Integrating BIM in higher education programs: Barriers and remedial solutions in Australia

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Abstract

Despite the increasingly widespread adoption of Building Information Modelling (BIM) in Australia, a steady pipeline of BIM-ready graduates needed to meet industry demand remains elusive. Anecdotal evidence suggests that universities in Australia have not been successful in delivering BIM-enabled graduates of the right calibre due to a plethora of barriers. This paper aims to identify, define and delineate barriers to integrating BIM education into programs in Australian higher education institutions (HEIs), and unearth the antecedents of these barriers. A post-positivist philosophical design was implemented to undertake a cross sectional and mixed methods approach to collecting and analysing primary data. Data was collected through qualitative methods – 18 structured and seven semi-structured interviews – with key BIM educators in Australia. Data were analysed using Nvivo. Findings reveal that four thematic groups of barriers hinder effective BIM education integration in Australian HEIs. These are: 1) change management challenges; 2) curriculum and content limitation; 3) educators' problems; and 4) disconnect with the industry. The research concludes that a major overhaul is needed to change the *modus operandi* via which the industry, accreditation bodies and government policy makers engage with HEIs to define BIM education programs. However, given a notable dearth of investment and collaboration from the industry and government, HEIs cannot manage the change needed for running effective BIM training programs. Therefore, cross government/industry collaboration and financial support is needed to stimulate a cultural shift in existing HEIs' provisions to generate future generations of highly skilled and competent BIM enabled graduates. This paper represents the first attempt to contextualise HEIs' capacity to deliver advanced BIM training given a wider and prevailing economic and political topology that currently fails to adequately support the supply of fully trained graduates.

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INTRODUCTION

BIM adoption is increasing within the architecture, engineering, construction and operations (AECO) industry in Australia (Hong et al. 2020); more businesses implement BIM and so demand for professionals with BIM competence is exponentially increasing (Hosseini et al. 2018a). To accommodate short-term BIM-related skill demands, AECO businesses can engage internal staff or outsource expertise (Wu and Issa 2014). However, from a longer-term perspective, a sustainable pipeline of competent BIM graduates supplied by HEIs is needed (Succar et al. 2012a; Wu et al. 2018). Students in HEIs constitute a significant part of the future industry workforce, therefore, BIM skills and competencies are needed to solve future problems confronting the sector (Bosch-Sijtsema et al. 2019; Hong et al. 2019; Jin et al. 2019).

Australian HEIs have commenced embedding BIM education within their programs but anecdotal evidence suggests that largely underdeveloped BIM awards are impeded by scant resources and inconsistency across programs and institutions (ACIF and APCC 2017). Indeed, several academics proffer that Australian HEIs have not successfully integrated BIM into their programs and that current graduates are ill-prepared to lead a digital future (Baradi et al. 2018; Kim et al. 2020; Puolitaival and Forsythe 2016). Previous studies unequivocally state that BIM educators must improve their programs through a consistent policy approach, for which identifying the barriers to BIM education resides at the vanguard of priorities (Baradi et al. 2018; Jin et al. 2019). Identifying barriers will expedite the process of developing appropriate measures to tackle challenges posed and identify remedial solutions needed (Babatunde Solomon 2019; Succar et al. 2012b).

Research suggests that charting BIM educators' practices and perceptions toward BIM (identifying the barriers, causes and solutions to BIM education) is an essential first step towards enhancing graduates' BIM employability (Babatunde Solomon 2018; Babatunde Solomon 2019; Jin et al. 2019). In Australia, this enigmatic conundrum remains largely unchartered territory and consequently, scant academic attention has been given to identifying the challenges of BIM education in Australian universities. Those limited studies conducted focus upon the views and perceptions of students, for example Olatunji (2019) and Jin et al. (2019) explored BIM education challenges in Australia based on primary data collected from student samples. Elsewhere, BIM education studies from international perspectives have been conducted (Babatunde Solomon 2018). Nevertheless, at present, a cohesive mass of impactful research eludes Australia (Baradi et al. 2018).

This conspicuous gap within the prevailing body of knowledge provides the motivation for this paper, namely to: systematically identify the barriers to BIM education integration into the programs of Australian HEIs from the perspective of educators; assess the causes; and offer remedial solutions to address these barriers, all from the vantage point of educators. In realising these aims, concomitant objectives are to: engender wider polemic debate within HEIs and government policy makers to ensure that future generations of trained and competent (BIM enabled) graduates can meet industry employment demands; and create opportunities for the Australian AECO sector to upskill the workforce and in so doing, augment industry performance and profitability.

CONTEXTUAL BACKGROUND

The Australian construction industry contributes 8.1% of gross domestic product (GDP), employs over 1.1 million people and in 2022, employment growth is forecast to be circa 10.9% (ABAB 2018). Despite this significant scale and inextricably linked economic contribution to national wealth, the construction industry faces several challenges. MacDonald and Mills (2013) suggest that the general quality of construction documentation is declining and in addition, reports suggest that 30% of Australia's $200 billion construction investment can be categorised as wasted (ABAB 2018). Moreover, clients are further exacerbating these challenges with their ever intensified demands for higher quality, faster schedules and lower costs (Abbasianjahromi et al. 2016). To overcome these major challenges, projects within the AECO sector must be delivered differently (Chinowsky and Songer 2011) using innovative and digital advanced technologies such as BIM (Gruszka et al. 2017; Hosseini et al. 2016; Hosseini et al. 2018b; Mitchell et al. 2012).

The observed increase in BIM adoption is a global trend (Kim et al. 2017; Ozorhon and Karahan 2017) and BIM adoption in Australia is no exception, accelerating exponentially in the last two decades (Atazadeh et al. 2017; Hong et al. 2020). This growth is attributed to a concerted government push towards wider Industry 4.0 adoption that seeks to engender smart and more sustainable cities and infrastructure (Newman et al. 2020; Pärn and Edwards 2017). Despite this promising advancement, Australia faces many barriers to BIM implementation on projects (Gelic and McLeod 2018; Hosseini et al. 2018b). Of these barriers, lack of knowledge and, BIM education and training are identified as primary causes (Hosseini et al. 2016; Jin et al. 2019; NBS 2019; Puolitaival and Forsythe 2016).

In Australia, BIM is known by the AECO industry as: *"a foundational activity, a critical need for both industry and academia and a priority due to the apparent skill shortage in this sector in Australia."* (Succar et al. 2012a) Given this demand from the AECO industry, Australian HEIs have made some progress in fostering BIM education and/or have offered compelling rhetoric that they are BIM enabled (Jin et al. 2019; Kim et al. 2020; Olatunji 2019; Rooney 2018). Despite this interest, BIM-related content delivered across universities greatly varies (Olatunji 2019) and on occasion, HEIs have anecdotally been accused of BIM-wash. Even leading Australian universities are failing to create BIM-ready graduates (ACIF and APCC 2017). Existing curricula is inadequate and generally addresses basic BIM concepts with a focuses on developing specific software skills (Rooney 2018). A core element of BIM is consistency in approach and collaboration across all disciplines involved in a construction project management team (Baradi et al. 2018; Mignone et al. 2016). Yet, Australian universities continue to drive students down specific roads suited to the institutional capability and capacity (Jin et al. 2019; Olatunji 2019). Evidence shows that Australian universities are treating BIM as an optional addition, not a core element of their programs (McPhee 2016). The community of BIM educators must address this observed shortfall in contemporary pedagogical practice and adopt a common, consistent policy approach (Gelic and McLeod 2018; NBS 2019).

BIM-related higher education programs

The higher education sector in Australia contributes 8.5% of GDP, supported by its graduate workforce (28% of the total workforce). Australian universities are said to generate employment market growth (Parker 2018); they employ over 120,000 staff and enrol 1.3 million students (Deloitte 2015). It is estimated that the stock of research activity and knowledge generated equates to $160 billion in 2014, namely, around 10% of Australian GDP (Deloitte 2015). Despite the importance and size of universities, their BIM-related programs are fraught by a plethora of shortcomings (ACIF and APCC 2017). The 2019 BIM Education Global Report by Rooney (2019) summarises Australia's situation as one in which no BIM program is delivered at more than a basic software package usage level; and no BIM program integrates across the AECO disciplines. BIM education has plateaued and stagnated due to toxic combination of scant educators and resources combined with an apathy for change (Kim et al. 2020). There is little collaborative effort across the HEIs in Australia, consequently industry and other stakeholders (such as clients) that must be engaged in adopting and improving BIM education (Kuiper and Holzer 2013; MacDonald and Mills 2013).

Academia and industry recognise that developing a sustainable pipeline of BIM-ready graduates and embedding the required curricula within Australian HEIs are essential to deliver consistent and quality BIM education (ACIF and APCC 2017; Hosseini et al. 2016; Hosseini et al. 2018b; NBS 2019) – they are also fundamental to preserving future generations of sector performance and profitability. The National Building Information Modelling Initiative (buildingSMART Australasia 2012) states that educators must: *"deliver a broad industry awareness and retraining program through a national BIM education taskforce based on core multi-disciplinary BIM curriculum, vocational training and professional development."* Against this backdrop, a stream of research has been allocated to exploring the status quo of BIM-related education.

Previous research

Effective BIM education within HEIs requires cultural change and industry-oriented curricula (Best and Langston 2005) – such has yet to be realised (Baradi et al. 2018; Jin et al. 2019; Mills et al. 2013; Puolitaival and Forsythe 2016). Whilst academia may criticise AECO industry practitioners for operating in a traditional manner (Durdyev et al. 2019), the irony is that many Australian universities mirror the same ineffective practices. This could be because academics either have minimal industrial experience or that experience is outdated. As a result, graduates can be ingrained with an outdated and traditional approach taught from textbooks vis-à-vis practice (MacDonald and Mills 2013; Merschbrock et al. 2018).

To facilitate a meaningful change within the sector requires effective education within Australian HEIs. To develop a consistent national approach to BIM adoption, the Australasian BIM Advisory Board called on: *"industry, government and academia to further research BIM education and training"* (ABAB 2018). In addition, there is a disconnection between curricula and the industry, where graduates are not prepared to perform BIM-related tasks (ACIF and APCC 2017). Furthermore, there is no widespread consensus on the requirements and intended learning outcomes of BIM-related programs globally (Wu et al. 2015). Australia is no exception. This disconnection between curricula and industry needs is the primary reason of graduate unemployment and employer dissatisfaction (Witt and Lill 2010). Criticism has suggested that BIM does not offer solutions to real-world management and construction issues and is limited to simply a communication, visualisation and simulation tool (Arashpour and Aranda-Mena 2017). Because of this, some doubt the cost effectiveness of teaching BIM (Arashpour and Aranda-Mena 2017; Hosseini et al. 2016; MacDonald 2012). Inconsistency in use of BIM across Australian universities is further exacerbating the disconnection between students, disciplines, curricula and industry (Jin et al. 2019; Puolitaival and Forsythe 2016).

In the main, Australian universities still only offer BIM courses, primarily as elective content (Puolitaival et al. 2015). The resources include large files, software, reliable and realistic data input and difficulty in exchanging data among multiple software packages (Arashpour and Aranda-Mena 2017; Rooney 2019). An additional barrier is the lack of educators and support with expertise in the subject (Mills et al. 2013); educators are not trained to teach BIM content hence, negatively impacting upon the curricula they design and deliver (Hon et al. 2015). So too, educators are unwilling to define new subject areas, where courses are at capacity and there is no room for new subjects like BIM (MacDonald 2012). These barriers are the main causes cited by previous researchers who suggested that Australian universities have been lagging behind the AECO industry in effectively training and educating BIM (ACIF and APCC 2017; Jin et al. 2019; MacDonald 2012; MacDonald and Mills 2013). According to Puolitaival and Forsythe (2016) *"the finer points of how best to learn about BIM is still a relatively under-explored area."*

RESEARCH METHODS

To analyse the perceptions and experiences of educators, this research adopted a post-positivist philosophical design (Roberts et al. 2019) to analyse qualitative primary data collecting from a cross sectional time horizon. This broad approach has been used extensively within construction literature, for example: Dixon et al. (2020) undertook an investigation into the erroneous access and egress behaviours of building users and their impact upon building performance; Al-Saeed et al. (2020) developed an automated manufacturing procedures using BIM digital objects; and Mohamed et al. (2019) explored industry practitioners' knowledge of fire prevention following the Grenfell disaster. This body of work justifies this overarching epistemological design being implemented in this current study.

For an operational perspective, qualitative research allows researchers to elicit facts and gain deeper insights into the experiences, processes and perceptions of people (Bazeley 2013; Rowley 2012). One of the most effective qualitative methods for collecting information from a natural context (namely Australian universities in this context) is carrying out interviews with experts active in the context at hand (Bazeley 2013).

Respondents

The '*purposive sampling'* approach is used to identify and select individuals who are especially knowledgeable about and experienced with BIM teaching at Australian universities. Purposive sampling is used because it enables researchers to fulfil the research objectives in terms of access to knowledge and experience, as well as ensuring that experts are available and willing to participate. Australian universities with BIM-related programs and subjects provide the target population. An exhaustive exploration of university websites revealed that 24 out of 43 universities in Australia (see The Study in Australia (2019)) provide BIM-based subjects and programs. Educators in charge of these programs and subjects are contacted personally by research team members. This resulted in 18 experts agreeing to participate (75% response rate) with only two failing to reply.

Data collection

The interviews were conducted in two stages using two different methods. Stage one entailed conducting 'structured interviews' in which interviewees responded to questions on describing the programs they administer and improve a list of barriers, considering the challenges they face in integrating BIM-related education into their programs. An a priori list of barriers was generated through an exhaustive review of literature of studies on BIM education, from Australia and elsewhere. Participants were presented with the list and asked to include or remove items. This approach was taken following the recommendation of Johnson and Onwuegbuzie (2004), that is, structured interviews are used as the qualitative mini-study to initiate and inform the leading approach – semi-structured interviews in the present paper. As a common practice in construction literature, initial structured interviews serve the purpose of discovering additional barriers beyond those found through the review of the literature; structured interviews enable researchers to customise the list of barriers for the specific context of the study (Fernando et al. 2017; Ijasan and Ahmed 2016). Additionally, structured interviews were needed to generate descriptive data on the context of the study and provide a picture of the field.

Participants came from institutions located in all states of Australia, except for Tasmania and Northern Territory: Western Australia (3) ; Queensland (4); South Australia (1); Victoria (7); New

South Wales (2); and Australian Capital Territory (1). The data for structured interviews were collected through questionnaire surveys that included both Likert Scale type questions, as well as, open-ended questions. Participants were asked to indicate their agreement with the suitability of include items within the list using a scale of 1 to 5 and provide comments and suggestions for revising the items within the blank boxes provided for each item. This approach is in line with the recommendation to treat each structured interview as a 'self-administered' quantitative questionnaire in both its form and underlying assumptions (see Alshenqeeti (2014) for details).

Participants were asked to indicate their willingness to further contribute by participating in 'semi-structured interviews' and discuss the nature of barriers identified. Of the 18 participants, seven participated in semi-structured interviews primarily conducted via online video meetings. The interview duration was circa 30-44 minutes of video recording with BIM educators in various states of Australia (refer to Table 1). The adequacy of the sample size is justifiable, given that of the 24 Australian universities, 18 were included in structured interviews and seven contributed to semi-structured interviews. Moreover, as argued by Bazeley (2013) data saturation can occur once more than six participants have been interviewed.

Table 1. Participant information (semi-structured interviews)

Participant	Expertise	Location
1	Quantity Surveyor and Academic	Western Australia
2	Architect and Academic/accreditor	New South Wales
3	Engineer, Academic and BIM specialist	Victoria
4	Academic and BIM specialist	Victoria
5	Engineering Academic	Victoria
6	Engineer Academic	Victoria
7	Academic and BIM/Sustainability specialist	Australian Capital Territory

Data analysis

For structured interviews, the quantitative data were analysed using descriptive statistics techniques. Open-needed questions yielded word-based accounts. These were treated as qualitative data and coded – like unstructured interviews – following the lesson by Alshenqeeti (2014). The audio recordings from semi-structured interviews were converted into written transcripts using Sonix, an automated transcription software (https://sonix.ai/). These transcripts were then submitted to NVivo 12 qualitative data analysis software for coding. NVivo 12 software was selected instead of a manual process as it is an advanced research tool for data organisation, coding, analysis and visualisation (Bazeley 2013). The software was deployed for coding the interview transcripts because it can enhance the rigour and accuracy of data analysis as well as expedite data analysis (Bazeley 2013). The analysis of data follows the principles of thematic analysis for qualitative data as described by Gibson and Brown (2009). This was to fulfil two primary aims, namely: (1) examining commonalities across the interview transcripts and structured interview documents to pool together elements of data and (2) examining relationships to identify how different pieces of information relate to each other (Gibson and Brown 2009).

The purpose of structured interviews was to allow researchers to create a list of codes, to be used in semi-structured interviews. This was to follow an effective method to extract meaning through coding interview transcripts centring on similarity, comparison and contrast against a priori list of codes (Bazeley 2013). Such an approach was deemed suitable for the present study, where the objective is to identify barriers, and discuss the causes behind the identified barriers. This form of qualitative analysis was termed by Merriam (2014) as *"analytic induction"* where researchers achieve a perfect fit between their data and a formulated explanation of the phenomenon under question (here causes of barriers). Participants' information was utilised here to shape, modify and expand the knowledge base on the topic to align with the Australian context. This is a common application of this qualitative technique (Bazeley 2013; Merriam 2014).

THE LANDSCAPE OF BIM EDUCATION IN AUSTRALIA

According to the data acquired through structured interviews, as of 2020, a total of 101 BIM-related subjects are offered across 24 Australian HEIs, in levels six to nine, according to the Australian Qualifications Framework (AQF 2013). Of these HEIs, 75% offer BIM related programmes at AQF level 7 or lower levels; almost 63% offer post-graduate programmes (AQF level 9) in BIM; just over half (58%) offer BIM-related program in graduate studies at AQF level 8. Notably, almost one-third (29%) offer BIM curricula across all educational levels, and only four offer BIM-based intensive short courses. BIM-related subjects are taught both in the mainstream AECO subjects and as a part of interdisciplinary study programmes within computational design, property management and specialised subjects such as furniture design. However, only two universities are currently offering independent BIM masters degrees.

FROM SEMI-STRUCTURED INTERVIEWS TO CAUSES

As discussed, participants of structured interviews were provided with the list of barriers extracted from the literature and were asked to share their experiences in terms of agreeing with the level of significance of each barrier. This also included spotting any lack of items in the list, changing the terms of concepts, suggestions for adding new barriers or removing any existing ones to contextualise and customise the model for Australia. The structured interviews resulted in a list of a priori codes to facilitate conducting and analyses of semi-structured interviews.

Various barriers emerged out of coding and analysing the transcripts – refer to Figure 1. The relative importance of each code was assessed in view of the number of references to each code within the interview transcripts. Treating the number of references to codes as an indication of their weight or relative importance is a common practice in analysing qualitative data in construction research (Chileshe et al. 2016). Such inference is methodologically defensible, given that: *"people repeat ideas that are of significance for them."* (Bazeley 2007) The 14 codes identified (within four constructs) are presented in Figure 1 and now explained in further detail.

Change management

One of the major barriers identified oscillated around the various dimensions of change management and the problems associated with shifting from traditional taught programs to digital visualizations and coding inherent within BIM. This was described under four categories of barriers (i.e. codes).

Current academic culture does not favour change

Resistance to change is perceived as a systemic barrier across the academic domain. BIM inherently favours and encourages interdisciplinary collaboration, while academic disciplines are used to work in silos and compete for prestige, grants and kudos (via papers published etc.). Participant two offered pragmatic insight into the cultural change needed viz:

> *"collaboration and that whole philosophy, that whole approach to design and planning and project management and so on, ought to be core to the way in which we teach…the academic culture needs to embrace these technologies more than just seeing them as an exciting tool."*

Academic egos apart, the physical layout of the teaching environment was also accused of impacting upon BIM education. It was suggested that considering the collaborative principles behind BIM, teaching spaces should avoid lecture theatre style environments (with seats in rows facing forward). As a viable solution, rooms should simulate design environments in practice with group tables each supported by a monitor to effectively support BIM content delivery but also better prepare students for working in the sector.

Figure 1. Map of barriers, constructs and causes

Inadequacy of software and hardware

It was identified that hardware used in certain universities does not support the effective teaching delivery of BIM content. As hardware is a key enabler and tool for BIM, having access to quality hardware to test and learn BIM is a crucial and essential basic need of the teaching environment. This finding had a variety of facets including hardware incapable of managing large class sizes but also IT and management colleagues who were resistant to upgrade existing systems. Typical problems encountered were offered by participant five who said:

"hardware is likely to become slower and slower when you have many students connected to that platform… frozen systems waste time and cause some students to lag behind."

In addition, participant five also felt that the university IT staff were bottlenecks for change, viz:

"[they] don't want to update the hardware in line with how rapidly the software is growing…usually require a great amount of paperwork or justification…are a bit slow to update…causing problems for educators."

Software problems were well engaged and understood by all participants, a barrier had the most mentions of all. All participants had experience personally dealing with inefficient software. Secondly, students have been facing difficulty in simply operating the software.

Lack of support from peers and leaders

A consistent and resounding comment from all participants was that staff members and leaders alike must improve their attitudes towards change. It was identified that the change BIM will trigger to current working processes must be supported. Participant two said:

"Teaching and management staff need to understand that the design practice is changing."

Staff members must align themselves with international approaches and be open to this inevitable change. Participant four felt that reflection upon international practice could act as a catalyst to engender change viz:

"if academics were aware of where their curriculum sits in line with some of the other programs internationally, they'd feel like they'd need to make things change now."

Legacy of traditional teaching norms

A common desire expressed by participants was that if the change required to support BIM education is to take place, digital approaches should replace resources in existing units. Participants one and four stated:

"we teach paper based legacy processes that I've never used in my working life for the last 15 years." (Participant one)

"if we didn't just stick to the traditional syllabus, the whole situation of education would be much, much better." (Participant four)

At a basic level it was identified that given the constraints and complexities of changing to digital learning methods, fundamentals must be taught correctly. Students do not need to learn the intricacies of BIM software but rather, they must be taught the content informed by the intention that when they graduate, they have the awareness needed to lead Australia's digital future.

Curricula and content

The current status quo of curricula and content (encapsulating common programs and arrangement of courses and units) were identified by the interviewees as major barriers. Three key barriers were:

Current curriculum is at capacity

Participants argued that BIM requires new content to be taught and added into the existing curriculum structure. For courses that are full (and particularly lack, space for the addition of subjects), attempts to include BIM will causes strain and competition among champions of existing traditional units. This was described as a demanding task to justify the need to make room for BIM subjects within the saturated structure of courses. For example, Participant six said:

> *"there is always resistance to introducing new subjects because there's a competition between the subjects. So, you will need to justify why new subject is going to be helpful and how it's going to attract students."*

Additionally, it was recognised that not only was the curriculum at capacity but also the semester duration was a major constraint to teach BIM-related topics in an effective manner. To exemplify this point, Participant four said:

> *"we only have twelve weeks to cover all those elements (BIM specific content) so students don't have sufficient time to practice [various] BIM skills."*

Because of this time constraint, selecting strong BIM fundamentals to be included has been the focus of many courses.

Difficulty of designing BIM-related subjects

Designing course material for such a rapidly changing subject has proven difficult. It was also argued that understanding BIM content is more important for a graduate today than learning traditional skills, yet students need to understand basic aspects of work in the industry, prior to exposure to BIM subjects. Including BIM as a subject at the end of programs can be a solution, yet it requires rearranging whole programs, as another problem of designing BIM units. Similarly, another comment related to this was on the challenges of contextualising BIM-related content, raised as another dimension to this barrier. Participant two said:

> *"We talk about designing in context, yet we still build BIM models that sort of float around in space. The reality is that whatever we design sits in a context…it's about understanding this context; climate context, socio demographic context and economic context."*

Difficulty of designing horizontal and vertical curricula

Inconsistency in developing BIM knowledge horizontally and vertically across multiple semesters and years was identified as a challenging barrier. It was noted that students may have developed certain skills in their first semester, which were not vertically matched and built upon smoothly in later years. Some students complain about this issue and some struggled to keep up with the increase in expectations. Most participants elucidated upon the fact that certain educators have preferred software platforms. Whilst this may suit educators, it created added difficulty in understanding multiple software packages – for students enrolled in various subjects of the course. Participant five said:

> *"it is really not easy for students to switch between platforms."*

One potential reason for the curriculum misalignment and sharp increase in expectations is due to the different rate of change horizontally across units as explained by participant five:

> *"as the subjects evolve and people sort of move around, it is difficult to keep up with what's happening. We have different levels of knowledge being delivered in different subjects and you can't really control if their learning outcomes are being met or not."*

This makes it very difficult for staff to assess whether students are competent in certain BIM content, particularly referring to vertical curriculum integration.

Educators

Serious issues associated with educators were referred to as barriers to BIM education by a majority of participants – four clusters of barriers were identified.

Educators lag behind industry practices

This barrier referred to the rapid change associated with BIM and other associated digital technologies (such as sensor based technologies that fall under the umbrella of Industry 4.0). BIM is currently going through a fast-paced innovation cycles where changes and new features occur at a rapid pace – Participant one for example proffers that this offers inherent challenges for educators to stay on the leading edge of advancements viz:

> *"it's fast paced and aging. So, it's constantly evolving and therefore educating educators becomes a major issue…it's very hard for anybody who's not got their finger on the current economic pulse of the state to be aware of all of these things."*

It was implied that the content provided by Australian universities is somewhat antiquated and that research and development teams in Australian BIM industry are ahead of universities. Consequently, the current BIM content is taught in isolation, with little reference to the leading practices of industry leaders or contemporary BIM advancements.

Lack of collaboration among HEIs

One barrier identified to thwart enhanced awareness of leading BIM advancements is the failure of universities to collaborate, despite the fact that BIM fundamentals are grounded in collaboration and sharing of knowledge. Australian universities would benefit from forming communities of practice for enhancing BIM training and education. Best practices and leading approaches of BIM teaching must be shared within such a community of practice, to be referenced to and learnt from. For example, participant four said:

> *"if academics were aware of where their curriculum sits in line with some of the other programs internationally, they'd want to make things change now."*

Lack of professional development opportunities

An overarching perception was that educators must improve their professional development. Participant one summarise this feeling by stating that:

> *"educators are not off the leading edge of the advancements…and must be educated on internationally competitive and contemporary innovations."*

This problem is clear and triggers exploration into the deeper roots of the issue. Educators are supposed to remain exposed to a broad variety of opportunities for learning about innovations – often through practice based-interactions as part of continual professional development. However, the modernity of academic life dictates that where educators must teach a wide variety of units, simultaneously publish, conduct research and complete various administrative jobs. Even for the most experienced academic this represents a demanding schedule and a major barrier to acquiring time from line managers to upskill in BIM-related areas. Participant one summarised the prevailing situation:

> *"The problem I see is that people are so busy with their day to day responsibilities that they can't always invest the time required. Or they might not understand the benefit of investing the time required to increase their skill base."*

Lack of appropriate expertise

Being such a rapidly evolving and contemporary subject, BIM requires educators to possess the expertise needed to effectively deliver its relatively complicated content. Broadly, the imbalance between the demand for educators with such expertise and resourcing is a problem; participants two and six captured the sense that there is a resounding demand for high quality expertise in this field.

> *"It's very hard to get design tutors who are actually on the leading edge of design practice in terms of the adoption of technology. And so, they're [students] getting this sort of warped view of what design is and they're not getting that design, collaboration, experience." (Participant two)*

> *"we don't have experts in our university necessary to be able to teach BIM concepts. It can be a challenge to find the right people." (Participant six)*

Industry

Three different barriers were revealed, all attributed to the problems associated with the ways Australian universities and practitioners engage with each other.

Lack of alignment with industry requirements

Graduates are expected to enter the industry with an appropriate level of preparedness for the challenges they will face. Consequently, in delivering relevant and highly valuable content, educators must be aware of industry content and events to tailor their content to it. Many universities have 'hand-picked' industry advisory boards that advise them on what to include in their current and planned curriculum. This tenuous connection to the industry is paramount for BIM-related subjects but the reliance upon known (and best described 'friendly') practitioners inadvertently supports a tick box culture. So while the knowledge provided by these boards were assessed as essential, lack of access to impartial industry-based knowledge is a barrier. Participant one stated:

> *"I think the key is integration with industry…our teaching should not be limited by our subscription or reliance on particular software packages but teach because industry needs it"*

When impartiality is preserved, the best outcomes suggested may require additional effort of academic staff to address observed shortfalls. One HEI had an industry advisory committee that suggested the curriculum had a knowledge gap. This was then prioritised and addressed by redesigning that subject. Another participant suggested their industry panel stressed the importance of digital engineering and information, after which the advice was used for making updates to the existing curriculum. The gap between industry know-how and academic pontification is all too apparent as suggested by participant one.

> *"industry specific training is far sharper than theoretical training…the excellence that's in the industry must be promoted to the universities so that they're aware of it."*

Trails were completed where industry were invited to run certain classes and lectures. These were highly successful; students were said to be highly receptive to the expertise presented and the industry relevance (participant two).

Lack of industry attention to educational challenges

There was consensus that adopting BIM education courses and units rely heavily on the level of demand from the industry. Besides, educational barriers are suggested through the single educational lens; however, universities need support from the industry in addressing these barriers. Participant one stated:

> *"People are so busy with their day to day responsibilities that they can't always invest the time required [...] What I say for educators applies 90 times more for the industry and its supply chain as well."*

Industry is aware that the technology and innovation inherent within BIM is the way forward. It has been clear that if industry were to understand the challenges faced by educators, their input would provide added confidence to educators.

Unfavourable professional accreditation processes

Participants concurred that accreditors have a significant influence on the curriculum and content which plays a crucial role in the context of BIM and its development in education. Anecdotal evidence from one participant suggested that some accreditors refer to BIM simply as decorative walkthrough of the building model - they however, lack assertiveness to push HEIs to enhance their BIM education programs. One participant who had resided on an accreditation panel, explained that although the panel had made thorough technical suggestions, it was unlikely that the university would implement these based on an evaluation of their current resourcing and awareness (participant 2). That said, participant four argued that accreditation is a steppingstone for driving the change BIM education requires at HEIs viz:

> *"this accreditation process is the first starting point to adjust the current program towards improving BIM in the school."*

PROPOSED REMEDIAL SOLUTIONS

Responses from the structured interviews and subsequent discussions resulted in identifying two categories of remedial solutions, namely: (1) collaborative cultural shift; and (2) improving connection between academia, industry and the government

Collaborative cultural shift

Participants continuously raised the point of collaboration as an underlying foundational ethos of BIM and a solution to many of the barriers identified. Firstly, collaboration was stressed from an educational perspective – participants two encapsulated the general consensus.

> *"the key to teaching BIM is to teach collaboration and multi multidisciplinary design processes...that whole philosophy, that whole approach to design and planning and project management and so on, ought to be core to the way in which we teach."*

The same participant, having offered support to an accreditation board suggested that despite the recommendations made to HEIs, it was unclear as to whether they had the capability and capacity to implement them with the dominant culture viz:

> *"really my bottom line is that the culture needs to embrace these technologies more than just seeing them as an exciting tool..." (Participant 2)*

> *"But so, it's really the two things, understanding the technology. Digital technology is a core to design practice these days and it shouldn't be ignored. And the second one, of course, is collaboration."*

The second key solution raised by participant four was that instead of fostering a collaborative culture, collaborative assessment tasks should be designed.

> *"we need to improve assignment design because we don't really evaluate their (students) BIM ability and skills in assessments."*

One proposed solution to this was to upgrade classroom layouts so that three to four students could work collaboratively on one single BIM model (Participant five). Another solution was to integrate the assignments with different engineering schools, e.g. facilities management and sustainability to reflect the interdisciplinary nature of the industry (participant seven).

Finally, it was noted that the industry must develop as well as academia. Both sides must improve collaboration individually and collaboratively – a point well made by participant three:

> *"we need to develop together."*

Improving connection between academia, industry and the government

The final suggested category of solutions was represented by addressing the success achieved by using industry professionals in delivering university training. Participant one suggested that:

> *"They've [industry] also come in and helped the students during the tutorials on how to implement the technologies and the students have been hugely responsive…bringing the industry into the classroom and then educating in a different way is a great solution…To further integrate current industry working practice into university content would be a solution."*

This concept of external recruitment supporting the university classes was again added to by participant six:

> *"we basically recruit someone from outside and provide them with some training on university…So it is the best solution and it also brings more of an industry view to the subject and becomes a bit more practical. Usually students also like that."*

The final solution raised was to increase awareness and professional development through continual promotion of industry events and developments to students to assist in engaging and leading them into the industry. The other suggestion related to this category identified by the participants was to provide a standardised body of knowledge (participant seven).

DISCUSSION OF THE FINDINGS

Both academia and industry recognise the need for building a sustainable pipeline of BIM-ready graduates in Australia. Establishing education curricula, BIM-related professional development and business requirements within Australian HEIs are seen as critical milestones in the move towards widespread use of BIM (ACIF and APCC 2017; NBS 2019). Previous studies have repeatedly shown that Australian universities are not preparing students for industry jobs of the BIM market (Baradi et al. 2018; Puolitaival and Forsythe 2016). This study confirms that this problem doggedly persists because educators confirm that Australian universities are failing to produce BIM-ready graduates. The problem is particularly acute in terms of failure in preparing graduates for BIM-related processes and collaborative tasks. If the Australian construction industry is to transform from one epitomised by litigation to one of collaboration, both the technologies and working practices promoted by BIM must be adopted (Mills et al. 2013) and taught at universities. Educators and HEIs aim to produce professionals for the construction sector yet, fail to foster collaboration themselves (Merschbrock et al. 2018). This stagnation is caused by a lack of educators and resources, combined with an apathy for change (Rooney 2019). Change is central to BIM adoption in the industry, where a major overhaul across the supply chain is needed and an effective change management strategy must be followed to smoothen the change (Papadonikolaki and Wamelink 2017). This current research reveals that the same principle applied to BIM education at universities. Thus, for BIM to be effective, a major cultural change is required.

Barriers related to new BIM curriculum and content development constitute important research findings. Current BIM curricula is underdeveloped, many courses are at capacity (Mills et al. 2013; Puolitaival and Forsythe 2016) and HEIs characteristically have disassociated learning outcomes and work preparation. Not only are courses already at capacity, but educators are unable to move from their areas of expertise and are another major barrier to BIM education, as pointed out previously by MacDonald (2012). There is still a significant lack of educators with BIM subject matter expertise, the same issue raised by Mills et al. (2013). This is hardly a surprise, given that university resources and teaching support is lacking. Little is being done to upskill teachers or develop contemporary curricula and educators are reluctant to expand upon their traditional area of expertise (MacDonald 2012). In addition, the number of institutions and instructors able to effectively deliver BIM courses is insufficient to realise an effective change (Mills et al. 2013; Puolitaival and Forsythe 2016). The industry is already being forced to adopt a more collaborative approach among multidisciplinary, dispersed teams of construction-related disciplines. In preparing students for their role in the industry, educators must be prepared to understand and embrace this approach to BIM education (MacDonald and Mills 2013).

It is revealed that Australian universities continue to lag behind the AECO industry in embracing advanced BIM content (cf.MacDonald 2012; MacDonald and Mills 2013). Students, however, must be taught to recognise the future BIM-related roles. Latest industry developments must be integrated into BIM assessments at universities (Arashpour and Aranda-Mena 2017; Hosseini et al. 2018a). Perhaps the only good thing coming out of the globally catastrophic COVID-19 pandemic is the HEIs have been forced to use collaborative digital platforms to run classes and manage university affairs. This demonstrates that digital technology adoption does work as a collaborative platform within academia and that *"necessity is the mother of invention"* – HEIs thus, need a stronger stimulus to become engaged and fully committed to change.

It was also revealed that truly impartial accreditors should play an active role in filling the gap between curricula and current industry practice. In summary, BIM education will face difficulty in changing without support from the industry, government and accreditation – professional – bodies, given the continuously evolving BIM domain (Baradi et al. 2018). As such, aligned with this core messages and outcome of this research, an agenda for change is suggested to link the identified barriers with potential solutions.

An agenda for change

Using a triangulation (cf.Edwards and Holt 2010) of extant literature reviewed (which informed the research direction and questions posed), participant analysis (to feedback on the questions sourced from literature), and the tacit knowledge and experiences of the authors in running BIM education programs across various universities internationally, a series of pragmatic recommendations are made viz:

Accreditation bodies and professional institutions must act as a linchpin to facilitate knowledge transfer between industry and universities. They must reflect the needs and requirements of the industry to the universities and ask for the transformation of courses and programs to accommodate such changes, as conditions for accreditation.

- Minimum criteria for accreditation should target the unification of BIM courses across various universities, so that all graduates acquire the same skill sets required by the AECO industry.

- Professional bodies of the AECO industry must take an active role in complementing university courses by appreciating the constraints of curricula (such as time and resource constraints) that restrict universities. Close meaningful collaboration between the industry and universities can facilitate addressing this issue but also, if industry wants highly trained and competent graduates, then they must sponsor courses and invest in the industry's future. Such arrangements are commonplace in the UK with many of the tier one contractors (constituting the major sectors players) sponsoring studentships at HEIs such as Loughborough University.
- Researchers must focus on providing data on the links between the preparedness of graduates on BIM and their employability in the Australian market. This can provide the justification for allocating resources to improve BIM education programs at universities.
- Universities and government bodies must provide incentive for BIM researchers that address industry needs. In many cases, research is driven to fill theoretical gaps within the BIM domain whereas industry is more interested in the application to real life (vis-à-vis manufactured and esoteric) problems. Researchers should highlight industry needs and pool resources to pursue 'impactful' research which attracts industry investment.
- Digital transformations are taking place in every aspect of our lives and the AECO industry is highly affected and, in most cases, benefited from this change. However, this change is a lengthy process and requires significant research. Policy makers must treat 'digitalisation of the construction industry' as a growth centre in defining research funding and grants. This will enhance the capability of researchers in providing data and information for improving BIM-related training programs.
- The industry must treat engagement with professional bodies, and accreditation programs in communicating the demands to universities as a long-term investment to secure the future of the industry and lower the costs of training employees and upskilling the workforce.

CONCLUSION

Australian universities are failing to prepare students to lead a digital future for the construction sector. Studies repeatedly show that universities are not preparing students adequately for BIM-related roles. This research sought to identify barriers to BIM education at Australian universities. This paper, as one of the first in its kind, identifies the barriers to BIM education at Australian universities from the perspective of educators and extends this to the recognition of causes and reasons behind the identified barriers. Identifying the root causes of barriers that thwarts efforts for establishing effective BIM education programs would act as the driver towards spotting the areas of top priority for managing the required reform. The research outcomes are likely to engender much-needed polemic debate and stimulate efforts by educators, industry and government in strengthening the much-needed connection between academia and the industry. That is, previous studies in the field approached this topic through an inward-looking lens, in defining the barriers. To date, studies on this topic have introduced educators and universities as major culprits and the sources of barriers. The main contribution of this paper is to challenge this insight and broaden the perspective. That is, university are at the end of a supply chain and the skills and competencies of graduates produced must be shaped by industry professional organisations, accreditation bodies and government who provide demand. All parties must act in unison and must responsible and held accountable for the quality of graduates produced. The industry, accreditation bodies and the government also play a crucial role in the failure of success of BIM education efforts at Australian universities. In the absence of investment and collaboration from the industry and government, universities cannot manage the change needed for running effective BIM training programs. This is therefore need for government support; the industry must actively participate in a collaborative cultural shift and strengthen connections with HEIs as an investment needed for access to the workforce with the skillsets needed for the BIM-related jobs of the future. The role of accreditation bodies and scant attention to research funding on the topic was highlighted for the first time in this paper, as another contribution of this paper.

Whilst the research presented is a useful vignette (‘snapshot’) of the phenomena under investigation to stimulate wider debate, there are several limitations. First, barriers and solutions proposed in the present study are designed for Australia. Though they can provide valuable lessons for other countries, direct application of them must be treated with caution. That is, BIM-related aspects in any context are affected by two major categories of variables: (1) technical and (2) non-technical strategic issues within the enabling environment. These non-technical factors like BIM-related skills, capabilities, and existing regulations are context-specific and vary among different countries (Gu and London 2010). BIM work streams, the skills needed and accordingly the type of BIM-ready graduates expected by the industry are shaped by local BIM players and country specific policies (Kassem et al. 2014).

Second, the work is largely qualitative; qualitative findings may not be completely replicable for other researchers. Besides, the qualitative data in the present study reflect the HEI perspective only; the work samples perceptions rather than hard quantifiable evidence; and the success of otherwise of remedies suggested remain largely untested. Bolstering confidence in findings of the study through supplementing qualitative data from other sources and triangulating the findings with quantitative data provide fertile grounds for future studies. Further work is therefore required to: broaden the sector perspectives by involving industry practitioners, professional bodies and government bodies; conduct longitudinal participant action research to observe, record and report upon the student experience (across a presentative sample of Australian universities) and measure differences in skills and competence sets acquired whilst studying when compared to those required in industry. Such a comparative analysis should lead to a better defined and delineated curriculum design; and similarly measure the broader social, political and economic implications of remedies adopted in test case scenarios. In addition, further research is needed at the subject level, to identify the barriers – and their underlying causes – to introducing and designing BIM-related subjects. So too future studies must address the challenges of delivering such subjects. Such works are worthy of further investigation because it is the human resource that industry needs most as BIM *per se* would not resolve the many challenges it faces.

DATA AVAILABILITY STATEMENT

Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

ABAB (2018). “Digital Economy Strategy: Submission to Australian Government Department of Industry, Innovation and Science.” Australian BIM Advisory Board.

Abbasianjahromi, H., Rajaie, H., Shakeri, E., and Kazemi, O. (2016). “A new approach for subcontractor selection in the construction industry based on portfolio theory.” *J. Civ. Eng. Manage.*, 22(3), 346-356.

ACIF, and APCC (2017). “Building Information Modelling (BIM) Knowledge and Skills Framework.” <https://www.acif.com.au/documents/item/799>. (11 Novermber 2019).

Al-Saeed, Y., Edwards, D. J., and Scaysbrook, S. (2020). “Automating construction manufacturing procedures using BIM digital objects (BDOs).” *Constr. Innov.*

Alshenqeeti, H. (2014). “Interviewing as a data collection method: A critical review.” *English linguistics research*, 3(1), 39-45.

AQF (2013). “Australian Qualifications Framework.” <https://www.aqf.edu.au/sites/aqf/files/aqf-2nd-edition-january-2013.pdf>. (21 October, 2019).

Arashpour, M., and Aranda-Mena, G. (2017). “Curriculum renewal in architecture, engineering and construction education: Visualizing building information modelling via augmented reality.” *Resilient Structures and Sustainable Construction*, 1-6.

Atazadeh, B., Kalantari, M., Rajabifard, A., and Ho, S. (2017). “Modelling building ownership boundaries within BIM environment: A case study in Victoria, Australia.” *Comput. Environ. Urban Syst.*, 61(Part A), 24-38.

Babatunde Solomon, O. (2018). “Analysis of the drivers and benefits of BIM incorporation into quantity surveying profession.” *J. Eng. Des. Technol.*, 16(5), 750-766.

Babatunde Solomon, O. (2019). “Barriers to the incorporation of BIM into quantity surveying undergraduate curriculum in the Nigerian universities.” *J. Eng. Des. Technol.*, 17(3), 629-648.

Baradi, K., Oraee, M., Hosseini, M. R., Tivendale, L., and Pienaar, J. (2018). “Teaching collaboration in tertiary BIM education: A review and analysis.” *42nd AUBEA Conference*, 218-227.

Bazeley, P. (2007). *Qualitative data analysis with NVivo*, SAGE, London.

Bazeley, P. (2013). *Qualitative data analysis : practical strategies*, SAGE, Thousand Oaks, Calif.

Best, R., and Langston, C. (2005). *International comparisons of construction industry performance: further investigations*, Queensland University of Technology.

Bosch-Sijtsema, P. M., Gluch, P., and Sezer, A. A. (2019). “Professional development of the BIM actor role.” *Autom Constr*, 97, 44-51.

buildingSMART Australasia (2012). “National Building Information Modelling Initiative. Vol.1, Strategy.” <https://buildingsmart.org.au/wp-content/uploads/2014/03/NationalBIMIniativeReport_6June2012.pdf>. (11 Novermber 2019).

Chileshe, N., Rameezdeen, R., and Hosseini, M. R. (2016). “Drivers for adopting reverse logistics in the construction industry: a qualitative study.” *Engineering, Construction and Architectural Management*, 23(2), 134-157.

Chinowsky, P., and Songer, A. (2011). “Introduction.” *Organization management in construction*, P. Chinowsky, and A. Songer, eds., Spon Press, New York

Deloitte (2015). “The importance of universities to Australia’s prosperity ”, <https://www2.deloitte.com/au/en/pages/economics/articles/importance-universities-australias-prosperity.html>. (29 September 2019).

Dixon, C., Edwards, D. J., Mateo-Garcia, M., Lai, J., Thwala, W. D. D., and Shelbourn, M. (2020). “An investigation into the erroneous access and egress behaviours of building users and their impact upon building performance.” *Facilities*.

Durdyev, S., Hosseini, M. R., Martek, I., Ismail, S., and Arashpour, M. (2019). “Barriers to the use of integrated project delivery (IPD): a quantified model for Malaysia.” *Eng. Constr. Archit. Manage.*

Edwards, D. J., and Holt, G. D. (2010). “The case for “3D triangulation” when applied to construction management research.” *Constr. Innov.*

Fernando, C. K., Hosseini, M. R., Zavadskas, E. K., Perera, B., and Rameezdeen, R. (2017). “Managing the financial risks affecting construction contractors: implementing hedging in Sri Lanka.” *International Journal of Strategic Property Management*, 21(2), 212-224.

Gelic, G., and McLeod, A. (2018). “How BIM is slowly shaping Australia’s infrastructure.” <https://www.ipwea.org/blogs/intouch/2018/07/25/how-bim-is-slowly-shaping-australias-infrastructur>. (11 April, 2020).

Gibson, W. J., and Brown, A. (2009). *Working with qualitative data*, SAGE Publications, London.

Gruszka, A., Jupp, J. R., and De Valence, G. (2017). "Digital Foundations: How Technology is Transforming Australia's Construction Sector." <https://opus.lib.uts.edu.au/handle/10453/124861>. (30 October 2019).

Gu, N., and London, K. (2010). "Understanding and facilitating BIM adoption in the AEC industry." *Autom Constr*, 19(8), 988-999.

Hon, C., Utiome, E., Drogemuller, R., Owen, R., Nepal, M., Gray, J., and Coffey, V. (2015). "Gearing up academics for collaborative building information modelling (BIM) education." *International Conference on Innovative Production and Construction*, IPC, Perth, WA.

Hong, Y., Hammad, A., Zhong, X., Wang, B., and Akbarnezhad, A. (2020). "Comparative Modeling Approach to Capture the Differences in BIM Adoption Decision-Making Process in Australia and China." *J Constr Eng Manage*, 146(2), 04019099.

Hong, Y., Hammad, A. W., Sepasgozar, S., Akbarnezhad, A. J. E., Construction, and Management, A. (2019). "BIM adoption model for small and medium construction organisations in Australia." 26(2), 154-183.

Hosseini, M. R., Banihashemi, S., Chileshe, N., Namzadi, M. O., Udeaja, C., Rameezdeen, R., and McCuen, T. (2016). "BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model." *Construction Economics and Building*, 16(3), 71-86.

Hosseini, M. R., Martek, I., Papadonikolaki, E., Sheikhkhoshkar, M., Banihashemi, S., and Arashpour, M. (2018a). "Viability of the BIM Manager Enduring as a Distinct Role: Association Rule Mining of Job Advertisements." *J Constr Eng Manage*, 144(9), 04018085.

Hosseini, M. R., Pärn, E., Edwards, D., Papadonikolaki, E., and Oraee, M. (2018b). "Roadmap to mature BIM use in Australian SMEs: competitive dynamics perspective." *J Manage Eng*, 34(5), 05018008.

Ijasan, K., and Ahmed, V. (2016). "Studentification and the housing needs of international students in Johannesburg: an embedded mixed methods approach." *Research Methodology in the Built Environment*, Routledge, 149-166.

Jin, R., Zou, P. X., Li, B., Piroozfar, P., and Painting, N. (2019). "Comparisons of students' perceptions on BIM practice among Australia, China and UK." *Eng. Constr. Archit. Manage.*, 26(9), 1899-1923.

Johnson, R. B., and Onwuegbuzie, A. J. (2004). "Mixed methods research: A research paradigm whose time has come." *Educational researcher*, 33(7), 14-26.

Kassem, M., Iqbal, N., Kelly, G., Lockley, S., and Dawood, N. (2014). "Building information modelling: protocols for collaborative design processes." *Journal of Information Technology in Construction (ITcon)*, 19, 126-149.

Kim, K. P., Mostafa, S., and Park, K. S. (2020). "Integrated BIM Education in Construction Project Management Program." *Claiming Identity Through Redefined Teaching in Construction Programs*, IGI Global, 134-152.

Kim, S., Chin, S., Han, J., and Choi, C.-H. (2017). "Measurement of Construction BIM Value Based on a Case Study of a Large-Scale Building Project." *J Manage Eng*, 33(6), 05017005.

Kuiper, I., and Holzer, D. (2013). "Rethinking the contractual context for Building Information Modelling (BIM) in the Australian built environment industry." *Construction Economics and Building*, 13(4), 1-17.

MacDonald, J. (2012). "A framework for collaborative BIM education across the AEC disciplines." *37th Annual Conference of the Australasian Universities Building Educators Association*, AUBEA, UNSW, 223-230.

MacDonald, J., and Mills, J. (2013). "An IPD approach to construction education." *Australasian Journal of Construction Economics and Building*, 13(2), 93-103.

McPhee, A. (2016). "Where is BIM in Education." <https://practicalbim.blogspot.com/2016/12/where-is-bim-in-education.html>. (23 October 2019).

Merriam, S. B. (2014). "Qualitative Research : A Guide to Design and Implementation." Wiley, Somerset.

Merschbrock, C., Hosseini, M. R., Martek, I., Arashpour, M., and Mignone, G. (2018). "Collaborative role of sociotechnical components in BIM-based construction networks in two hospitals." *Journal of Management in Engineering*, 34.

Mignone, G., Hosseini, M. R., Chileshe, N., and Arashpour, M. (2016). “Enhancing collaboration in BIM-based construction networks through organisational discontinuity theory: a case study of the new Royal Adelaide Hospital.” *Arch. Eng. Des.*, 333-352.

Mills, J., Tran, A., Parks, Andrea, and MacDonald, J. (2013). “Collaborative building design education using Building Information Modelling (CodeBIM).” University of Technology, Sydney, Sydney.

Mitchell, J., Plume, J., Tait, M., Scuderi, P., and Eastley, W. (2012). “National Building Information Modelling Initiative.” BuildingSMART Australasia Sydney.

Mohamed, I. F., Edwards, D. J., Mateo-Garcia, M., Costin, G., and Thwala, W. D. D. (2019). “An investigation into the construction industry’s view on fire prevention in high-rise buildings post Grenfell.” *International Journal of Building Pathology and Adaptation*.

NBS (2019). “Australia and New Zealand BIM Report 2019.” <https://www.thenbs.com.au/bim-report>. (24 October 2019).

Newman, C., Edwards, D. J., Martek, I., Lai, J., and Thwala, W. D. (2020). “Industry 4.0 Deployment in the Construction Industry: A Bibliometric Literature Review and UK-based Case Study.” *Smart and Sustainable Built Environment*.

Olatunji, O. A. (2019). “Promoting student commitment to BIM in construction education.” *Eng. Constr. Archit. Manage.*

Ozorhon, B., and Karahan, U. (2017). “Critical Success Factors of Building Information Modeling Implementation.” *J Manage Eng*, 33(3), 04016054.

Papadonikolaki, E., and Wamelink, H. (2017). “Inter- and intra-organizational conditions for supply chain integration with BIM.” *Building Research & Information*, 45(6), 649-664.

Parker, S. (2018). “Reimagining tertiary education: From binary system to ecosystem.” <https://home.kpmg/au/en/home/insights/2018/08/reimagining-tertiary-education.html>. (26 September 2019).

Pärn, E., and Edwards, D. (2017). “Conceptualising the FinDD API plug-in: A study of BIM-FM integration.” *Autom Constr*, 80, 11-21.

Puolitaival, T., and Forsythe, P. (2016). “Practical challenges of BIM education.” *Struct. Surv.*, 34(4/5), 351-366.

Puolitaival, T., Forsythe, P., and Kahkonen, K. (2015). “Challenges facing BIM education: Development of appropriate teaching and learning resources.” *COBRA*, RICS, Sydney.

Roberts, C., Edwards, D. J., Hosseini, M. R., Mateo-Garcia, M., and Owusu-Manu, D.-G. (2019). “Post-occupancy evaluation: a review of literature.” *Eng. Constr. Archit. Manage.*

Rooney, K. (2018). “BIM Education - Global – 2018 Update Report.” <https://www.icis.org/wp-content/uploads/2018/05/BIM-Education-Global-2018-Update-Report-V5.0.pdf>. (23 October, 2019).

Rooney, K. (2019). “BIM education global 2019 update report.” NATSPEC, ed.Australia.

Rowley, J. (2012). “Conducting research interviews.” *Management research review*.

Succar, B., Agar, C., Beazley, S., Berkemeier, P., Choy, R., Giangregorio, R. D., Donaghey, S., Linning, C., Macdonald, J., Perey, R., and Plume, J. (2012a). “E1 - BIM Education & BIM Learners.” <https://wp.architecture.com.au/bim/groups/education/>. (23 October 2019).

Succar, B., Agar, C., Beazley, S., Berkemeier, P., Choy, R., Giangregorio, R. D., Donaghey, S., Linning, C., Macdonald, J., Perey, R., and Plume, J. (2012b). “E2 - BIM Learning Providers.” <https://wp.architecture.com.au/bim/groups/education/>. (23 October 2019).

The Study in Australia (2019). “Universities and Higher Education.” <https://www.studyinaustralia.gov.au/English/Australian-Education/Universities-and-Higher-Education>. (12 April, 2020).

Witt, E., and Lill, I. (2010). “The mismatch between graduate competencies and market skills requirements in the construction sector.” *COBRA 2010*, RICS, London.

Wu, P., Feng, Y., Pienaar, J., and Zhong, Y. (2015). “Educational attainment and job requirements: Exploring the gaps for construction graduates in Australia from an industry point of view.” *Journal of Professional Issues in Engineering Education and Practice*, 14(4), 1-6.

Wu, W., and Issa, R. R. A. (2014). “BIM education and recruiting: Survey-based comparative analysis of issues, perceptions, and collaboration opportunities.” *J Prof Issues Eng Educ Pract*, 140(2).

Wu, W., Mayo, G., McCuen, T. L., Issa, R. R., and Smith, D. K. (2018). "Building information modeling body of knowledge. I: Background, framework, and initial development." *J Constr Eng Manage*, 144(8), 04018065.