Students Perceptions of BIM Education in the Higher Education Sector – a UK and USA perspective

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Purpose: Building Information Modelling (BIM) use has increased in the global Architecture, Engineering, Construction and Owner-Operated (AECO) industry. The increased use has contributed to project stakeholders recognising its importance across the building lifecycle, leading to higher education (HE) institutions rethinking their AECO provisions. There has been much debate about how BIM is currently employed in undergraduate curricula around the world; is BIM included as a stand-alone subject in a programme, or an underlying theme across the programme. Alongside this research has been conducted around theories of practice of what BIM education should look like. This paper builds upon previous research in the codeBIM project and describes student's perceptions of current practice in the USA and UK.

Methodology: The paper begins with a literature review of current theories of BIM teaching in AECO, and a summary of good practice. The use of focus groups is described and the findings from those held in the UK and USA are discussed.

Findings: The paper has found that there are six key areas to be considered in order for BIM to be inclusive in education in the HE sector. These are: Collaborative Curricula; Space; Teamwork; Relevance to Industry; Technical / Technological Skills; and Role of the Professor / Lecturer. Each of these is discussed with findings from focus groups used to highlight key issues.

Originality / value: This paper discusses original research from leading HE organisations in the provision of Built Environment education in the USA & UK. First-hand accounts of students experiences are described.

Keywords: Building Information Modelling (BIM); Architecture, Engineering, Construction and Owner-Operated (AECO); Education; Student feedback

Paper type: Research paper

Introduction

Due to the success of some BIM software vendors' marketing campaigns, many members of the construction industry believe that one or more of these vendors invented or patented BIM and that by buying the vendor's software, their company is automatically 'doing BIM'. However, this is false; no single person can claim to have invented BIM, though Eastman, generally, is credited with coining the term (Yessios, 2004). Eastman's (1975) paper "*The use of computers instead of drawings in building design*", published in 1975, described a working prototype "*Building Description System (BDS)*".

BIM is process-driven (Lim et al. 2015) and does not rely on any single piece of software to work. It does not have to be a single building model or single database. It can (more accurately) be described as a series of interconnected models and databases (Kassem et al. (2015).

The increasing adoption of BIM has been instrumental in some of the major changes that are occurring in the broader Architecture, Engineering, Construction and Owner-Operated (AECO) industry (Parn, Edwards & Sing, 2017). Over the past 30 years, we have witnessed the change from the drawing board to the two-dimensional (2D) electronic CAD (computer aided design) drawing, with little change in the format of the drawings, or the process by which they are produced. The CAD drawing is still generally composed of lines that have no intelligence associated with them. Changing from 2D CAD to 3D BIM requires a shift not only in the technology used, but also in the way design and construction teams work together (Allen Consulting Group, 2010).

Unfortunately, some of the loudest 'BIM evangelists' (Dainty et al. 2015) have assisted in BIM washing and keeping the focus on the 3D modelling aspects of BIM. Many current BIM managers have come from a drafting background, working their way up from 2D CAD to 3D CAD to 'BIM' and commanding large salaries and elevated titles due to the demand for BIM skills. Many do not have professional qualifications beyond drafting-related qualifications, and have a tendency to approach problems from the tools/modelling perspective, not necessarily from an information-management or process perspective. The AECO community really needs to examine what skills are actually needed for the new BIM paradigm. Higher Education (HE) institutions are reflecting on these changes. HE institutions have provided some insights into some of their changes, however there is little research on the learners' perspective of these changes. This paper describes student feedback from focus groups conducted in the USA and UK on their education in collaborative working and BIM. It provides an insight into their thoughts and their issues associated with their learning in BIM and collaborative working in the two countries.

BIM in Global AECO Education

McGraw-Hill has published various reports based on surveys of North American AECO firms. The 2009 SmartMarket Report (McGraw Hill, 2009) stated that more internal staff with BIM skills, more external firms with BIM skills, more incoming entry-level staff with BIM skills and more readily available training in BIM were required in order to realise the potential value of BIM. The 2012 report (McGraw Hill, 2012), shows slight decreases in the percentages allocated to BIM skills required (possibly reflecting uptake by the industry), but BIM training was still placed among the top three targets for investment by industry. Henderson and Jordan (2009) suggested that some of the skill-sets that modern construction professionals need to acquire, in addition to their traditional uni-disciplinary training, include: "*knowledge of data management, information technology, energy and material conservation, integrated building design, systems thinking, life cycle analysis, the design processes, business and marketing skills, and project finance*" (p.35).

Educators should be able to instil in undergraduates in the AECO professions the concepts of collaborative design and the full potential of BIM, before they learn about the "*old ways*" of working once they graduate and get drawn into adopting existing practices in the industry. The concept of creating job-ready graduates brings to the fore the "*training vs. educating*" debate. There has been a resistance in the past among educators to providing training in computer technologies in Universities (e.g. Gerber *et al.*, 2013). Many AECO educators are unfamiliar with these technologies and hence if BIM is used at all within courses, educators currently expect students to learn it by themselves, as they do many other software applications (Williams et al., 2009). This default approach to learning BIM means students will not develop an understanding of how BIM tools enable them to work effectively with others in a collaborative environment.

Many educators still view BIM as just another CAD program that students should learn in their own time. Some argue that it is not the university's role to produce "*CAD technicians*" and that there is no educational value in using CAD, or that CAD "*threatens creativity*" (e.g. Becerik-Gerber *et al.*, 2011). These concerns are reasonably justified as the adoption of computers and 2D CAD has coincided with a decrease in documentation quality and productivity (Engineers Australia, 2005).

However, this argument misses the point that BIM is not merely a new CAD tool or computer application: it is a new paradigm and its benefits extend much further than mere visualisation. Students cannot be expected to "*teach themselves BIM*" any more than they could be expected to "*teach themselves structural engineering*" (Engineers Australia, 2005). From a pedagogical point of view, there is little difference between learning manual drafting techniques and learning 2D CAD. However, BIM provides opportunities to model every part of the design and construction process and can allow multiple design proposals to be compared and building performance to be modelled. 2D (and even 3D) CAD merely provides a way of documenting information about the building whereas BIM actually represents the building virtually with critical information contained within it, depending on who has built the model however.

In addition to the resistance to using new technologies in teaching, the current structure of AECO faculties is a major barrier to collaborative teaching practice. Since engineering and architecture emerged as separate professions from the historic job title of "Master Builder", students of the different AECO disciplines have been educated in isolation from each other. According to Pressman (2007: p3), "*many academic programs still produce students who expect they will spend their careers working as heroic, solitary designers. But integrated practice is sure to stimulate a rethinking of that notion. Pedagogy must focus on teaching not only how to design and detail, but also how to engage with and lead others, and how to collaborate with the professionals they are likely to work with later*." Starzyk and McDonald (2010) note that the focus of architectural education in the past was on developing individual skills such as being able to draw. Now, however, they state, "*the importance of personal skill is yielding to the primacy of collective knowledge*".

In the majority of universities in US, Europe and Australia, AECO students continue to be educated in separate departments, with little or no integration or collaboration between the disciplines (Scott, 2015). Often the first time that students from each AECO discipline are exposed to working with team members from other disciplines is in the workplace after graduation. It is important for graduates to have an understanding of the roles played by other AECO professionals and the impact that their decisions have on projects overall. However, the isolated manner in which they are currently educated does not provide this understanding.

It is not only students of the separate AECO disciplines working in isolation from each other. One usually finds AECO departments in separate schools or faculties and they are sometimes even located on separate campuses to each other. Sharing teaching across these academic silos is a challenge that institutions must overcome if they are to produce graduates possessing the key skills in collaborative working using BIM (Shelbourn et al. 2016). The need for change instigated by the BIM revolution provides a great opportunity to rethink the way AECO courses are developed and to become more efficient in delivering them.

The complexity of modern building projects and technologies means that nobody can be a master of all anymore. Often the separate professions do not have a deep understanding of the information that each requires at different stages of a project. Time is thus wasted stripping out and even rebuilding models, when the models could have been set up more efficiently from the start of the process and unnecessary detail excluded prior to model exchange. Such observations have come from the authors working closely with industry on BIM enabled projects. If students are educated to work collaboratively and to learn the requirements of the other disciplines before they graduate, this level of misunderstanding is likely to be removed in future and trust improved.

BIM offers a great opportunity to engage students more effectively and to aid understanding of how buildings are constructed. Hardy, quoted in Deutsch (2011, p202) states: "*When I look at the logic of construction means and methods that BIM inherently teaches, I see the potential to educate*…" Nawari (2010) states, "*students need to know how each discipline is related to the other and how one discipline impacts the other*". However, in order to bridge the disciplinary silos in industry, we need to start by breaking down the silos that exist in academia.

Mark *et al.* (2001) proposed "*the ideal computer curriculum*" framework for architectural education, which modified the existing curriculum to take advantage of computing technologies without having to introduce new subjects and/or remove existing ones. In fact, they offered two alternative frameworks; one that merged technology into an existing traditional architectural curriculum, and a more radical approach that displaced some existing subjects. Both frameworks were split into Basic, Intermediate and Advanced level courses. Unfortunately, the frameworks only focused on using new computer technologies to teach modelling for visualisation or analysis within the architectural discipline alone; they did not consider collaboration with the other disciplines. Scott (2016) highlighted the case for setting AECO education in the pragmatic paradigm. Scott goes onto say "…*the freedom to work within the pragmatic paradigm offers diversity that can draw together some of the thoughts that challenge and build the arguments about the role and position of theory in construction education*…" certainly a useful consideration when looking at collaborative BIM education. The challenge for academics wanting to educate undergraduates, to be able to work effectively within collaborative teams, putting together virtual (and eventually real-life) buildings, is *when* and *how* to introduce elements of disciplinary knowledge, BIM technologies and development of team working skills. BIM education should be developed in stages, increasing in complexity as the students' knowledge of the building design and construction process grows (e.g. Gordon *et al*., 2009).

Learning Frameworks – their importance

In developing a framework to assist academics in developing more collaborative, BIM-enabled curricula, the approach taken by the papers authors in the codeBIM project (Macdonald & Mills, 2013; Shelbourn et al. 2016) followed principles of constructivism and mastery learning. In essence, constructivism holds that students "*construct*" knowledge based on their (active) learning experiences. Vygotsky (1978) (a social constructivist), developed the idea of the "*zone of proximal development*", which is the stage where most effective learning takes place: where students can, with the help of teachers or peers, master concepts that they wouldn't be able to on their own.

A related concept (of experts assisting novices to learn) is the idea of "*scaffolding*" of learning, and, indeed the terms "*scaffolding*" and "*zone of proximal development*" are sometimes used interchangeably in the literature. The use of the term "*scaffolding*", in relation to learning, appears to have first emerged in a paper by Wood, Bruner and Ross (1976). Bruner described scaffolding as "*the steps taken to reduce the degrees of freedom in carrying out some task so that the [learner] can concentrate on the difficult skill [they are] in the process of acquiring*" (Bruner, 1978, p.9, cited in Mercer, 1994). Scaffolding provides lots of support to learners in the early stages of developing a particular skill, thus reducing the steepness of the "*learning curve*". The support gradually lessens as the student progresses, until they are able to achieve learning goals by themselves.

The term "*Mastery Learning*" was coined by Bloom in 1968; Bloom believed that "*perhaps over 90 percent*" of students could master a subject, given the right support materials and tuition (Bloom, 1968). In Mastery Learning, students are required to master a (prerequisite) simpler subject before moving on to the next, more complex one. Recent applications of Mastery Learning include the self-paced or flipped learning approach (e.g. Bergmann & Sams, 2012; Driscoll & Petty, 2013, Suen, 2014), where technologies are harnessed to allow students to work through topics at their own pace, moving on to the next when they are ready. This is an approach that could be encouraged for the earlier stages of the development of collaborative curriculum, for topics than can be studied by students in their own time, without the need to work with others. For example, students might be required to work through online-based tutorials on certain software tools at their own pace, before they are allowed to take more complex courses requiring them to apply their software skills. The revised version of Bloom's taxonomy by Anderson *et al.* (2001), and the uni-structural to extended abstract categories of the SOLO Taxonomy (Biggs, 2014) follows a constructivist, scaffolded approach to learning, with each stage building on experiences gained in the previous stage.

Koltich and Dean (1999), described two paradigms of teaching; the transmission model and the engaged critical model. The latter emphasises the need for students to engage with what they are studying and thus develop a deeper level of understanding, and promotes the use of teaching methods such as problem based learning.

The philosopher Seneca the Younger is generally credited with the statement "*by teaching we learn*" and the theory that students learn more from teaching others has been proven through research (Annis, 1983; McKeachie et al, 1986). The teacher acts more like a peer in the collaborative environment. The Learning Pyramid, attributed to the National Teaching Laboratory (Magennis & Farrell, 2005), has been quoted often in educational literature, though as Magennis & Farrell (2005) pointed out, the original research source supporting the percentages of retained learning cannot be traced. However, Magennis & Farrell (*ibid*) conducted research that generally corroborates the order of activities in the pyramid, in terms of the amount of learning that is retained following each type of activity. A professor quoted by Burr (2009, p.2) states: "…*allowing students to take responsibility for their learning and for course design and delivery has in the past fostered an 'uncovering' style of learning, high student motivation, and excellent attendance, even in the academic's absence. Some learning theorists have suggested that supplemental instruction – that is, teaching others a subject – helps to promote a higher level of learning*…". As practice by doing and teaching others/immediate use of learning are the activities shown to provide the deepest levels of learning should be included in any collaborative BIM curricula.

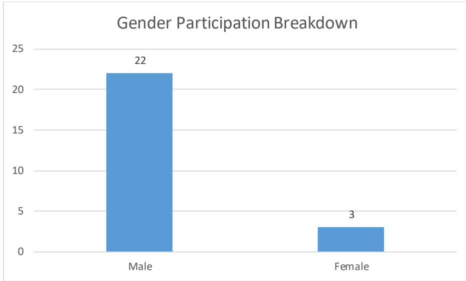
The aim of this paper is to describe and discuss students' opinions on BIM education from the UK and USA. The paper will describe the methodology used to gather data from the two countries, the results from the data gathered, and what lessons can teachers of BIM education learn for future teaching are discussed.

Research Methodology

As this research study was concerned with gathering students' perceptions and thinking of their education in Collaboration and BIM it was considered that a qualitative approach was appropriate. The focus groups built on previous research findings from the codeBIM project (Macdonald & Mills, 2013; Shelbourn et al., 2016). This project was funded by the Office for Learning and Teaching through the Australian Government. Its primary aim was to develop transferable collaborative BIM curriculum that can be used by all universities who offer AECO programs/degrees.

The use of focus groups was chosen as the main data gathering technique for the research as it was felt that deeper answers to the questions being posed could be collected. This approach also allows the focus group leader to expand and ask supplementary questions if needed. The Universities in the USA and the UK agreed to host the focus groups. This worked well for the authors as the same person was able to run the focus groups in the different countries. The two countries were chosen for their experience of running built environment courses for a number of years, and the leaders of these courses were interested in learning and improving their BIM education. Participants were invited to join the groups. In the USA the focus groups were conducted with Interior Design (ID), Architecture, and Construction Science students. All the students, except one who was in his 2nd year of a Masters degree in Construction Science, were in their 'senior' or final year of their studies. In the UK focus group, there were fourteen participants, all male final year Construction Project Management students. Three of the fourteen were part-time students giving a slightly different flavour to the data being collected. Figure 1 details this further.

Country	University	Participant No.	Subject Area	Level	Gender
USA	Oklahoma	1	Interior Design	Senior	Male
USA	Oklahoma	2	Interior Design	Senior	Female
USA	Oklahoma	3	Interior Design	Senior	Male
USA	Oklahoma	4	Interior Design	Senior	Female
USA	Oklahoma	5	Construction Science	Senior	Male
USA	Oklahoma	6	Construction Science	Senior	Male
USA	Oklahoma	7	Architecture	Senior	Female
USA	Oklahoma	8	Architecture	Senior	Male
USA	Oklahoma	9	Architecture	Senior	Male
USA	Oklahoma	10	Construction Science	Senior	Male
USA	Oklahoma	11	Construction Science	Masters (2)	Male
UK	UWE	12	Construction Project Management	6	Male
UK	UWE	13	Construction Project Management	6	Male
UK	UWE	14	Construction Project Management	6	Male
UK	UWE	15	Construction Project Management	6	Male
UK	UWE	16	Construction Project Management	6	Male
UK	UWE	17	Construction Project Management	6	Male
UK	UWE	18	Construction Project Management	6	Male
UK	UWE	19	Construction Project Management	6	Male
UK	UWE	20	Construction Project Management	6	Male
UK	UWE	21	Construction Project Management	6	Male
UK	UWE	22	Construction Project Management	6	Male
UK	UWE	23	Construction Project Management	6	Male
UK	UWE	24	Construction Project Management	6	Male
UK	UWE	25	Construction Project Management	6	Male



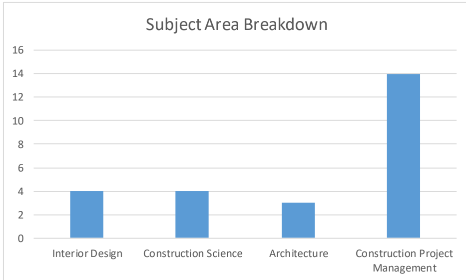


Figure 1: Breakdown of the participants in the study

The authors agreed a script for the capturing of the data (see appendix A). The script was circulated to the different HE institutions for comments before the focus groups being conducted in 2016. The data was collated from the different events. The focus groups were recorded, listened back over, documented and sent to the different institutions for comment. These documents were then compared to enable similarities to be discovered.

Students' perceptions of the Collaborative BIM education

Here, the results from the different focus groups will be described and discussed. Figure 1 shows the makeup of the focus groups across the countries taking part in the research. The findings of the focus groups showed a number of key themes that were critical in the student's opinions for using BIM tools to improve collaborative working teaching and learning. These are: collaborative activities; space; teamwork; relevance to industry; technical skills; the role of the professor/lecturer. These are discussed in more detail giving examples of the participant experiences in them from the different institutions surveyed.

Collaborative Activities

All students who participated in the focus groups in the USA and UK have had some form of collaborative activity in their studies. This means group work where BIM was seen as an essential tool to be used to undertake these activities. The use of BIM for collaboration was predominantly part of the taught activities in both countries, however in the USA, they had extra activities that were voluntary and described as extra-curricular – student competitions. Competitions included those organised as part of Regions V and VIII of the Associated Schools of Construction (ASC). The collaborative activities from both institutions are taught in the final year of study.

The experiences described from the USA were all very positive, one participant saying "*…bringing it all together is the most beneficial part…"*. However, it was noted by one US student that understanding their own role in industry was needed before trying to learn what others contributed to a project, saying "*…you have to understand your own job before you can start to tell other people what you need from them…"*.

The interior design students in the USA also participated in collaborative activities. It was noted that they had little or no knowledge of how their design decisions made using BIM would affect the cost and programme of a project. One US Interior design student felt that "*…perhaps this class could come earlier* (sophomore / junior years), *but then again would we have the knowledge and understanding to complete it so well…*". These students also had little or no knowledge of other members of the project team, the estimator / quantity surveyor or the construction manager / superintendent until they undertook such collaborative classes. It was good for these students to understand what the estimator / quantity surveyor or the construction manager / superintendent roles are. Typically, their interactions have been limited to architecture students. All students in the USA felt that participating in collaborative activities and using BIM tools benefitted them when talking with potential employers.

Experiences from UK students who took a multi-disciplinary collaborative practice module, and using supporting BIM tools were not so positive. Yes, they thought that there was a clear need for collaborative activities using BIM tools in the curriculum, and the collaborative practice module could achieve this, in fact "…*it would be silly not to have one*…". However, their comments suggested that if such teaching and learning is not well organised it loses its appeal. One student from the UK commented on the ability of students to actually participate in collaborative modules of this nature. One of the key issues is the reliance of students meeting outside the class time to organise their work. The student said "…*you can't rely on students doing anything for themselves*…" and questioned whether more structure could be added to the module classes to help in this regard. Another UK student commented that they had not really had many interactions with other disciplines during the first two years of their studies. It was felt that more was needed as "…*it is important to know what the other disciplines are doing as these are people you are going to be working with in the future*…". This was similar to the comments from the US participants and should be noted for future collaborative teaching and learning.

One positive note from the collaborative practice module in the UK was the use of industrial speakers in the lecture series. Although they were too focussed on the architecture and design discipline, perhaps reflecting the stronger use of BIM tools in these fields, it was good to see a number of different types of projects for different clients showcasing their collaborative activities being discussed in the lectures. The lectures on BIM were very informative – for some this was their first introduction to this topic.

After considering the thoughts and perceptions from the students it can be determined that the following aspects can be observed:

- Students are coming together to work on joint projects in both the USA and UK;
- Real-world problems were given to the US students to solve. They were not given partly-finished BIMs, they were expected to build them as part of the classes;
- The students from the UK learnt about the types of contract that facilitates BIM and collaborative working;
- Students in both the USA and UK continued to learn about group dynamics and improving teamwork from their collaborative activities.

Although not high levels of collaboration level have been observed it can be seen from the discussion above that students feel they are getting sufficient teaching and learning in collaborative working and BIM. As part of an annual university assessment of student satisfaction of their teaching and learning, 16 UK students were asked to use the scale "*…successful/partly successful/not successful…*" to assess whether their program had improved their understanding of collaborative design, the role that the other disciplines play in the design and construction process, and the impact new technologies and processes, such as BIM, are having on the construction industry. Thirteen students said partly successful and one student said successful. These numbers suggest that what has been observed by the authors in the focus groups is in line with the participants of the focus groups, in that they seem to be in agreement.

Space

Whilst the taking part in collaborative BIM activities was seen as a benefit, the actual space to allow students to do this was limited in both the US and UK, making it difficult for students to work in a collaborative way. The interior design participants in the USA were very keen to stress the importance of having the right space available to carry out collaborative work. Although some subject areas may have had a dedicated space for them to work, the majority felt that there was not enough of the participants coming together in these spaces, with one participant commenting "…*never the twain shall meet*…". All participants in the USA felt that having dedicated spaces to undertake collaborative activities would enhance their ability to work as a team. They commented that face-to-face meetings were key to the success of collaborative activities so meeting type spaces are definitely needed.

In contrast the UK participants concentrated their comments on the only module that was seen to be collaborative in nature, it was called 'Collaborarive Practice'. The collaborative practice module had so many students taking it (approx. 120) that the lecture theatre allocated simply was not big enough, with some students having to stand or sit on the floor – clearly not a satisfactory situation. This could have been a contributory factor to some participants describing a poor experience, with one participant in the UK commenting that they preferred lectures to be in a tiered theatre rather than a flat classroom. There was little appreciation of classroom design making a difference of enabling collaborative working by the UK participants. This could be that the UK participants are not aware, or been exposed to spaces that do enable collaboration.

It is clear from these comments that built environment schools and colleges at universities need to provide collaborative learning spaces. These spaces need to include an area for the inclusion of ICT and BIM tools. Spaces are needed to enable teamworking around a table with access to the ICT and BIM tools. It can be seen from the US comments that such spaces will enhance the learning experiences of students, especially if using interdisciplinary group work on such courses.

Teamwork

Participants from both the USA and the UK studying construction science / construction project management commented that the small group size of their classes –around 15-20 students – made for a better working environment, and a closer knit group. This meant they got to know each other more easily and felt more comfortable with each other making it easier to learn from each other when discussing problems or generating ideas. Classes of this size are advantageous when designing spaces for ICT to develop and manipulate BIMs as well as spaces to sit and discuss what needs designing and including in such BIMs collaboratively.

All US students felt that they had become a better team player from their engagement with collaborative working activities using appropriate BIM tools. One US participant reflected that "…*working in a team had made me realise my weaknesses* (*sic.*in group working) *and it had made me reflect on different things I can do to try and improve my working practices to make me more collaborative*…". Those participants that had participated in the extracurricular activities – industry sponsored student competitions and the ASC competitions – felt that they were better team players as a result. Whilst this was good for the construction science students, one female architecture student commented that such activities need to be more widely advertised in the college to enable other students to realise such benefits.

At the time of writing there is little opportunity for UK students to participate in extracurricular activities so their reflections and opinions are purely based on their experiences with scheduled teaching[1]. The UK participants found this question hard to answer as they had not really been asked or discussed the issue as part of their studies. An initial comment from one participant was "…*there is no I in team*…", showing some

[1] Region 8 of the Associated Schools of Construction now runs a UK based student competition in November of each year around a construction management and planning problem. It takes a similar format to other ASC region competitions in the USA.

understanding that working together is important. Another UK participant used his experiences from working on the collaborative practice module to say "…*there were people in my group that didn't want to be there, people didn't care about the group, one member was quite head strong and dominated the group, but this was good experience as you are forced to work with people…you very rarely get to choose…it is going to be difficult but you just have to get through it…in this respect it was good for my learning*…". Reflections such as this provide evidence to lecturers and professors that collaborative activities, although sometimes difficult to set up and manage, are relevant and an essential learning experience for students on architecture and built environment programs.

Relevance to industry

Participants in the UK included part time students which means they are already working in the industry, there were no students in the USA on a part time route. A part time participant in the UK was wary of contradicting the lecturer in their classes. He was worried that he could be seen to be "*moaning*" all the time. He went onto explain that lecturers are giving the theory in the class, and it is very hard not to keep saying "…*but this doesn't happen in the industry*…". Another participant from the UK commented that having the part time students in the class was a benefit as it enables him to ask questions about BIM practices in the industry and enhance his learning from them. The full time students found this question hard to answer as they had not been working in the industry very much. There was little or no industry participation in their teaching, and no projects or briefs set by, and run by industry. Participants in the US had mixed feelings on this topic. The architecture students would like to have more industry participation in their learning. They would like to see more critiques of their work from clients and architects from industry that were using BIM tools, a view shared by the interior design participants. Two architecture participants went further to discuss software used by architects. It highlighted the importance the participants place on having knowledge and understanding of BIM software used in the industry. All the architecture participants were in agreement that having collaborative classes with other disciplines made them "…*realise the implications of what they are designing has on constructability and cost*…". These experiences were best learnt from their peers in collaborative teaching and extracurricular activities such as student competitions.

The interior design participants felt that they "…*had wasted their money*…" in the 'Culture for Collaboration' classes in their first year. Although it seemed the class had good intentions of providing learning of the industry to the students, it just didn't work as it felt it was "…*forced collaboration*…". Another participant agreed with this and commented "…*how are we expected to know what these others do when we don't know what we are ourselves*…". There was a recognition that when these participants took the class it was the first running of the class and in the four years since, they conceded that it could well have improved. The understanding of different roles in the industry is important to the participants and was seen as a vital component of collaborative working education.

Technical / technology skills

One of the US construction science participants had an issue with the teaching and learning of BIM tools such as Revit (the industry standard BIM tool in the UK and USA). They were confused as to why they were being asked to build a BIM when they were only interrogating them when they were working either in the industry now or previous internships. Yes, they could understand the architects building BIMs, but not for the construction science students to build them. A construction science graduate needs to gather information from such models to enable them to inform their decision making in managing projects. Another construction science participant contradicted this by saying he liked the building of the BIMs as he felt he did not really have to think too much to get through the module. He went further to say "…*I have found a new respect for architects in realising the amount of time and effort and the skills they need to build a model*…". This is a significant reflection and shows the importance of including BIM tools teaching in all university curricula.

Interior design participants had a similar perspective to the architects and construction science participants. They were being taught Revit but they felt there was a difference between "…*industry Revit and school Revit*…". One of the main challenges identified was there was only one professor capable of teaching it and they lacked industry experience.

Another key talking point was the topic of sketching. Two participants felt there was too much of it, one was ok with it, and one felt there needed to be more. When asked to elaborate there seemed to be too many hours spent sketching 'still life' objects and not subjects seen as relevant to the course. One participant felt that sketching buildings "…*had little relevance to her studies when most things were completed in the computer now*…". In contrast another participant saw sketching as "…*a key area for communicating concepts*…", which ironically all others agreed with. There needs to be a balance between the two to provide students with the required skills to communicate their design ideas.

For the UK participants similar issues were raised about software used in the industry. One participant was strong in his beliefs that Microsoft Project is an essential software that they needed to learn. This was countered by a part time student saying that industry doesn't use Microsoft Project and students needed training in Primavera or Asta Powerproject. Whether universities train or educate has already been debated, but what all participants agreed was they needed a "…*raw understanding of the software as a minimum*…". Similar comments were made surrounding BIM. All UK participants agreed that BIM is perhaps the one subject where they needed more teaching and learning. The UK BIM mandate requiring all publicly procured construction projects to have BIM included in them, is now in force. As new graduates entering the industry it could be seen by some employers that it is these graduates that should have BIM knowledge. Many of the full time participants were worried in this regard as some felt "…*if I was to be asked* (about BIM) *I couldn't tell them very much*…". This was reinforced by a part time student by saying "…*having BIM knowledge could give new graduates a competitive advantage on site*…". It is clear that BIM is seen as a key topic, the question then arises what is left out or replaced? Participants felt that subjects such as 'Human Resource Management', 'Ethics and Professionalism' were not needed. Of course these are dilemmas for all course teams and professional accrediting bodies, but what is clear is that students want more BIM.

Another UK participant posed the question "…*there are so many different BIM software out there, how do you choose which one to teach?*" One participant felt that a construction project management graduate is never going to design in BIM that is the role of the architect, structural engineers etc. but as seen in the USA discussion it was said understanding how a model is built is key to understanding other roles in the industry. This is an issue to be wrestled with by course management teams, and something this paper has no clear answer to. A part time UK student said that "…*there are so many different BIM software out there, how do you choose which one to teach?*…" others completely disagreed. One adding that as part of the UK government BIM mandate a client will ask for it, making construction project managers use it on a day-to-day basis so they do need the skills. Another UK participant commented "…*Revit was taught at level 4 and many students thought that was BIM – this is obviously not the case*…". He was only able to make this comment as he was doing his dissertation in the BIM arena. A clear consensus came from the group that as a minimum construction project management students need to know how to interact with such models to enable them to do their jobs more efficiently.

It is clear from the discussions in the USA and the UK that there is some confusion as to the extent students need knowledge and understanding of BIM and supporting software used in support of collaboration when working in the industry. A key challenge for educators is getting the right balance between teaching theory and software tools. As educators become more experienced in this field, and more importantly, begin to share their knowledge and understanding, the confusion of students will remain. Developments in frameworks for BIM education (Macdonald & Mills, 2013; Shelbourn et al., 2016) challenges educators to reflect on current collaborative working and BIM tools teaching and highlights areas for improvement. Perhaps a first step for many educators is using such frameworks to understand where they actually are before diving head first and teaching Revit to their students as the starting point.

Role of the professor / lecturer

Participants from both the UK and USA have mixed feelings about those that teach them. A participant from the UK group commented that the worst thing about their collaborative practice module was "…*the lecturing staff and their lack of organisation and delivery of the material*…". However, he did praise the organisation of external industrial speakers on the module, even though he felt they were too biased towards architecture, meaning that construction project management students were "…*less likely to engage*…" in the module. For the US students it was clear that the interior design participants were more comfortable with classes from certain professors when they were learning about BIM. The classes that were more structured and expectations of them more clearly laid out were seen to be more enjoyable. Two key ideas were put forward to improve their learning:

1. What are the major milestones I will reach along the four-year journey of the program?

2. What is expected of me during my time on the program?

These could be easily articulated at both the course and module level, however, it could be argued that the student's ability to think for themselves is removed. Participants from architecture and construction science agreed with this when they made similar comments. One architecture student was very disappointed in this area, commenting "…*it felt they winged it*…" and "…*they really didn't seem to have a solid idea of what they were doing*…". Although these comments could be down to poor student experience with an individual professor and should be taken with some caution.

Table 1: A summary of the key comments from the students in the USA and UK in the key areas identified

Issue	USA	UK
Collaborative Activities	*bringing it all together is the most beneficial part*	*it would be silly not to have one*
	you have to understand your own job before you can start to tell other people what you need from them	*you can't rely on students doing anything for themselves*
	perhaps this class could come earlier (sophomore / junior years), *but then again would we have the knowledge and understanding to complete it so well*	*it is important to know what the other disciplines are doing as these are people you are going to be working with in the future*
Space	*never the twain shall meet*	
Teamwork	*working in a team had made me realise my weaknesses* (*sic*.in group working) *and it had made me reflect on different things I can do to try and improve my working practices to make me more collaborative*	*there is no I in team*
		there were people in my group that didn't want to be there, people didn't care about the group, one member was quite head strong and dominated the group, but this was good experience as you are forced to work with people…you very rarely get to choose…it is going to be difficult but you just have to get through it…in this respect it was good for my learning
Relevance to industry	*realise the implications of what they are designing has on constructability and cost*	*but this doesn't happen in the industry*
	had wasted their money	
	forced collaboration	
	how are we expected to know what these others do when we don't know what we are ourselves	

Technical/technology skills	*I have found a new respect for architects in realising the amount of time and effort and the skills they need to build a model*	*raw understanding of the software as a minimum*
	industry Revit and school Revit	*if I was to be asked* (about BIM) *I couldn't tell them very much*
	had little relevance to her studies when most things were completed in the computer now	*having BIM knowledge could give new graduates a competitive advantage on site*
	a key area for communicating concepts	*there are so many different BIM software out there, how do you choose which one to teach?*
		there are so many different BIM software out there, how do you choose which one to teach?
		Revit was taught at level 4 and many students thought that was BIM – this is obviously not the case
Role of the professor/lecturer	*it felt they winged it…*" and "*…they really didn't seem to have a solid idea of what they were doing*	*the lecturing staff and their lack of organisation and delivery of the material*
		less likely to engage

To summarise there has been some strong views expressed in the six areas above. Whilst it is clear there is some discourse in both the US and UK with current teaching in the area of collaborative working and BIM, there are pockets of good practice too that educators can learn from.

Conclusions

This paper has highlighted issues surrounding the pedagogical challenges for teaching and learning of collaborative working and BIM at the university level. It is proposed for future research that to negate some of these issues frameworks for implementing collaborative working and BIM into the teaching and learning of AECO education could be utilised; the IMAC Framework from Macdonald & Mills (2013) and Shelbourn et al. (2016) for example. In order for the developers of BIM learning and teaching materials to prevent similar comments from their students in their teaching, it would be beneficial if they could access resources to help with such developments. Future research is needed in this area to begin to identify, collate and disseminate learning and teaching materials that have proven to be successful in the AECO arena. Macdonald & Mills (2013) and Shelbourn et al. (2016) have begun this process, however it is clear that more work is needed in this area. It is important to stress that such material should be 'collaborative' in nature and not specific to the different discipline silos, points that have been stressed by both the authors in their work and the students in the focus groups.

There are clear pedagogical recommendations to be made from the work discussed in this paper. The focus groups held in the USA and the UK have helped in developing these recommendations. These include:

- it is important to know what the other disciplines are doing as these are people you are going to be working with in the future;

- dedicated spaces are needed for interdisciplinary / collaborative group work, using appropriate BIM tools to support learning;
- learning relevant industry software is important for all participants;
- it is important to understand different roles in the industry as this is seen as a vital component of collaborative working;
- innovative teaching and learning is needed to enable students to document and communicate their ideas to other members of their interdisciplinary stakeholders as well as the client;
- peer to peer learning is important in understanding design decisions, in particular for architecture students; and
- as a minimum construction project management students need to know how to interact with BIMs to enable them to do their jobs more efficiently.

It is clear from the paper that there is still much to do pedagogically to improve the teaching and learning of collaborative working and supporting BIM tools to the graduates of the future in the USA and the UK.

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Appendix A – Focus group script

Proposed transcript to be used by external Focus Group Leader

Introduction

Hello, and thank you for agreeing to meet with me and share your views on the [insert name of course here] course. My name is [insert name] and I am leading this focus group discussion today on behalf of Dr Mark Shelbourn from the University of Huddersfield in the UK. The research you are helping us with will help academics improve the teaching of collaborative architecture, engineering and construction courses, including BIM tools and processes.

Before we begin, let me review the ground rules. Your responses will be recorded, but all individual comments will be kept confidential. Your lecturer or tutor will not have access to who said what! Keep in mind that we are just as interested in negative comments as we are in positive comments (though please remember to be respectful), and often the negative comments can be the most helpful. A diversity of views will also help us understand how you really feel about your courses. We will finish sharply at [time].

First of all, could you just tell me what discipline (architecture, engineering, construction management) you are studying, and what year level you are in? [self-intro one-by-one]

1. **Overall course impression**

Structure:

- What did you think of the group size; class duration; delivery mode (semester long/intensive/distance); venue; mix of disciplines?

Quality:

- Did you feel that this course was pitched at the right level for you?
- Was the amount of content covered too much/just about right/too little?
- Did you feel more or less engaged (actively involved/interested) in this course compared to your other courses?

Relevance

- In general, did you feel the course met your needs/will be relevant to your future career?
- What do you feel you can apply (if anything) from this course to your career after University?

2. **Understanding of other disciplines' roles in the design/construct process**

Pre-course bias:

- What stereotypes/views of the other disciplines (architecture/ engineering/construction management) did you have before you started the course?
- Did your views change during the course?
- For better or worse?

Understanding:

- Do you feel that you have a better understanding of the roles of other disciplines involved in construction now that you have finished the course than you had at the beginning?

3. **Teamwork / Collaboration / Tech skills**

Teamplayer:

- What have you learned about yourself as a team player (or future member of a multidisciplinary team) in this course?

Peer support:

- Do you feel the collaborative/peer learning components of the course contributed to your learning of the course content?
- What were the advantages and disadvantages of the collaborative/peer learning work?

Team confidence:

- Do you feel that you have improved your skills in working in a collaborative team?
- Do you have more/less/the same confidence about working in a collaborative team after University than before you started this course?

Technical:

- Do you feel that you have improved your skills and awareness of new technologies/processes being adopted by the industry?

4. **Feelings about course within overall University program structure**

Structure:

- What connections (if any) do you see between what you have learned on this course and your other University courses?

- Did the course appear to fit within an overall structure (i.e. one subject leading smoothly into another) or did it seem to be isolated from your other courses?

Best/Worst:

- What was the best/worst/most challenging aspect of the course?
- What did you expect to see covered in the course that was not?

5. **Conclusion**

In conclusion, some of the aims of the changes made to your course this year were to improve your understanding of collaborative design, the role that the other disciplines play in the design and construction process, and the impact new technologies and processes, such as BIM, are having on the construction industry, particularly in terms of increased collaborative working practices. Do you feel the course was successful/partly successful/not at all successful in achieving these aims?

Thank you very much for your time!