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USING BIM TO ACHIEVE ARCHITECTURAL ENGINEERING UNDERGRADUATE LEARNING OUTCOMES

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INTRODUCTION:

BIM is now a requirement in architectural education. The profession is driven by the construction industry which is facing new complexities and challenges. One major challenge is the issue of global warming. We need to construct buildings which meet the requirements and needs of human activities. Yet we need to achieve this using less material resources and consumption of energy. This applies at both the CAPEX and OPEX stages. There is a need to reduce CO2 emissions. In order to limit these emissions, it is essential to predict the impact of the building on the environment through specialized models and assessment. The technology of BIM offers a solution in designing a more efficient building that takes into account sustainability requirements and promotes for buildings with less impact on the environment especially during the energy intensive operation and maintenance phase. The challenge here falls on the architectural engineer. Their role is to ensure that the design of the building combines art, science and BIM methodology based on numerical values and data that allows him to explore energy efficient architectural solutions. "*No job can be done well without the right tools – regardless of profession.*" (Valance et al 2018)

The development of building designs and production information has predominantly moved to one which utilizes digital tools and technologies. Emerging tools and technologies raise new questions how the design student of today can develop the skills necessary to work in today's industry and the emerging industry of tomorrow. This paper specifically looks at how architectural engineering undergraduates in the UK can develop the necessary skill to achieve the benefit of working in a BIM environment and also be able to integrate collaboratively their contribution with other in the building design and development professions. The professional body for Architects and Architectural Engineers in the UK is the RIBA. 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)

As a professional body the RIBA has a responsibility to ensure member are trained with the necessary skill to provide an appropriate product to the client or customer. Two questions arise as part of the pedagogical discussion what should be taught and what is the most effective way for it to be taught. The reason for the use of tools is that they augment are capabilities either in a physical sense or a cognitive sense. (Engelbart 1962) characterized the component of digital cognitive tools as artifacts, language, methodology and training. Building Information Modelling is the current emerging system being adopted by the UK design and construction industries. "*As we move towards a digitized built environment we are rapidly having to reassess education against the backdrop of a digital future."* (Philp 2015)

ARCHITECTURAL ENGINEERING AND ARCHITECTURAL EDUCATION, THE SIMILARITIES AND DIFFERENCES

An abundance of architectural engineering courses exist around the world, often with diverse and sometimes even conflicting meaning. Architectural Engineering courses for example in the US, typically refer to courses with a strong emphasis on the environmental and mechanical services of buildings. They revolve around the integration of appropriate techniques of servicing buildings and achieving comfortable environmental solutions and the integration with the design and interiors of a building is what attributes to them the "*architectural engineering*" title. Similarly, in the UK, there are also similar courses of BSc Architectural Engineering, that focus on building services, such as the BSc Architectural Engineering course of Nottingham University. However, most Architectural Engineering UK courses, refer to a heavy integration with Structural Engineering, making them essentially an engineering course, with a strong emphasis on structural engineering. These courses in the UK will be typically be attributed the BEng title, to signify their strong engineering aspect, sometimes their accreditation by the Institute of structural engineers and clearly distinguish themselves from the BSc Architectural Engineering courses.

An entirely different approach to Architectural Engineering curricula is seen in courses of the Middle east. In the MEA context, it is an umbrella term to include Architecture related courses, which have anyway a stronger engineering understanding than typical UK and US courses. This paper will use the term Architectural Engineering to refer to the course currently delivered by University of Salford. The philosophy of Salford's Architectural Engineering course is to create a graduate "*with robust knowledge of building structures and the capability to lead a multidisciplinary approach to building design*", as also mentioned on the programme's website.

ARCHITECTURE IN DIGITAL AGE

The programs of the AEC industry are limited in their courses when it comes to performing modifications because to keep up with the standards of accreditation, they have to maintain a certain level. (Sharag-Eldin et al, 2010). With BIM, new skills and opportunities are required especially that in architectural education the system is aligned to these requirements. It is also critical to utilize the features of BIM in order to achieve the architectural learning objectives that shall enhance the performance on the educational level and the career level. The architectural education of parts 1 and 2 has a criteria that is set out by the Architects Registration Board UK.

A lot of changes are taking over the 21st century which have a great impact on the learning styles that are being adopted. One of the most major changes is the reflection of new technologies on the educational level where universities are competing with non-traditional education associations. This shall enhance the teaching methods and enforce universities to understand how students learn best. Aspects of current trends include distance learning, mobility, modularization, globalization, flexible learning and work based learning (Ashworth et al, 2004).

The new technologies that are being adopted encourage the idea of independent learning and requires students to develop new skills. This implies a gradual shift from traditional teaching and learning forms into new ones where the information does no longer require the physical interaction between teachers and students but rather focuses on the self of the student (Knowles, 1975). One example for this approach is the problem based learning where the learner needs to be independently responsible for his own learning. The impact of the digital age will continue to grow whilst having economic and social impacts on society. The tools and methods for self-learning are becoming more available for learners where they can now learn and work from home without the physical need to attend on campus. Moreover, the act of increasing modularization allows students to learn at their own pace and according to the time that best suits them (Ashworth et al, 2004).

STATUS OF BIM WITHIN THE EDUCATION

The topic of BIM education in response to the demands of the industry have been the focus of previous studies. Surveys that investigated this area were concerned with:

1. BIM implementation within the AEC curriculum and its existing status
2. The expected outcomes of BIM education by the participants of the industry
3. The future perception of BIM education regarding AEC modules.

Reviews in the literature have always involved debates about whether or not BIM technical skills are dominant in their importance than BIM conceptual knowledge in AEC education. According to a study carried out by Wu and Issa (2014), the skills of BIM software are considered the most desired learning objective in BIM education within universities. Yet, other researchers considered that the conceptual knowledge of BIM is of higher importance than the software skills. Since BIM technology is still evolving and mastering the skill through a single course might not be effective in the long term implementation strategy (Dossik et al., 2014, Ku and Taiebat, 2011).

Although there are two opposing views concerning the importance of BIM, BIM instructors are highly advised to cover both, the conceptual and the technical skills in the learning modules (Dossick et al., 2014). The outcomes of the performed surveys reveal gaps that exists in BIM education. These deficiencies are mainly concerned with the lack of understanding towards the importance of collaboration between different disciplines, the lack of BIM experience and the lack of communication between sharing work and communication (Wu and Issa, 2014). However, other surveys show that inter-disciplinary BIM processes are well attained in internships and professional practice more than the AEC programs (Sacks and Pikas, 2013).

Studies also highlight on the fact that there is no defined strategy in AEC programs which deals with how BIM should be integrated within the curriculum, while some studies suggest how to introduce the concepts of BIM (Becerik-Gerber et al. 2011). Several studies have also highlighted on the need to build technical and managerial skills for undergraduate students. Some studies suggest that the basic knowledge related to BIM should be covered in the early modules of the curriculum while more advanced BIM modules should occur on the advanced and senior levels (Lee et al., 2006).

BIM AND THE AUGMENTED ARCHITECTURAL ENGINEER

BIM is a type of intellectual augmentation that improves on CAD software, which at the time of computer adoption was a form of technological advancement. This transition from drafting concepts to modelling and simulation approaches have elevated representations in the form of a digital model.

The operation of the industry is significantly affected by the adoption of integrated digital methods in the delivery of buildings. BIM applies an information approach and develops collaborative practices across the whole building lifecycle (Macdonald 2011). From the architect's perspective, BIM gives the opportunity to view the building through a detailed and developed model where spaces are tested prior to the commencement of the construction phase. From the RIBA digital plan of work perspective, BIM defines what is to be created and communicated.

It is essential that BIM implementation is synchronized to achieve the objectives and values of the architectural process. From an architect's perspective, the main approach has always been how the design is represented conceptually in a model, how the design serves the function ideally and whether any innovative method is used. Others might have different objectives and areas of focus. Hence, different analysis and simulation tools need to be available (Liu et al 2005).

BIM as an Information Capturing Tool

The first step of a BIM process is to understand the context and project requirements. Capturing the project's information and implementing them into the BIM model acts as a basic step in understanding the surrounding and providing accurate data input for analysis (Coates 2013). BIM requirements capture tools such as Trilligence Affinity can be used. One powerful, accessible and affordable tool for capturing existing building is photogrammetry where measurements information are taken directly from the photographs that are captured for a building and then upload them to generate a BIM model (Tuttas et al., 2017). Laser scanning offers an alternative way of capturing a point cloud which can for the basis from which to create a BIM model of existing buildings.

BIM as an Authoring Tool

BIM offers the designer the ability to create the geometric components and spaces with associated descriptive data. Early stages may include the development of simple massing models. At further stages of the project, the added level of detail and information can aid in the structural and environmental analysis of the building (Ching, 1979). At times, the creation of the desired geometrical form might be complicated and require external algorithmic modelling before transferring the model into the BIM authoring tool.

BIM as an Analysis and Rapid Prototyping Tool

"*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) The model generated in BIM links graphical objects together with their respective data. Thus the model can be used to perform different forms of analysis such as energy analysis, GIS integration and the generation of schedules. These models may use different forms of data representation to provide insight and understanding. One of the most important forms is the building energy simulation model. This is of a great interest when considering global warming concerns (Hopfe et al 2017). The results of the analysis can provide the designer with concrete data on which to make decisions (Maver 2000). Moreover, BIM model offers a rapid prototyping tool especially for large scale manufacturing methods such as contour crafting and production of building components (Khoshenevis, 2012). The production of these models is done using CNC machines is reliable and feasible option (Kolarevic, 2005).

BIM as a Structural Analysis Tool

BIM has the ability to make structural concepts and enquiry visible. The architectural engineer is faced with multiple challenges of developing a structure which is effective, efficient, constructible and within project cost constraints. Analysis can involve both static and gravity analysis. The ability to switch between structural solutions allows greater understanding to be gained of structural solutions. Tekla

Structural Designer is a BIM tool which allows for frames generated in steel to be reproduced in concrete and vice versa. There is a need to get the students using such tools in an enquiry driven approach.

BIM as a Sustainability Analysis Tool

Developing buildings which offers environmentally friendly solutions is a requirement and necessity. The main considerations are concerned with the indoor air quality, integrity in its different forms of acoustics, thermal, light and space. These are analyzed and imported to suitable programs depending on the type of analysis to be performed (Wong and Jan, 2003; Oyedele et al., 2012). Placing a new building within the existing built environment requires sustainable thinking in order to meet the future challenges and expectations especially when it comes to the aspects of availability of material resources, energy consumption and land use. BIM as an Output or Communication Tool Communication and collaboration between different parties is important (Mitchell, 2005). BIM acts as a communication tool between the architect and other project stakeholders. BIM can be used for 3D visualization of the building and integrated with augmented and virtual reality prior to and during the construction phase. Stakeholders in the construction industry showed a great interest in the growing use of BIM and are therefore requesting BIM as a in the delivery of the project output. Considerations of accuracy and interoperability are also important aspects of BIM.

BIM as a Visualization Tool

Having the advantage to visualize the design from the initial phases to the final renders makes BIM a cutting edge tool in the revolution of visualization (Corke, 2017). BIM goes beyond any hidden lines in the interior space and provides a full view to the designers and to the users (Yakeley, 2000). Part of the skill of the architectural engineer is defining and creating appropriate visualizations related to providing insight the tasks in hand.

BIM to Manufacture

The changes imposed by BIM on the design have also been reflected in the manufacturing process (Mitchell, 2005). BIM offers students and engineers the chance to model and generate and actual demonstration of their model using machines (Lave et al. 1996). Buildings produced directly from the BIM model either by additive or subtractive manufacturing is a growing field in the creation of our built environment.

BIM in Professional Practice

The practices of BIM involves professional practice. The process of BIM involves the asset data which requires moving from the process of approval, authorization to verification (ISO 19650-1, 2018). The practice of BIM process resembles the professional practice one where the architect's efforts take place prior to the approval step which is fully clarified by the NBS BIM Toolkit (NBS BIM Toolkit 2018).

BIM Management

The implementation of BIM in the concept of construction project management offered project's stakeholders new advantages. On the level of management, BIM increases the value of the building, shortens the project duration, provides accurate quantities and estimate and optimizes the operation and maintenance process of the building (Eastman et al., 2011).

BIM Collaborative Tool

Since BIM involves different disciplines in a common environment, it is one form of a collaborative tool. The collaborative workflow process acts as the essence for the success of BIM. It is necessary that the project's participants collaborate together in order to deliver an effective product (Succar 2009). The challenges that are encountered in the construction process are mainly cooperation, coordination and integration. With the use of BIM, a great solution to overcome these challenges is offered. BIM allows the exchange of information on one platform and highlights any clashes between different design disciplines. This ensures effective communication between all parties and provides accurate and updated information to better make a reliable decision and maximize their return on investment. Collaboration can only be achieved between all parties when it is aligned self-interest, the requirements of the requirement and project objective. Hence, BIM as a collaborative tool is achieved when the overall process is based on collaboration and when knowledge and technology are both considered.

DIFFERENT APPROACHES ADOPTED TO IMPLEMENT BIM IN EDUCATION

The adoption of digital technologies like BIM changes the how and what of 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. 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 advisable to combine strategies of learning general concepts of BIM and the skills to use the technology.

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). 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). Other surveys convey that interdisciplinary 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 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.

RESEARCH PROBLEM

When investigating the status of BIM in AEC modules, studies showed that the implementation of BIM in undergraduate courses is more than in graduate ones (Becerik-Gerber et al., 2011). Yet studies which followed later (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).

RESEARCH METHODOLOGY

The BIM modelling technology provides a smooth flow in the process of information from throughout the project's lifecycle, from the design till the construction where it facilitates simultaneous work of different disciplines on one common building model (Smith 2014, Ajibade et al 2012, and Goucher et al 2012). Hence, BIM proves to stand as a digital modelling tool and an information management system which stores and transfers all data among users on one platform (Ajibade et al 2012, Underwood et al 2010). The developments of BIM revolve around the process of innovative technology and information management which is affected by the demand for change by the market. When researching BIM as a technological development tool or as a new software for designers, a methodology is needed in order to evaluate the potential of this tool and its impact on the built environment upon its introduction (Kehily et al 2015). This research aims to solve a technical social problem by developing a framework to embed the BIM within the architectural engineering curriculum. The Design Science Research is an appropriate method to solve the research problem.

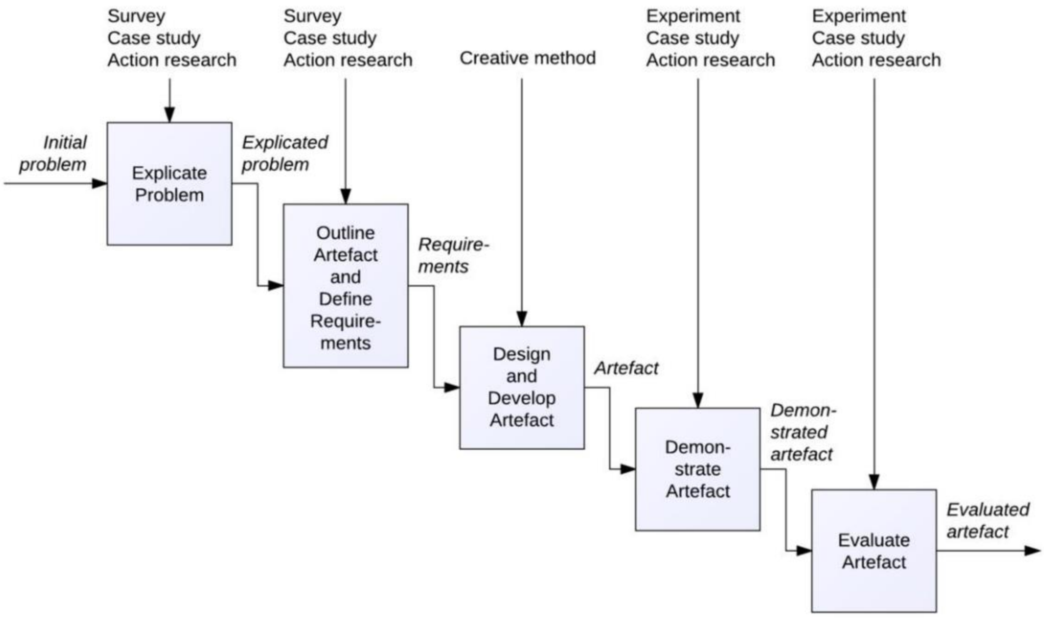

Figure 1: Suggested use of research strategies in the design science method (Johanesson 2012)

The methodology of the design research focuses on the design and development of artefacts and on the processes of evaluation and demonstration. The process of literature review leads to problem explication and the definition of the requirements of the solution. The developed artefacts are a result of efficient research approaches such as surveys, case studies and interviews. After these are undertaken the next step is designing and developing the artefacts which in turn lead to solving the explicated problem and therefore achieve the requirements. The final activity is concerned in evaluating the developed artefact in order to determine if it fulfils the requirements and solves the problem.

In this research semi structured interviews aimed at making two contributions. The first aspect relies in gathering the answers to the questions and gaps formulated from the literature review and the second aspect relies in deducting a solution based on the responses of the interviewed BIM experts. For the purpose of achieving the objective, the selection of the interviewees was based on the criteria of achieving the previously mentioned goals where the participant's background had to be compatible for the interview questions asked. Out of an invitation for 37 personnel, only 11 responses were obtained. This varied between practitioners and professional academics. The whole interview process followed a professional approach where the invitation took place via a formal email and official approvals were sent back and documented. The type of the interview was semi structured where it gives some freedom for the participant to express his opinion and opens up the discussion with the interviewer. The time frame of the interview was approximately half an hour, performed face to face or through video calls for international participants.

The primary goal of the interviews was to go in depth with the questions that were based on the identified gaps and outcomes derived from the literature review. The interview structures were divided into categorized questions which allows further filtration of answers under themes in the analysis process. The main themes are:

BIM advantages within the institutions

The first theme examines how BIM could serve the design related modules in the architectural curriculum. Responses agreed on the concept of implementing BIM at early stages gradually in order to reach the process of full implementation at more senior levels.

BIM disadvantages and limitations

The first question discussed whether BIM limits the creativity and imagination of students. Responses were divided into a group who think that BIM actually does impose these limitations since they are not fully able to express their ideas, especially the complicated ones. The other group's view opposes the first where they consider that awareness is the most important aspect when introducing BIM where students tend to use the BIM tool to develop their skills.

The second question aims to highlight the experienced disadvantages of BIM implementation. The main responses were concerned with the time required for students to learn the tool, and starts with practicing it shortly and with the associated cost for professional companies.

The third question discusses the implementation of BIM in the curriculum. Responses agreed that the goal is to teach students how to learn and apply new tools since the technology is under evolution. Hence the student shall be prepared to stay updated with any new tool that rises in the market.

Implementation strategy and the required needs.

The first question examines which BIM method is more suitable for implementation: the standalone course or the multi-disciplinary course. The views came up varied between both options. Respondents believe that there is no right or wrong but the framework of implementation is the key for the success of the process.

The second question inspects the possible ways to implement BIM within taught courses. Different criterias were suggested for the possible implementation but most responses agree that BIM should be introduced in the design related courses which allows the student to practice BIM on their own project and therefor ensures better understanding.

The final question under this theme surveys whether interviewers support the need for a technician at the university to aid the students in the massing essential. Views were divided between the idea supporting the student is the best person capable in translating his own ideas and between supporting the presence of a technician to aid students.

BIM post-graduation.

The assessment was performed through interviews with 12 students in order to explore the challenges they face post-graduation. • This discussion dealt with the level of BIM experience that students have at graduation level and which is nowadays a main requirement in the recruitment process. The idea of implementing a credited internship courses within the curriculum was favourable to most respondents.

SUGGESTED IMPLEMENTATION METHOD - Discussion and validation

The validation process for the suggested framework involved a presentation to RIBA professionals and experts followed by a discussion. The invitation was composed of a brief explanation about the topic and it was sent to around 30 possible participants. 11 respondents were interested in taking part of the study in a timeframe of 40 mins. The discussion explored 5 main areas in the process of validation. The first point tests whether the presentation is clear and easy to understand. Next, the discussion examines the willingness and interest of the interviewer to implement the framework and by how far they agree with the idea of internship practice as part of the curriculum assessment. Finally, suggestions about further improvements are deliberated. Responses came either supporting the framework or neutral with some suggestions for improvement and enhancement.

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. Educators 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 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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