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

SUBMITTED: July 2017
REVISED: December 2017
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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 curriculum 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...
AEC schools in the United States into accredited programs in architecture and construction education'. There have been some earlier studies 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 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 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 Cezeck-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 Modelling”, “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.

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

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.

<table>
<thead>
<tr>
<th></th>
<th>ARCOM</th>
<th>ASC</th>
<th>ASEE</th>
<th>AUBEA</th>
<th>BAF</th>
<th>BAS UK</th>
<th>CIB W078</th>
<th>CIB W089</th>
<th>RICS COBRA</th>
<th>Per year</th>
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<tr>
<td>2002</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
<td>X</td>
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<td>2003</td>
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<td>X</td>
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<td>2004</td>
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<td>2005</td>
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<td>2006</td>
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<td>X</td>
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<td>2007</td>
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<td>3</td>
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<td>X</td>
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<td>X</td>
<td>0</td>
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<td>2008</td>
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<td>2</td>
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<td>1</td>
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<td>X</td>
<td>0</td>
<td>X</td>
<td>4</td>
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<td>2009</td>
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<td>3</td>
<td>0</td>
<td>X</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td>0</td>
<td>X</td>
<td>3</td>
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<tr>
<td>2010</td>
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<td>2</td>
<td>2</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>0</td>
<td>X</td>
<td>X</td>
<td>7</td>
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<tr>
<td>2011</td>
<td>0</td>
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<td>2012</td>
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<tr>
<td>2013</td>
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<td>4</td>
<td>5</td>
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<td>X</td>
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<td>2014</td>
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<td>-</td>
<td>X</td>
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<td>0</td>
<td>0</td>
<td>X</td>
<td>11</td>
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<td>2015</td>
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<td>2</td>
<td>5</td>
<td>*</td>
<td>X</td>
<td>23</td>
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<td>1</td>
<td>5</td>
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<tr>
<td>2016</td>
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<td>2</td>
<td>1</td>
<td>5</td>
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<td>0</td>
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<td>27</td>
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<tr>
<td>2017</td>
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<td>62</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>143</td>
</tr>
</tbody>
</table>

‘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.](image)
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
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 Galantereau 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 Jazzizadeh (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.

![Collaborative learning Active/action learning Experiential learning Other](image)

**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.

6. ACKNOWLEDGEMENTS

The authors would like to thank Kathryn Davies for her invaluable assistance at the preliminary stage of the research.

7. REFERENCES


## Relevant case studies

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Appendix A
Appendix A


## Other studies

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