Teaching collaboration in tertiary BIM education: A review and analysis

Abstract
The pervasiveness of BIM adoption is unprecedented, and with this rise, tertiary education institutions are required to address and satisfy the rising market demand for sufficiently skilled BIM professionals. BIM is inherently a team-based activity and possessing the knowledge, skills, and abilities (KSAs) to collaborate across various disciplines and organisations is central for BIM-ready graduates. There is, nevertheless, no systematic attempt to analyse the current approaches to teaching collaboration KSAs across tertiary education institutions. This study is an attempt to provide an account of the current approaches taken by leading universities for training and educating collaboration, as a part of their BIM education programs. To this end, 63 articles on BIM education were identified, of which 18 were used to extract their practices to teaching collaboration. As the first in its kind, the present study provides an analysis and synthesis of the best practices for teaching educating collaboration, and therefore, assists educators and curriculum builders in integrating collaboration KSAs into BIM education in construction related curricula.

Keywords:
Building Information Modelling (BIM), Collaboration, Education, Training, Curriculum, University.

1 Introduction

Building information modelling (BIM) is rapidly gaining importance in the construction industry. The BIM market is predicted to grow from US$3.16 billion in 2016, to US$7.64 billion in 2022, projecting an annual growth rate of over 16%. This presents the construction industry with multiple challenges, one being the task of ensuring construction firms are staffed with employees capable of handling the growing number of BIM-enabled projects across the industry. With such pressing need to recruit BIM talents, it is important to focus on the exact competencies required (ACIF & APCC 2017).

BIM implementation is inherently a team-based activity, strongly relying on collaboration, that requires practitioners to integrate information from several disciplines into a single digital model (Mignone et al. 2016). With the above in mind, lack of skill in multi-disciplinary collaboration has therefore become a major barrier to successful use of BIM (Oraee et al. 2017). Despite the significance of collaboration skills, research on team member collaboration knowledge, skills and abilities (KSAs), and the best approaches for teaching and training the related KSAs have remained under-researched. Indeed, the current literature on the topic only comprises showcasing of attempts for teaching collaboration at a few universities around the world (Merschbrock et al. 2018). An overall evaluation and analysis of these attempts and creating an integrated illustration of the best practices is currently missing from the literature. This study is an attempt to address this gap through (1) providing a review of cases of teaching collaboration as a part of BIM tertiary education at universities around the world, and (2) identifying, synthesising and putting on display the best practices.

The study will assist educators in developing curricula and assessment structures in order to integrate collaboration knowledge, skills, and abilities, into BIM education for tertiary students.

2 Literature Review

2.1 BIM: The crucial role of collaboration

There is consensus in the industry that BIM is a useful tool, and as such, its wider adoption in the industry is needed (ACIF & APCC 2017). BIM has applications in almost every stage of the life cycle, such as design visualisation, code compliance, clash detection, energy simulation, quantity take off, procurement management, scheduling, site management, site safety and facilities management, among others (Mignone et al. 2016). The creation of a BIM model is an inherently multidisciplinary activity that requires effective collaboration and information exchange between all stakeholders involved during the life cycle of the building (Merschbrock et al. 2018).

Collaboration for the construction context is defined as "a non-adversarial team based environment, where through the early involvement of key members and the use of the correct contract, everyone understands and respects the input of others and their role and responsibilities." (Hughes, Williams & Ren 2012, p. 365) Implementing BIM in the absence of effective collaboration is described as merely 'scratching the surface.' (Mignone et al. 2016). The challenge of making multiple disciplines and organisations collaborate with each other is a major impediment to harnessing the potentials of BIM. With this in mind, problems facing BIM-enabled projects in maintaining collaboration and corresponding remedial solutions have become an active field of research (Merschbrock et al. 2018), and a wide range of factors are identified as the enablers of collaboration in BIM-enabled projects (Mignone et al. 2016).

From a contractual perspective, Olatunji (2011) argued that traditional notions of responsibility and the conventional legal structure dominating BIM-enabled projects hinder collaboration. A wide range of studies, however, attempted to enhance collaboration through the use of more effective collaboration technologies (Merschbrock et al. 2018). Despite the extensive availability of effective collaboration tools, the problem of collaboration on BIM-enabled projects is far from being resolved. According to Emmitt and Ruikar (2013, p. 107) "It is therefore not so much a technological issue as it is a human behaviour one." With this in mind, many investigators (Becerik-Gerber, Ku & Jazizadeh 2012; Pikas, Sacks & Hazzan 2013; Sacks & Pikas 2013) suggested the incorporation of the principles of collaboration into tertiary BIM education programs. This insight was acknowledged by the world of practice, where a lack of training and BIM skill in university graduates is still treated as a major limitation to BIM implementation (ACIF & APCC 2017). This resulted in attempts towards including collaboration within the tertiary BIM education is several institutions. A brief description of the theoretical grounds of such attempts is presented next.

2.2 Collaboration in tertiary BIM education

Communication, trust, good faith, and mutual support are prerequisites of collaboration. These underscore the interdependence of systems, culture, and individual attitudes in enabling collaboration in the workplace (Merschbrock et al. 2018). Oraee et al. (2017) argued that factors such as the 'Task'—the nature of the work being performed— and 'Actors'—the skills and knowledge of the individuals involved—are indispensable to effective collaboration in BIM-enabled projects. These insights are echoed by studies asserting that conflicts encountered during collaboration largely stem from interactions between competing priorities of individual, project and organisation (Dossick & Neff 2010). These further highlight the crucial role of individuals in establishing collaboration (Merschbrock et al. 2018; Mignone et al. 2016).

Effective collaboration therefore is rooted in an understanding of the role of other disciplines and an ability to manage interactions between different disciplines (Merschbrock et al. 2018). This is independent of the technical knowledge and emphasises the need for including teamwork and collaboration KSAs among the learning outcome for tertiary BIM education (Adamu & Thorpe 2016; Becerik-Gerber, Ku & Jazizadeh 2012).

3 Research Methods

The objectives of the present study necessitates identifying the concepts, reviewing the related literature and analysing the studies related to the topic. All these objectives are deemed in accordance with the capabilities of systematic review method. For this analysis, a 3-staged systematic review approach is considered, as illustrated in Figure 1. This entails the process of identifying: (1) studies discussing BIM education, (2) studies that describe BIM education in tertiary education, (3) studies that discuss collaboration in BIM education at tertiary education.

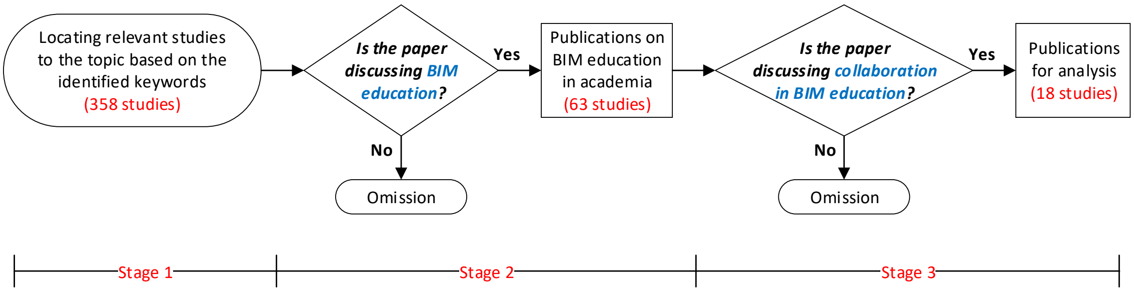

Figure 1. Research design and procedure

The data are obtained by running a keyword search on the Scopus database with the keywords: building information modelling, BIM, BIM education, and collaboration. Scopus is selected given its wider coverage and its quick turnaround in indexing new studies, a point argued by Oraee et al. (2017). The search process results in identifying a pool of 358 studies discussing various aspects of BIM education. In the second stage, and after this broad search, these papers are further analysed upon satisfying the below criteria:

- They feature a case study of one or multiple courses taught in a tertiary education institution.
- The case study features use or discussion of BIM in the course
- The course involved team based work, or discussed collaboration more broadly.

As a result, 63 relevant studies that discuss BIM education in tertiary education in particular are filtered out. In the final stage, these studies are then analysed to identify pedagogical aspects or course structure elements that contribute to the learning of collaboration KSAs by the students (18 studies). Positive contributions are identified based on evaluations, or inferred based on the outcomes and limitations. The best practices among these are highlighted and discussed. The emphasis is on practices that are easily reproducible and contribute to the fundamental collaboration KSAs.

4 From the literature to findings

The 18 papers identified as the now available literature on teaching collaboration in tertiary BIM education are tabulated in the Appendix. The content analysis of these studies revealed that the best practices identified can be presented under 4 broad categories, as illustrated in Table 1.

Table 1: The best practices in identified studies (see the Appendix for details)

Category	Best practice	Papers ID
Instructional approach	Project based learning	1-18
	Industry mentors	2,4,7,8
	Standards, tools and documentation	5
	Team building exercises	4
	Self-Analysis tools	5
Prerequisites	Complementary construction knowledge	1-18
	Familiarity with BIM	1-18
Marking and evaluation	Readiness evaluation	10
	Technical deliverables	1-18
	Peer evaluation	2,7
Feedback	Industry jurors	13,14
	Student feedback	1,2,3,5,6

4.1 Instructional approach

The instructional approach covers the method of delivery, the deliverables, the resources provided to students, and the interactions between them and their instructors. In selecting these, it is important to focus on whether the approach will give students an insight into the challenges and the conflicts associated with working collaboratively, and whether it will give them a framework within which to resolve those conflicts. It is not sufficient to organise students in a team, give them a task to perform and allow them to work on it. Moreover, instructional features must also highlight the reciprocal interactions between students' technical skills and soft skills. The main dimensions related to instructional features are discussed below.

4.1.1 Project based learning and task selection

As illustrated in Table 2, all 18 studies support Project Based Learning (PBL) and Team Based Learning (TBL) as their primary instructional approach. Under PBL, students are assigned a task (single large project or a series of smaller projects) that is to be completed over the duration of the course. Collaboration learning is classified under Bloom's taxonomy as an affective educational domain, and therefore, the experiential learning model can be an appropriate method to teach collaboration skills (Bloom, College & Examiners 1964). In the context of collaboration education however, this means that students need to possess the required domain knowledge necessary to complete the project (this is discussed further in subsection 4.2.1). The complexity and the information requirements of the task therefore play a crucial role. This was highlighted by Solnosky, Parfitt and Holland (2015), in comparing the learning outcomes in a capstone project with different types of tasks assigned over various iterations of one course. They find that the course outcomes are best when the task assigned to students has the following characteristics.

- The case comes from a live project with a professionally produced request for proposal.
- The students don't have access to completed design, and are required to generate alternatives for the design.
- The case requires unique and interdependent deliverables from all team members.

Due to the volume of effort required to effectively complete such a task, many universities opt to include it as a capstone project, conducted with students in their final year, typically as standalone final project with little to no other coursework alongside them (Zhang, Xie & Li 2017). Students that engaged with a collaborative task as a part of regular coursework suggested reduced success in collaboration, including challenges with scheduling and time management between competing priorities (Ghosh, Parrish & Chasey 2015; Wang & Leite 2014; Wu & Luo 2016). The coursework based exercises also require less complex projects and rigidly-defined scope of work in the interest of time.

4.1.2 Industry mentors

In the PBL methodology, the role of instructors is one of guiding and facilitating the process, rather than teaching the domain knowledge. When students are simulating a design or planning exercise in a BIM enabled environment they need access to mentors that can guide them on both the technical and workflow related challenges that arise. Mentors that work in the industry or are otherwise actively engaged with workplace practices can ground the process in the current standard and even help the students exceed those standards (Mathews 2013). Industry mentors also increase student engagement and increase their confidence in their practical skills.

4.1.3 Standards, tools, and documentation

Collaboration relies on all participants having similar expectations of communications and workflow so following a standardised framework can be a remedial solution. Students can bring awareness and familiarity with such standards into the industry and improve practices within their organisations after graduation. As an example, Adamu and Thorpe (2016) emphasise the importance of training graduates to be versed with the BS1192 series.

Collaboration tools for BIM include both technologies, like data sharing platforms, and management tools like the Dependency Structure Matrix (Pektaş 2014). Mandating the use of an organisational tool like the DSM helps students understand how their tasks fit into the overall building life cycle. The deliverables should also include documentation of the collaboration and the tools used. This can take the form of meeting minutes (Wang & Leite 2014), progress reports (Wu & Luo 2016), regular posts on a discussion board (Mathews 2013), or simply giving access to the instructor to the work-in-progress files (Zhao et al. 2015). This type of documentation is a form of group processing and encourages cooperation and positive outcomes.

4.1.4 Team building exercises

A formal team building process prior to the commencement of the project supports the building of trust and group identity. Team building exercises are essentially structured interactions where team members can introduce themselves, express their roles and preferences and understand the preferences of their team (Korsgaard, Brodt & Sapienza 2005). As an example, McCuen and Pober (2016) began their project work with an 8-hour intensive introductory session, where teams were assigned, introduced through team building exercises, and then asked to work together to set standards to share information and define platforms for communication and co-ordination. The students identified this as one of the critical factors to project success.

4.1.5 Self-analysis tools

Alongside group processing, individual students must also be supported in reflecting on their own collaborative behaviours. Self-analysis tools like an emotional intelligence test (Zhao et al. 2015) or reflective assignments (Mathews 2013) do not directly contribute to the deliverable in the short term, but in the long term are important to adjust behaviour and improve their overall affect (Coleman & Voronov 2003). These tools can also be used to support underperforming team members and address their individual challenges.

4.2 Prerequisites

In this context, prerequisites focus on the competencies that student need prior to starting a collaborative BIM project.

4.2.1 Complementary construction knowledge

Teaching collaboration is only effective when complementary domain knowledge exists in the team, namely, every member of the team has a unique role and expertise on some dimension of construction knowledge (Latane, Williams & Harkins 1979). The exception to this is when students are collaborating on a cross course project, as attempted by Wu and Luo (2016). In this case, students on each project team were learning a different set of technical knowledge and applying it to the collaborative group project. The primary challenge in this case was logistics, for both the students and instructors.

4.2.2 Familiarity with BIM tools

Skill in BIM is slightly different in this context. As all participants will be expected to prepare some elements of the BIM model it is possible to introduce BIM alongside collaborative coursework, however better learning outcomes are seen when participants already have a level of familiarity with BIM methodology (Mathews 2013). Bozoglu (2016) addressed this by organising a workshop on the basics of BIM with an industry partner at the start of the coursework. Subsequently, the students will engage in co-learning and support team members with lower skills (Becerik-Gerber, Ku & Jazizadeh 2012).

4.3 Marking and evaluation

The marking and evaluation practices suggested here are those used in previous studies in order to enhance the quality of output, make students accountable to each other and the task.

4.3.1 Readiness evaluation

Prior to starting the task, instructors can administer a 'Readiness Assessment Test' (RAT) to both individuals and the team (Zhang, Wu & Li 2018). The purpose is to evaluate the understanding of the task scope, context and team characteristics. This evaluation ensures that all the key elements of the task have been understood equally by all participants.

4.3.2 Technical deliverables

Any project-based task includes some technical deliverables that students are expected to produce. The quality of the technical deliverable is the ultimate objective of the exercise for marking and evaluation purposes.

4.3.3 Peer Evaluation

Peer evaluation helps instructors assess if individuals contribute to their tasks and pay attention to peer accountability. Being on a group with a 'social loafer' is a universal experience. When individual contributions in a group project are not apparent, certain individuals will not contribute to the project expecting that their lack of productivity will be compensated for by other team members. This phenomenon is minimised when individuals are accountable to their peers and have tangible negative consequences to a lack of contribution (Latane, Williams & Harkins 1979). Peer evaluation can take the form of standardised tool like surveys (Becerik-Gerber, Ku & Jazizadeh 2012; Solnosky, Parfitt & Holland 2015).

4.4 Feedback

Data collection is necessary for modifying the course structure on multiple iterations, as well as for complying with industry requirements. This can be achieved by integrating feedback from industry and students.

4.4.1 Industry jurors

According to project-based learning pedagogy, the outcome of a student project should be shared with the professional community for feedback as well as to share any insight offered by the findings of the project (Leite 2016). Inviting jurors from the industry to comment on students' projects is the best approach towards these goals. It has the advantage of increasing student engagement as well as giving them an opportunity to network with potential future employers (Solnosky, Parfitt & Holland 2014).

4.4.2 Student feedback

Most university systems already incorporate student feedback within the curriculum building process. For collaboration teaching based on project-based learning, however, the importance increases as every iteration of the course will be unique with specific challenges. Student feedback helps identify these challenges in order to tackle with them.

5 Conclusion

This study is unique as it is the first one providing a review of studies on teaching collaboration within BIM education. This is through identifying 12 best practices in the realm of BIM collaboration education. Many of these practices can be applied to any project-based learning within the construction context. The best practices identified are focused on ensuring that students see the collaboration process as positively contributing to the quality of their output. As collaboration teaching still relies on experimental approaches, the process must be managed to avoid students deeming the act of working in a team as inherently negative and inconvenience. The best practices provided here are invaluable in addressing this objective. The biggest barrier to teamwork in the learning process is the conflict between collaboration learning outcomes and the technical deliverables of the project. In the absence of appropriate guidance and management, the deliverables interfere with the collaboration learning and prevent the students from taking advantage of the process. Another major issue is a lack of clarity on what constitutes collaboration KSAs for individuals. There has been an attempt in this paper to frame those KSAs in terms of collaboration tools, standards and self-awareness. This is, however, limited and warrants further investigation to identify what teachable characteristics an effective collaborator in the construction industry requires.

The research is limited by the reliance on published papers, the lack of consistency in the type of data available across papers, and the limited papers from universities outside the USA. The papers reviewed are all in English and may exclude relevant research in other languages. This limits the generalisability of the findings, and the effectiveness of some of these practices may be affected by cultural differences. The assessment of best practices is partly subjective. Further research can include a comparative study between collaboration learning outcomes across universities where some of these practices are implemented versus students not trained in collaboration through these techniques. As discussed earlier, more research is also needed to identify the key collaboration KSAs in BIM.

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Appendix. Available studies on teaching collaboration in tertiary BIM education

ID	Paper	University
1	(Ghosh, Parrish & Chasey 2015)	Arizona state university, USA
2	(Becerik-Gerber, Ku & Jazizadeh 2012)	Virginia Polytechnic Institute and University of Southern California , USA
3	(Dossick, Homayouni & Lee 2015)	Indian Institute of Technology Madras, National Cheng Kung University, National Taiwan University, University of Twente, University of Washington, Washington State University, Yonsei University
4	(Gnaur, Svidt & Thygesen 2015)	Aalborg University, Denmark
5	(Zhao et al. 2015)	Virginia Polytechnic Institute and State University, USA
6	(Pikas, Sacks & Hazzan 2013)	Technion-Israel Institute of Technology, Israel
7	(Leite 2016)	University of Texas, Austin, USA
8	(Bozoglu 2016)	Illinois Institute of Technology, USA
9	(Zhang, Xie & Li 2017)	Chang'an University, China
10	(Zhang, Wu & Li 2018)	Chang'an University, China
11	(Wang & Leite 2014)	University of Texas, Austin, USA
12	(Mathews 2013)	Dublin Institute of Technology, Ireland
13	(Solnosky, Parfitt & Holland 2015)	The Pennsylvania state University, USA
14	(Solnosky, Parfitt & Holland 2014)	The Pennsylvania state University, USA
15	(McCuen & Pober 2016)	University of Oklahoma, USA
16	(Wu & Luo 2016)	California State university, USA
17	(Ahn, Cho & Lee 2013)	Western Carolina University, USA
18	(Adamu & Thorpe 2016)	Loughborough, UK