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CURRICULUM RENEWAL IN ARCHITECTURE, ENGINEERING, AND CONSTRUCTION EDUCATION: VISUALIZING BUILDING INFORMATION MODELING VIA AUGMENTED REALITY

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Building information modeling (BIM) has long been utilized in the Architecture, Engineering and Construction (AEC) education. Learning and teaching (L & T) research has revealed a range of shortcomings in using BIM such as unfamiliarity of students and graduates with real-world field operations and decision making processes. Better visualization of BIM via augmented reality (AR) is an innovative educational approach that can address the aforementioned problems. This paper, proposes AR-powered BIM as a robust platform to be adopted in the AEC education with the aim of improving student experience and learning. After discussing advantages and disadvantages of BIM and AR as two separate platforms, opportunities and challenges to combine the two are investigated. This work contributes to the body of knowledge in the field of AEC education by investigating the dynamics of using AR-powered BIM in curriculum design.

Keywords: AR-powered BIM, Bloom's taxonomy of learning objectives, Cognitive domains, Learning and teaching, Off-site construction, Pedagogy, Construction project management, Occlusion and registration, Prefabricated buildings, Remote sensing, Tertiary education theory, University students.

1 INTRODUCTION

Many computer-based tools are being utilized to support tertiary education in architecture, engineering and construction. For example, BIM has been long at the center of attention among other research topics within the learning and teaching literature because of its role in preparing work-ready students and graduates (Barison and Santos 2010). BIM represents functional and physical characteristics of facilities and enhances collaboration and communication. Industry move towards higher BIM maturity levels has encouraged AEC educators to invest in and develop required platforms and pedagogical methods to accommodate BIM in their curriculums (Kumar and Mukherjee 2009). Predominant research within the learning and teaching literature has explored benefits of BIM for students and graduates (Martín-Gutiérrez *et al.* 2011).

BIM, however, has been criticized as a pure virtual reality platform that does not provide a sound understanding of real-world issues around field operations. Although beneficial in learning design tasks and simulations, BIM offers limited support in learning the execution and management of engineering and construction processes (Succar *et al.* 2013). This is due to the

fact that in utilizing BIM, students' sensory receptors do not interact with real objects/issues in projects. BIM platforms such as Revit and Catia are yet to transfer a real sense of physical objects and engineering issues to students and graduates (Cubillo *et al.* 2015).

The aforementioned problem can be addressed by better visualizing BIM via other techniques such as augmented reality (Ma and Choi 2007). This research investigates the strengths and challenges around utilizing AR-powered BIM as an innovative platform in the AEC pedagogy. After reviewing the advantages and disadvantages of using full-fledged BIM models in the AEC education, benefits of utilizing AR in this area are explained. Finally, the idea of AR-powered BIM in the AEC education is explored and directions for future research are suggested.

2 BUILDING INFORMATION MODELING IN THE AEC EDUCATION

Building Information Modeling (BIM) represents functional and physical characteristics of facilities and enhances collaboration and communication amongst stakeholders. BIM or building ICT is an important part of curriculum in the AEC education and frequently used as a platform in delivering courses (Ahn *et al.* 2013). BIM has the potential to optimize collaboration and communication amongst current students who will be future architects, engineers, and construction managers. This will minimize the current fragmentation within the AEC industry (Arashpour and Arashpour 2015).

The implementation of BIM in the AEC education has not been homogenous over the past years. Architecture programs have been leading the use of BIM followed by engineering and construction programs (Bourque *et al.* 2003). Similar to their respective industries, architecture and construction educations have been two ends of a spectrum in adopting BIM (Construction 2011). New developments such as 5D and nD BIM have been initiated by architecture companies and researchers while the construction industry has been cautious to adopt BIM technologies (Arashpour *et al.* 2015a).

The cost-effectiveness and overall performance of BIM in the AEC education have been controversial issues. Architecture-oriented BIM focuses on incorporating as much detail as possible to represent geometry and location of each and every building element. Understandably, containing this much detail will result in large costs attached to BIM modeling (Macdonald 2012). Construction-oriented BIM, however, focuses on general aspects of operations and overall management of workflow. While this approach creates more user-friendly models with a cheaper cost, the amount of accessible information is significantly less than architecture-oriented BIM models (Arashpour *et al*. 2012).

Table 1. Advantages and disadvantages on adopting BIM in the AEC education.

	Advantages	**Disadvantages**
BIM-oriented curriculum	Students can easily access detail characteristics of facilities	Models are time consuming and expensive to make
	Students are familiarized with design and simulation tasks	Models does not transfer real sense of physical project issues
	Students can retrieve information from different parts of BIM models	Heavy models with large quantities of data
	Students can view the results of changing building elements	Errors in exchanging data between different software platforms

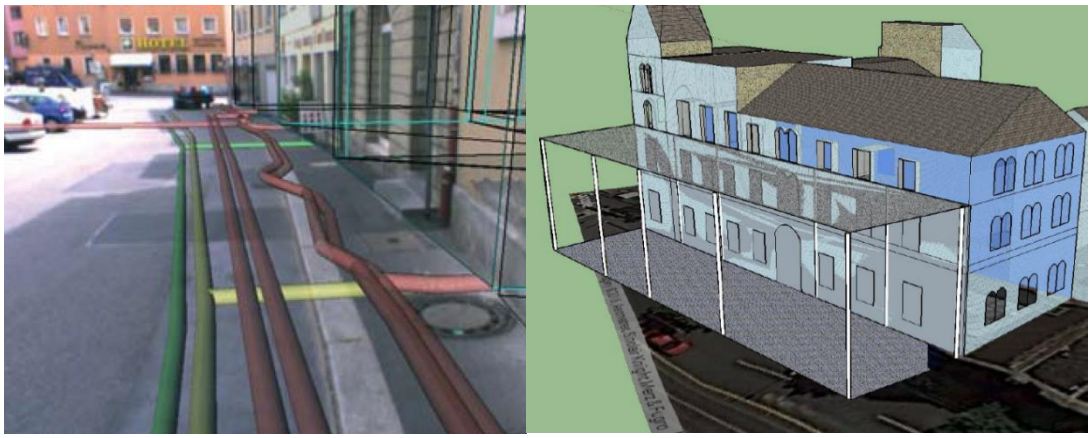
A second source of controversy in adopting BIM as a platform in the AEC education is its capacity to prepare graduates to undertake real-world project tasks (Sacks and Pikas 2013). While BIM models are ideal educational tools for design and simulation tasks, full-fledged BIM

models are purely virtual and students' sensory receptors do not interact with real objects/issues in the project (Arashpour and Wakefield 2015). Although BIM platforms such as Revit and Catia are effective in creating virtual reality models, they cannot transfer a real sense of physical objects and engineering issues to students and graduates (Xiang *et al.* 2016). Table 1 summarizes advantages and disadvantages of incorporation BIM into AEC curriculums.

3 EMERGENCE OF AUGMENTED REALITY (IN EDUCATION)

The main focus in the contemporary AEC education has been on virtual reality using a variety of applications such as CAD engineering, educational games, and virtual training (Sottilare *et al.* 2012). Over the past years, however, mediated or augmented reality has added a new dimension to the AEC pedagogy. AR is blending physical elements of real-world environments with virtual elements generated by computers (Arashpour *et al.* 2016a). By creating a mixed 3D space, AR reinforces awareness of students' sensory receptors of real-world data and supplementary information such as GPS data. AR-based education has not been exclusive to the AEC sector and other fields have also benefited from AR (Fotouhi-Ghazvini *et al.* 2009). For example, medical students overlay results pf physical examinations on digitally manipulated images such as CT scans to optimize disease diagnosis and patient management. In another example, students of media and communication use real-world scenes as the background to computer games and applications.

AR-based education has many applications in architecture, engineering and construction. For instance, students can witness excavation safety improvements in underground utility projects using AR, see Figure 1(a). Supplementary georeferenced data maximizes the precision of operations and minimizes the risk of striking existing subsurface utilities (Dong 2012). In a second example, approval of an arbitrary client can be obtained by students about architectural and/or structural extensions to existing buildings. As Figure 1(b) illustrates, addition of a large canopy is proposed to the client in order to improve the thermal insulation of the western face of an existing building.



(a) Improving excavation safety. (b) Addition of a sunshade to the existing building.

Figure 1. Examples for AR applications in the AEC education.

4 VISUALIZING BIM VIA AR

AR-powered BIM is a new trend in the AEC education that has already made pedagogical changes to tertiary education methods (Arashpour *et al.* 2016b). In contrast to pure BIM,

students' sensory receptors are not isolated from real-world information and objects. Visualizing BIM via AR provides a more realistic sense of materials, project issues and decision making processes to AEC students and graduates (Martin-Gutierrez *et al*. 2011). This is perfectly in line with Bloom's taxonomy of the cognitive domain and supports learning, teaching and assessing. AR-powered BIM can cater for all learning steps of remembering, understanding, applying, analyzing, evaluation and creating (Arashpour *et al*. 2014a). As an example, nD CAD can be visualized via AR using time-based animations with the aim of applying the information generated by BIM to on-site operations. This is an important development in complex projects where both off-site and on-site operations are concurrently in progress. AEC students can utilize AR-powered BIM as a robust tool that improves collaboration and communication in different project phases from architectural design to manufacturing prefabricated building elements to on-site construction operations (Martín-Gutiérrez *et al.* 2010).

Visualizing BIM via AR enhances the functionality of BIM for AEC students and graduates by making BIM relevant to each and every field operation (Wang *et al.* 2012) and (Arashpour *et al.* 2014b). Extension of BIM to on-site operations on top of design phase is an important step towards the 4th Level of BIM maturity in which an integrated BIM provides optimum outcomes. This is a departure from current fragmentation in the AEC industry because of utilizing architecture-oriented, engineering-oriented and construction-oriented BIM models. AR-powered BIM empowers current students and future graduated to better orchestrate design and field operations over the project lifecycle and improve tangible performance measures (Dossick and Neff 2009).

Utilizing BIM+AR in the AEC education has a number of important challenges, though. Models usually contain large quantities of data and even small educational models are difficult to upload and handle on current learning management systems such as Blackboard and Moodle (Woodward and Hakkarainen 2011) and (Arashpour *et al.* 2015b). The second important challenge is aligning virtual and real entities (registration) in educational AEC projects (Williams *et al.* 2014). Thirdly, sophisticated visualization techniques need to be used in order to blur the line between virtual and real entities (occlusion) so that students achieve a real sense of field operations (Redondo *et al.* 2012) and (Arashpour *et al.* 2016c). Finally, educators should have context awareness in using AR-powered BIM in AEC curriculums and have a sustained strategy to decide what BIM data to be accessed and visualized where (Vähä *et al.* 2013). This insures proper reinforcement of knowledge in modules where BIM+AR is used and avoid repetition and/or student burnout.

5 CONCLUSION

Predominant learning and teaching research in the AEC domain introduces BIM as a beneficial tool that familiarizes students with time and cost saving opportunities over design, construction and operation phases (Kiviniemi *et al.* 2011). However, actual performance and cost-effectiveness of adopting BIM in the AEC education has been criticized by educators (Meadati *et al.* 2010). Furthermore, the capacity of BIM as an educational platform to prepare graduates to undertake real-world project tasks has been controversial (Khanzode *et al.* 2008). This paper, proposes AR-powered BIM as a robust platform that can address the aforementioned issues in the AEC education.

Visualizing BIM via AR enhances the functionality of BIM for AEC students and graduates by making BIM relevant to each and every field operation. This is consistent with Bloom's taxonomy of learning objectives and supports hierarchy of knowledge transfer to students. However, adaptation of BIM+AR as a component of AEC pedagogy has its own challenges.

These are related to large quantities of data, creating a constant registration, real-time occlusion handling, and context awareness (Behzadan and Kamat 2007).

This work contributes to the body of knowledge in the field of AEC education by investigating the benefits and challenges of adopting AR-powered BIM as an innovative platform for learning and teaching. "Future research should address the challenges and pave the way for wide implementation of this robust platform in the AEC education."

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