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TEACHING AND LEARNING IN AEC EDUCATION –THE BUILDING INFORMATION MODELLING FACTOR

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SUMMARY*: Building Information Modelling (BIM) is effecting a fundamental change through the architectural, engineering and construction industry (AEC) and simultaneously influencing curricula and course delivery within these disciplines. The aim of this research was to assist AEC educators in curricula and course development, and also to make the results of future research on BIM education more profound by identifying a wide body of literature which addresses learning theories, approaches and methods used. This research systematically reviewed research methods, data collections, and location and discipline information involving BIM education literature, under the categories of learning theories, learning approaches and learning methods. These theories, approaches and methods were investigated using an inductive analysis. In-depth discussion on learning theories in the literature was quite limited. There was found to be much discussion on learning approaches and methods, collaborative and active approaches, with project and problem-based methods being the most popular. BIM has encouraged and enabled the use of realistic project simulation and problem setting and the nature of BIM as a collaborative way of working has also pushed the AEC educators to trial multidisciplinary delivery models.*

KEYWORDS*: Building Information Modelling; Education; Learning Theory; Learning Approach; Learning Method; Systematic Literature Review; Inductive Analysis.*

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1. INTRODUCTION AND BACKGROUND

This research is focused on Building Information Modelling (BIM) education in more detail to offer collected and comprehensive information on the authors, research methods, geographical location and discipline information as a background and to map existing BIM education literature. Most importantly, this research is set to answer the question "What is the Building Information Modelling (BIM) factor in reference to teaching and learning methods in architectural, engineering and construction (AEC) education?". This systematic literature review aims to help the construction educators in their curricula and course development. It also aims to make the results of future research on BIM education more profound, when the results are able to be linked to a wide body of literature, which addresses the learning theories, approaches and methods.

BIM is effecting a fundamental change throughout the AEC industry. Jung and Lee reported in 2015 that "North America, Europe, Oceania, and Asia were advancing rapidly toward the mature stage of BIM, whereas the Middle East-Africa and South America were still in the early phase" (p. 512). BIM is seen as an innovative approach and an improved process for both design and construction, which reduces errors and omissions, increases building performance, quality and productivity by improved collaboration, communication, coordination, analysis and visualization of the project (Eastman et al., 2011).

BIM is changing the way individual companies and ultimately the whole industry operates. This change does not come without challenges. The most common ones are limited demand for BIM from clients or from other stakeholders on a project, lack of standardisation, lack of expertise due to different set of competences, and insufficient training. Various initiatives have been set up to overcome these challenges. Many countries have developed BIM adoption and implementation strategies and support mechanisms around these such as BIM guidelines to address the lack of standardisation, and academia and industry collaboration to address the competence and training issues (Puolitaival et al., 2016).

Simultaneously, whilst BIM is changing the AEC industry it is also influencing AEC curricula and course delivery. The curricula need to reflect the current and future industry practice for the graduates to be employable. Although the industry in general has been very supportive to introduce BIM in the AEC curricula, there has been some cases in the past where BIM integration has resulted in issues with outdated accreditation criteria, which has not included or allowed inclusion of BIM (Macdonald and Mills, 2011; Suwal et al., 2013).

BIM has been both taught as a separate topic, but more commonly as an integrated part of the existing curricula (Puolitaival and Forsythe, 2016). Several different approaches have been adopted: vertical integration (Forsythe et al., 2013, Ghosh et al., 2015), integrated project delivery approach (Macdonald and Mills, 2013) and other interdisciplinary models (Demirdroven, 2015) to name a few. All these come with their benefits, but also with challenges to the staff, students, and the institute and its facilities.

Lee and Hollar (2013) have collated from the literature some of the benefits of BIM in AEC education: better understanding of

- design, construction and engineering information,
- roles and responsibilities of other disciplines, and
- the collaborative work environment for the construction process.

In addition, BIM has created an effective content environment for active learning (Lee and Hollar, 2013).

A lack of expertise amongst staff, around the understanding of the processes and the ability to use the software hence the need for ongoing up-skilling to be current, despite a constantly evolving BIM environment are discussed by many authors as important challenges to the implementation of educational BIM (Becerik-Gerber et al., 2011; Clevenger et al., 2010; Forsythe et al., 2013; Gier, 2015; Johnson and Gunderson, 2009; Kiviniemi, 2013; Lee and Dossick, 2012; Underwood and Ayoade, 2015; Wong et al., 2011). As a solution, Lee and Dossick (2012) proposed that staff should stay in regular contact with industry to reflect the industry trends and practice. Clevenger et al. (2010) are also in support of this approach. In their study, industry experts complemented the staff skills and knowledge. Issues with the existing curricula and the BIM curriculum have been discussed by Sabongi (2009), arguing that existing curricula are often crowded, making it difficult to find room for additional elective courses, and that staff are unwilling to change courses /curriculum to incorporate BIM. Becerik-Gerber et al. (2011) discuss

the same topic, stating that there is not enough support from colleagues or from the administrative staff to make the changes in the curriculum. Moreover, the academic BIM education literature rarely addresses these challenges.

Another practical challenge is the lack of educational resources (Becerik-Gerber et al., 2011; Gier, 2015; Puolitaival and Forsythe, 2016; Sabongi, 2009; Woo, 2007). This concurs with the curriculum challenges described, in terms of the time required to create course resources, the level of available support from the tertiary institute, and staff expertise to create the required resources. Clevenger et al. (2010) have solved this by using industry models and modellers in their courses' model resources, Gier (2015) agreed, by explaining that industry now has a good portfolio of models, which could be used for educational purposes.

The rapidly evolving technology, and the complexity of the topic confront both students and educators (Sacks and Pikas, 2013). In many ways, BIM is resource consuming, and building models are the central element in both project and educational settings.

Several authors have mapped the academic BIM literature and case studies on BIM education. Santos et al. (2017) completed a literature analysis and review of Building Information Modelling literature published between 2005 and 2015. The authors focused on journal articles in the Web of Science database with an impact factor higher than 1.0 (measure of the frequency with which the "average article" in a journal has been cited in a particular year), as well as inclusion in the 100 most cited articles. The authors identified collaborative environments and interoperability, sustainable construction, BIM adoption and standardisation and BIM programming the main research trends. BIM training and education was found as one of the gaps in research with only three articles found in their sample.

In 2016 Badrinath, Chang and Hsieh investigated BIM education texts to create a conceptual categorisation of BIM educationalist and researchers' efforts in tertiary education systems. They created six categories:

1. Identifying needs for BIM in tertiary educational institutions
2. Identifying essential BIM skillsets for BIM education
3. Developing BIM educational frameworks
4. Developing BIM curricula
5. Experimenting with BIM courses
6. Developing strategies to overcome BIM educational issues.

The year before that Yalcinkaya and Singh (2015) completed a 'latent semantic analysis' to identify patterns and trends in BIM research between 2004 and 2014. Similarly, as to Santos et al. (2017) the authors found implementation and adoption, energy performance and simulation, and interoperability among the four most common themes. However, among the four principal research areas there was academy and industry training, but Santos et al. (2017) found BIM training and education to be one of the gaps in the literature. The controversy might be explained by the use of the 'latent semantic analysis' compared to the 'quantitative bibliometric analysis' by Santos et al. (2017). The difference might also be explained by the fact that Santos et al. (2017) only looked at journal articles, whilst Yalcinkaya and Singh (2015) also included certain conference proceedings in databases. Those particular proceedings were American Society of Civil Engineers (ASCE), Cumulative Index about publications in Computer Aided Architectural Design (CuminCAD), International Council for Building (CIB) library, Institute of Electrical and Electronics Engineers (IEEE) Xplore and Proquest. The ratio between the journal and conference articles was 525:450 in the study of Yalcinkaya and Singh (2015).

Abdirad and Dossick (2016) focused specifically on BIM curriculum design in AEC education. In addition to a selection of journals, they also included conference proceedings of ASCE and Associated Schools of Construction (ASC) in their literature review. The authors found out that nearly every issue in BIM curriculum design lends itself for further, more in-depth research, because only very few scholars reported details of their strategies or what the educational outcomes were. Abdirad's and Dossick's (2016) study included a sample of 59 articles and focused on curriculum design issues when integrating BIM into AEC courses answering the questions 1) What are the trends and context of existing research? 2) What are the findings, arguments, and claims in existing research?

There have been some earlier studies such as Barison and Santos (2010) 'Review and analysis of current strategies for planning a BIM curriculum' and Joannides et al. (2012) 'Implementation of Building Information Modeling into accredited programs in architecture and construction education'. These survey-based studies have focused on AEC schools in the United States of America (USA). Considering how much of the BIM literature and BIM

education literature has been published after these two studies (Yalcinkaya and Singh, 2015), there is a lot of new material to be investigated from the USA and elsewhere.

The literature studies mentioned earlier are useful in allocating relevant literature. The Abdirad and Dossick (2016) research for example was useful in terms of BIM integration issues and curriculum specifically, but they do not offer any deeper discussion on learning theories, or what learning approaches or methods are appropriate considering the nature of BIM.

Learning is broken down into three levels in this research: learning theories, learning approaches and learning methods. Learning theories are conceptual frameworks for learning describing how learning occurs. Although there is not just one agreed way to categorise and list these theories, most commonly behaviourism, cognitivism and constructivism are referred as the three major theories (Yilmaz, 2011). Behaviourism operates on a principle that behaviour is changed through external stimuli. The learner is receiving either positive or negative reinforcement, and behaviour can be explained through the external stimuli without the need to consider learner's consciousness. (Skinner, 1985) Cognitivism involves adding a thought process to the behaviour. The role of the learner is more active in seeking ways to understand and process new information. 'Learning' is seen as a change in knowledge and not just as change in behaviour (Arponen, 2013). Constructivism is sometimes considered as a branch of cognitivism. The constructivist view is based on the thinking that individuals construct new knowledge on the foundation of existing knowledge. Individual mental models differ from each other and are based on individual experiences, while cognitivists (and behaviourists) believe that knowledge is not dependent on the individual. In constructivism the role of the learner is an active information constructor (Karagiorgi and Symeou, 2005). Social constructivism is a variety of constructivism and demonstrates that knowledge is constructed through social interaction (D'Aprile et al., 2015). There is a fourth emerging learning theory called connectivism (Siemens, 2014). This theory is an attempt to revise and evolve the existing theories taking into consideration the shrinking half-life of knowledge and how we are connected to each other and knowledge through technology.

The second level (learning approaches) and third level (learning methods), have been used to better categorise the findings, but there is no consensus in educational literature, as to what these levels should be called or what they should entail.

The different learning approaches describe how the learner approaches the information. It is a set of principles and beliefs about the nature of learning and therefore relates closely to the learning theories. A very common way to separate the learning approaches from each other is to divide them into teacher-centred and learner-centred approaches (Giles et al., 2006). In addition, there are others such as collaborative, active and inquiry learning. The line between the different learning approaches is not always clear. Within one course usually one type dominates, but it can be a combination of many approaches.

Learning methods are more procedural, being a step by step organisation of learning, and relate closer to the instructional techniques. Examples of learning methods are project-based learning, problem-based learning and team-based learning (Oh, 2015; Soares et al., 2013). A certain learning method e.g. project-based learning can be categorised as an active learning approach or inquiry learning approach depending on how the learner approaches the information and it can be categorised under a learning theory, in the case of project-based learning either cognitivism or constructivism.

2. RESEARCH METHOD

2.1 Systematic literature review

The research method follows principles of systematic literature review as outlined by Pickering and Byrn (2014), who described a systematic literature review process as explicit and reproducible, quantitative, comprehensive and structured. The origin of systematic reviews is argued to be in medical sciences (Boell and Cezec-Kecmanovic, 2011) and they are widely used also in psychology and education (Borrego, Foster and Froyd, 2014, recently, in information sciences also (Boell and Cezec-Kecmanovic, 2011). While there are many advocates of systematic literature reviews (Borrego et al., 2014; Denyer and Tranfield, 2009; Pickering and Byrn, 2014), there are also opponents. The advocates argue that systematic reviews "follow transparent, methodical and reproducible procedures…selecting a collection of appropriate studies that will address the review question from the vast and rapidly increasing knowledge base and extracting trends, patterns, relationships, and the overall picture from the

collected studies" (Borrero et al., 2014, p. 46). The opponents such as Boell and Cezec-Kecmanovic (2011) highlight the limitations of systematic literature review, such as systematic reviews are only possible for a limited number of problems, in an attempt to capture all relevant literature. These benefits and limitations have been taken into consideration when planning this research method.

The purpose of the research was to assist the construction educators in their curricula and course development by identifying how and which literature addresses learning theories, approaches and methods. A systematic literature review was considered an appropriate research method as the researchers wanted to identify which learning theories, approaches and methods prevailed in the chosen sample. The limitations of the chosen method within this research context is discussed in more detail in the Limitations and Future Research chapter.

Pickering and Byrn (2014) have identified fifteen steps in undertaking a systematic literature review, including the steps for writing and submitting the review as an article. For this research the following steps have been selected and adopted: 1) Define topic, 2) formulate research question(s), 3) identify keywords, 4) identify and search databases, 5) read and assess publications, 6) structure data, 7) enter first 10% papers, 8) test and rewrite the categories, 9) enter bulk of papers, 10) produce and review summary tables, 11) evaluate key results and conclusions.

The main research question was "What is the Building Information Modelling (BIM) factor in reference to teaching and learning in architectural, engineering and construction (AEC) education?". The main question was broken down into three sub-questions:

1. What are the underlying learning theories?
2. What learning approaches are used?
3. What learning methods are used?

2.2 Database search

2.2.1 Keywords and years included

Some iteration rounds were needed to find the suitable selection of keywords for the database search. 'Boolean operator' "AND" was used to form a search pair of the words "Building Information Model", "Building Information Model(l)ing", "BIM", "Virtual Design and Construction", "Virtual Design", "Virtual Construction" or "VDC" AND "education", "learning", "teaching", "curriculum", "syllabus", "course", "programme" or "qualification" and their possible derivates. For some of the conference publications it was not possible to use advanced database search and the search was done manually conference by conference and article by article. The search was done by looking at titles, keywords, abstracts and subjects of the articles. Years included were 2002-2017 (March). This decision was based on Yalcinkaya and Singh (2015) database search, which found over 50 articles between 2004-2006 and Santos et al. (2017) search, which showed 4 articles for 2006. For these reasons, year 2002 was considered as a good starting point for the literature search in order not to miss any relevant literature.

2.2.2 Database identification

Both journal and peer reviewed conference articles were identified important for the research due to their quality assured nature and wide coverage of BIM education cases globally. Non-academic publications such as reports and white papers were excluded for the same reasons: uncertain quality assurance status and/or random and patchy coverage. Conference articles were identified as the key data, because they present a wide variety of case studies and therefore give a much wider and richer picture of the landscape of BIM education than the journal articles alone can give. Most research published as conference articles never end up in a journal. However, journal articles usually present completed research and include a wider background and findings information than conference articles. The journal selections were based on the relevancy, and quality assurance and international status of the publication. Association of Researchers in Construction Management (ARCOM) journal list was used as the main selection criteria for the peer reviewed journals. In addition, Professional Issues in Engineering Education and Practice journal was chosen due to the educational focus. This list was complemented by peer reviewed, international journals, which discuss computing in construction. Full list of journals is shown in Table 1.

TABLE 1: Journals selected, reason for selection and number of relevant articles in each.

Journal	Reason for selection	Number of relevant articles
Architectural Engineering and Design management	ARCOM journal list	0
Automation in Construction	Computing in construction focus	3
Computing in Civil Engineering	Computing in construction	2
Construction Economics and Building	ARCOM journal list	0
Construction Engineering and Management	ARCOM journal list	1
Construction Innovation	ARCOM journal list	0
Construction Management and Economics	ARCOM journal list	0
Engineering, Construction and Architectural Management	ARCOM journal list	0
Engineering, Design and Technology	ARCOM journal list	1
Information Technology in Construction	Computing in construction focus	4
International Journal of Construction Education and Research	ARCOM journal list	7
Professional Issues in Engineering Education and Practice	Educational focus	9
Total		**27**

The conferences were selected based on their relevancy in terms of the research topic, and their international and quality assurance status. The conferences selected were:

- Association of Researchers in Construction Management (ARCOM)
- Associated Schools of Construction (ASC)
- American Society for Engineering Education (ASEE)
- Australasian Universities Building Education Association (AUBEA)
- BIM Academic Forum UK (BAF)
- BIM Academic Symposium US (BAS)
- International Council for Building Working Commission 78 Information Technology for Construction (CIB W78)
- International Council for Building Working Commission 89 Education in the Built Environment (CIB W89)
- Royal Institute of Chartered Surveyors Construction, Building and Real Estate Research Conference (RICS COBRA)

Where a certain 'conference series' was identified as relevant to this review, the following approaches were taken to locate the proceedings:

- Internet search for proceedings repository for conference series
- Internet search of conference organisation, host and publisher websites for individual conference proceedings
- Library search for hard copies of individual conference proceedings
- Query to academic and industry contacts for access to hard copy or electronic copy of individual conference proceedings

Table 2 shows the access to the conference proceedings and how many relevant articles, based on the abstracts, were identified in each. Despite this thorough search, only patchy coverage was found for many of them.

TABLE 2: Relevant conferences identified, access to proceedings and number of relevant articles in each.

	ARCOM	ASC	ASEE	AUBEA	BAF UK	BAS US	CIB W078	CIB W089	RICS COBRA	Per year
2002	0	0	0	X	-	-	0	0	X	0
2003	0	0	0	0	-	-	0	0	X	0
2004	0	0	0	X	-	-	0	0	X	0
2005	0	0	0	X	-	-	0	0	X	0
2006	0	1	0	0	-	-	0	0	X	1
2007	0	3	3	X	-	X	0	0	X	6
2008	0	2	1	1	-	X	0	0	X	4
2009	0	3	0	X	-	X	0	0	X	3
2010	0	2	2	X	-	X	3	0	X	7
2011	0	2	2	X	-	X	1	1	X	6
2012	0	2	10	X	1	X	0	0	X	13
2013	0	2	4	5	X	6	0	0	X	17
2014	0	2	2	-	X	7	0	0	X	11
2015	1	2	5	*	X	23	1	1	5	38
2016	0	1	2	1	5	16	0	0	2	27
2017	-	-	-	-	-	10	-	-	-	10
Total	**1**	**22**	**31**	**7**	**6**	**62**	**5**	**2**	**7**	**143**

'X' = no access to the conference material

'-' = no conference organised

'*' = in 2015 AUBEA was organised together with RICS-COBRA, all relevant articles included in RICS column

Abstracts of all articles were read and assessed against the topic and the research question, and irrelevant articles were excluded from the database. After this exclusion, the total amount of articles to be analysed in this review was 170, including 27 journal articles and 143 conference articles.

Quantitative analysis of the data (articles) was conducted to establish out the trends in the data for background information, to assist in the further analysis of the data and to provide a database for future research. For this the publication years, research methods, data collection locations and discipline information (architecture, engineering, construction or other) was analysed. The analysis sought to establish whether there were authors who had published more than one article, and if these articles were part of the same research or were unique. These results are discussed as part of 'Findings'.

As the focus of the research was to investigate the learning theories, approaches and methods used in BIM education, the case studies were chosen as the focus of more in-depth research to look at a wide variety of separate and different modules, courses and programme development, and delivery samples. In total there were 129 case studies. Based on the title, keywords and abstracts, the case studies were allocated into three different categories in terms of their relevancy for this research: 1) relevant, 2) possibly relevant, 3) not relevant.

In category 1 there were originally 104 case studies, which were then analysed in depth to collect information about learning theories, approaches, methods, and even delivery and assessment methods (discussion of the latter is excluded from this article).

Inductive data analysis was used to find answers to the questions:

1. What are the underlying learning theories?
2. What learning approaches are used?
3. What learning methods are used?

The inductive analysis approach to qualitative data, basically condenses extensive and varied data into a brief summary format, whilst establishing links between the research objectives and the findings that are transparent and defensible (Thomas, 2006). "The data analysis is guided by the evaluation objectives, which identify domains and topics to be investigated. The analysis is carried out through multiple readings and interpretations of the data, the inductive component. The findings arise directly from the analysis of the data, not from priori expectations or models." (Thomas, 2006).

Seven articles were allocated to category 2 after the detailed analysis, which revealed that there was not discussion on learning theories, approaches or methods in the context of the case studies.

In category 2, there were originally 25 case studies, which were also read in full to see if there were relevant findings in the full text and would therefore need to be included in the category 1. One article was found to have relevant findings and was included in category 1.

For category 3 case studies, it was already relatively clear after reading the abstract that they were not necessarily relevant for this research, but regardless the full text was searched for indications of learning theory, approach and methods to confirm that this was the case. Although the original search words were included either in the title, abstract or keywords of these articles, these articles:

1. did not discuss BIM, but some other form of digital design and construction,
2. had an industry and not educational focus,
3. didn't have any discussion on pedagogics or
4. they were not case studies.

No articles were found within category 3, that would have added value to this research.

3. FINDINGS

The background data includes 170 articles. The full article list is available in Appendix A. The publication year, data collection location, discipline and research method are discussed. Journal and conference articles are looked at separately for any anomalies between the two types. Later the case studies are separated from the rest of the data and further analysed to answer the research questions.

3.1 Background data

The first article published was in 2006 in Associated Schools of Construction conference proceedings, where Gier et al. (2006) discussed whether Building Information Models could be used to teach productivity analysis to construction management students. In 2007 the number of relevant articles increased to seven. Most of the journal articles have been published in 2012 and 2013, 6 journal articles each year, whilst in the conference articles there was a peak of 41 articles in 2015 (Fig. 1).

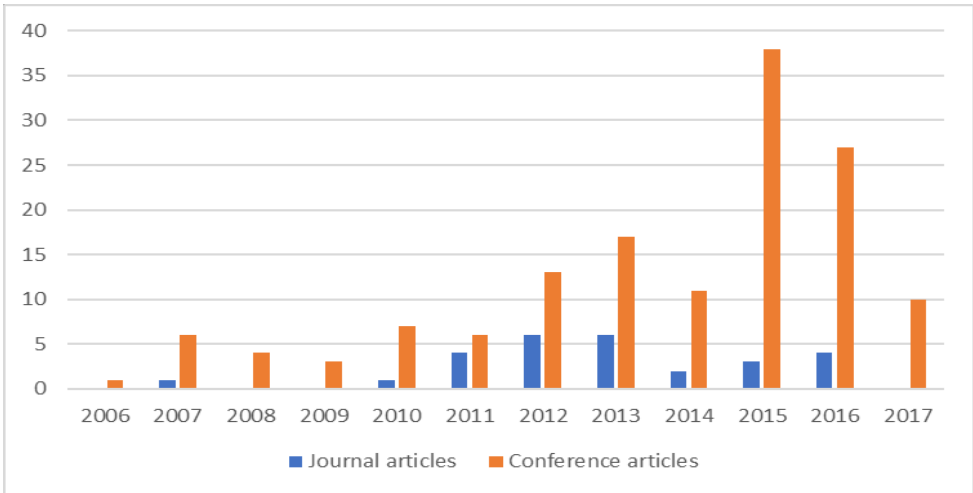

FIG. 1: Number of journal and conference articles published each year.

Most of the articles included are based on data collected in USA. This is partly due to the selection criteria and availability of proceedings of relevant conferences. From the nine conference series selected, three were in USA. From the two BIM specific conferences the BIM Academic Symposium USA is almost purely educational, whilst the BIM Academic Forum UK is about BIM research in general. 65 out of 144 conference articles included were published in BIM Academic Symposium USA. In addition, the availability of the proceedings of the USA-based conference proceedings was better, compared to the others.

However, USA is the origin of the data for most of the journal articles with 21 out of 27 had data either fully or partly collected in USA and therefore it is relatively safe to say that most of the published research about BIM education is done in USA regardless of the bias of USA-based conferences. When it comes to other countries, Australia and New Zealand (ANZ), and UK looked strong in terms of the number of conference articles, but not when it comes to the number of the journal articles. (Fig. 2).

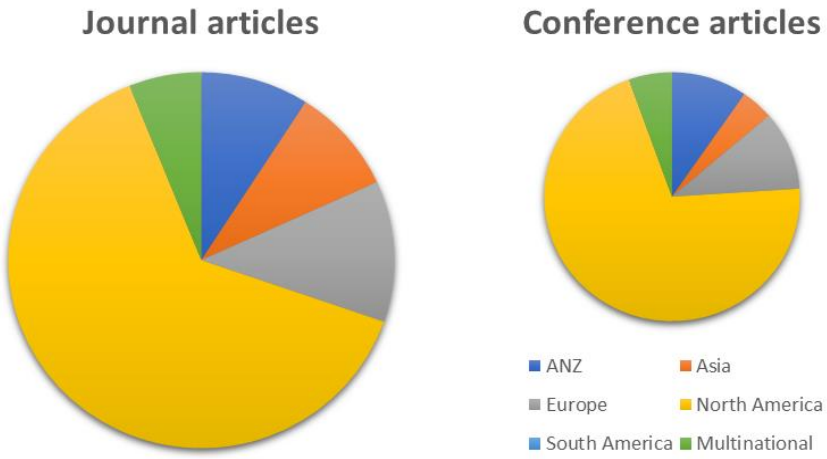

FIG. 2: Data collection location

Most of the research was done within the construction management discipline (87/171, Fig. 3). 34 studies were about all of the AEC disciplines or the AECO (O=operation), 25 about architecture, 20 engineering and the rest concerned more detailed subject areas such as sustainability or quantity surveying or remained undefined. This aligns roughly with the findings by Adbirad and Dossick (2016) where 65% of their sample entailed civil engineering and construction management disciplines, and 35% architecture and building science related. There was no significant change around frequency when it came to the timeline i.e. all disciplines were equally popular as a research topic from 2006 to early 2017. The origin of BIM use in the industry was in the design disciplines. However, the use of BIM by contractors has now caught up with BIM use by designers. (McGraw Hill Construction, 2014) This same pattern cannot is not evident in the BIM education literature.

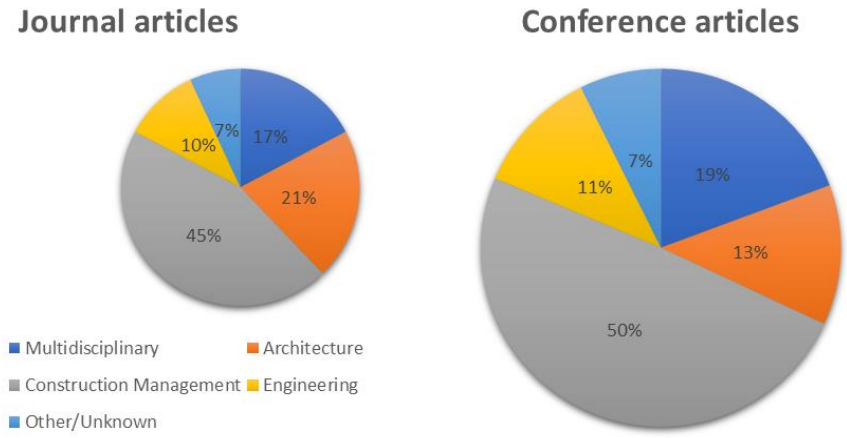

FIG. 3: Discipline information

The selection method, of selecting not only journals but also conferences resulted in a positive outcome in terms of the number of case studies found. Case study was the most commonly used research method with 128 studies (70%, Fig. 4). The proportion of case studies was 10% higher than in the literature review completed by Abdirad and Dossick (2016). Survey was the second most popular with 14%, often as a questionnaire and in some cases as an interview. Among the other methods were prototype and tool development, and literature and document analysis. In several articles the research method was not discussed, but the method was somewhat implicit when reading the full text. In four articles there was no mention about the research method used, nor was the research method implicit in the text. Three of these four articles read more like viewpoints or discussion articles than research articles.

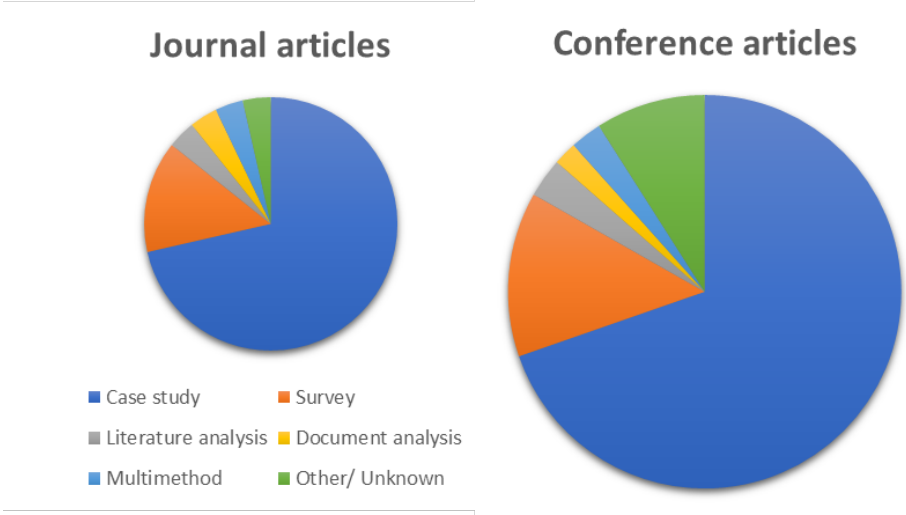

FIG. 4: Research methods' popularity.

3.2 Inductive data analysis

The case studies were analysed to answer the research questions regarding learning theories, learning approaches and learning methods used in BIM education. If these were mentioned only in the literature review part of the article, but no connections were made with the case study itself, this was not recorded as findings. Only explicit discussion of pedagogics was recorded although it was acknowledged that pedagogics existed also in implicit form in the research. The findings of the inductive analysis will be discussed further in the following sub-chapters. Due to the large amount of data, a full table with reference information and notes on learning theory, approaches and methods is included as Appendix A.

3.2.1 Learning theories

There was very little in-depth, explicit discussion in the case studies on the learning theories such as behaviourism, cognitivism and (social) constructivism. Some referred to the theories in the literature section, but in most of these articles there was no discussion on the learning theories when describing the case itself or when discussing the findings. As an example Martin et al. (2015) discussed constructivist learning theories and active learning approaches in their literature review section, but there were no explicit connections drawn between this discussion and the BIM education case study that they described. In some case studies it was implicit rather than explicit that a certain learning theory was underpinning the learning approaches and methods. As an example Gier and Pe (2007) explained that "all learning builds on what has gone before", which aligns with a constructivist learning theory.

Bloom's Taxonomy as a cognitive domain was mentioned by multiple authors. Ahn et al. (2013) applied Bloom's Taxonomy and categorised the learning objectives of their 'BIM in construction management' course to cognitive, affective and psychomotor ones. Ghosh et al. (2015) studied 'vertically integrated BIM curriculum in an undergraduate construction management programme' and developed a set of BIM learning objectives based on Bloom's taxonomy. Barison and Santos (2010) for instance, argued that "BIM allows the students to reach the peak of Bloom's Taxonomy evaluation level, in terms of intellectual behaviour". Sacks and Pikas (2013) compiled 39 topics required for BIM competence in construction management, which was not a case study and therefore not

included in this research. However, Pikas et al. (2013) continued from there by developing and testing a set of guidelines for the BIM integration. Bloom's cognitive domain was used as the basis for planning and assessing students' levels of achievement. Shelbourn et al. (2016a; 2016b) have written two conference articles published in 2016 in BIM Academic Symposium, Orlando, Florida and RICS COBRA. Both articles discussed the Illustration, Manipulation, Application and Collaboration (IMAC) framework development for BIM education. The IMAC framework was partly influenced by Bloom's taxonomy as described by Shelbourn et al. (2016b) "As the IMAC framework aims to assist development of both technical (I.T & discipline-specific) & interpersonal (collaborative & teamwork) skills, it straddles the cognitive & affective domains of Bloom's Taxonomy" (p. 47).

Multiple authors used the word 'cognitive' without further exploring learning theories. For example McCuen and Pober (2013) mentioned software skills and Bozogly (2017), Xie and Boden-McGill (2014), and Xie et al. (2017) problem-solving skills as 'cognitive' tools. Mathews (2013) mentions software itself as a cognitive tool. Ghosh (2012) and Ghosh et al. (2013) discussed cognitive learning indicators such as knowledge, application and evaluation. Glick et al. (2012) mentioned cognitive spatial abilities. Yan et al. (2011) added into that visual cognitions in a design-think process. Udeaja and Aziz (2015) cited Galarneau and Zibit (2007, p. 81) "to flex their cognitive and social muscle in an environment where anything is possible and experimentation is safe, permissible and desirable" when describing their multidisciplinary collaboration environment. Becerik-Gerber, Ku and Jazizadeh (2012) used "team presentations and peer evaluations to keep students cognitively active during the class" (p. 236). Arnett and Quadrato (2012) argued that through using BIM the students will reach higher levels of cognitive achievement.

Vlasek (2016) chose a constructivist approach for the development of a BIM-enabled undergraduate construction management programme. The author suggested immersing the construction curriculum into a BIM-enabled environment for visualisation, communication and collaboration, and saw it as a socio-technical process. Boon and Prigg (2011) discussed constructivist theory from the aspects of social constructivism, which included the need to interact with other people, and scaffolding, which is supporting the learner during the learning process. This discussion was used to create an ideal, supported process for learning construction subjects. Mathews' (2013) research on 'BIM collaboration in student architectural technologist learning' was based on constructivist learning environment created using BIM applications, studio setting and real world group project. In the IMAC framework by Shelbourn et al. (2016a; 2016b) constructivism and mastery learning were used as a theoretical base for the approach. Whereas constructivism is explained as students constructing knowledge based on their learning experiences, in mastery learning students are required to master a simpler subject before they move on to the next, more complex subject.

Peterson et al. (2011), and Boon and Prigg (2011) were the only authors discussing behaviourism, the latter disregarding it as their learning approach, the former suggesting combining cognitive and behavioural approaches by "developing complex real-world situations for learning integrated project management", where formal project management theories would be applied through role-play in simulated environments (p. 116).

Irizarry et al. (2013) categorised the learning theories into constructivism, holistic learning, action learning, reinforcement and sensory stimulation theory. It is unusual to combine learning theories and approaches under the common heading of learning theories. The reinforcement and sensory stimulation theory was chosen for their research in 'Human computer interactions modes for construction education applications: experimenting with small format interactive displays'. Reinforcement and sensory stimulation theories are also known as behaviourism (Skinner, 1985). Holistic learning is a form of constructivist learning, because it emphasises constructing information (Tangney, 2014). Action learning on the other hand is a related concept to active and problem-based learning, whereas learning is achieved through problem-solving (Weltman, 2007). In this study action learning was seen as a learning approach, similar to active learning and not a learning theory.

Cognitivism, constructivism and social constructivism, and behaviourism were mentioned as underpinning learning theories in BIM education. Cognitivism was mentioned most often in the literature, implicitly taking a form of Bloom's taxonomy used to structure and create learning objectives, or by describing cognitive skills related to software, problem-solving, and visual and spatial thinking. Constructivism, in the form of social constructivism, although only mentioned couple of times, was discussed more in depth as a base for learning approaches and methods than behaviourism or cognitivism. Behaviourism was mentioned only twice in conjunction with cognitivism.

3.2.2 Learning approaches

Terms within the learning approaches that arose were: collaborative learning (including cross-/inter-/multi-disciplinary learning), active/action learning and experiential learning being the three most popular (Fig. 5). Cooperative learning, experimental learning, flipped learning, inquiry learning, mastery learning, role-based learning, universal design for learning and work-based learning were also discussed. See Appendix A for detailed information article by article.

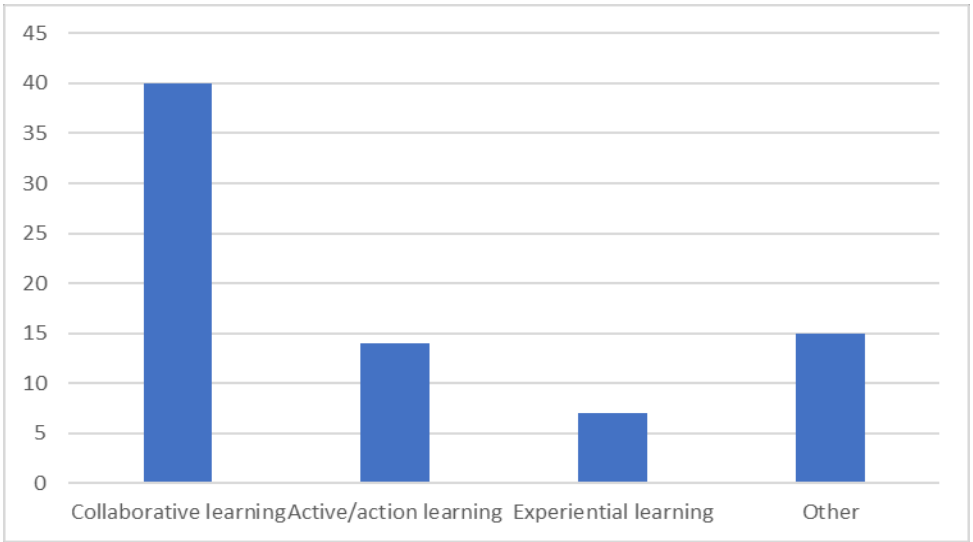

FIG. 5: Popularity of different learning approaches. The number on the left represents the number of case studies, where the learning approach was used.

Collaborative learning was the most commonly mentioned learning approach, some forms of it were used in 40 case studies. There were different variations of this:

- collaborative design (Plume and Mitchell, 2007),
- collaborative course project (Pikas et al., 2013),
- collaborative team-learning (Solnosky et al., 2013) and
- multi-disciplinary collaboration by Udeaja and Aziz (2015) to name a few.

Many authors for example Kelly et al. (2016), Kovacic et al. (2016), McCuen and Pober (2015), Plume and Mitchell (2007), Shelbourn et al. (2016a), Shelbourn et al. (2016b), Udeaja and Aziz (2015) described a use of a multi-disciplinary approach to collaborative learning, where students from two or more disciplines work together on the course.

Active/action learning was the second most popular learning approach being applied in 14 case studies. Interactive e-learning was also included in this category. In many cases the approaches intertwined with each other forming a combination of two or more approaches for example Becerik-Gerber et al. (2012) used a collaborative, experimental, role-based, active learning, Richards and Clevenger (Richards and Clevenger, 2011; Richards and Clevenger, 2012) discussed interactive, collaborative e-learning in two separate articles. Hore et al. (2016) had an active e-learning (virtual classroom and online platform) approach. Gao and Dakota (2012) used active, cooperative learning. Irizarry et al. (2013) implemented active and visual learning through sensory stimulation theory, which refers to behaviouristic learning theory. Kamardeen (2013) and Peterson et al. (2011) wrote purely on active learning. Martin et al. (2015) used active, experiential learning arranging full day BIM workshops with the industry for the students to work in. Udeaja and Aziz (2015) described their approach as multidisciplinary collaboration and active learning. Xie et al. (2017) used inquiry, collaborative and active learning.

Experiential learning was mentioned in seven case studies. Bozogly (2017) and Bozogly et al. (2016) referred to experiential learning in two separate articles. The authors used a definition from Felicia (2011) to describe experiential learning as learning through reflection on doing. Burr (2009) used fairly traditional delivery and

assessment methods such as lectures, readings, assignments and tests, but had a learner-centred course design with experiential learning. Gier and Pe (2007) used experiential learning where they utilised BIM for visualisation and simulation. Hogle (2013) used BIM as a problem-based learning tool. As mentioned above, Martin et al. (2015) had a combination of active and experiential learning. McCuen and Pober (2013) also used a combination, but selected collaborative and experiential learning to facilitate integrated design. Wu and Hyatt (2016) had students working on a tiny house project to achieve experiential learning.

Other approaches: cooperative learning, experimental learning, flipped learning, inquiry learning, mastery learning, role-based learning, universal design for learning and work-based learning were all mentioned in one or two separate articles.

The approaches discussed earlier are all learner-centred approaches, but there were many studies, where it was not clearly indicated what the learning approach was and whether it was teacher-centred or learner-centred. In many cases it was possible to determine this by looking at the learning methods or the delivery and assessment methods. In most cases the learning approach was either relatively purely learner-centred or at least partly learner-centred. Traditional purely teacher-centred learning approaches were in a minority. If a traditional approach was used, it was not explicitly discussed in the article. Traditional delivery and assessment methods such as lectures and exams were also used with learner-centred approaches together with other types of learning methods.

The learning approaches were further divided into learning methods, which will be discussed in the next subchapter.

3.2.3 Learning methods

Within the learning approaches several different learning methods were identified: project-based, problem-based and process-based amongst the most commonly used. Virtual learning, e-learning and blended learning, Integrated Project Delivery (IPD), BIM-based methods, team-based learning, anchored instructional model, student leadership, case-based learning, role play, scaffolded learning, structured discovery learning and gaming were also mentioned. Refer Appendix A for detailed information article by article.

Project-based learning as described by Helle et al. (2006) in their article 'Project-based learning in post-secondary education –theory, practice and rubber sling shots' distinguished three different models for project-based learning: project exercise, project component and project orientation. In the 'project exercise' the project is just a small part of the course, subject of an exercise, whilst in the 'project orientation' the project is the central part of the curriculum. Project-based learning in some form was used in 38 separate case studies, authors reporting on the same case study in two separate articles. In some cases the project was a live real-world project (Inguva et al., 2014; McCuen and Pober, 2015; Udeaja and Aziz, 2015; Wu and Hyatt, 2016), but in most cases a simulated one either a fully fictional or a recreation of an already finished project. Becerik-Gerber et al. (2012), Matthews (2013), McCuen and Pober (2013), Salazar and Gomez-Lara (2013) and Udeaja and Aziz (2015) used a combination of project-based and problem-based method. Project-based learning mapped in most cases under collaborative learning approach, which is natural in construction context, where team work is required.

Problem-based learning was discussed in 13 separate case studies. The same way as project-based learning, problem-based learning introduces authentic tasks to students. The difference is, that when project-based learning is directed to the application of knowledge, problem-based learning is more directed to the acquisition of knowledge (Helle et al., 2006). Kamardeen (2013) used an anchored instructional model with problem-based learning. In this model students were presented with real-world construction management problems and supported to solve the problems by using BIM. Monson (2013) and Monson et al. (2015) used flipped learning approach with problem-based learning to learn BIM related software. Each software was learned via problems that were limited in range and scope.

Process-based learning was identified by Ahn et al. (2013) as "process-based curriculum i.e. activity-based learning" (p. 295) and collaborative learning as their major constructs and considerations when characterising their course 'BIM in Construction Management'. Leite (2015; 2016) continued the work of Wang and Leite (2014), who introduced 'Process oriented approach of teaching Building Information Modelling in construction management'. Instead of focusing on the end product, process-based learning focuses, as the name implies, on the process of creating the product instead (Wang and Leite, 2014). Liu and Berumen (2016) also reported on process focus instead of product focus.

Virtual learning environments were discussed by Brewer et al. (2015), who exported a Building Information Model into a game engine to develop and offer virtual site visits. Vogt (2012) offered an introductory course to Revit online with recorded lectures, step by step instructions for the software use, quizzes and online message board. Richards' and Clevenger's (2011) online environment consisted of interactive, narrated animations, where one was for guidance and two for assessments. This module was created to support classroom delivery in structural engineering and construction management disciplines. This work was further expanded into a journal article by the same authors in 2012 (Richards and Clevenger, 2012).

"Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction." as defined by American Institute of Architects (2007). IPD was used as a learning method by Setterfield et al. (2010), Solnosky et al. (2013), Shelbourne et al. (2016a; 2016b), and Xie and Boden-McGill (2017).

Some authors described their delivery method through BIM: BIM-based virtual learning environment as described above (Brewer et al., 2015), BIM-based teaching approach, where BIM was used as a virtual environment to learn sustainability themes (Kim, 2015), and BIM-supported project-based learning by Peterson et al. (2011), where BIM was used to develop more realistic project-based assignments.

The learning methods discussed herein support learner-centred learning approaches There are also indications of a requirement for more flexible delivery methods such as e-learning. BIM has been found to be useful when creating the project, problem and process context, and the virtual e-learning environment. BIM has also been used as a solution to solve problems.

4. SUMMARY AND CONCLUSIONS

This research systematically reviewed and created significant information on authors, research methods, data collection location and discipline information involving BIM education literature. The aim of this research was to help architecture, construction and engineering (AEC) educators in curricula and course development, but also to make the results of future research on BIM education more profound. The results of future research could be connected to this wide body of literature, which addresses learning theories, approaches and methods. Most importantly, this research set out to answer the question, "What is the BIM factor in AEC education?". The chosen method was a systematic literature review to collect quantitative background data, and then investigate through inductive analysis the patterns of learning theories, approaches and methods in the case studies identified.

Although most AEC educators have completed pedagogical studies, the level of study varies depending on the requirements of each institute, and the interest of the individuals. Educators seem to be reluctant to step inside the territory of learning theories and learning approaches. It also might be that the publishers of discipline specific journals and conferences are reluctant to publish strongly pedagogical articles and therefore the discussion of learning theories within the sample of 170 articles was limited. Most of the discussion in the articles was at the implicit level, using Bloom's taxonomy to structure the learning objectives or describing certain cognitive skills such as visual and spatial thinking instead of discussing the learning theories explicitly.

There was more discussion on learning approaches and methods than on learning theories, although similarly as with the learning theories, part of it was implicit rather than explicit and in-depth discussion was limited. Learner-centred methods such as collaborative and active learning approaches with project- and problem-based learning methods were popular. The nature of the construction industry lends itself to project-based learning, but it is evident that BIM has both encouraged and enabled the use of realistic project simulation and problem setting. The nature of BIM as a collaborative way of working has also pushed the AEC educators to trial models, where students from two or more disciplines work together on either simulated or real-life projects. Educators approach BIM in several different ways, ranging from software-centric view, to being more focused on the process, or as an add-on topic, or as a new way of working to achieve the goals of a construction project.

5. LIMITATIONS AND FUTURE RESEARCH

Limitations of this research relate first of all to the sample. Selected publications were all AEC discipline specific. Just reading purely educational publications could have resulted in findings that only involved in-depth discussion about learning theories. Availability of pertinent conference proceedings was patchy, and some relevant articles might also have been missed. In addition, the line between the relevancy of categories was very fine, especially in terms of what was considered explicit, and implicit (implicit was disregarded from this research). As an example, if a project assignment was mentioned and described, it was investigated to determine the actual form of project-based learning. In some cases this was evident, in some cases it was not.

Delivery and assessment methods could be the next step in this research, to give more practical direction to BIM educators in their course planning and delivery. Future research could widen the literature base of this research by looking into purely educational publications for more discussion specifically on learning theories in the context of BIM education. Alternatively, future research could take a closer look at the nature of BIM and what learning approaches and methods are a natural match. A further research area could be industry training for BIM, as although there is a good amount of literature on BIM education in the tertiary environment, the literature on BIM industry training is still very limited.

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7. REFERENCES

Abdirad, H., & Dossick, C.S. (2016). BIM curriculum design in architecture, engineering and construction education: A systematic review. *Information Technology in Construction (ITcon)*, *21*(21), 250271. Retrieved from http://www.itcon.org/2016/17

Ahn, Y. H., Cho, C., & Lee, N. (2013). Building information modeling: Systematic course development for undergraduate construction students. *Professional Issues in Engineering Education and Practice*, *139*(8), 290-300.

American Institute of Architects (2007). *Integrated Project delivery: A guide.* American Institute of Architects. Retrieved from https://info.aia.org/SiteObjects/files/IPD_Guide_2007.pdf

Arnett, K. P., & Quadrato, C. E. (2012, June). Building Information Modeling: Design instruction by integration into an undergraduate curriculum. In *Proceedings of the ASEE Annual Conference and Exposition, Conference*. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84864982920&partnerID=tZOtx3y1

Arponen, V. P. (2013). The extent of cognitivism. *History of the Human Sciences*, *26*(5), 3-21. http://doi: 10.1177/0952695113500778

Badrinath, A. C., Chang, Y-T and Hsieh, S-H. (2016). A review of tertiary BIM education for advanced engineering communication with visualization. *Visualization in Engineering, 4*(9), 2-17. http://doi: 10.1186/s40327-016-0038-6

Barison, M. B., & Santos, E. T. (2010, November). Review and analysis of current strategies for planning a BIM curriculum. In *Proceedings of the CIB W78 2010: 27th International Conference* (pp. 16-18). Cairo, Egypt. Retrieved from http://itc.scix.net/data/works/att/w78-2010-83.pdf.

Becerik-Gerber, B., Ku, K., & Jazizadeh, F. (2012). BIM-enabled virtual and collaborative construction engineering and management. *Professional Issues in Engineering Education and Practice*, *138*(July), 234-245.

Boell, S. K., & Cecez-Kecmanovic, D. (2011). Are systematic reviews better, less biased and of higher quality? In *Proceedings of the European Conference on Information Systems*. Retrieved from http://aisel.aisnet.org/ecis2011/223

Boon, J., & Prigg, C. (2011, June). Releasing the potential of BIM in construction education. In *Proceedings of the CIB, Management and Innovation for a Sustainable Built Environment*. Amsterdam, Netherlands.

Borrego, M. , Foster, M. J. and Froyd, J. E. (2014). Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields. *Journal of Engineering Education, 103*, 45-76. http://doi:10.1002/jee.20038

Bozogly, J., Dos Santos, A., Santos, D. C. V., Dias, F. C. B. B., Junios, N. S., Manicoba, R. P., & Bottacin, W. E. (2016, April). Collaboration with BIM: An experiential learning case. In *Proceedings of the BIM Academic Symposium*. Orlando, Florida.

Bozogly, J. (2017, April). Performance and optimization learning models for BIM education. In *Proceedings of the BIM Academic Symposium*. Boston, Massachusetts.

Brewer, G., Smith, S. P., & Maund, K. (2015). Towards BIM-based educational environments using game engine technology. In *Proceedings of the RICS COBRA 2015*. Sydney, Australia.

Burr, K. L. (2009, April). Creative course design: A study in student-centered course development for a sustainable building/BIM class. In *Proceedings of the ASC Annual International Conference*, Gainesville, Florida.

Clevenger, C. M., Ozbek, M. E., Glick, S.,& Porter D. (2010). Integrating BIM into construction management education. *EcoBuild Proceedings of the BIM-Related Academic Workshop*.

D'Aprile G., Di Bitonto P., De Asmundis R., Ulloa Severino A. (2015). Social, constructivist and informal learning processes: Together on the edge for designing digital game-based learning environments. *Journal of e-Learning and Knowledge Society*, *11*(3), 23-39.

Demidroven, J. (2015). An interdisciplinary approach to integrate BIM in the construction management and engineering curriculum. In *Proceedings of the 9th BIM Academic Symposium & Job Task Analysis Review*, Washington, DC.

Denyer, D., & Tranfield, D. (2009). *Producing a systematic review.* In D. A. Buchanan & A. Bryman (Eds.), The Sage handbook of organizational research methods (pp. 671-689). Thousand Oaks, CA: Sage Publications Ltd.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook a guide to building information modeling for owners, managers, designers, engineers and contractors* (2nd ed.). Hoboken: Wiley.

Felicia, P. (2011). *Handbook of research on improving learning and motivation*. Hershey, PA: IGI Global.

Forsythe, P., Jupp, J., & Sawhney. A. (2013). Building Information Modelling in Tertiary Construction Project Management Education: A Programme-wide Implementation Strategy. *Journal for Education in the Built Environment, 8*(1), 16-34, http://doi:10.11120/jebe.2013.00003

Galarneau, L., & Zibit, M. (2007). Online games for 21st century skills. In G. Conole and M. Oliver (Eds), *Contemporary perspectives in e-learning research: Themes, methods and impact on practice*. London, UK: Routledge.

Gao, Z. J., & Dakota, N. (2012, June). Integrating Building Information Modeling (BIM) in teaching project scheduling and control. In *Proceedings of the ASEE Annual Conference & Exposition*. San Antonio, Texas.

Ghosh, A. (2012). Virtual Construction and Collaboration Lab: Setting a new paradigm for BIM education. In *Proceedings of the ASEE Annual Conference & Exposition.* San Antonio, Texas.

Ghosh, A., Parrish, K., & Chasey, A.D. (2013, June). From BIM to collaboration: A proposed integrated construction curriculum. In *Proceedings of the ASEE Annual Conference and Exposition.* Atlanta, Georgia.

Ghosh, A., Parrish, K., & Chasey, A.D. (2015). Implementing a vertically integrated BIM curriculum in an undergraduate construction management program. *International Journal of Construction Education and Research*, *11*(2), 12-139.

Gier, D.M. (2015). Integrating Building Information Modeling (BIM) into core courses within a curriculum : A case study. *International Journal of Engineering Research and General Science, 3*(1), pp. 528–543.

Gier, D. M., Loftin, E. & Coogan, K. (2006, April). Are Building Information Models effective for teaching productivity analysis? In *Proceedings of the ASC Annual International Conference*. Fort Collings, Colorado.

Gier, D. M., & Pe, M. S. (2007, April). Does learning Building Information Modeling improve the plan reading skills of construction management students? In *Proceedings of the ASC Annual International Conference.* Flagstaff, Arizona. Retrieved from http://ascpro0.ascweb.org/archives/2007/CEUE146002007.pdf.

Giles, J., Ryan, D. A., Belliveau, G., de Freitas, E., & Casey, R. (2006). Teaching style and learning in a quantitative classroom. *Active Learning in Higher Education*, *7*(3), 213-225. https://doi: 0.1177/1469787406069055

Glick, S., Porte, D., & Smith, C. (2012). Student visualization: Using 3-D models in undergraduate construction management education. *International Journal of Construction Education and Research*, *8*(1), 26-46.

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-Based Learning in post-secondary education – theory, practice and rubber sling shots. *Higher Education*, *51*(2), 287-314. http://doi:10.1007/s10734-004-6386-5

Hogle, L. G. (2013, January). Industry and academia: The perfect partnership. In *Proceedings of the BIM Academic Symposium*. Washington, DC.

Hore, A. V., Scott, L., West, R., & Tibaut, A. (2016, April). Benefits of inter-institutional collaboration in the delivery of BIM education in Ireland: Reflections of an Irish masters programme. In *Proceedings of the BIM Academic Symposium*. Orlando, Florida.

Inguva, G., Leewis, A., Clevenger, C. M., & Valdes-Vasques, R. (2014, January). Teaching modules documenting the development of a center for VDC. *In Proceedings of the BIM Academic Symposium* (pp. 1-100). Washington, DC.

Irizarry, J., Gheisari, M., Zolfagharian, S., & Meadati, P. (2013). Human computer interaction modes for construction education applications: Experimenting with small format interactive displays. *International Journal of Construction Education and Research*, *9*(2), 83-101. http://doi: 10.1080/15578771.2012.720356

Joannides, M. M., Olbina, S., & Issa, R. R. A. (2012). Implementation of Building Information Modeling into accredited programs in architecture and construction education. *International Journal of Construction Education and Research*, *8*(2), 83-100.

Johnson, B. T., & Gunderson, D. E. (2009). Educating students concerning recent trends in AEC: A survey of ASC member programs. In *Proceedings of the 45th ASC Annual International Conference*. Gainesville, Florida.

Jung, W., & Lee, G. (2015). The Status of BIM Adoption on Six Continents. *International Journal of Civil, Structural, Construction and Architectural Engineering, 9*(5), 512–516.

Kamardeen, I. (2013, November). Anchored BIM instructional model for construction management education. In *Proceedings of the Australasian Universities Building Education Association Conference.* Auckland, New Zealand.

Karagiorgi, Y., & Symeou, L. (2005). Translating constructivism into instructional design: Potential and limitations constructivism – An overview of the learning theory. *Educational Technology & Society*, *8*,17-27.

Kelly, M., Costello, M., Nicholson, G., & O'Connor, J. (2016, September). Utilising an academic-industry collaborative partnership to inform the implementation of a BIM strategy in a higher education institute in Ireland. In *Proceedings of the First International Conference of the BIM Academic Forum*, Glasgow, Scotland.

Kim, J. (2015, June). Closing achievement gaps using the green-BIM teaching method in construction education curriculum. In *Proceedings of the ASEE Annual Conference & Exposition*. Seattle, Washington.

Kiviniemi, A. (2013). Challenges and opportunities in the BIM education –How to include BIM in the future curricula of AEC professionals. BIM Academic Workshop 2013.

Kovacic, I., Flizmoser, M., Vasilescu, D., & Oberwinter, L. (2016, September). Challenges in teaching integrated BIM-supported building design. In *Proceedings of the First International Conference of the BIM Academic Forum*. Glasgow, Scotland.

Lee, N., & Dossick, C.S. (2012). Leveraging Building Information Modeling technology in construction engineering and management education. In *119th ASEE Annual Conference and Exposition, June 10, 2012 - June 13, 2012*.

Lee, N., & Hollar, D.A., (2013). Probing BIM education in construction engineering and management programs using industry perceptions. In *Proceedings of the 49th ASC Annual International Conference*. San Luis Obispo, CA.

Leite, F. (2015, April). An example project-based course on BIM for construction management. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.

Leite, F. (2016). Project-based learning in a Building Information Modeling for construction management course. *Information Technology in Construction*, *21*, 164-176.

Liu, R., & Berumen, L. (2016, April). Digital project coordination experience in undergraduate construction education. In *Proceedings of the BIM Academic Symposium*. Orlando, Florida.

Macdonald, J. A., & Mills, J. E. (2011). The potential of BIM to facilitate collaborative AEC Education. In *Proceedings of the ASEE Annual Conference & Exposition*. Vancouver, B.C.

Martin, D.W., Plugge, P.W., & Socha, D. (2015, April). BIM, 4D scheduling, active learning, and industry collaboration: Filling the CM program void. In *Proceedings of the ASC Annual International Conference* (pp. 43-52). College Station, Texas.

Mathews, M. (2013). BIM collaboration in student architectural technologist learning. *Engineering, Design and Technology*, *37*(8), 613-621.

McCuen, T., & Pober, E. (2013, January). Bimstorm: A platform facilitating integrated design. In *Proceedings of the BIM Academic Symposium*. Washington, DC.

McCuen, T., & Pober, E. (2015, April). Process and structure: Performance impacts on collaborative interdisciplinary team experiences. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.

McGraw Hill Construction. (2014). *The business value of BIM for construction in major global markets*. *SmartMarket Report*. Bedford, MA: McGraw Hill Construction.

Monson, C., (2013, January). Student collaboration as the foundation for learning BIM software: Ideas from a project-based introduction. In *Proceedings of the BIM Academic Symposium*. Washington, DC.

Monson, C., Homayouni, H., Dossick, C., & Anderson, A. (2015, June). Improving the understanding of BIM concepts through a flipped learning lab environment: A work in progress. In *Proceedings of the ASEE Annual Conference & Exposition* (p. 16). Seattle, Washington.

Oh, E. (2015). Case studies of team project based instruction. *International Journal of u- and e-Service, Science and Technology, 8*(9), 231-240. http://doi.org/10.14257/ijunesst.2015.8.9.24

Peterson, F., et al. (2011). Teaching construction project management with BIM support: Experience and lessons learned. *Automation in Construction*, *20*(2), 115-125. http://doi: org/10.1016/j.autcon.2010.09.009

Pickering, C. & Byrne, J. (2014). The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. *Higher Education Research & Development, 33*(3), 534-548. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/07294360.2013.841651

Pikas, E., Sacks, R., & Hazzan, O. (2013). Building Information Modeling education for construction engineering and management. II: Procedures and implementation case study. *Construction Engineering and Management*, *139*, 1-13. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000765

Plume, J., & Mitchell, J. (2007). Collaborative design using a shared IFC building model: Learning from experience. *Automation in Construction*, *16*(1), 28-36.

Puolitaival, T., Amor, R., Ghaffarianhoseini, A., & Park, K. S. (2016). Supporting BIM adoption and implementation – Case New Zealand. In *Proceedings of the 1st International UK BIM Academic Forum*. Glasgow, Scotland.

Puolitaival, T., & Forsythe, P. (2016). Practical challenges of BIM education. *Structural Survey, 34*(4/5), 351-366. http://doi.org/10.1108/SS-12-2015-0053.

Richards, E. L., & Clevenger, C.M. (2011, April). Interoperable learning leveraging Building Information Modeling (BIM) in construction management and structural engineering education. In *Proceedings of the ASC Annual International Conference*. Omaha, Nebraska.

Richards, E. L., & Clevenger, C. (2012). Interoperable learning leveraging Building Information Modeling (BIM) in construction education. *International Journal of Construction Education and Research*, *8*, 101-118. https://doi.org/10.1080/15578771.2011.647249

Sabongi, F. (2009). The Integration of BIM in the undergraduate curriculum: An analysis of undergraduate courses. In *Proceedings of the 45th Annual Conference of ASC*. Gainesville, Florida.

Sacks, R., & Pikas, E. (2013). Building Information Modeling education for construction engineering and management. I: Industry requirements, state of the art, and gap analysis. *Construction Engineering and Management*, *139*(11), https://doi.org/10.1061/(ASCE)CO.1943-7862.0000765

Salazar, G.F., & de Lourdes Gomez-Lara, M. (2013, January). Use of Building Information Modeling in student projects at WPI. In *Proceedings of the BIM Academic Symposium*. Washington, DC.

Santos, R., Costa, A. A., & Grilo, A. (2017). Bibliometric analysis and review of Building Information Modeling literature published between 2005 and 2015. *Automation in Construction*. Retrieved from http://linkinghub.elsevier.com/retrieve/pii/S0926580517302297

Setterfield, C., Dunn, E., & Marcks, R. (2010, June). Simulating the collaborative design process through a multidisciplinary capstone project. In *Proceedings of ASEE Annual Conference and Exposition*. Louisville, Kentucky. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0 77955937186&partnerID=40&md5=10c6a5841e93996a69b7eabbd9892bad.

Shelbourn, M. A., Macdonald, J., & Mills, J. (2016a, April). Developing an international framework for BIM education in the HE sector. In *Proceedings of BIM Academic Symposium*. Orlando, Florida.

Shelbourn, M., MacDonald, J., & Mills, J. (2016b, September). An international framework for collaborative BIM education. In *Proceedings of RICS COBRA 2016* (pp. 2015-2016). Toronto, Canada.

Siemens, G. (2014). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*, *1*, 1-8.

Skinner, B. (1985). Cognitive science and behaviourism. *British Journal of Psychology*, *76*(Pt 3), 291-301.

Soares, F., Sepúlveda, M., Monteiro, S., Lima, R., & Dinis-Carvalho, J. (2013). An integrated project of entrepreneurship and innovation in engineering education. *Mechatronics*, *23*(8), 987-996.

Solnosky, R., Parfitt, K., & Holland, R.J. (2013). IPD and BIM-focused capstone course based on AEC industry needs and involvement. *Professional Issues in Engineering Education and Practice*, *140*(4), A401300 1-11. http://doi/abs/10.1061/(ASCE)EI.1943-5541.0000157

Suwal, S., Jäväjä, P., Rahman, A., & Gonzalez, V. (2013). Exploring BIM-based education perspectives. In *Proceedings of Australasian Universities Building Education Association Conference*. Auckland, NZ.

Thomas, D. R. (2006). A general inductive approach for analysing qualitative evaluation data. *American Journal of Evaluation, 27*(2), 237-246.

Tangney, S. (2014). Student-centred learning: A humanist perspective. *Teaching in Higher Education*, *19*(3), 266-275.

Udeaja, C., & Aziz, Z. (2015, September). A case study of fostering multidisciplinary in built environment using BIM. In *Proceedings of the Annual ARCOM Conference* (pp. 701-710). Lincoln, UK.

Vlasek, S. P. (2016, April). Development of a BIM-enabled curriculum: Planning freshman year. In *Proceedings of the BIM Academic Symposium*. Orlando, Florida.

Vogt, B. M. (2012, June). The road to creating, evaluating and changing a BIM learning environment. In *Proceedings of ASEE Annual Conference and Exposition*. San Antonio, Texas. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84865046483&partnerID=tZOtx3y1.

Wang, L., & Leite, F. (2014). Process-oriented approach of teaching Building Information Modeling in construction management. *Journal of Professional Issues in Engineering Education and Practice*, *140*(4), 04014004-1-9. http://doi/10.1061/%28ASCE%29EI.1943-5541.0000203

Weltman, D. (2007). *A comparison of traditional and active learning methods: An empirical investigation utilizing a linear mixed model*. (Unpublished doctors dissertation). The University of Texas at Arlington, Arlington, Texas.

Wong, K. A., Wong, K. F., & Nadeem, A. (2011). Building information modelling for tertiary construction education in Hong Kong, *Journal of Information Technology in Construction (ITcon*), 16, pp. 467-476.

Woo, J. (2007). BIM (Building information modeling) and pedagogical challenges. In *Proceedings of the 43rd ASC National Annual Conferenc.,* Flagstaff, AZ.

Wu, W., & Hyatt, B. (2016, April). Integrating BIM across an undergraduate construction management curriculum: Experiential learning through a tiny house project. In *Proceedings of the BIM Academic Symposium.* Orlando, Florida.

Xie, H., & Boden-McGill, C. J. (2014, January). Encouraging students' involvement through structured discovery learning strategy in teaching BIM courses. In *Proceedings of the BIM Academic Symposium* (pp. 1-100). Washington, DC.

Xie, H., Shim, E., & Schmidt, K. (2017, April). Integrated project delivery and team based learning in BIM education. In *Proceedings of the BIM Academic Symposium*. Boston, Massachusetts.

Yalcinkaya, M., & Singh, V. (2015). Patterns and trends in Building Information Modeling (BIM) research: A latent semantic analysis. *Automation in Construction*, *59*, 68-80.

Yan, W., Culp, C., & Graf, R. (2011). Integrating BIM and gaming for real-time interactive architectural visualization. *Automation in Construction*, *20*(4), 446-458. http://doi.org/10.1016/j.autcon.2010.11.013

Yilmaz, K. (2011). The cognitive perspective on learning: Its theoretical underpinnings and implications for classroom practices. *Journal of Educational Strategies, Issues and Ideas, 84*(5), 204-212.

Relevant case studies

Reference	Year	Discipline	Data collection location	Research method	Learning theories	Learning approaches	Learning methods
Ahn, Y. H., Cho, C., & Lee, N. (2013). Building information modeling: Systematic course development for undergraduate construction students. *Professional Issues in Engineering Education and Practice*, *139* (8), pp. 290-300.	2013	CM	US	Case study	learning objectives categorised according to Bloom's taxonomy to cognitive, affective and psychomotor	learner-centered instructions, collaborative through group discussion, reports and presentations, activity-based learning	process-based curriculum, case-based curriculum
Alshanbari, H., Giel, B., & Issa, R. R. A. (2014). Project coordination using cloud-based BIM computing in education. In *BIM Academic Symposium: Advancing BIM in the Curriculum* (pp. 1-100). Washington, DC.	2014	CM	US	Case study			
Andersson, N., & Andersson, P. H. (2010, November). Building Information Modeling in engineering teaching: Retaining the context of engineering. In W. Thabet, (Ed.), *Proceedings of the CIB W78 2010: 27th International Conference* (pp. 16-18). Cairo, Egypt.	2010	CM	Denmark	case study, survey		role play, case-based learning	
Arnett, K. P., & Quadrato, C. E. (2012, June). Building Information Modeling: Design instruction by integration into an undergraduate curriculum. In *Proceedings of the ASEE Annual Conference and Exposition.* San Antonio, Texas. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84864982920&partnerID=tZOtx3y1	2012	Engineering	US	Case study		active learning	
Ayer, S. K. A., Cribbs, J., Hailer, J. D., & Chasey, A. D. (2015, April). Best practices and lessons learned in BIM project execution planning in construction education. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study		situated learning approach	project-based assignments
Batie, D. L. (2015, April). *Introductory BIM classs-design/builder project.* In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	?	US	Case study			project-based components
Becerik-Gerber, B., Ku, K., & Jazizadeh, F, (2012). BIM-enabled virtual and collaborative construction engineering and management. *Professional Issues in Engineering Education and Practice* , *138* (July), pp. 234-245.	2012	CM	US	Case study		collaborative learning, experimental learning, active-learning, role-based learning	problem-oriented project-based learning
Boon, J., & Prigg, C. (2011, June). Releasing the potential of BIM in construction education. In *Proceedings of the CIB, Management and Innovation for a Sustainable Built Environment Conference.* Amsterdam, Netherlands.	2011	CM	NZ	Case study	learning as a social constructivist activity		
Bozogly, J. (2017, April). Performance and optimization learning models for BIM education. In *Proceedings of the BIM Academic Symposium.* Boston, Massachusetts.	2017	AEC	US	Case study	cognitive tools	experiential learning = learning through reflection on doing	
Bozogly, J., Dos Santos, A., Santos, D. C. V., Dias, F. C. B. B., Junios, N. S., Manicoba, R. P., & Bottacin, W. E. (2016, April). Collaboration with BIM: An experiential learning case. In *Proceedings of the BIM Academic Symposium.* Orlando, Florida.	2016	Engineering	US	Case study		experiential learning = learning by doing	
Brewer, G., Smith, S. P., & Maund, K. (2015, July). Towards BIM-based educational environments using game engine technology. In *RICS COBRA 2015 Proceedings* (p. 12). Sydney, Australia.	2015	CM	Australia	Case study/tool development			virtual learning environment, BIM-based learning environment
Burr, K. L. (2009, April). Creative course design: A study in student-centered course development for a sustainable building/BIM class. In *Proceedings of the ASC Annual International Conference*. Gainesville, Florida.	2009	CM	US	Case study		student-centred course design, experiential learning	
Cribbs, J., Hailer, J. D., Horton, P., & Chasey, A. (2015, April). Enhanced collaboration between construction management and architecture students utilizing a BIM environment. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review* . Washington, DC.	2015	Architecture, CM	US	Case study		collaborative learning	project-based learning, cross-disciplinary pedagogical model
Demirdoven, J. (2015, April). An interdisciplinary approach to integrate BIM in the construction management and engineering curriculum. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	AEC	US	Case study			Project-based assignments
Dossick, C. S., Anderson, A., & Osburn, L. (2017, April). Curriculum to prepare students for BIM-enabled globally distributed team network. In *Proceedings of the BIM Academic Symposium* . Boston, Massachussetts.	2017	CM	US, Asia	Case study		collaborative learning,	
Dossick, C. S., Anderson, A., Homayouni, H., & Monson, C. (2015, April). Exploring flip for BIM: Tutorials at home, exercises in lab. In *BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study		flipped learning	
Dupuis, M., Thompson, B., Bank, L., & Herridge, J. (2008, June). Experiences implementing an undergraduate civil engineering course in BIM. In *ASEE Annual Conference and Exposition, Conference Proceedings* . Pittsburg, Pennsylvania.	2008	Engineering	US	Case study			project-based assignments
Ferrandiz, J. (2016, April). BIM implementation at the building systems course at the Untied Arab Emirates university. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	Architectural Engineering	UAE	Case study			project-based learning
Friedland, C. J., Orooji, F., Zhu, Y., Chokwitthaya, C., Pexquet, C., & Kenney, J. (2016, April). Integration of BIM (3D CAD) throughout an industrial construction educational track. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	?	US	Case study		real-world learning framework	project-based learning
Gao, Z. J., & Dakota, N. (2012, June). Integrating Building Information Modeling (BIM) in teaching project scheduling and control. In *Proceedings of the ASEE Annual Conference & Exposition* . San Antonio, Texas.	2012	Engineering	US	Case study		active learning, cooperative learning	
Gegana, G. A., & Widjarnarso, T. H. (2015, April). BIM course development and its future integration at university of Indonesia and Institute of Technology Bandung, Indonesia. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	Architecture	Indonesia	Case study			

Ghosh, A., & Chasey, A. D. (2013, January). Design engineer construct integrated management lab: Leveraging collaboration in the classroom with Virtual Design and Construction through BIM. In *Proceedings of the BIM Academic Symposium* . Washington, D.C.	2013	CM	US	Case study		collaborative learning, socratic method of teaching	
Ghosh, A., (2012, June). Virtual Construction + Collaboration Lab: Setting a new paradigm for BIM education. In *ASEE Annual Conference and Exposition, Conference Proceedings*. San Antonio, Texas. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84864998679&partnerID=tZOtx3y1.	2012	CM	US	Case study		collaborative learning, socratic method of teaching	
Ghosh, A., Parrish, K., & Chasey, A.D. (2013, June). From BIM to collaboration: A proposed integrated construction curriculum. In *Proceedings of the ASEE Annual Conference and Exposition.* Atlanta, Georgia. Retrieved from http://www.asee.org/file_server/papers/attachment/file/0003/3343/130407_FINALPaper.pdf.	2013	CM	US	Case study	cognitive learning indicators (knowledge, application, evaluation)		project-based learning (case scenarios)
Ghosh, A., Parrish, K., & Chasey, A.D. (2015). Implementing a vertically integrated BIM curriculum in an undergraduate construction management program. *International Journal of Construction Education and Research* , *11* (2), 121-139.	2015	CM	US	Case study	cognitive learning indicators (knowledge, application, evaluation)		project-based learning (case scenarios)
Gier, D. M., & Pe, M. S. (2007, April). Does learning Building Information Modeling improve the plan reading skills of construction management students? In *ASC Annual International Conference Proceedings*. Flagstaff, Arizona. Retrieved from http://ascpro0.ascweb.org/archives/2007/CEUE146002007.pdf.	2007	CM	US	Case study	implicit Constructivism "all learning builds on what has gone before"	experiential learning, learner-cemtered	
Glick, S., Porte, D., & Smith, C. (2012). Student visualization: Using 3-D models in undergraduate construction management education. *International Journal of Construction Education and Research*, *8* (1), 26-46.	2012	CM	US	Case study	cognitive spatial abilities		
Gonzalez, M. A. (2015, April). BIM course development and integration in a multi-discipline civil engineering department. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	AEC	US	Case study			project-based learning
Graham, E. T., King, V. & Hopson, B. L. (2016, April). A comparison study: SketchUp pro and Revit Architecture in a sophomore construction engineering management class. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CEM	US	Case study		exploratory teaching methodology	
Grahan, T. E., Shofoluwe, M. A., & Pyle, R. B. (2015, April). Industry-academic BIM alliance: A pragmatic approach to enhance students' BIM knowledge. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study			project-based learning
Hardi, J. (2015, July). Case study: Lessons learned from Building Information Modelling (BIM) extracurricular activity organised for architectural, engineering and construction students within a UK university. In *RICS COBRA 2015 Proceedings.* Sydney, Australia.	2015	AEC	UK	Case study		collaborative working	project-based assignment
Hasso, M .H., (2017, April). Incorporating BIM Technologies in the CM Program at Wentworth Institute of Technology: Successes and challenges (Case Study). In *Proceedings of the BIM Academic Symposium* . Boston, Massachusetts.	2017	CM	US	Case study			project-based learning
Heesom, D., & Boden, P. (2016, September). Implementing Scan2BIM processes to asit teaching BIM approaches in undergraduate architectural education. In *First International Conference of the BIM Academic Forum.* Glasgow, Scotland.	2016	Architecture	UK	Case study		collaborative learning	project-based learning (module)
Henderson, L., & Jordan, N. (2015, April). Two year graduate transdisciplinary building lifecycle core curriculum. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	AECO	US	Case study		collaborative learning	project-based learning
Hjelseth, E. (2015, October). Use of BIM for learning engineering: Change of paradigm. In *Proceedings of the CIB W78 Conference 2015* (pp. 275-284). Eindhoven, The Netherlands.	2015	Engineering	Norway	Case study			project-based and problem-based in collaboration with industry and research
Holland, R., Wing, S., & Goldberg, D. (2013, January). Interdisciplinary collaborative BIM studio. In *Proceedings of the BIM Academic Symposium* . Washington, DC.	2013	AEC	US	Case study		collaborative learning	project-based learning
Hore, A. V., Scott, L., West, R., & Tibaut, A. (2016, April). Benefits of inter-institutional collaboration in the delivery of BIM education in	2016	AEC	Ireland, inte	Case study		active learning	
Hyatt, B. (2011, April). A case study in integrating lean, green, BIM into an undergraduate construction management scheduling course. In *ASC Annual International Conference Proceedings*. Omaha, Nebraska. Retrieved from http://ascpro0.ascweb.org/archives/cd/2011/paper/CEUE304002011.pdf.	2011	CM	US	Case study			project-based learning
Inguva, G., Leewis, A., Clevenger, C. M., & Valdes-Vasques, R. (2014, January). Teaching modules documenting the development of a center for VDC. In *Proceedings of the BIM Academic Symposium*. pp. 1–100. Washington, DC.	2014	CM	US	Case study		collaborative learning	team learning, project-based learning
Irizarry, J., Gheisari, M., Zolfagharian, S., &Meadati, P. (2013). Human computer interaction modes for construction education applications: Experimenting with small format interactive displays. *International Journal of Construction Education and Research*, *9* (2), 83-101. Retrieved from https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/human-computer-interaction-brief-intro	2013	Construction	US	Experiment	reinforcement and sensory simulation theory	active learning, visual learning, sensory simulation theory	
Irizarry, J., Meadati, P., Barham, W., & Akhnoukh, A. (2012). Exploring applications of Building Information Modeling for enhancing visualization and information access in engineering and construction education environments. *International Journal of Construction Education and Research* , *8* (2), 119-145.	2012	Engineering and CM	US	Case study, survey			problem-based learning

Kamardeen, I. (2013, November). Anchored BIM instructional model for construction management education. In *Proceedings of the Australasian Universities Building Education Association Conference* . Auckland, New Zealand.	2013	CM	Australia	Case study		student-directed learning, active learning	anchored instructional model, problem-based learning
Kang, J., & Ryoo, B.Y. (2012, April). Application of personal learning environment to teaching BIM for construction. In *Proccedings of the ASC Annual International Conference* . Birmingham, UK. Retrieved from http://ascpro0.ascweb.org/archives/cd/2012/paper/CEUE154002012.pdf	2012	Construction	US	Case study			personalised learning
Kang, J.H. (2012, June). Experimental application of the personallzed learning method to a BIM class. In *ASEE Annual Conference and Exposition, Conference Proceedings* . San Antonio, Texas.	2012	Construction	US	Case study			personalised learning
Kelly, M., Costello, M., Nicholson, G., & O'Connor. (2016, September). Utilising an academic-industry collaborative partnership to inform the implementation of a BIM strategy in a higher education institute in Ireland. In *Proceedings of the First International Conference of the BIM Academic Forum* , Glasgow, Scotland.	2016	Engineering	Ireland	Case study		collaborative learning	
Kim, J. (2015, June). Closing achievement gaps using the green-BIM teaching method in construction education curriculum. In *Proceedings of ASEE Annual Conference & Exposition* . Seattle, Washington.	2015	Construction	US	Case study			BIM-based teaching approach, project-based learning (course)
Kim, J. L. (2014, June). Effectiveness of green-BIM teaching method in construction education curriculum. In *Proceedings of the ASEE Annual Conference and Exposition* . Indianapolis, Indiana. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84905180300&partnerID=tZOtx3y1.	2014	Construction	US	Case study			BIM-based teaching approach, project-based learning (course)
Kim, J., (2012). Use of BIM for effective visualization teaching approach in construction education. *Professional Issues in Engineering Education and Practice* , *138* (3), 214-223.	2012	CM	US	Case study		BIM-based learning approach	
Kovacic, I., Flizmoser, M., Vasilescu, D., & Oberwinter, L. (2016, September). Challenges in teaching integrated BIM-supported building design. In *Proceedings of the First International Conference of the BIM Academic Forum.* Glasgow, Scotland.	2016	Architecture, engineering	Austria	Case study		collaborative workshop	project assignment
Leite, F. (2015, April). An example project-based course on BIM for construction management. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study			process-based learning
Leite, F. (2016). Project-based learning in a building information modeling for construction management course. *Information Technology in Construction* , *21* , 164-176.	2016	CM	US	Case study			process-based learning
Liu, R. & Berumen, L. (2016, April). Digital project coordination experience in undergraduate construction education. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CM	US	Case study			process-based learning
Liu, R., & Hatipkarasulu, Y. (2014, June). Introducing Building Information Modelling course into a newly developed construction program with various student backgrounds. In *Proceedings of the ASEE Annual Conference & Exposition* . Indianapolis, Indiana.	2014	CM	US	Case study			project assignment
Liu, R., & Palomera-Arias, R. (2015, June). Term project design for undergraduate building information modeling education. In *ASEE Annual Conference and Exposition, Conference Proceedings. Seattle, Washington.* Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84941994843&partnerID=tZOtx3y1.	2015	CM	US	Case study, Survey			project-based learning, term projects
Liu, R., Gajbhiye, A., & Paromera-Arias, R. (2015, April). Using real life examples of building construction for student projecs to improve their understanding and cocnept of BIM implementation. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study		action learning	project assignment
Maghiar, M. (2014, January). Planning and scheduling curriculum integration of BIM with industry input. In *Proceedings of the BIM Academic Symposium* (pp. 1-100). Washington, DC.	2014	CM	US	Case study			
Maghiar, M. (2016, April). Knowledge transferi nto a BIM course through technology-driven solutions for real-world construction projects. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CEM	US	Case study			project-based learning (project scenarios), peer evaluation, teamwork, technology-based, industry-oriented
Maghiar, M., Jain, S., & Sullivan, J.G. (2013, June). Strategy to incorporate BIM curriculum in planning and scheduling classes. In *Proceedings of the ASEE Annual Conference & Exposition.* Atlanta, Georgia. Retrieved from http://www.asee.org/file_server/papers/attachment/file/0003/3347/ASEE_2013_upload_final.pdf.	2013	CM	US	Case study		action learning	
Martin, D.W., Plugge, P.W., & Socha, D. (2015, April). BIM, 4D scheduling , active learning , and industry collaboration: Filling the CM program void. In *ASC Annual International Conference Proceedings* (pp. 43-52). College Station, Texas.	2015	CM	US	Case study		active learning, experiential learning (what learners think, feel, perceive and do)	
Mathews, M. (2013). BIM collaboration in student architectural technologist learning. *Engineering, Design and Technology* , *37* (8), 613-621.	2013	AT	Ireland	Case study	constructivism"designing constructivist learning environments", cognitive skill development	student-centred learning, collaborative learning	project-based brief, problem-based scenario
Maund, K., Brewer, G., & Smith, S.P. (2016, July). Virtual learning environments: Conversion of BIM into gaming engines and the construction management discipline. In *Proceedings of the Australasian Universities Building Education Association Conference* (pp. 629-638). Cairns, Australia.	2016	CM	Australia	Case study, tool development		realistic virtual learning environment	gaming

McCuen, T. & Pober, E. (2013, January). Bimstorm: a Platform Facilitating Integrated Design. In *Proceedings of the BIM Academic Symposium* . Washington, DC.	2013	?	US	Case study	Software skills as cognitive tools	experiential learning, collaborative learning	project-based learning, interdisciplinary, problem-based learning (ill structured complex problem)
McCuen, T., & Pober, E. (2015, April). Process and structure: Performance impacts on collaborative interdisciplinary team experiences. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	AEC	US	Case study		collaborative interdisciplinary team experiences	real-world project
Miller, K. R. (2016, April). Incorporating BIM into the preconstruction services course at BYU. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CM & FM	US	Case study			project-based learning
Monson, C., (2013, January). Student collaboration as the foundation for learning BIm software: Ideas from a project-based introduction. In *Proceedings of the BIM Academic Symposium* . Washington, DC.	2013	CM	US	Case study		collaborative learning	problem-based learning
Monson, C., Homayouni, H., Dossick, C., & Anderson, A. (2015, June). Improving the understanding of BIM concepts through a flipped learning lab environment: A work in progress. In *Proceedings of the ASEE Annual Conference & Exposition* (p. 16). Seattle, Washington.	2015	CM	US	Case study		flipped learning	problems for software learning, blended learning
Orooji, F., & Aly, S. (2017, April). Experience and lessons learned through integration of Building Information Modelling (BIM) in the architectural science curriculum: An overview of the currect pedagogy approach. In *Proceedings of the BIM Academic Symposium* . Boston, Massachusetts.	2017	Architecture	US	Case study		collaborative BIM education	
Ozcan-Deniz, G., (2017, April). A case study on hybrid BIM course development. In *Proceedings of the BIM Academic Symposium* . Boston, Massachusetts.	2017	CM	US	Case study		collaborative delivery of a project	
Palomera-Arias, R., & Liu, R. (2015, April). Developing BIM laboratory exercises for a MEP systems course in a construction science and management programme. In *BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.	2015	CM	US	Case study			
Peterson, F., et al. (2011). Teaching construction project management with BIM support: Experience and lessons learned. *Automation in Construction* , *20* (2), 115-125. http://dx.doi.org/10.1016/j.autcon.2010.09.009	2011	CM	US, Netherlands	Case study	combine cognitivism and behaviorism	active learning (learning by doing)	BIM supported project-based learning
Pikas, E., Sacks, R., & Hazzan, O. (2013). Building Information Modeling education for construction engineering and management. II: Procedures and implementation case study. *Construction Engineering and Management* , *139* , 1-13. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000781	2013	CEM	Israel	Case study	Bloom's cognitive domain formed the basis for planning and assessing students' levels of achievement	collaborative course project	
Plume, J., & Mitchell, J. (2007). Collaborative design using a shared IFC building model: Learning from experience. *Automation in Construction* , *16* (1), 28-36.	2007	Architecture	Australia	Case study		collaborative design	
Puolitaival, T., Forsythe, P., & Kahkonen, K. (2015, July). Challenges facing BIM education: Development of appropriate teaching and learning resources. In *RICS COBRA 2015 Proceedings.* Sydney, Australia.	2015	CM	NZ	Case study			project-based learning
Puolitaival, T., Kestle, L., Davies, K., & Forsythe, P. (2015, July). Assessment in virtual design and construction education. In *RICS COBRA 2015 Proceeding.* Sydney, Australia.	2015	CM	NZ	Case study			project assignment
Richards, E. L., & Clevenger, C. (2012). Interoperable learning leveraging Building Information Modeling (BIM) in construction education. *International Journal of Construction Education and Research* , *8* , 101-118. https://doi.org/10.1080/15578771.2011.647249	2012	CM	US	Case study		interactive e-learning, collaborative learning	e-learning
Richards, E. L., & Clevenger, C.M. (2011, April). Interoperable learning leveraging Building Information Modeling (BIM) in construction management and structural engineering education. In *ASC Annual International Conference Proceedings* . Omaha, Nebraska.	2011	Engineering, CM	US	Case study		interactive e-learning, collaborative learning	e-learning
Rodriguez, G. (2014, January). Universal design for learning (UDL) within and interdisciplinary course for BIM. In *BIM Academic Symposium* (pp. 1-100). Washington, DC.	2014	Archtitectural technology	US	Case study		universal design for learning (UDL)	
Sacks, R., & Barak. (2010). Teaching building information modeling as an integral part of freshman year civil engineering education. *Professional Issues in Engineering Education and Practice*, *136* (1), 30-38.	2010	Engineering	Israel	Case study			
Salazar, G.F., & de Lourdes Gomez-Lara, M. (2013, January). Use of Building Information Modeling insStudent projects at WPI. In *Proceedings of the BIM Academic Symposium.* Washington, DC.	2013	CEM	US	Case study		collaborative learning	project-based education programme, real world problems
Schreyer, A. C. (2014, January). 3D modeling and virtual mockup building as teaching tools in AEC materials and methods curricula. In *Proceedings of the ASC Annual International Conference/CIB Workgroup 89* (p. 9). Las Vegas, Nevada. Retrieved from http://ascpro0.ascweb.org/archives/2014/CEUE215002014.pdf.	2014	AEC	US	Case study			
Setterfield, C., Dunn, E., & Marcks, R. (2010, June). Simulating the collaborative design process through a multidisciplinary capstone project. In *Proceedings of the ASEE Annual Conference and Exposition* . Louisville, Kentucky. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-77955937186&partnerID=40&md5=10c6a5841e93996a69b7eabbd9892bad.	2010	AEC	US	Case study		collaborative learning	IPD approach, student leadership, blended learning
Shanbari, H., Blinn., N., & Issa, R. A. (2015, April). Introducing laser scaning technology in a graduate BIM class. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study			project-assignment, team work
Shelbourn, M. A., Macdonald, J., & Mills, J. (2016, April). Developing an international framework for BIM education in the HE sector. In *Proceedings of the BIM Academic Symposium.* Orlando, Florida.	2016a	AEC	Australia	Case study, framework development	IMAC framework follows principles of constructivism and mastery learning	collaborative learning	scaffolded learning, problem-based learning, blended learning

Shelbourn, M., MacDonald, J., & Mills, J. (2016, September). An international framework for collaborative BIM education. In *Proceedings of RICS COBRA 2016 (* pp. 2015-2016). Toronto, Canada.	2016b	AEC	Australia, UK	Case study, framework development	IMAC framework follows principles of constructivism and mastery learning	collaborative learning	scaffolded learning, problem-based learning, blended learning
Shen, Z., Jensen, W., Fisher, B., Wentz, T. (2012, June). Using BIM to teach design and construction of sustainable buildings. In *Proceedings of the ASEE Annual Conference and Exposition*. San Antonio, Texas. Retrieved from https://www.engineeringvillage.com/share/document.url?mid=cpx_6e3d60139686bec03M662920613775 53&database=cpx.	2012	CM	US	Case study			project-based assignments
Solnosky, R., Parfitt, K., & Holland, R.J. (2013). IPD and BIM-focused capstone course based on AEC industry needs and involvement. *Professional Issues in Engineering Education and Practice*, *140* (4), A401300 1-11. http://ascelibrary.org/doi/abs/10.1061/(ASCE)EI.1943-5541.0000157	2013	Architectural Engineering	US	Case study		collaborative (team) learning	IPD approach, project-based learning
Taylor, J., Liu, J. & Hein, M. (2008, April). Integration of Building Information Modeling (BIM) into an ACCE accredited construction management curriculum. In *ASC Annual International Conference Proceedings* . Auburn, Alamaba. Retrieved from http://ascpro0.ascweb.org/archives/2008/CEUE246002008.pdf.	2008	CM	US	Case study		collaborative final project	
Udeaja, C., & Aziz, Z. (2015, September). A case study of fostering multidisciplinary in built environment using BIm. In *Proceedings of the Annual ARCOM Conference* (pp. 701-710). Lincoln, UK.	2015	AEC	UK	Case study	"flex cognitive muscle"	multidisciplinary collaboration, active learning	real life project, problem-centred, project-focused
Vlasek, S. P. (2016, April). Development of a BIM-enabled curriculum: Planning freshman year. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CM	US	Case study	constructivism		problem-based
Vogt, B.M. (2012, June). The road to creating, evaluating and changing a BIM learning environment. In *ASEE Annual Conference and Exposition, Conference Proceedings*. San Antonio, Texas. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84865046483&partnerID=tZOtx3y1.	2012	Architecture	US	Case study		collaborative design environment	online delivery
Wang, L., & Leite, F. (2014). Process-oriented approach of teaching Building Information Modeling in construction management. *Professional Issues in Engineering Education and Practice*, *140* (4), 4014004. http://www.scopus.com/inward/record.url?eid=2-s2.0-84913612611&partnerID=tZOtx3y1	2014	CEM	US	Case study			process-oriented learning
Wu, W., & Hyatt, B. (2016, April). Integrating BIM across an undergraduate construction management curriculum: Experiential learning through a tiny house project. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CM	US	Case study		experiential learning	project-based learning
Wu, W., & Luo, Y. (2015, April). Project-based learning fo enhanced BIM implementation in the sustainability domain. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Case study		collaborative learning	project-based learning,
Wu, W., & Luo, Y. (2015, June). Investigating the synergies of sustainability and BIM through collaborative project-based learning. In *ASEE Annual Conference and Exposition, Conference Proceedings*. Seattle, Washington. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84941996002&partnerID=40&md5=950e5932ca0e952367a787d9b93d4545.	2015	CM	US	Case study		collaborative learning	project-based learning
Xie, H., & Boden-McGill, C. J. (2014, January). Encouraging students' involvement through structured discovery learning strategy in teaching BIM courses. In *Proceedings of the BIM Academic Symposium* (pp. 1-100). Washington, DC.	2014	AEC	US	Case study	acquiring cognitive problem solving skills	collaborative learning	structured discovery learning
Xie, H., Shim, E., & Schmidt, K. (2017, April). Integrated project delivery and team based learning in BIM education. In *Proceedings of the BIM Academic Symposium* . Boston, Massachusetts.	2017	CEM	US	Case study	SDL seeks cognitive problem-solving skills	inquiry learning, collaborative learning, active learning	structured discovery learning (SDL)
Yan, W., Culp, C., & Graf, R. (2011). Integrating BIM and gaming for real-time interactive architectural visualization. *Automation in Construction* , *20* (4), 446-458. http://dx.doi.org/10.1016/j.autcon.2010.11.013	2011	Architecture	US	Case study	visual and spacial cognitiions in a design-think process	collaborative learning	gaming incl. problems
Zhao, D, McCoy, A. P., Bulbul, T., Fiori, C., & Nikkhoo, P. (2015). Building collaborative construction skills through BIM-integrated learning environment. *International Journal of Construction Education and Research* , *11* (2), 97-120.	2015	AEC	US	Case study		collaborative learning	project-based learning, learning in teams and across teams

Other case studies

Adamu, Z. A., & Thorpe, T. (2015, April). How should we teach BIM? A case study from the UK. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.	2015	AEC	UK	Case study
Ali, K. N., Mustaffa, N. E., Keat, J. Q., & Enegbuma, W. I. (2015, April). BIM educational framework for quantity surveying students: The Malaysian perspective. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.	2015	QS	Malaysia	Case study
Aly, S. (2014, January). BIM and its future in undergraduate architectural science capstone projects. In *Proceedings of the BIM Academic Symposium* (pp. 1-100). Washington, DC.	2014	Architectural science	US	Case study
Azhar, S., Sattineni, A., & Hein, M. (2010, April). BIM undergraduate capstone thesis: Student perceptions and lessons learned. In *ASC Annual International Conference Proceedings* (pp. 18). Boston, Massachusetts. Retrieved from https://www.researchgate.net/publication/267693889.	2010	CM	US	Case study
Beauregard, M., Alsafouri, S., & Ayer, S. K. (2016, April). Development of a peerreview-based activity to improve students' BIM process mapping understanding. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CM	US	Case study
Best, R. (2008, July). The development of a BIM based building measurement learning tool. In J. Williamson, (Ed.). *Australasian Universities Building Education (AUBEA 2008)* . Auckland, New Zealand.	2008	CM	Australia	Case study/tool development
Faust, R. (2016, April). BIM curriculum development. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	CM	US	Case study
Ghosh, A., Chasey, A.D., & Root, S.(2013, April). Industry and academia: A partnership to VDC curriculum. In *ASC Annual International Conference Proceedings*. San Luis Obispo, California. Retrieved from http://ascpro.ascweb.org/chair/paper/CEUE62002013.pdf.	2013	CM	US	Case study
Gier, D.M. (2008, April). What impact does using Building Information Modeling have on teaching estimating to construction management students ? In *ASC Annual Intrnational Conference Proceedings* . Auburn, Alamaba.	2008	CM	US	Case study, survey
Gier, D.M., Loftin, E. & Coogan, K.(2006, April). Are Building Information Models effective for teaching productivity analysis? In *ASC Annual International Conference Proceedings*. Fort Collings, Colorado.	2006	CM	US	Case study
Huang, Y, (2016, April). Integrating Building Information Modeling in existing courses: A systematic framework for undergraduate construction management programs. In *ASEE Annual Conference and Exposition, Conference Proceedings*. New Orleans, Louisiana.	2016	CM	US	Case study, framework development
Indraprahasta, A., & Widjanarso, T. H. (2015, April). Integration of BIM course into design curriculum case study: Study program of architecture, Institut Teknologi Bandung. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.	2015	Architecture	Indonesia	Case study
Kensek, K. M., & Becker, G. (2015, April). BIM pedagogy: Fundamentals and exploration. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.	2015	Architecture	US	Case study, longitudinal
Kubicki, S. & Boton, C. (2011, October). 4D-based teaching of high-rise structural. In *Proceedings of the CIB W078 Information Technology for Construction Conference* (pp. 26-28). Antipolis, France.	2011	architecture and engineering	Belgium	Case study
Lewis, A. M., Valdes-Vasquez, R., Clevenger, C., & Shealey. T. (2015). BIM energy modeling: Case study of a teaching module for sustainable design and construction courses. *Professional Issues in Engineering Education and Practice*, *141* (2), C5014005. http://ascelibrary.org/doi/abs/10.1061/(ASCE)EI.1943-5541.0000230#aHR0cDovL2FzY2VsaWJyYXJ5Lm9yZy9kb2kvcGRmLzEwLjEwNjEvKEFTQ0UpRUkuMTk0My01NTQxLjAwMDAyMzBAQEAw.	2015	?	US	Case study
Liu, J. & Killingsworth, R. (2012, April). A study of using BIM as an innovated teaching tool in an estimating class: A preliminary report. In *ASC Annual International Conference Proceedings*. Birmingham, UK.	2012	CM	US	Case study
Maghiar, M., & Fu, G. (2015, April). Framework for expanding BIM adoption within the taught curriculum. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review*. Washington, DC.	2015	CM	US	Case study
McCuen, T. (2007, April). The effect of Building Information Modeling on conflict and conflict management in interdisciplinary teams. In *ASC Annual International Conference Proceedings*. Flagstaff, Arizona. Retrieved from http://ascpro0.ascweb.org/archives/2009/CERT173002009.pdf.	2007	?	US	Case study
McCuen, T. L.. & Miller, K., (2017, April). BIM estimating in the classroom. In *Proceedings of the BIM Academic Symposium*. Boston, Massachusetts.	2017	CM	US	Case study
McGarrigle, M. (2013, November). Embedding Building Information Modelling (BIM) into Construction Systems 1 and other modules of the Unitec National Diploma. (Architectural Technology-AT, Construction Management-CM, Quantity Surveying-QS). In *Proceedings of the Australasian Universities Building Education Association Conference* . Auckland, New Zealand.	2013	AT, CM	NZ	Case study, survey, interviews, document analysis

McGarrigle, M. (2013, November). Models to provide assessment feedback. In *Proceedings of the Australasian Universities Building Education Association Conference (* pp. 600609). Auckland, New Zealand.	2013	AT, CM	NZ	Case study
Miller, K., & Farnsworth, C. B. (2015, April). Introductory course to construction and facilities management at Brigham Young University. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM, FM	US	Case study
Mulva, S., & Tisdel, R. (2007, June). Building information modeling: A new frontier for construction engineering education. In *ASEE Annual Conference and Exposition, Conference Proceedings*. Honolulu, Hawaii. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-84858495957&partnerID=tZOtx3y1.	2007	Architecture	US	Case study
Ozcan-Deniz, G. (2016, April). The AEC students' perspective in the learning process of CAD and BIM. In *Proceedings of the BIM Academic Symposium* . Orlando, Florida.	2016	Engineering	US	Case study, survey
Palomera-Arias, R., & Liu, R. (2016). BIM laboratory exercises for a MEP systems course in a construction science and management program. *Information Technology in Construction* , *21* , 188-203.	2016	CSM	US	Case study
Salazar, G. F., Romero, S. A., & de Lourdes Gomez-Lara, M. (2016, April). Site-building integrated BIM models: Lessons learned in education. In *Proceedings of the BIM Academic Symposium*. Orlando, Florida.	2016	Construction engineering	US	Case study, longitudinal
Salazar, G.F., Romero, S.A., & de Lourdes Gomez-Lara, M. (2017, April). Student-driven activity for FM-BIMmodels content definition. In *Proceedings of the BIM Academic Symposium* . Boston, Massachusetts.	2017	FM	US	Case study
Stadel, A., Eboli, J., Ryberg, A., Mitchell, J., & Spatari, S. (2011). Intelligent sustainable design: Integration of carbon accounting and building information modeling. *Professional Issues in Engineering Education and Practice* , *137* (2), 51-54. http://www.scopus.com/inward/record.url?eid=2-s2.0-79955547252&partnerID=40&md5=94c11c4fe2f739acb42d4fca53773625	2011	Architectural Engineering	US	Case study
Stone, T. A., & King, M. (2015, April). Design disassembled: Understanding building systems through BIM. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review. W* ashington, DC.	2015	Architecture	US	Case study
Sylvester, K.E., & Dietrich, C. (2010, April). Evaluation of Building Information Modelling (BIM) estimating methods in construction education. In *ASC Annual International Conference Proceedings*. Boston, Massachusetts.	2010	CM	US	Case study
Woo, J. (2007, April). BIM (Building Information Modeling) and pedagogical challenges. In *ASC Annual International Conference Proceedings* . Flagstaff, Arizona. Retrieved from http://ascpro0.ascweb.org/archives/cd/2007/paper/CEUE169002007.pdf.	2007	Engineering	US	Case study, survey

Other studies

Abdirad, H., & Dossick, C.S. (2016). BIM curriculum design in architecture, engineering and construction education: A systematic review. *Information Technology in Construction (ITcon)* , *21* (21), 250271. http://www.itcon.org/2016/17	2016	AEC	International	Literature review
Barison, M.B., & Santos, E.T. (2010, November). Review and analysis of current strategies for planning a BIM curriculum. In *Proceedings of the CIB W78 2010: 27th International Conference* (pp. 16-18). Cairo, Egypt. Retrieved from http://itc.scix.net/data/works/att/w78-2010-83.pdf.	2010	AEC	International	Document analysis
Becerik-Gerber, B., Gerber, D.J., & Ku, K. (2011). The pace of technological innovation in architecture, engineering, and construction education: Integrating recent trends into the curricula. *Information Technology in Construction* , *16* , 411-432.	2011	AEC	US	Document analysis
Blinn, N., & Issa, R. R. A. (2017, April). Utilisation of drawing management software to enhance BIM educational experiences. In *Proceedings of the BIM Academic Symposium* (pp. 1-8). Boston, Massachusetts.	2017	CM	US	Survey
Chen, D., & Gehrig, G.B. (2011, June). Implementing Building Information Modelling in construction engineering curricula. In *ASEE Annual Conference and Exposition, Conference Proceedings*. Vancouver, British Columbia. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-80051945892&partnerID=tZOtx3y1.	2011	ConE	US	Software review
Chen, D., & Hildreth, J. (2012, June). BIMing construction engineering curricula. In *ASEE Annual Conference and Exposition, Conference Proceedings*. San Antonio, Texas.	2012	ConE	US	Software review
Čuš Babič, N., & Rebolj, D. (2010, November). Learning about BIM in early design using Inpro training environment. In *Proceedings of the CIB W78 2010: 27th International Conference* (pp. 16-18). Cairo, Egypt.	2010	AEC	Europe	Tool development
Gerber, D.J., Khashe, S., & Smith, I.F.C. (2014). Surveying the evolution of computing in architecture, engineering, and construction education. *Computing in Civil Engineering* , *29* (5), p.131006171105002. http://ascelibrary.org/doi/abs/10.1061/(ASCE)CP.1943-5487.0000361.	2014	AEC	US, Canada, Europe, Asia, Australia	Survey
Guidera, S. (2007, June). Digital design, BIM, and digital fabrication: Utilization and integration in architectural engineering curriculums. In *Proceedings of the ASEE Annual Conference & Exposition*. Honolulu, Hawaii. Retrieved from http://www.icee.usm.edu/icee/conferences/asee2007/papers/1775_DIGITAL_DESIGN__BIM__AND_DIGITAL_FABRICA.pdf	2007	Architectural Engineering	US	Survey
Hjelseth, E. (2016, September). BIM in higher education based on pedagogical concepts. In *Proceedings of the First International Conference of the BIM Academic Forum.* Glasgow, Scotland.	2016	AEC	International	Literature review
Hogle, L.G. (2013, January). Industry and academia: The perfect partnership. In *Proceedings of the BIM Academic Symposium*. Washington, DC.	2013	Construction	US	Discussion paper
Hu, W. (2007, June). Implementing a simultaneous construction model to educate undergraduates in collaboration curriculums. In *Proceedings of the ASEE Annual Conference & Exposition*. Honolulu, Hawaii.	2007	CM	China	Discussion paper
Joannides, M. M., Olbina, S., & Issa, R. R. A. (2012). Implementation of Building Information Modeling into accredited programs in architecture and construction education. *International Journal of Construction Education and Research* , *8* (2), 83-100.	2012	Architecture, CM	US	Survey
Jurado Ege, J., Lieabana Carrasco, O,. & Agullo de Rueda, J. (2016, September). Implementation framework for BIM methodology in the bachelor degree of architecture. A case study in s Spanish unviersity. In *Proceedings of the First International Conference of the BIM Academic Forum* . Glasgow, Scotland.	2016	Architecture	Spain	Framework development
Khashe, S., Gerber, D. J., & Smith, I. F. C. (2016). Surveying the evolution of computing in architecture, engineering, and construction education since 2012. *Computing in Civil Engineering* , *29* (5), 131006171105002. http://ascelibrary.org/doi/abs/10.1061/(ASCE)CP.1943-5487.0000361	2016	AEC	US	Survey
Kugbeadjor, W., Suresh, S., & Renukappa, S. (2015, November). BIM awareness and readiness of postgraduate built environment students in West Midlands universities, UK. In C. Egbu (Ed.). *CIB Proceedings. Going north for sustainability: Leveraging knowledge and innovation for sustainable construction and development* (pp. 531-543). London, UK.	2015	AEC	UK	Survey
Lee, N. & Yun, S.H. (2015, June). A holistic view of Building Information Modeling education in post-secondary institutions. In *Proceedings of the ASEE Annual Conference & Exposition*. Seattle, Washington.	2015	CM	US	Survey
Lee, N., & Dossick, C. (2012, June). Leveraging Building Information Modeling technology in construction engineering and management education: American Society for Engineering Education. In	2012	CM	International	Literature review
Lee, N., & Hollar, D. (2013, April). Probing Building Information Modeling technology in construction engineering and management programs using industry perceptions. In *ASC Annual International Conference Proceedings*. San Luis Obispo, California.	2013	CM	International	Survey and literature analysis
Lee, N., & Reeder, L. (2016, June). A preliminary study on upper-level Building Information Modeling education for construction management students. In *Proceedings of the ASEE Annual Conference and Exposition, Conference Proceedings*. New Orleans, Louisiana.	2016	CM	US	Survey

Lee, N., Dossick, C.S., & Foley, S.P. (2013). Guideline for Building Information Modeling in construction engineering and management education. *Professional Issues in Engineering Education & Practice* , *139* (4), 266-274. Retrieved from http://10.0.4.37/(ASCE)EI.1943-5541.0000163%5Cnhttps://login.e.bibl.liu.se/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=aph&AN=90259395&site=eds-live&scope=site.	2013	CM	Internationa	Mixed
Lucas, J. (2014, April). Deriving learning outcomes for BIM implementation into the CSM curriculum based on industry expectation. In *ASC Annual International Conference Proceedings*. Blacksburg, Virginia.	2014	CSM	US	Interviews
Lucas, J. (2015, April). Student perceptions of BIM in the classroom. In *ASC Annual International Conference Proceedings* pp. 18-25. College Station,Texas.	2015	CSM	US	Survey
Macdonald, J. A., & Mills, J. E. (2011, June). The potential of BIM to facilitate collaborative AEC education. In *ASEE Annual Conference and Exposition, Conference Proceedings*. Vancouver, British Columbia.	2011	AEC	Australia	Survey
McCuen, T. (2014, January). The challenges of advancing BIM in the curriculum while addressing current accreditation standards for construction. In *Proceedings of the BIM Academic Symposium (* pp. 1-100). Washington DC.	2014	ACE	US	Document analysis
McLernon, T., McKane, M., Eadie, R., Comiskey, D. (2015, July). A review of curriculum design for Building Information Modelling. In *RICS COBRA 2015 Proceedings* . Sydney, Austalia.	2015	AEC	Internation al	Literature review
Miller, K., Farnsworth, C.B., & Weidman, J.E. (2013, June). Integrating industry BIM practices into university curriculum. In *ASEE Annual Conference and Exposition, Conference Proceedings (* pp. 1-12). Atlanta, Georgia.	2013	CM	US	Interviews
Morton, D. E. (2012, September). BIM: A transformative technology within the architectural curriculum in schools of architecture. In *Proceedings of the BIM Academic Forum*. Northumbria, UK.	2012	Architecture	UK	Literature review
Mutai, A., & Guidera, S. (2010, June). Building Information Modeling in construction: Current practices and their implications for construction engineering education. *ASEE Annual Conference and Exposition, Conference Proceedings*. Louisville, Kentucky. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-77955944517&partnerID=tZOtx3y1.	2010	Engineering	US	Survey
Nejat, A., Darwish, M.M., & Ghebrab, T. (2012, June). BIM teaching strategy for construction engineering students. In *ASEE Annual Conference and Exposition, Conference Proceedings*. San Antonio, Texas. Retrieved from https://peer.asee.org/bim-teaching-strategy-for-construction-engineering-students.	2012	Construction engineering	US	Mixed
Poirier, E. A., Forgues, D., Staub-Fench, S., & Newton, L. (2017, April). BIM in Canadian research and education. In *Proceedings of the BIM Academic Symposium.* Boston, Massachusetts.	2017	AEC	Canada	Strategic workshop
Raiola, J.A.I. (2016, June). Employability skills in BIM for construction managers: Recommendations for education. In *ASEE Annual Conference and Exposition, Conference Proceedings*. New Orleans, Louisiana.	2016	CM	US	Delphi study
Sabongi, F. (2009, April). The integration of BIM in the undergraduate curriculum: An analysis of undergraduate courses. In *ASC Annual International Conference Proceedings*. Gainesville, Florida. Retrieved from http://ascpro0.ascweb.org/archives/2009/CEUE90002009.pdf	2009	AEC	US	Survey
Salazar, G. F., Romero, S. A., & de Lourdes Gomez-Lara, M. (2015, April). Building a BIM-based platform to support delivery of construction methods and virtual construction courses at different universities. In *Proceedings of the BIM Academic Symposium & Job Task Analysis Review.* Washington, DC.	2015	CM	US	Virtual prototype development
Shelbourn, M. A., Macdonald, J., & Mills, J. (2016, April). Developing an international framework for BIM education in the HE sector. In *Proceedings of the BIM Academic Symposium*. Orlando, Florida.	2016	AEC	Australia, UK	Mixed
Succar, B., & Sher, W. (2013, November. A competency knowledge-base for BIM learning. In *Proceedings of the Australasian Universities Building Education Association Conference* (pp. 1-10). Auckland, New ZealandRetrieved from http://www.researchgate.net/publication/256633745_A_competency_knowledge-base_for_BIM_learning/file/5046352384853bb7cb.pdf.	2013	AEC	Australia	Mixed
Suwal, S., Jäväjä, P., Rahman, A., Gonzalez, V. (2013, November). Exploring BIM-based education perspectives. In *Proceedings of the Australasian Universities Building Education Association Conference* . Auckland, New Zealand.	2013	AEC	Internation al	Literature review
Taiebat, M., & Ku, K. (2009, April). Industry's expectations of construction school graduates' BIM skills. In *ASC Annual International Conference Proceedings* (p. 8). Orlando, Florida.	2009	CM	US	Survey
Tang, P., Aktan, H.M., & Polasek, J.S. (2012, June). Integrating sensing technology and Building Information Modeling into a construction engineering curriculum. In *ASEE Annual Conference and Exposition, Conference Proceedings*. San Antonio, Texas.	2012	Construction engineering	US	Mixed
Wood, H. L., & Madgwick, D. (2015, July). Embedding emerging technology in built environment education. In *RICS COBRA 2015 Proceedings.* Sydney, Australia.	2015	AEC	UK	Survey
Wu, W., & Issa, R. R. (2013, January). BIM Education for new careers options: An initial investigation. In *Proceedings of the BIM Academic Symposium.* Washington, DC.	2013	AEC	US, internation al	Survey