This reflects the dominance of Autodesk Revit on the market. The second most popular BIM authoring software is ArchiCAD, which is ranked 6th for the group of architects.

[Table 3 near here]

On the other hand, the results of soft skills required by groups show smaller variations (see Table 4). *Communication, team player, leadership, collaboration, coordination*, and *time management* are the core soft skills that were sought by all groups. Architects see *team player* as the most desirable soft skill, while BIM managers consider *leadership* the most critical skill. The remaining groups put the priority on *communication* skill.

[Table 4 near here]

Technically, BIM software skills were equally important for all groups. All positions were expected to be able to use a range of popular BIM software, such as Revit, Navisworks, Sketchup, Revizto, Dynamo, Grasshopper, Rhino, BIM360, Tekla, and AutoCAD. It is also crucial for all BIM professionals to understand and apply BIM processes and workflows. On the other hand, BIM managers, compared to BIM coordinator, BIM specialist, and Revit

Technician/ Specialist, were required to equip with a higher level of competencies with respect to BIM process, workflows, standards, and protocols, construction knowledge, and architecture design processes and workflows. The position was also expected to demonstrate a high level of leadership and communication skill.

Communication, *team player*, *leadership*, *collaboration*, *coordination*, and *time management* are the core soft skills that were sought by all groups. Architects see *team player* as the most desirable soft skill, while BIM managers consider *leadership* the most critical skill. The remaining groups put priority on *communication* skill.

To summarise, based on the competence framework proposed by Winterton et al. (2006), key BIM competencies that are required by the industry can be classified into four main categories: cognitive competence, functional competence, social competence, and meta-competence, as shown in Figure 2.

[Figure 2 near here]

4.2 Current BIM teaching status

BIM topics taught in New Zealand tertiary institutions can be classified into three main categories: conceptual BIM knowledge, BIM software, and BIM applications. Table 5 shows the conceptual BIM knowledge that was taught in each tertiary institution.

[Table 5 near here]

Software taught and used in class included, but were not limited to, Autodesk Revit, Autodesk Navisworks, Autodesk Design Review, ArchiCAD, CostX, Solibri Anywhere, Solibri Model Viewer, Solibri Office, Trimble Connect/Tekla BIMsight, Vico Office, SketchUp, Rhino, Grasshopper, Primavera, and MS Project.

A BIM use can be defined as “a method of applying BIM during a facility’s lifecycle to achieve one or more specific objectives.” (Kreider, 2013). Twenty-one BIM uses were defined in the New Zealand BIM Handbook (BIM Acceleration Committee, 2019b). Table 6 lists BIM uses that were taught in each tertiary institution.

[Table 6 near here]

Twenty one learning outcomes of seven conceptual aspects of BIM were collected, as presented in Table 7. In addition, learning outcomes of specific BIM uses are listed in Table 7.

[Table 7 near here]

A wide range of teaching and learning activities are implemented in BIM tertiary education. The main categories include lecture, tutorial, seminar, discussion, software workshop, team-based tasks, group projects, BIM essay and report, individual tasks and projects, project presentation, and Socrative Space race. Examples are provided in Table 8.
Assessment tasks that were utilised by BIM educators to assess students’ performance include: case studies, essay, examinations, group project assessment, individual BIM works assessment, multi-choice questions, online quizzes, oral presentations, BIM research projects, seminars, tests (including online), videos, and written reports.

[Table 8 near here]

4.3 Gaps between BIM education and practice

Results suggested that there were gaps in both the type and level of BIM competencies taught in the tertiary institutions and industry needs. A comparison between the key BIM competence identified from BIM job analysis and what was taught in tertiary institutions revealed that there were significant gaps in all four categories of competence as illustrated in Figure 2.

The results of BIM job analysis suggested that the industry was looking for people who possess a particular combination of various types of competence. It is clear that current BIM education places significant emphasis on functional competence, such as BIM software skills, BIM process and workflow, BIM data format and standards, and BIM uses. This is manifested by the fact that many teaching and learning activities were designed and implemented to achieve related learning objectives. Emphasizing these competences can be justified, since BIM software skills are an important basis for linking BIM functions with wider project management dimensions (e.g., progress, cost, quality, and safety).

On the downside, however, there is a lack of effective pedagogical design that combines certain functional, cognitive, and social competence into a meaningful and useful learning object. For example, 'architecture design', as a cognitive competence, was ranked highly for professionals, like architects, BIM manager, and Revit technician. However, not all tertiary institutions offered architecture design courses. As a result, some related BIM use learning, such as BIM authoring and design review, may quickly turn into "playing software", which resulted in a disconnection from industry needs. In addition, 'resource and building consent processes' was highlighted as a functional competence. However, this practical skill was generally missing in current BIM education in New Zealand.

Table 9 compares the number of tertiary institutions that are teaching a BIM use against the rank of BIM use in NZ in 2019. Results suggest that the extent to which a BIM use is valued and taught at the national level is largely consistent with its rank of industry use in 2019. A notable exception, however, is that site analysis is taught in only two tertiary institutions, while it is 5th most BIM use that is applied in the industry in 2019. It should also be noted that BIM uses like record modelling, construction system design, building system analysis, and space management & tracking are not taught in any NZ tertiary institutions.

[Table 9 near here]

Regarding social competence, offering collaboration and coordination opportunities was one of the major motivation to design group-based BIM project. In some courses, a project manager role was set up to allow students to practice and demonstrate leadership skills. Nevertheless, the key social competences were not explicitly embedded into BIM course design and implementation. Although most of the higher level of BIM uses were included in BIM courses, some of the key competencies underlying each BIM use were not taught. Figure 3 shows the discrepancies between the cognitive level of BIM competencies taught and required by the industry. *Remembering* the term of design review is significantly different than *performing* “design review” in a project context. Considering the fact that the same BIM competence (i.e., knowledge and skills) can be taught at different levels, it is important to understand the current level of student learning of BIM uses and evaluate if meaningful learning (or deep learning) is taking place in class.

[Figure 3 near here]

Results suggest that, in general, for several BIM uses (e.g., asset management, engineering analysis, digital fabrication, and construction system design), a large proportion of learning outcomes are focused on “understand”, while NZ BIM Handbook requires higher levels of understanding and application. This indicates that students in BIM class are taught more to "think" than to "do".

Note that BIM competencies required in NZ BIM Handbook involve a combination of different cognitive processes. Take asset management as an example. The BIM use requires not only the ability to manipulate an asset management system but also the knowledge of construction and the operation of a building (replacements, upgrade, etc.). The lower-level cognitive processes and teaching and learning activities are necessary to lay a foundation for a higher level of learning. They help students construct a richer meaning of BIM-based asset management, compared to the situation in which students are only taught how to use relevant software.

5. Discussion

5.1 A competency-based education perspective

The competencies expected by the industry are the core of CBE curriculum. CBE should be designed and delivered to meet societal and industry needs. Thus, identifying the BIM competences required by the industry and converting them into a set of assessable learning outcomes are essential. The results of this study indicated that BIM has been integrated into existing courses in almost all NZ tertiary institutions. Conceptual aspects of BIM and popular BIM uses and practices are well covered in tertiary education. A wide range of teaching and learning activities are designed and implemented to engage students and help them achieve pre-defined learning outcomes. There is also an enriching nexus between BIM teaching and research. For example, research in lean construction, disaster management, VR, AR, IoT, and construction management informs and enhances BIM learning and teaching.

However, several significant gaps exist. Firstly, current BIM tertiary education does not fully cover all BIM competence required by the industry at the national level (see Figure 2). Critical BIM competencies such as record modelling, construction system design, building system analysis, and space management & tracking were largely missing in the current BIM curriculum. Note that the competencies embedded in the current BIM curriculum were not generally informed by the industry. The scope and validity of the competencies need to be validated with the industry. It should also be noted that it is essential to teach subject knowledge that underpins the BIM uses and processes. BIM, by its definition, represents a digital technology and method to improve (not replace) the efficiency and effectiveness of traditional practices and solve long-lasting problems (e.g., low productivity, ineffective communication, cost overrun, delay, etc.). Learning BIM software skills are important, but the skills alone cannot provide solutions to the AEC industry's problems. For example, learning to use Navisworks for 4D modelling would be more effective when students already have had a suitable level of knowledge on construction processes and methods. The knowledge of different procurement methods is an important prerequisite for students to learn how BIM can be integrated into procurement processes. The skills of Revit do not automatically empower students to “create” when they have no architectural design or engineering knowledge.

Secondly, higher-level learning outcomes of some BIM uses are generally missing. A large proportion of learning outcomes of BIM uses are focused on “understand”, rather than “apply” or higher levels. Cognitive processes and learning activities that promote “understanding” are sufficient to help students build connections between concepts of BIM. However, they are insufficient and ineffective to teach procedural knowledge of BIM, such as BIM process, workflow, plans, etc. From a pedagogical perspective, it is easier and less resource-demanding to focus only on promoting student’s “understanding” of BIM knowledge. Teaching and learning activities that promote cognitive process at the “apply” level are essential to help them build the connection between conceptual BIM knowledge with the real-world practices. This allows students to develop problem-solving skills.

Performing learning activities at higher levels of cognitive processes like “analyse” and “evaluate” would be effective to provide students with opportunities to critically analyse and evaluate the role of BIM uses in affecting other dimensions of project lifecycle management (e.g., cost, time, quality, safety, sustainability, etc.). This helps students develop critical thinking, analytical and strategic planning skills. At the national level, BIM curriculums can be more practice-related, with more specific linkages to the competencies (both technical and soft) expected by employers. With support from the industry, deep teaching approaches can be developed to engage students appropriately and meaningfully. Combining theoretical and practical learning into the academic sphere, BIM educators should be more effective to create a learning environment in which students construct the meaning of BIM as a tool and method.

5.2 The way ahead

A conceptual framework was proposed to suggest the way ahead towards future competency-based BIM education. As shown in Figure 4, the framework consists of two sub-domains: (1) BIM practices in the AEC industry (left) and (2) BIM tertiary education (right). The BIM practice sub-domain consists of five main concepts (highlighted in green): (1) Project, (2) Phase, (3) Process, (4) BIM role, and (5) BIM use. The tertiary education sub-domain consists of six concepts (highlighted in blue): (1) BIM learning outcome, (2) Learning object, (3) Teaching & Learning activity, (4) Learning pathway, (5) Assessment task, and (6) Student. These two sub-domains are connected via two concepts (highlighted in grey): (1) BIM competence and (2) Graduate.

The linkage between the two domains conveys a vital notion, that is, BIM tertiary education cannot be isolated from the BIM applications in the AEC industry. Instead of “what to teach” being decided by instructors based on their expertise, BIM curriculums and programmers must have explicit learning objectives that reasonably address the industry’s needs and expectations. *BIM competence* is a useful concept that bridges the possible gaps between the two sides, and that offers several benefits. BIM competences can be identified and categorised by BIM uses, roles, disciplines, project phase and process, etc. This enables instructors to effectively and sensibly assemble teaching contents and topics in a well-defined sequence for specific performance standards.

[Figure 4 near here]

Conceptually, this framework enables to minimise the gaps between current BIM education and practices and integrate the principles of CBE proposed by Johnstone and Soares (2014) into BIM curriculum.

The framework highlight the role of BIM competencies in the development and implementation of BIM curriculum. As shown in Figure 5, a collection of BIM competences can potentially be identified by BIM uses (e.g., design review). To facilitate BIM learning design, another set of BIM learning outcomes needs to be developed based on the BIM competences. This will help learning designers, instructors, and students link BIM teaching and learning with BIM practices. Systematic efforts should be made to identify and validate the BIM competencies through workshops, focus groups, and interviews with the industry stakeholders. When defining learning outcomes, a holistic perspective should be adopted to explicitly include soft skills.

[Figure 5 near here]

Future BIM education should allow students to be able to learn at a variable pace. Developing BIM learning objects is a promising way to facilitate individualised and customised learning. Wiley (2000) defined a learning object as "any digital resource that can be reused to support learning." The fundamental idea behind the concept of learning object is that BIM learning designers (e.g., BIM instructors) can build small instructional BIM components that can be evaluated, shared, reused in different learning contexts. For example, 4D BIM modelling is one of the core topics of BIM courses in construction management programs. A learning object of 4D BIM modelling can be developed, evaluated, and reused in architectural engineering courses in which students learn the importance of constructability analysis.

5.3 Limitations

This study is with several limitations. First, this study is descriptive, focusing on identifying the current status of BIM tertiary teaching and the industry's expectations of BIM competencies. The authors made no attempt to address questions, like, "what BIM competencies *should be* taught in NZ tertiary institutions?" and "what BIM competencies *should be* taught in vocational education and training (VET) centres?", although these questions are important in their own right. Second, not all BIM lecturers develop and use learning outcomes in their class, and some learning outcomes collected were too general. Third, there was potential bias in the sample of job advertisements and BIM courses. Only four main job-posting websites were visited to search BIM job advertisements. There might be some relevant job advertisements posted in other websites missing. In addition, BIM courses were collected from NBEWG. Despite all due diligence, it is possible that universities and polytechnics that are not members of NBEWG may also teach BIM.

6. Conclusions

This paper reports a case study that investigated current status of BIM tertiary education in NZ and analyse the gaps between current BIM education and the industry's needs. Results indicated that there are discrepancies in not only the type but also the level (i.e., cognitive levels) of BIM competencies taught in NZ tertiary institutions and required by the industry. It was indicated that missing links exist in almost all BIM uses that are taught, except that necessary competencies in 4D modelling are well addressed in current BIM courses. In addition, regarding the level of BIM competencies, results suggested that, in general, for several BIM uses (e.g., asset management, engineering analysis, digital fabrication, and construction system design), a large proportion of learning outcomes are focused on “understanding”, while NZ BIM Handbook requires higher levels of application and evaluation.

In hindsight, the results of this study have highlighted the disparity between communication and collaboration within various disciplines. Ample studies have presented a strong argument for improving collaboration for improved BIM adoption. Thus, communication becomes a by-product of improved collaboration and trust within project teams. Due to the diverse nature of BIM courses in NZ tertiary institutions, improving interdisciplinary collaboration through group work would improve graduate attribute perception on project teams skill knowledge, mode of communication and problem-solving expectations. The digitalisation of the construction sector workflows occurs at a rapid pace. A wide variety of software packages keep emerging in the market, which promises to enhance BIM deliverable from a cost-benefit perspective. Hence, regular industry advisory committee update on competencies and desired software within tertiary programmes would improve the design of course contents.

In order to bridge the gaps between current BIM tertiary education and the industry’s requirements, core competence sets should be determined by discipline (e.g., construction management, architecture, structural engineering, quantity survey, etc.). BIM competencies can also be classified based on BIM uses, BIM processes and phases, and project roles. In addition, the boundaries and connections between tertiary education and vocational education and training (VET) should be made more explicit. At the national level, confusion and contest should be avoided, and collaboration should be encouraged and sought. This would shed light on what BIM competencies should be covered in tertiary education and how these competencies will be connected with VET. Within the boundary of tertiary education, BIM educators should decompose a higher level of BIM competencies into concrete and measurable BIM learning outcomes (LOCs) at both the programme and course level. To enable quality learning, BIM educators need to constructively align LOCs with teaching and learning activities and assessment tasks.

The results of job content analysis reveal that the industry is expecting a combination of BIM-related cognitive, functional, social, and meta-competence. Compared to technical knowledge and skills, individual and social skills are equally emphasised in job advertisements. By nature, BIM is closely related to, and partially based on, soft skills like communication, collaboration, coordination, team-working, and leadership. Future efforts should be made to review whether or not, what, and how the vital soft skills are embedded in the instructional process.

7. Acknowledgements

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8. Data Availability Statement

All data (in aggregated form without any personal identifiers) that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. Distribution of all BIM courses by course level and type

Attributes	Category	Number of courses
Course level	Level 6 Diplomas	7
	Level 7 Bachelor's Degree; Graduate Diplomas and Certificates	21
	Level 8 Postgraduate certificates Level 9 Master's Degree	5
Course type	BIM stand-alone courses	9
	BIM as a topic	24

Table 2 BIM job categories

Group	Group name	Job titles	Number of ads
G1	Architect	Architect; Architect Technician; Architectural Designer; Architectural Graduate; Architectural Project Lead; Design Manager	74
G2	BIM coordinator	BIM coordinator; BIM Coordinator / Technician; BIM Design Technician;	11
G3	BIM Manager	BIM Manager; BIM Information Manager; BIM Lead; BIM Leader; BIM Model Manager - Infrastructure; BIM Project Manager; Digital Engineering Lead; Digital Delivery Manager;	45
G4	BIM Specialist/Engineer	BIM Modeller; BIM Specialist; Digital Modeller; Digital Modelling Technician; BIM Draughter; BIM Engineer	27
G5	Engineer	Electrical Engineer; Mechanical Engineer; HVAC Graduate Design Engineer; Services Engineer; Structural engineer; Hydraulic Engineer; Project Engineer; Project Services Engineer;	23
G6	Revit Technician/ Specialist	Revit / BIM Modeller; Revit Architectural Technician; Revit Design Draughter; Revit Design Technician; Revit Drafter; Revit Technician; Revit Specialist	72
G7	Structural Draftsperson	Revit Structural Draftsperson; Revit Structural Technician; Structural and Architectural Drafter; Structural BIM Designer; Structural CAD Technician; Structural Drafter; Structural Revit Technician;	59

Table 3 Technical BIM competence ranking by groups

BIM Technical Competencies	G1	G2	G3	G4	G5	G6	G7
Revit	1st	1st	1st	1st	1st	1st	1st
Architecture design (process, workflow)	2nd		5th			10th	
Structural engineering design						4th	2nd
NZ building code and standards	3rd	4th	9th		4th	5th	4th
Technical drawings and documentation	4th		6th	6th		2nd	3rd
Construction knowledge (constructability, processes, materials, methods)	5th	8th	4th			5th	
ArchiCAD	6th						
Project Management	7th						
Consenting processes	8th					3rd	7th
AutoCAD	9th		7th	10th	2nd	5th	5th
BIM process, workflow, plans, standards, protocols	10th	10th	1st	2nd		8th	
Navisworks		1st	3rd	8th			6th
Clash detection		3rd					
Sketchup		4th				8th	
Revizto		4th					
Model review		4th					
Dynamo		8th		3rd			
Civil 3D			8th				
12D[1]			9th				
Grasshopper				4th			
Rhino				5th			
BIM360				7th			
Tekla				9th			
Engineering analysis, design, assessment					3rd		
CAD Duct & MEP					4th		

[1] https://www.12d.com/

Table 4 Top five soft skills by group

Soft skills	G1	G2	G3	G4	G5	G6	G7
Team player	1st	5th			3rd	3rd	5th
Communication	2nd	1st	2nd	1st	1st	1st	1st
Leadership	3rd		1st	4th	3rd		
Problem-solving	4th			5th			
Collaboration	4th		4th			5th	3rd
coordination	4th	2nd	3rd				
Professionalism		3rd					
Self-motivated		4th		2nd			
Time management			5th		2nd		2nd
A willingness to learn				2nd			
Organisational skills					3rd	2nd	
Critical thinking					3rd		4th
Attention to detail						3rd	

Table 5 Conceptual BIM knowledge taught

NO	Conceptual BIM knowledge	A	B	C	D	E	F	G	H	I
1	Basics of BIM	√	√	√	√	√	√	√	√	√
2	Level of Development	√		√	√			√		
3	Interoperability	√	√					√	√	
4	BIM Data structure, governance, integration, sharing	√					√		√	
5	BIM lifecycle process, workflow	√	√	√						
6	BIM and lean construction		√							
7	BIM Maturity Levels			√						
8	BIM in construction					√			√	
9	New Zealand BIM Handbook			√	√		√			
10	Parametric design							√		
11	Augmented Reality and Virtual Reality integration to BIM	√	√					√	√	
12	BIM Integration with recent technology (IoT, AI, and Big Data)								√	

Table 6 BIM uses taught in tertiary institutions

NO.	BIM uses	Tertiary institutions								
		A	B	C	D	E	F	G	H	I
1	Existing conditions modelling	√	√	√			√	√	√	
2	Cost estimation	√		√	√		√	√	√	√
3	Phase planning (4D modelling)		√	√	√		√	√	√	
4	Spatial programming						√		√	
5	Site analysis		√				√			
6	Design review		√	√		√	√	√	√	√
7	Design authoring	√		√			√	√		
8	Engineering analysis (energy, fire, lighting, mechanical, structural, other)	√	√			√	√	√	√	
9	Sustainability analysis		√				√			
10	Code validation			√			√			
11	3D coordination	√	√	√	√	√	√	√	√	
12	Site utilisation planning		√				√			
13	Construction system design (virtual mockup)		√				√	√	√	
14	Digital fabrication						√	√	√	
15	3D control and planning (digital layout)		√	√			√		√	
16	Record modelling									
17	Asset Management			√	√	√	√		√	
18	Building (Preventative) Maintenance Scheduling						√		√	
19	Building System Analysis						√			
20	Space Management & Tracking					√	√		√	
21	Disaster Planning		√				√			

Table 7 Learning outcomes of conceptual knowledge of BIM

Conceptual knowledge of BIM	Learning outcomes defined in BIM courses
Basics of BIM	• Describe what BIM is • Understand how BIM can bring benefits to a number of stakeholders in the construction • Identify the benefits of BIM • Identify the level of BIM adoption in NZ; Explain the BIM dimensions • Know the basics of BIM • Know and understand the basics of BIM • Understand the principles of building information modelling with regard to the New Zealand BIM Handbook and BIM user definitions
Level of Development (LOD)	• Describe the LODs each project stage • Illustrate the implications of the LODs in project delivery
Interoperability	• Explain how data exchange (i.e. interoperability) works and can export .ifc file from BIM tools • Know IFC and COBie • Understand the importance of interoperability • Understand how software data such as primavera or project professional are imported into Navisworks • Understand how software file are interrelated
BIM lifecycle process, workflow, and plan	• Understand that BIM is an approach to the entire building life cycle • Understand the importance of collaboration
NZ BIM Handbook	• Have a hands-on understanding of the practical elements (templates) within the NZ BIM handbook • Understand and be able to use the New Zealand BIM Handbook templates
BIM Maturity Levels	• Describe BIM maturity levels; Determine the level prevalent in NZ and implications • Discuss NZ maturity level in relation to other countries
Parametric design	• Understand the principle of parametric design and create a simple script using parametric modelling software (e.g. Grasshopper) • Understand that BIM is a parametric modeller – defining properties from which one's data is drawn
BIM integration with recent technologies	• Identify, compare and use Virtual Reality (VR) and Augmented Reality (AR) solution to visualise BIM projects • Create an Augmented Reality model and perform an application on-site while communicating the project • Know BIM integration with Internet of Thing (IoT), Artificial Intelligence (AI) and Big data for integrated Facilities Management
Data management	• Understand the opportunities Data embedded models have on the 5 stages of building • Data maintenance prior to building hand over
Legal implications	• Understand regulatory and legal factors affecting BIM

Table 8 Teaching and learning activities

Type of TLAs	Examples
Lecture	• Traditional lecture • Mini-lecture • Guest lecture (e.g., presenting case studies)
Tutorial	• In-class • Online
Seminar	• Student-led seminar • Industry-led seminar
Discussion	• In-class group discussion
Software workshop	• Solibri Model Checker (3D coordination) • Navisworks Manage (3D coordination, quantity takeoff, 4D Phase planning, Construction system design) • Revit and Navisworks Manage to create site utilisation plans • CostX (5D Cost estimation) • Students use appropriate software and processes to create the documentation
Individual Assignment	• Creating three types of buildings in Revit. Residential, Light commercial and Medium commercial buildings. • Import consultant documents for coordination and clash issues. • Create a Project BIM Brief
Individual project	• The students are assessed individually. They work on individual BIM model. Class tutorials use sample BIM model from Autodesk Revit. The project has the following tasks: ✓ Develop a digital project plan for future projects ✓ A detailed plan of schedule/programme and cost ✓ A detailed plan of legal liability, site monitoring and issue resolution • Reflection report Personal digital implementation plan
Group assignment	• Team investigation on the benefits and challenges of BIM in general ✓ Review definitions for virtual design and construction (VDC) and BIM
Group project	• Five students per group. There are three different roles to play, including 1 Project Manager, 2 Quantity Surveyors (QS), and 2 Schedulers. Groups work on a two-story office model and are required to complete to following tasks: ✓ Quantity takeoff and cost estimating ✓ Schedule development ✓ 4D schedule simulation ✓ BIM learning reflection (5 min Youtube video)
Project presentation	• Students present their BIM works as a group or individual.
Socrative Space race	• Socrative Space race to get familiar with the BIMinNZ website and course project scenario.

Table 9 BIM uses teaching against rank of industry use

BIM uses	The number of tertiary institutions that are teaching	Percent (%)	Rank of NZ industry uses in 2019
Design review	7	77.8	1st
3D coordination	8	88.9	2nd
Existing conditions modelling	6	66.7	3rd
Design authoring	4	44.4	4th
Site analysis	2	22.2	5th
Asset Management	5	55.6	6th
Cost estimation	7	77.8	7th
Engineering analysis (energy, fire, lighting, mechanical, other)	6	66.7	8th
Phase planning (4D modelling)	6	66.7	9th
Record modelling	0	0	10th
3D control and planning (digital layout)	4	44.4	11th
Digital fabrication	3	33.3	12th
Construction system design	0	0	13th
Spatial programming	2	22.2	14th
Site utilisation planning	2	22.2	15th
Building System Analysis	0	0	16th
Space Management & Tracking	0	0	17th
Code validation	2	22.2	18th
Building (Preventative) Maintenance Scheduling	2	22.2	19th
Disaster Planning	2	22.2	20th
Sustainability analysis	2	22.2	21st

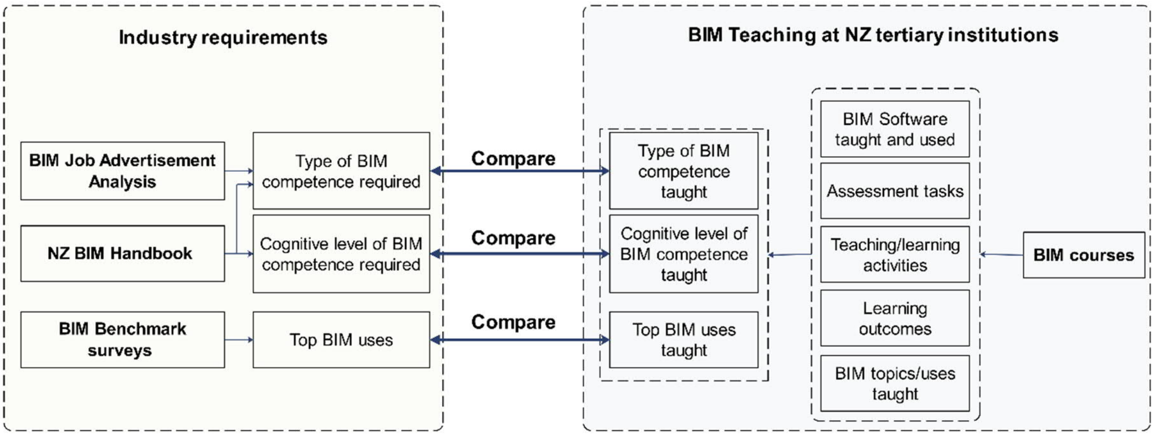

Figure 1 Data analysis workflow

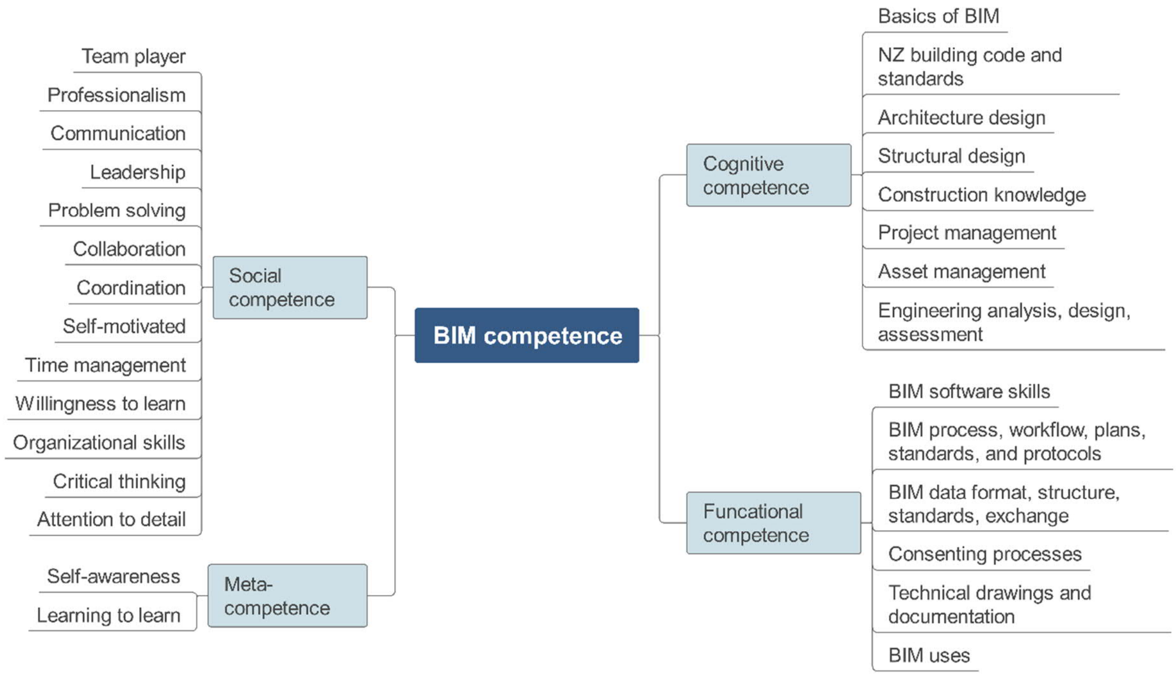

Figure 2 Core BIM competences required by the industry

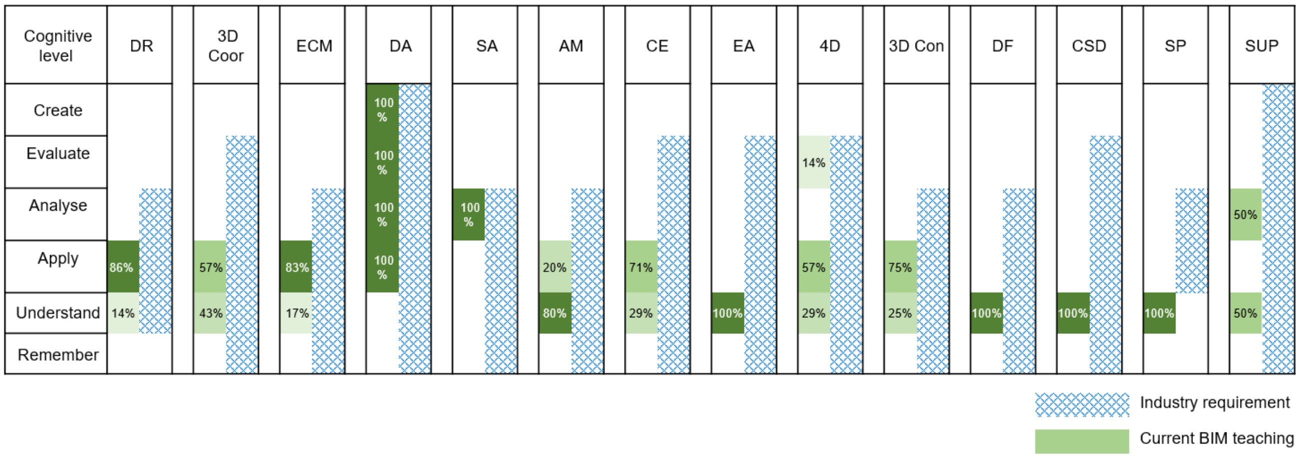

Figure 3 Discrepancies in cognitive level between learning outcomes and industry requirements

Note: DR=design review; 3D Coor=3D Coordination; ECM= Existing Conditions Modelling; DA= Design Authoring; SA=Site Analysis; AM=Asset Management; CE=Cost Estimation; EA=Engineering Analysis; 4D=phase planning (4D modelling); 3D Con=3D Control and Planning; DF=Digital Fabrication; CSD=Construction System Design; SP=Spatial Programming; SUP=Site Utilisation Planning
The percentage values mean the proportion of the learning outcomes on specific cognitive levels

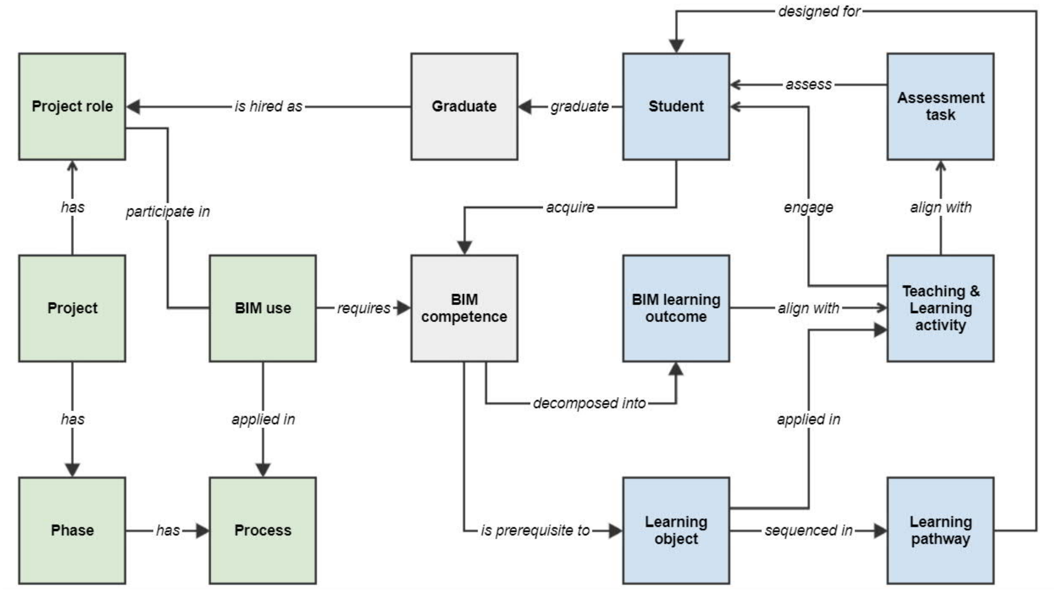

Figure 4 A conceptual framework of competency-based BIM education

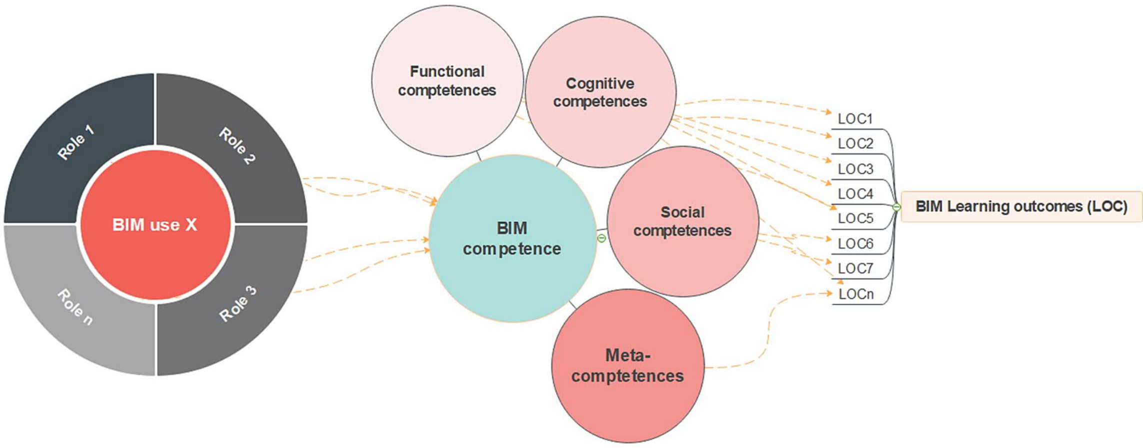

Figure 5 Linking BIM uses with BIM competence and LOCs

Figure captions

Figure 1 Data analysis workflow

Figure 2 Core BIM competences required by the industry

Figure 3 Discrepancies in cognitive level between learning outcomes and industry requirements

Figure 4 A conceptual framework of competency-based BIM education

Figure 5 Linking BIM uses with BIM competence and LOCs