

THE UTILIZATION OF BIM TO ACHIEVE PRESCRIBED ARCHITECTURAL UNDERGRADUATE LEARNING OUTCOMES

Main Author : Dr. Paul Coates

PhD ARB RIBA MCIAT

Architecture Design and Technology Program Director

School of the Built Environment

Room 408, Maxwell Building, University of Salford, Manchester M5 4WT

T: +44(0) 0161 295 2165

s.p.coates@salford.ac.uk

Author : Dr Sara Biscaya

PhD ARB RIBA FHEA

School of the Built Environment

Room 5.40, New Adelphi, University of Salford, Salford M5 4WT

t: +44 (0) 161 295 2095

s.biscaya@salford.ac.uk

Co-Author: Arch. Ali Rachid

Architect, Teaching Assistant, Phd Student

School of The Built Environment

University of Salford, Manchester M5 4WT

t: +961 70 606 825

a.h.rachid@edu.salford.ac.uk

Abstract

Building Information Modelling, a process integrating 3D graphics and data, is being adopted into the AECOO industries and by default into the delivery of undergraduate Architectural Programs. This object oriented approach offers a range of benefits over the

more traditional CAD approach that uses lines and arcs and manual techniques, by adding the third dimension and creating a database model. It redefines the ways of thinking and working for students and future architects. The requirements of architectural programs are defined through their learning objectives meeting professional requirements such as those set by the ARB and the RIBA. This paper aims to investigate how the capabilities of BIM can be utilized to more effectively deliver the requirements of undergraduate architectural programs.

Purpose: The aim of this paper is to illustrate how BIM can be utilized to meet the needs of undergraduate architectural learning outcomes.

Methodology: This study considers the learning outcomes as defined under ARB and RIBA graduate criteria for Part 1 by analyzing a study case curriculum and learning objectives.

Findings: This paper provides a recommendation for how teachers can more effectively integrate BIM into architectural undergraduate programs assisting undergraduate student development.

Originality / Value: This paper addresses changing technologies and process and provides a timely consideration of how BIM can be adopted in the architectural undergraduate domain.

Keywords

Building Information Modeling BIM, Education, Architecture Undergraduate Program, Curriculum

1 Introduction:

“Everywhere we remain unfree and chained to technology, whether we passionately affirm it or deny it.”

(Heidegger, 1954)

The RIBA was founded in 1834 for ‘the general advancement of Civil Architecture, and for promoting and facilitating the acquirement of the knowledge of the various arts and sciences connected therewith’.

RIBA (2016)

The professional body has a responsibility to ensure affordable, up to date, reassuring and reliable services are delivered by their members and they are educated in the methods to achieve this (Susskind and Susskind 2015).

The lack of innovation, lack of predictability and the lack of collaboration have been identified as shortfalls of the current UK construction industry (Farmer 2016). The adoption of BIM across the construction industry has been put forward as one approach to address these issues. Accepted core knowledge areas defined on current architectural programs have been shaped by historic methods of design, analysis and production (Prensky 2001, Harris 2016).

The skills that were needed in the past are not the skills needed in the future. The new prevailing digital transformation and automation requires a change in the core knowledge and ideology provided within architectural education. Yet pedagogical discussion and development has historically been lacking in schools of architecture (Moore 2001).

The student invests time, money and effort in the belief that through education a better future at an individual and collective level will be created. A vision of the future although indeterminate should shape how educators educate students (Facer 2001).

A predominate view of the future is that we are in a period of transitional change leading to the convergence of industrial production and communication technologies. This is called Industrie 4.0 (Hermann et al 2016). In this new paradigm architects are likely to return to being part of the manufacturing process as well as conceptualizing designs.

Already the BIM tools of today are predicted to be replaced by more collaborative working environments based on high frequency data management (Autodesk University 2017). Also the rise of Artificial Intelligence may fundamentally change the professions and the design process (Susskind & Susskind 2015).

The UK Governments vision of the future was set out in the report “Digital Built Britain level 3 Building Information Modelling – Strategic Plan” published 2015. From this report it is clear that BIM and the development of BIM is viewed by the UK Government as central to the future of UK construction. It also gives an indication of the cultural change

and the learning framework that will be required moving to a post digital age. BIM in the UK has been described as currently the most advanced in the world, therefore the UK is used as the focus of this paper (HM Government 2012).

“As we move towards a digitized built environment we are rapidly having to reassess education against the backdrop of a digital future.”

(Philp 2015)

“No job can be done well without the right tools – regardless of profession.”

(Valance et al 2018)

The tools and technologies the architect uses can be considered as forms of human augmentation. They enhance the capabilities of the user or compensate for the knowledge gap of its users linking with manufacturing and construction. According to Engelbart (1962) augmenting human intellect can be achieved by developing artifacts, languages, methodology and training.

To understand how to educate for the integration of BIM we need to understand the increasing demands of the task to be performed and the nature of the tools. Students need both to understand the theory, concepts and be able to use the technology. Academics need to discuss develop and deliver content and learning aligned to the new directions architecture is following.

Two areas of application of BIM in the architectural curriculum have been identified; 1) modelling and representation and 2) collaborative working (Kocaturk et al 2013). This is in line with level 2 of BIM Maturity (Bew Richards 2008) which uses file based collaboration. The use of integrated or interoperable systems is defined as level 3 BIM. Data driven design has also been suggested as the natural extension on BIM (Deutsch 2015). BIM as a digital form of informational transfer can also be seen as potentially providing a paperless building production process. Here again students need to understand the capabilities and relevance of these approaches.

2 The demands on the Architect of the future

AEC programs have limited ability to modify their courses since they have to maintain a specific standard for their accreditation status. (Sharag-Eldin and Nawari, 2010). BIM requires new skills and offers new opportunities and it is important that the architectural education system is aligned to these requirements and capabilities. It is also essential that the special attributes of BIM are utilized to assist in the achievement of architectural learning objectives for better educational and career performances. Architecture education in the UK falls under the European Directive 2005/36/EC but has different structure than the other European systems. The criteria for an architectural education part 1 and part 2 are set out by the Architects Registration Board UK are as follows:

These criteria are further elaborated in the QAA Benchmark documents.

	ARB Requirements (General Criteria)	BIM Application
GC1	Ability to create architectural designs that satisfy both aesthetic and technical requirements	Can be demonstrated using BIM
GC2	Adequate knowledge of the histories and theories of architecture and the related arts, technologies and human sciences	An understanding of how BIM relates to history and theory underpins its use
GC3	Knowledge of the fine arts as an influence on the quality of architectural design.	The knowledge can be demonstrated through BIM
GC4	Adequate knowledge of urban design, planning and the skills involved in the planning process.	Can be demonstrated using BIM
GC5	Understanding of the relationship between people and buildings, and between buildings and their environment, and the need to relate buildings and the spaces between them to human needs and scale.	Urban Modelling
GC6	Understanding of the profession of architecture and the role of the architect in society, in particular in preparing briefs that take account of social factors.	Social Skills
GA7	Understanding of the methods of investigation and preparation of the brief for a design project.	Be aware of Plain Language questions and the role of the ER and EIR
GC8	Understanding of the structural design, constructional and engineering problems associated with building design.	Need to understand how structures, materials and details can be recorded and expressed through BIM
GC9	Adequate knowledge of physical problems and technologies and the function of buildings so as to provide them with internal conditions of comfort and protection against the climate.	Need to be able to apply analysis techniques to BIM models
GC10	The necessary design skills to meet building users, requirements within the constraints imposed by cost factors and building regulations	Need to be able to apply cost analysis techniques to the different BIM models

GC11	Adequate knowledge of the industries, organizations, regulations and procedures involved in translating design concepts into buildings and integrating plans into overall planning.	Knowledge needed of BIM procedures and requirements
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Table 1: Considering BIM application against ARB requirements

Core knowledge is required to be developed at student level as opposed to higher levels in the profession (see figure 1). In later sections Blooms taxonomy (Bloom et al 1956) is used to define the level of knowledge that needs to be achieved in relation to BIM competencies.

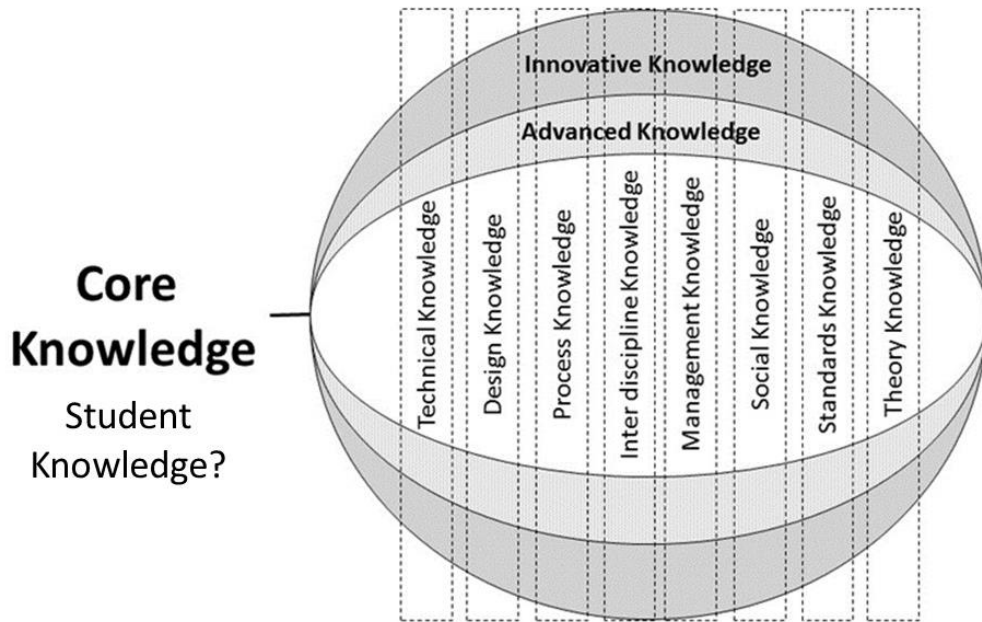


Figure 1: Depth of knowledge needed by Architectural Students

Through the way architectural programs are evaluated students are required to demonstrate both non propositional or procedural knowledge. The knowledge is to be acquired as a framework for action combined with the knowledge of application creative development.

A major element in defining architectural programs is the input from architectural practices.

“In a fast changing, challenging and technologically driven industry, it’s more important than ever to build your knowledge and skills to get the job done better and faster.”

(Valance et al 2018)

3 BIM and the Augmented Architect

Intellect augmentation aims to improve operational efficiencies through the use of technology. BIM represents one form of intellect augmentation. Building Information Modelling (an object oriented system) is now replacing CAD software (a vector based system) which was used for many years since the adoption of computers within the AECO industries (see figure 2).

According to NBS report (2018) 74% of the profession in the UK are now using BIM. This represents a 50% increase in 6 years. In BIM models data is linked to graphical entities representing build elements or objects with parametric capabilities.

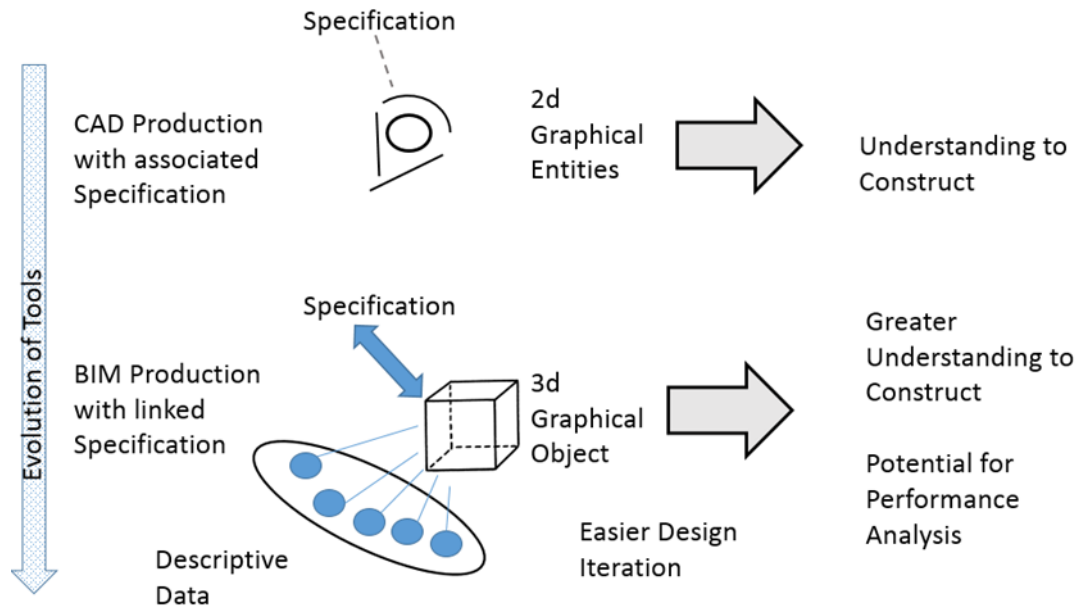


Figure 2: The changes brought about by the use of BIM

Thus there is a transition from the concepts of drafting to the concept of modelling and potentially simulation. Using a data based (data and geometry) approach multiple representations can be generated from a single model (see figure 3). Chandrasegaran et al (2012) defined the range of models required as part of a product development process. These included requirements models, functional models, concept models and detail design models. Models can also be defined by their purpose i.e. as developmental, presentational or for testing.

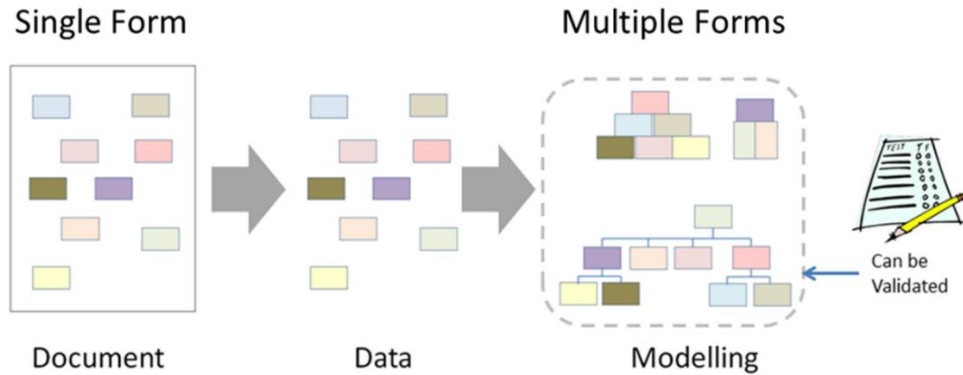


Figure 3: The move from single fix constructs to multiple situational constructs

BIM which is a socio technical system, can be defined by what it is, what concepts it is based on or what it does (Maunula 2008). BIM can be seen as an integrated digital method of building delivery applying the capability of information systems and defined informatics into the AECO industries. BIM potentially develops interoperability and collaborative practices across the whole building lifecycle (Macdonald 2011). This interoperability fundamentally changes the modus operandi of the industry.

For the architect BIM represents a modelling and testing space prior to construction instruction. Virtual preconstruction or testing how the building is predicted to operate in use can be modelled.

From the RIBA digital plan of work, what is to be created and communicated is defined. Many further forms of BIM, Nd modelling (Aouod et al 2007) may be applied as part of project delivery. Such functions may include quality takeoff for cost estimating, clash detection, energy analysis, structural analysis, integration with project planning and facilities management. Many more capabilities are available depending on the task in hand or are in development.

Architects are instrumental in the defining, creating, reviewing and communication of the constructs assembled from BIM objects (Coates 2010).

BIM tools can be considered in four forms. These forms are as a BIM capture tool, as a BIM authoring tool, as a BIM analysis tool (a move from implicit to explicit solutions), or a BIM output or collaboration tool. These tools types maybe integrated into or considered as a multi agent system (Liu et al 2005).

The architectural geometry is numerically defined and as a result can be parametrically or algorithmically transformed using programmable attributes and parametric rules. This provides the ability to use generative design across all levels of the built environment from the micro to the macro scale.

Models can be derived from the graphical entities or the associated data or a combination of both. BIM graphical entities use solid modelling as opposed to boundary representation. Through the development of enhanced visualization and the potential for more immediate

performance analysis the design process changes. Digital tools can be used to evolve, iterate and optimize designs empowering the designer to better solutions. The architectural process can be seen as a process of developing knowledge representations.

Within the BIM process the level of detail is defined using documents such as the Employers Information Requirements. BIM when properly managed provides just in time data to avoid “making do” in the design process (Koskela 2004). From this perspective BIM can be considered a facilitated exchange decision support system.

4 The importance of sketching, physical models and prerequisite knowledge

Achieving the best design results is central to the architectural role. Research has indicated that using a combination of alternative mixed media (that is sketching and CAD) better results can be achieved by the designer (Yi et al 2015). There are those who “extol the virtues of getting touchy-feely rather than digitalizing” (Cook 2008). Thus address the haptic element of architecture. Physical models have been used to teach first year architectural student history at Oxford Brookes University (Trojani Igea). Further development of software interface technologies may overcome current limitations.

Chandrasegaran et al (2012) also recognized there is a need for knowledge collection as a prerequisite before embarking on design development (see figure 4).

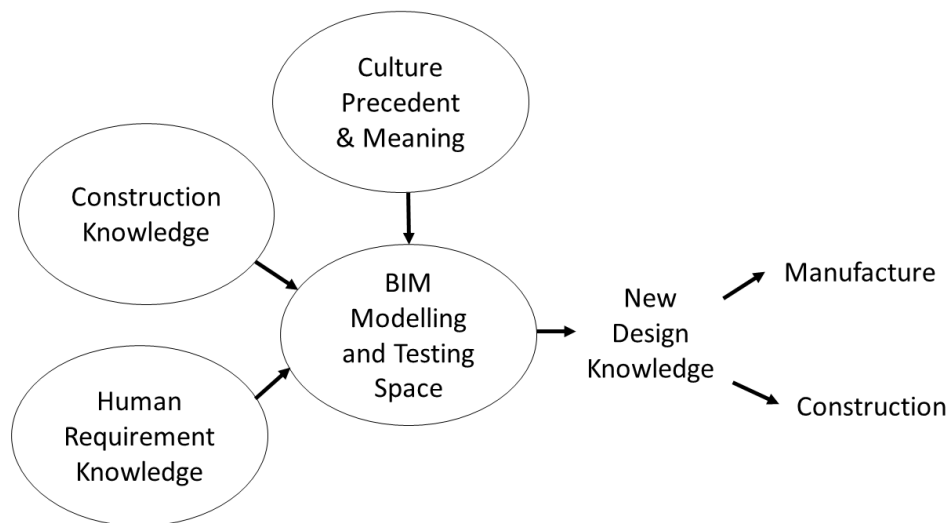


Figure 4: Input and output from the BIM Modelling and testing space

If we consider BIM as a form of procedural knowledge effective development relates to appropriate instructional scaffolding and structured assimilation with other forms of knowledge development. The tasks that students undertake allow them to construct meaning through constructive alignment. So the tasks that students perform and the connections between the areas of knowledge developed is important. This raises question

of where the introduction to BIM should sit within the overall development sequence of the architectural education.

5 Issues related to BIM integration in architectural education

The adoption of digital technologies like BIM changes necessarily the how and what concerned with architectural design. The questions of how we do and what we do are changing and are transformed to the way architecture is being taught today. The introduction of BIM into the education process requires innovative thinking (Cheng et al 2006).

Communication and representation conventions act as determining factors in the proposal of new architecture. In order for architectural education to embrace new design outputs, the design process must also be developed. The future of architecture in terms of concepts and practice are at crossroads between BIM and PM (project modelling). The architectural profession is shifting from traditional practice into a dynamic and model oriented digital practice (Abdirad et al 2016).

The design studio is the place where a model for the building design starts. The process of analyzing structural, electrical and mechanical systems can act as a basic agenda set for the design studio. Perhaps one of the most potential present in the application of BIM is that the actual construction of products and components are directly derived from the design studio. BIM offers the possibility from starting from the whole building rather than ending up with one in the case of the traditional process(Abdirad et al 2016). This shall expose students to new possibilities and challenges in the comprehensive design studio.

The attempt to update existing modules should involve core courses that cover the full potential of BIM. Moreover, BIM rather than CAD, imposes additional cognitive skills for users in order to make the computer learning curve more significant (McLaren, 2008, Pikas et al., 2013). One of the strong examples of the efficiency of BIM adoption is in the case study of Pikas et al. (2013) where it was found that students who had BIM background in a cost estimation course, had improved learning experience. On the contrary, students who didn't have basic BIM course faced difficulties in utilizing BIM tools.

When dealing with the limitations imposed by BIM as a standalone course or integration of BIM into modules implemented in AEC courses, it is advised to combine strategies of learning general concepts of BIM and the skills to use the technology.

Previous studies that focused on the topic of BIM education in relation to the industries demands and expectations had their surveys investigate the following areas:

- The current status of BIM implementation within the AEC curriculum.
- The future expectations of BIM education by the industry participants.
- The perspective on the future of BIM education regarding AEC modules.

In the literature there has been a debate about whether or not technical BIM skills are more important than conceptual BIM knowledge when it comes to AEC education. For instance, according to the study of Wu and Issa (2014), BIM software skills are ranked as the most desired learning objective in BIM education at a university level. However, other researchers considered that BIM concepts and knowledge process are considered more important than BIM software skills since the BIM technology is always evolving and mastering BIM in a single course is not effective on the long term implementation strategy (Dossick et al., 2014, Ku and Taiebat, 2011).

In spite of the two opposing views relative to the importance of BIM concepts and skills, it is highly recommended that BIM instructors cover both the technical and conceptual skills in their modules (Dossick et al., 2014). However, outcomes of performed surveys detect existing deficiencies in BIM education which involves: lack of understanding towards the inter-disciplinary collaboration in BIM, the lack of BIM experience in related projects and the lack of understanding between work sharing and BIM based communication (Wu and Issa, 2014). On the other hand, other surveys convey that inter-disciplinary BIM processes are well covered in internships and professional practice more than by AEC programs (Sacks and Pikas, 2013).

Some studies highlights the lack of existence of a clear and specific strategy in the AEC programs concerning BIM integration within the curriculum, while other studies suggest how to merge BIM in education and introduce its concepts (Becerik-Gerber et al. 2011).

Several studies have highlighted on the need of building up technical and managerial skills for undergraduate students, however some suggest that basic knowledge and process should be covered in early modules of the curriculum while advanced and more specific BIM uses and integration should be concerned for senior level modules (Lee et al., 2013). Thus these questions require further investigation in this research.

When investigating the status of BIM in AEC modules, studies showed that the implementation of BIM in undergraduate courses in more than in graduate ones (Becerik-Gerber et al., 2011). Yet studies followed by a couple of years highlighted a shift towards graduate programs (Dossick et al., 2014). These results supports the idea of the need to implement more BIM courses at undergraduate and graduate levels as a requirement for AEC degrees.

When it comes to BIM educational requirements, previous studies have analyzed the contents of BIM curriculums in relation to BIM job descriptions. The findings have focused on the importance of teamwork, communication and analytical thinking skills in using BIM tools, also the importance of the knowledge in BIM standards, process and coordination (Sacks and Pikas, 2013).

Summing up the areas of focus and previous research, the knowledge of BIM concepts, technical skills, BIM enabled collaboration and integration within the AEC industry are all complementary factors to one another. BIM competences should be aligned with the core topics of AEC curriculum to achieve best educational outcomes. Moreover, there is a need

to see more BIM implementation in undergraduate and graduate levels (Abdirad et al 2016).

6 The Competences related to BIM

The role of architectural education is to produce architects that are both effective and efficient. An architectural education aim to train students to formulate built environment solutions that both meet the needs and aspirations of the users and are feasible and practical to deliver. The use of tools is a symbiosis requiring the application of the knowledge of the user and the capabilities of the tool to achieve architectural outcomes. BIM competency indexes exist (Bilal Succar 2009) but these are not specifically oriented towards architects and architectural students (Hjelseth 2015). Through a review of requirement a competency list was developed (see Table 2). The competences and the suggestion made in this paper is to be used for further design science research to validate the views expressed.

BIM Competence for UG Architectural Students				Blooms Taxonomy
Concepts and Theory of BIM	Pre Theory	New Knowledge		Comprehension
BIM Authoring	Pre Theory	New Knowledge BIM Authoring		Application
BIM for Analysis and Prototyping	Prerequisite Knowledge Theory	BIM Authoring	New Knowledge Area of Analysis Analysis Tool	Application
BIM for Information Capture	Prerequisite Knowledge Theory	BIM Authoring	Capture Process	Application
BIM for Visualization	Prerequisite Knowledge Theory	BIM Authoring	Vis Methods	Application
BIM for Communication	Prerequisite Knowledge Theory	BIM Authoring	Data Process	Application
BIM for Manufacture	Prerequisite Knowledge Theory	BIM Authoring	Output Methods	Application
BIM in Professional Practice	Desirable Pre knowledge Theory	BIM Authoring	Standards	Application
BIM Management	Desirable Pre knowledge Theory	BIM Authoring	Systems	Comprehension

Table 2: BIM Competences and knowledge development required

6.1 *A theoretical understanding of BIM in Architecture and Design*

The requirement of a theoretical knowledge is a criteria of architectural education. New tools bring with them changing knowledge sets required in order that they can be used effectively and efficiently (Ambrose 2009).

The teaching of architectural theory provides the basis of direction for architects and architectural students. It is important that appropriate theory is taught to allow the effective understanding and integration of BIM approaches.

BIM, a digital system of development and the use of ICT delivery can be considered as the most current iteration of procedural knowledge architectural students need to acquire.

Frameworks do exist for digital design, these include methods of interaction with objects through an intermediate moderating algorithmic digital interface (Oxman 2006). The increased capability of digital tools in geometric generation have influence the forms often used for *avant –garde* and iconic architecture today. Advanced geometric generative capabilities are not always built into the tools used for BIM authoring. But automation between multiple tools is continually developing. Highly customized organic or kinetic and dynamic architectural forms are now being developed raising new challenges for BIM and design. Conceptual frameworks now exist indicating how BIM can be integrated with generative design (Abrishani et al 2013).

Explaining how BIM can be integrated into the process of design is important. A unified design theory is provided by the C-K Theory (Hatchuel et al 2003). Through a process of testing concepts (iterative design) knowledge is developed. BIM models have their role to play here through the use of comparative optioneering. Design can be defined as ‘the optimum solution to the sum of the true needs of a particular set of circumstances’ Matchett (1968). The process of design has been described as an experimental process (Schon 1983) an exercise in dialectical thinking. Students need to understand the principles of theory and practice in order to manage their work and the interactions with others effectively. Students learn better when they understand the relevance and significance of what they are learning. Therefore it is important that students are made aware how BIM is reshaping the AECOO industries.

6.2 *BIM for information capture and concept design*

The architectural process starts with the development of an understanding of requirements and context. Site related information be it in the form of survey, laser scans, and photogrammetry or from GIS or mapping system may need integrating with the BIM model and the common data environment. Students need to be aware of how to undertaking this information integration.

There is little literature about how BIM can contribute to the project definition process (Forgues et al 2010). The integration of BIM and formulation requirements engineering

remains an area for further technological development of ontologies linking objects directly to requirements.

Moving forward students will need to know how to use digital design intent tools. Models by their nature are forms of abstraction or simplifications. In order for models to be used effectively the user needs to understand the simplification that has taken place. Architects need to understand the context of their developments. Site analysis is an important part of this.

6.3 BIM as an authoring tool

Current BIM authoring interfaces lack the affordance necessary to be used without the upskilling of the operators. Where this is undertaken in practice this is the major overhead of BIM adoption.

Creating BIM models objects and object compilations is usually a roll that falls architectural practices. Massing digital tools are such as Formit and Sketchup are often used at the conceptual stage. Then BIM author is simultaneously creating two components geometric forms and the information related to those forms. Although the level of detail attached to an object may increase over time. Also the information attached to an object is determined by how it is to be analyzed. For example the object to be analyzed for thermal or structural modelling need appropriate properties attached. Overtime more data rich objects may become available so the task of the designer becomes one of object compilation as opposed to object creation.

Central to development of architecture is the creation of space meeting functional and aesthetic requirements. Creation of appropriate spaces is constrained by the ability to create appropriate geometry. To create complex geometries, external modelling tools maybe necessary before bringing the geometry into the authoring tool.

Creating construction details is also an important skill. Detail development ideally should be created within BIM authoring tools.

BIM authoring tools have a wide range of capabilities and complexities. Learning how to use the tool often takes place through enquiry at the point of use. Developing BIM skills to address the adhoc challenges of design projects allows the student to develop the skills of problem solving within the BIM environment. The ability to find out how to achieve a desired result in a BIM environment is a core skill to achieve a BIM authoring capability.

6.4 BIM analysis and rapid prototyping tool (a move from implicit to explicit solutions)

Central to the role of an architect is how effective design can be achieved to meet building performance criteria? Using model analytics to student architect moves it applied science approaches although this still maybe influenced by the arts and humanities.

“Data and analytics are already shaking up multiple industries, and the effects will only become more pronounced as adoption reaches critical mass.”

(McKinsey Global Institute 2016)

For the architectural student BIM provides the modelling and testing space combining concepts of construction and human requirements. These two areas of knowledge provide the objectivity in the design process and are a prerequisite of effective design. One of the greatest advantages of BIM is the detection of design issues at the initial phase of design. The information is loaded into the model, each building component transmits data related to specifications of size, material and cost. BIM is a useful tool to accurately estimate the cost of a project and its energy performance since the parameters of a certain project are all defined from the start.

The adoption of BIM means that a building model is a derived model from the building process. This model prepared by default can then be used as the basis of building analysis. The linking of graphical objects and assigning data can be used for many forms of analysis and to answer many questions. With more explicit information, designers are better able to understand and communicate their decisions (Maver 2000). BIM can be used for structural design, cost models, energy analysis, GIS integration and scheduling of ordering equipment (Eastman et. al, 2008). As a result of growing concerns related to global warming, the consideration of building energy simulation is of particular importance.

When teaching BIM, building energy simulation is taught sometimes as a standalone subject. While other times it is integrated into a design module (Hopfe et al 2017).

6.5 BIM for Visualization

One major learning objective in the architecture program is to produce a design that serves both the aesthetic and the technical requirement of the stakeholders and social environment. The introduction of BIM to this objective serves in better visualizing and understanding the design through its 3D based system which offers more design control and a better way to work with the design interface. Another learning objective for architectural students deals with developing student's skills such as visual and thinking skills. Here, BIM assists in linking between the drawings and the realistic view of the project which develops the imagination of the student and makes the image closer to his or her thinking.

Using BIM to visually convey a design proposal is an important ability for architects and architectural students. An understanding of the context of the interior and exterior space is essential in the process of learning. Through the use of BIM, the urban context becomes closer with the working space and allows the student to view different perspectives, providing an in depth understanding to the spaces being designed.

The student must learn the difference between developing an idea through representation using objects to think with and representing an idea for presentation creating objects to look at (Yakeley, 2000). Knowing what different stakeholders in the building process require is important.

The current approach adopted allows students to create 2d representation from their model in the form of drawings. The design may also need to provide photo realistic

representations of their proposals in the form of renderings or animations. There is also a question of visual authenticity of the objects produced. When the BIM objects are rendered do they appear correctly? Development of BIM as the basis of Virtual Reality simulation represents the cutting edge of design visualization (Corke 2017). Cyberspace also offers the possibilities of virtual architecture unrestricted by the laws of nature. As we move to a time of producing smart and intelligent buildings new forms of visualization maybe required.

BIM has been linked to the concept of virtual preconstruction but the architect equally needs to consider the operation of the building and the user experience. The visualization capabilities of the tools does not take away the importance of the ability of the student to envisage solutions before they are modelled.

The clear visual understanding of all building features and its potential issues which represents a replica of the construction process through the coordination of multiple design inputs can be tested. As models for different disciplines are combined into a single model geometric clashes can be visualized and resolved. This acts as great advantage to all involved parties where any order variations resulting from design errors are practically avoided and resolved before breaking ground (Azhar, 2008).

6.6 BIM for communication with other disciplines

Hopkins (2006) expresses BIM use as something hard to teach since it is hard to define. However, the three elements that form BIM are always emphasized: Building Information Models, Modelling and Management. McGough (2013) emphasizes the importance of taking BIM beyond modeling software where he states that “teaching need to be clear that BIM goes beyond 3D modeling, with efficient information sharing a critical factor which needs to be adopted and understood.”

The architect needs to communicate design, this maybe be indicative during design development then made explicit for manufacture or construction. Outputs maybe evaluated for design quality, technical appropriateness and statutory compliance. These outputs maybe filtered using model views and maybe defined by COBie requirements. PAS 1192 part 2 shows how different levels of status can be given to these boundary objects. Industrial foundation classes may also be used to provide the method of informational transfer. Common data environments have a role to play in the sharing of information.

6.7 BIM to Manufacture

BIM enabled Design for Manufacture and Assembly is part of the UK Government Strategy (HM Government 2012).

There is a shift in design and manufacture and assembly to the use of digital forms away from the use of drawings. Non euclidean geometry is an important element of this. This represents both a change in the process and the product (Mitchell, 2005).

It is not uncommon for architectural students to build life size projects. BIM offers the opportunity for students to model and then machine create buildings demonstrating

Figure 4: BIM to enable better decision, be more effective, more productive and automation of the process.

Although undergraduate students need to develop the skills to integrate into industry they also should have the potential to be part of a developmental process moving the industry forward. This requires the ability to be critical about the exist processes and tools include those which are part of the BIM paradigm.

7 Strategies for BIM implementation in Architectural education

Different strategies have been adopted in the AEC curriculum. While some universities have integrated BIM in the core courses, other universities have implemented BIM in elective courses only (Lewis et al., 2014). Yet, when covering BIM concepts in elective courses only, the concern that some students might miss the opportunity to acquire the basics of BIM knowledge and skills is raised. According to Becerik-Gerber et al. (2011), the number of AEC programs offering elective BIM courses is significantly higher than programs which require BIM courses for a degree. Also it is possible that a program could be fundamentally redeveloped to adopt BIM skill development.

Clevenger et al. (2010), classifies the BIM adoption strategies into three: First, the development of BIM as standalone courses to cover various BIM issues, second the update of current courses towards more BIM oriented ones, and third a combination of the previous two strategies along with a BIM course.

Some studies recommend that offering standalone BIM courses should take place in parallel with other courses to allow students to apply their gained skills in different modules (Ghosh et al., 2013, Gier, 2008, Clevenger et al., 2010).

Traditionally, the common thought of implementing BIM in the learning process is through the use of BIM based software in a course. However, the understanding of BIM goes beyond this limit and is much broader than a software use. It involves both, processes collaboration and processing of information, that serve in understand and solving tasks. BIM in education is influenced by a wide range of definition.

Whichever approach is adopted process to develop BIM adoption can follow the ADDIE model to allow a controlled development approach. A process of Analysis, Design, Development, Implementation, Evaluation (Dick et al., 2005) to meet BIM learning requirements.

8 Standalone BIM modules

BIM can be introduced to students as a standalone module either within or outside the assessment regime. Table 3 provides a standalone approach for consideration.

		1hr	1hr	1hr	1hr
Week 1		Introduction	Theory	BIM Authoring	
				Intro to Software	Sources of Help
Week 2		BIM Authoring		BIM Authoring	
		Massing	Exercise	Walls and Families	Exercise
Week 3		BIM Authoring		BIM Authoring	
		Roof and Floors	Exercise	Room and Spaces	Exercise
Week 4		BIM Authoring		BIM Authoring	
		Use of Families	Exercise	Spaces and Rooms	Exercise
Week 5		BIM Authoring		BIM Authoring	
		Stairs / Railings	Exercise	Foundations	Exercise
Week 6		BIM Authoring		BIM Authoring	
		Materials	Exercise	Schedules	Exercise
Week 7		BIM Authoring		BIM Authoring	
		Detailing	Exercise	Workgroups	Exercise
Week 8		Area of Analysis	Analysis Tool	Workshop	Workshop
			GBS or similar		
Week 9		Data Process	Data Process	Workshop	Workshop
		Cobie output	Model Review		
Week 10		Output Methods	Output Methods	Workshop	Workshop
		Creating Drawings	VR and Rendering		
Week 11		Standards	Standards	Workshop	Workshop
		PAS 1192		Create EIR	
Week 12		Capture Process	Systems	Workshop	Workshop
		Point Clouds			

Table 3: Proposed outline for standalone module

9 Integration into existing modules

It is also possible to redesign the architectural programs and into interrelationship with other programs based on the emerging digital practices (see table 4 and 5).

	Year 1	Year 2	Year 3
Concepts and Theory of BIM	●	●	●
BIM Information Capture		●	●
BIM as an authoring tool	●	●	●
BIM for Analysis and Prototyping		●	●
BIM for Communication		●	●
BIM for Visualization		●	●
BIM for Manufacture		●	●
BIM in Professional Practice			●
BIM Management			●

Table 4: Proposed Integration of BIM across Architectural Programme

The module table 5 shows the possible BIM overlay of learning outcomes on existing modules. This is based on the undergraduate architectural modules undertaken at the University of Salford. This table is to be used as the basis of further discussion.

Year	Sem	Module Name	Possible BIM Learning Outcome
1	1	History and Theory of Architecture (6.1)	The development of the concept of a building as an assembly of parts
		Design Representation Modelling (6.1) (6.4)	The significance of Digital forms as a method of design representation and rapid prototyping
		Design Studio 1A (6.3)	Ability to produce simple BIM models
	2	Principles of Architectural Structures (6.2)	Linking material concepts into BIM objects
		Introduction to Building Services and Systems (6.2)	Modelling services in BIM

		Design Studio 1B (6.2)	More sophisticated BIM output
2	1	Design Studio 2 (6.6)	BIM output to physical models
		History and Theory of Architecture 2 (6.1)	Parametric Theory
		Construction Technology in Architecture	Detailing with BIM
	2	Performance Modelling and Integrated Design (6.4)	Energy analysis using BIM
		Principles of Sustainable Built Environment (6.2)	Linking material selection with BIM
		Multidisciplinary Project (6.5)	Collaborative BIM Models for other disciplines, ideas of CDE
3	1	Design Studio 3 (6.5)	BIM output to rendering, animation
		Design Research Project	
		Re-creating the City: reuse and regeneration (6.2)	Data capture for BIM
	2	Design Studio 4 (6.5)	BIM output to VR
		Practice Management and Law (6.7)	BIM in a management context, model and data management
		Environmental Architectural Technology	Advance Façade design and linking BIM with algorithmic design

Table 5: Suggested BIM learning outcomes applied to the undergraduate architectural program at the University of Salford

10 BIM and Design

The design process and the ability to apply it is central to architectural education. Design requires the combination of critical reasoning and lateral or creative thinking.

Student need to be able to create new knowledge related to new situations as well as utilize their existing knowledge. The early process of design may require the use of metaphors and heuristics to tackle ill-defined problems (Rowe 1987). These metaphors may not easily be worked with in the BIM paradigm which has predefined cognitive linguistics which include walls, roofs, windows, doors etc. Although buildings can be thought of as an assembly of objects or architectural elements most building rely on their details to achieve the necessary quality and ensure effective performance. BIM also facilitates new design procedures and target value design is consider in the next section.

Many of the BIM authoring tools, without the use of other software's do not have the capabilities of geometric generation that may be required as part of architectural designs. In the future using a generative approach of digital tectonics the designer may interact with the digital environment to develop the objects within that environment. Architectural educators must find ways to expose and demonstrate the new creative potential of BIM systems

11 Provision of Facilities

Integration of BIM within AEC courses necessitates certain upgrades in the equipment and softwares, in addition to technical support, maintenance and logistics issues (Clevenger et al., 2010). The provision of appropriate spaces linked with the necessary hardware and software may require additional investment in these facilities. The appropriateness of the facilities may very much depend on the pedagogical method adopted. The move to a more collaborative style of working integrated with BIM discussed in the following section bring in another range of facility considerations. Peer learning also has a role to play in the way a student learn.

12 A Transdisciplinary Collaborative approach to learning BIM

There is an increasing need for more collaborative and interdisciplinary work environments (Kocaturk, 2013; Thomsen et al., 2015) and the education to reinforce these approaches. To achieve effective collaboration enabling collective problem solving has been put forward as an objective of the construction industry (Latham 1994).

“the notion that one person sits alone and is inspired to design misses both the nature of design and the countless contribution from others”.

(Macomber and Barberio 2007)

Bounded rationality limits our abilities to process information means that selective filtering occurs so different disciplines can focus on their matters of concern (Broadbent, D 1958). The different student disciplines represent distinct knowledge communities (Becher & Trowler 2001). Underpinning this is the acceptance of common goals, mutuality and the acceptance of interdependence.

Various terminology and approaches have been developed in relation to transdisciplinary design. These approaches include Integrated Design Solutions (Prins 2009), Target Value Design (Zimina et al 2012) and Integral Design (Zeiler 2018).

The process of project development can be considered as collaboration including continual multi-user immersion 3D information rich virtual environments or collaborative computer aided modelling. To engage in such activities it is important that the student has an awareness of their own role and a vicarious appreciation of the role of others.

The design / development of modern building has led to a proliferation of professions and a compartmentalization of associate knowledge (Ochshorn 1989). Current thinking recognizes the importance of open innovation based on collaboration (Chesbrough, H, 2003).

Architects and practices need to look outside themselves to achieve new forms of efficiency and effectiveness. Collaborative behavior goes beyond the system adopted its success depends on positive interdependence, individual accountability, promotive interaction, social skills and group processing (Johnson et al 2009). New approaches of Project Partnering, Integrated project delivery and Target Value Design have been developed. BIM allows improvement in cooperation and communication across disciplines (Ambrose, 2007) and the ability to more effectively undertake architectural tasks.

The uses of a common data environment is also part of the BIM concept BS 1192 part 4. The use of a CDE is key to the facilities of sharing and collaborating through BIM. The collaborative aspect of BIM suggests elements of curriculums should co-created across disciplines. Collaboration is an anthropological issue

Through collaboration designers can better understand the implications of the design they produce through collaboration and feedback from other disciplines. Collaboration has been recognized as an important ability to operate within the construction industry. Architectural practices operate as communities of practice relying on collaboration at discipline level (Yip S.L. 2014). Indiscipline collaboration of architectural students can be achieved by incorporating group work.

BIM is an element of Integrated Project Delivery. Frameworks have been developed to teach IPD (Macdonald, 2012).

BIM is a transdisciplinary subject some areas of understanding are universally applicable while others fall within a specific discipline. Ideally the integration of BIM should be across and integrate all building disciplines within a University (Zulfikar et al 2016).

An Integrated Design Studio was introduced by Pennsylvania State University to teach students from different disciplines BIM (Barison & Santos, 2010). Teaching BIM as a collaborative subject has the benefit of allowing architecture students to understand the informational needs and contributions of other disciplines (Miller et al 2013).

Collective intelligence and the ability to create it is recognized as an important architectural education (Beaubois 2015). BIM offers opportunities to develop integrated project delivery approaches. Undertaking multi-disciplinary modules is one mechanism to develop collective intelligence. Learning outcomes of such modules can be classified as follows:

1. To provide students with an opportunity to work in multi-disciplinary teams and to enable them to perform in a role/discipline in the context of a team based project
2. To promote reflection on individual and team working and the multi-disciplinary nature of built environment projects

3. To allow students to practice and further develop both discipline based and generic key skills required by a built environment professional
4. To encourage self-reflection and enable students to further their personal development plan, that aligns the learning needs and career aspirations and the requirements of the business sector and the professional institutions
5. To further develop written/oral communication, team working and inter-personal skills

When using BIM collaboratively it is important individual parties perform their tasks correctly as failure to deliver may cascade negative impact through the project teams.

13 Conclusion

When explaining the concepts of BIM to students clarity is the key. It is important to introduce the technical terminology of the subject area slowly to allow effective assimilation to take place.

The process and product of design are in a radical state of change as a result of developing digital tools and applied informational systems. A changing world demands new smarter architectural products and associated forms of generation. BIM is not the only tool that is used word processing, photo editing, use of search engines are some of the many other examples of the tools also used. Perhaps we should be considering the task as one of integrating digital skills into the architectural curriculum as opposed to the integration of BIM.

The intention of the paper has been to discuss how BIM can be best integrated with undergraduate architectural programs but also to highlight the importance of digital changes that are taking place. The linking of research with teaching has a role to play in educating students. The theory of constructive alignment (Briggs 2003) would suggest the importance of including requirements within program and module learning outcomes.

BIM facilitates new methods of collaboration. Educator need to consider how inter-disciplinary, multi-disciplinary, trans-disciplinary learning related to BIM can be built into the curriculum.

Development of appropriate teaching and learning environments aligned to the development of remain an important element in the integration of BIM into architectural programs.

Suggested levels of competency were developed for this paper but development of a more expansive competency index would form a better basis for integrating BIM education into undergraduate architectural programs.

Software developers also have the responsibility to work towards developing tools that are easier to learn and use. BIM tools themselves ideally should have the ability to act as vehicles for computer aided education.

Education aims to teach the architects of tomorrow. If we are to train the architect of tomorrow there is the question of what provision should be made for innovations that go beyond the traditional BIM paradigm.

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