Immersive Virtual Reality Environment for Construction Detailing Education Using Building Information Modeling (BIM)

Maha ElGewely and Wafaa Nadim

Abstract Construction site visits are real-life practical experience where the AEC students' conceptual knowledge is developed and serves as an extension of in-class learning tools. Nevertheless, very low rates of construction site visits have been reported worldwide due to certain limitations, such as the limited visit time, the lack of visit objective, potential hazards, etc. In addition, site activities may also meet specific class needs. During a construction site visit, students mainly learn through their own observation, not by involvement in the site work or having the possibility to take decisions. Besides, students have only the chance to attend one phase of construction. Virtual reality (VR)—as a game-friendly, interactive, and immersive technology—may facilitate virtual construction site visits to meet learning needs and provide the learner with a near-real experiential learning environment where he/she can "learn by doing" in a zero-risk environment. In this essence, this paper describes "VRConDet" project which builds on the VR technology as a medium and Building Information Modeling (BIM) as a source of technical information taking into consideration adults' active learning and gamification of learning materials. "VRConDet" is a computer-assisted learning (CAL) conceptual framework for construction detailing that aims at enhancing the learning experience and learning outcomes for construction education within architecture curricula. This paper focuses on "VRConDet" system architecture and the design of its diverse, scalable, and adaptive modules according to the correspondent complexity and intended learning outcomes of construction education. The results of this first phase feed into a second phase of VR environment development and the validation thereof.

Keywords Building construction education · Building information modeling (BIM) · Computer assisted learning (CAL) · Virtual construction site · Virtual reality

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1 Introduction

If not supported by practical experience, construction-related education is arguably limited. Real-world experience cannot be conducted through traditional lectures and teacher-centered way of education. Construction site visits help students to relate what they study in books to real-life situations (Eiris Pereira and Gheisari 2017). Construction site experiential learning's benefits have been highlighted by a number of researchers (Aliu and Aigbavboa 2019; Irizarry et al. 2012), such as enhancing students' understanding of real construction practices, improving students' knowledge of industry expectations, and addressing different learning styles for students, especially that a construction site visit is mainly considered an auditory and visual learning environment, which may arguably result in a better understanding of course material and consequently qualified future workforce.

1.1 Challenges of Construction Site Visits

Despite the benefits with which construction site visits support the construction education and learning experience, low rates of such visits are reported in extant literature. Many challenges prevent such visits from taking place on a regular basis during an academic semester. Based on a survey conducted on a number of construction programs in USA universities, graduates have had zero or one to two site visits for each construction core subject areas taught throughout their careers (Eiris Pereira and Gheisari 2017). Inclusion of site visits within a course schedule is not always feasible due to varying reasons, such as unavailability of construction sites meeting the intended learning outcomes (Haque et al. 2005), time conflicts with other classes, large class sizes, and safety issues. In addition, other aspects limit the benefits of construction site visits; for example, during a site visit, students are able to see one set of activities on a particular type of project (e.g., high-rise building). This does not allow students to see how the activities fit together in the dynamic nature of the construction process; therefore, they are able to learn from observation, but not from experimenting and active participation (Messner and Horman 2003). Furthermore, a lack of clear objectives for site visits can also lower the benefit for students (Eiris Pereira and Gheisari 2017). In this respect, the need for supplementary methods for experiential learning is needed to make site visits both more often and more beneficial.

2 Virtual Construction Site

Advancements in information technology have allowed innovative ideas to bring construction site to the classrooms to bridge the gap between AEC—Architecture, Engineering and Construction—industry and academia. One of the most significant applications is virtual construction sites. Virtual site visit is introduced from different points of view in multiple studies as semi- to all-immersive virtual experience of construction projects that might be accessible anytime, anywhere by construction students employing some sort of photo/video-graphic medium as a teaching aid to either observe the construction project or interact with construction professionals (Eiris Pereira and Gheisari 2017). Virtual site visits may include tours by PowerPoint, time-lapse videos of large construction projects, and video conferencing between class and jobsite (Eiris Pereira and Gheisari 2017). With the help of cellular Internet service, a hand-held computer, and standard digital video camera, students are engaged in “Virtual Project Tours”; and are allowed to view and hear real-time construction activity being completed at remote project locations without leaving the classroom (Becker et al. 2011). “Virtual Supervision” is another research-based project that has been developed at the University of Calgary which is a web-based enabled view and recording cameras that include remote-controlled functionality, such as directional movement and close views for specific construction operations (Becker et al. 2011). Furthermore, adaptive e-tutorials were introduced by Kamardeen (2014) as a time- and place-flexible learning system in construction education following active engagement and interaction aspects to promote deep learning. These innovative ideas adopted technology in various ways to overcome the challenges and risks of typical construction site visits which may not be possible due to safety concerns or other project-related constraints. Neverthelees, these innovative approachesrequire cooperation and flexibility between industry and academia. Furthermore, these unconventional ways of learning have other social and technical challenges that might limit their application as a main stream; for example, reforming the lecturer’s pedagogical input in digital, adaptive, and stand-alone media is time- and effort-consuming relatively to the traditional approach of teaching. In addition, unfamiliarity with new computer-assisted learning (CAL) systems may need more time and effort from both teachers and students in order to get used to the new technology and is also challenging to achieve with large numbers of students (Kamardeen 2014).

3 Building Information Modeling

BIM holds different meanings to different people. From a technical point of view, BIM represents sophisticated software that enables technical industry standard. On a deeper level, it describes a philosophical framework that offers a paradigm shift within the construction sector (Khosrowshahi 2017). Isikdag (2015) defined BIM, from a process perspective, as a facility that enables information management throughout the lifecycle of a building, while building information model is the (set of) semantically rich shared 3D digital building model(s) that form(s) the backbone of the process itself. There exist worldwide trials to integrate BIM in AEC curricula as part of preparing students for the workforce through educating BIM approach

(Ghosh et al. 2013; Sacks and Pikas 2013). BIM visualized models and associated property databases provide an enhanced platform for teaching and training (Clevenger et al. 2012). It is confirmed that BIM, as a learning and teaching tool, has the potential to assist construction education as it can make information available in a manner that is much more accessible to visual learners (the majority of learners). In addition, BIM's 4D capabilities enable students to better understand the assembly process through the production of assembly animations (Boon and Prigg 2011; Le et al. 2015; Gledson and Dawson 2017; Irizarry et al. 2012).

In light of the above, BIM can be used as a teaching/learning tool targeting a wide spectrum of topics and courses as it provides the faculty with an interactive tool and information repository to facilitate teaching of engineering and construction concepts in a more visual and interactive manner, extending along the way the learning environment beyond the classroom boundaries; thus, having the potential to considerably enhance the educational experience of students (Irizarry et al. 2012).

As a user-friendly, interactive repository of information, BIM has been integrated with other technologies such as virtual reality and augmented reality in different forms (Horne and Thompson 2008; Vassigh et al. 2018; Gheisari et al. 2016; Gledson and Dawson 2017).

4 Virtual Reality

According to Collins Dictionary (2014), virtual reality is "a computer-generated environment that, to the person experiencing it, closely resembles reality." From a technical point of view, virtual reality represents an advanced Human—Computer Interaction (HCI) and interface tool. VR environments provide an immersive experience in which participants wear tracked glasses to view stereoscopic images and listen to 3D sounds, while being free to explore and interact with a 3D world (Chan 1997). It has been proven that VR became an area of increasing research and development activities in architecture and construction (Leinonen et al. 2003). The research areas may include e.g. design methods, architectural theory and history, performance evaluation, human interaction, representation, process and management, etc. (Freitas and Ruschel 2013). The majority of studies primarily emphasize means to apply VR and AR, with a focus on how to use them for visualization as well as how to use them in practice; this is followed by the use of VR and AR in education. Virtual-reality and mixed-reality concepts are now being introduced into gamification, game enhanced learning, and pure education (Shavinina 2013). Publications in the field of virtual reality in education have been exponentially increasing over the past 20 years (Liu et al. 2017). According to Lui et al. (2017), 160 worldwide peer-reviewed papers were published in 2016 on virtual reality in education. Scientific research has proved that VR enhances students understanding, allowing them to learn by doing and engaging learners in a learning environment close to reality; thus, stimulating various information perception points (Blazauskas et al. 2017). In this respect, virtual reality arguably opens new ways of learning in the field of education.

5 Computer Assisted Learning

According to Knowles et al. (2012), adults learn best when learning is active, self-directed, based on problems, related to their experience, and perceived as relevant to their needs and they are intrinsically motivated. Integrating BIM and VR may facilitate the principles of computer-assisted learning (CAL) which emphasizes *"learning by doing"*. Traditional CAL resources consisted primarily of tutorials, which were essentially computer-based forms of programmed instruction (PI) or intelligent tutoring system (ITS) that typically contain a sequence of contents broken into sections and questions in between (Dalgarno 2001). In addition, CAL may take a form of gamified learning materials or simulation of real-life situations which focus on the learning experience leading to better understanding and behavioral outcomes, which is the core of the learning process (Hamari et al. 2014).

6 VRConDet

Building on the potentials of integrating BIM and VR, this paper introduces the first phase, the architecture, of a learning environment to enhance construction education. VRConDet is a computer-assisted learning (CAL) conceptual framework for construction detailing that aims to enhance the learning experience and learning outcomes for construction education within architecture curricula. It builds on the VR technology as a medium and Building Information Modeling (BIM) as a source of technical information following aspects of adult's active learning and gamification of learning materials. VRConDet is a head-mounted display (HMD), interactive, virtual-reality construction-detailing environment for educational purposes. It focuses on construction detailing which is considered a continuous thread in almost all vertical curricula of construction education. According to a survey—conducted by the researcher—on one hundred architecture students in different semesters, construction detailing represents the highest challenging topic to students in all construction courses. VRConDet is not proposed to replace the traditional ways of learning Building technology and Building Construction; it is meant to assist as a computer-assisted learning (CAL) tool to overcome limited construction site visits and to offer a contemporary active way of learning to increase student motivation through different complexity levels based on the intended learning outcomes (ILOs).

6.1 Scalability

VRConDet was designed to be a modular expandable system in order to be able to expand vertically to cover advanced BIM dimensions as well as horizontally to broaden the tackled topics.

6.2 Soft System Methodology

The soft system aims to map the main functions of VRConDet in regards to its potential users, in other words, who is able to do what? Besides, it defines the process behind the user interface. Primarily, VRConDet has two types of users: the instructor and the student (Fig. 1). Each has their own interface and controls. The instructor mainly interacts with VRConDet through a desktop interface, whereas students have their own VR environment and another desktop-based interface for rechecking what they have done in the virtual environment. The instructor interface empowers students to determine which approach of construction detailing classifications is the most appropriate for the session's objective. The system supports classifications based on materiality, function, or building element. The instructor can also define the course and level of complexity, according to which the VR system adapts by filtering the information displayed and the complexity level of problems which the student is required to solve. The instructor has control over what is displayed to the students through a desktop interface, which also facilitates feedback and assessment. The instructor can also add any BIM model (exported as .fbx) and its correspondent information in a form of ".csv" schedules either exported from a BIM platform or prepared by the instructor him/herself. The system attaches scheduled information to its correspondent object by its unique ID using a dynamic parsing code. Besides, the system is able to request numeric data from online calculators or offline documents such as environmental data, fire rating, or any other relevant numeric input. For the other type of users, the student has a customized portal where he/she enters their

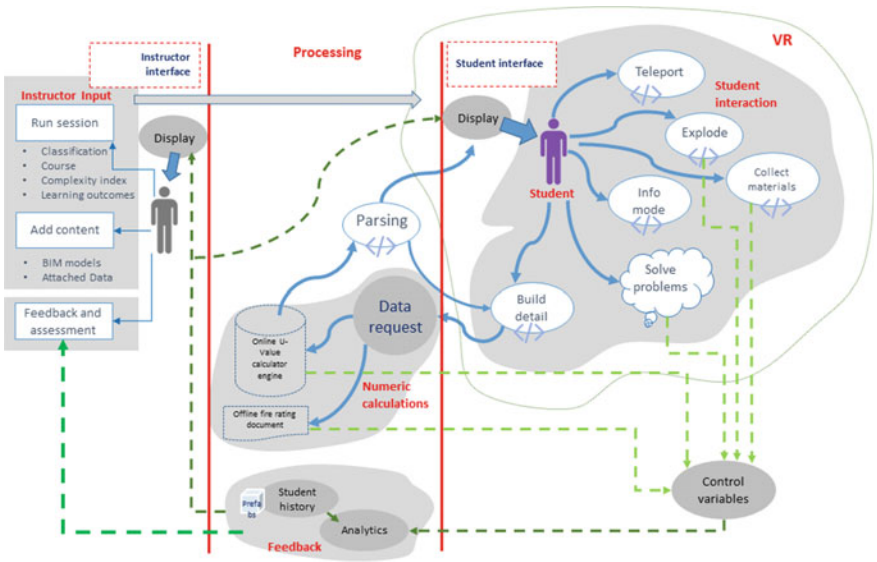

Fig. 1 Soft system methodology

name and ID as a player. This will help later in generating the analytics and in giving feedback to both the instructor and student with his/her earlier plays and results to point out the progress.

With regards to students interface, a student is able to teleport or move to explore space, select objects to get information, collect different building materials, solve problems, and explode and build construction details. There are also hidden control variables which direct the gameplay and lead upgrading from a module/game level to another, in order to ensure knowledge transfer to the student. Furthermore, there exist control variables containing number of collected building materials, exploded details, solved problems, etc.

Through the instructor's portal/interface, he/she has access to the history of the gameplay of each and every student. The system provides analytical feedback to the instructor (e.g. achievement percentage, achievement time, how many problems have been solved, number of wrong trials, etc.). In addition, the system automatically archives the student gameplay history for a later accessibility.

6.3 Curricular Unit

The above scenario is supported by a curricular unit, which is a three-level environment that follows four methods out of five construction detailing self-study and in-class exercise methods (Allen and Rand 2016) which include the following: analyze and modify existing details, design variations of existing detail, design from scratch, and use the patterns (see Fig. 2). VRConDet three-module curricular unit adapts to several construction detail approaches and different complexity levels.

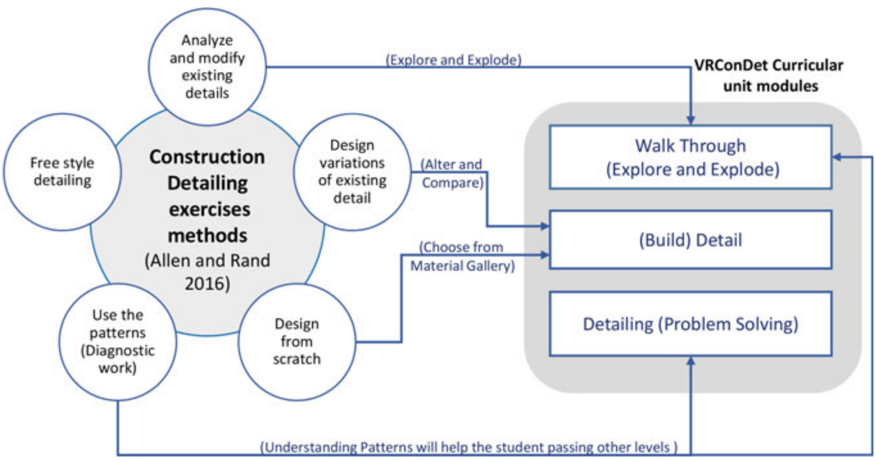

Fig. 2 Curricular-unit modules to their corresponding exercise method(s)

6.3.1 Module 01: Walkthrough (Explode and Explore)

The student walks through a BIM model, enjoying the ability to explore construction materials and products, technical installations, and different connections. Adding to this, he/she should explode few construction connections and explore their components, understand patterns, and get technical information. This helps the student to pass to the next modules. During the journey, the student finds tokens of construction materials or tools that he/she is required to collect and acquire knowledge about in order to use it in a later stage in the problem-solving module.

6.3.2 Module 02: (Build) a Detail

This level allows the student to build a construction detail using different components and construction materials. The detail is determined by the educator input and adapts to the course content. The student should be able to choose the various layers or components of the construction detail and their order relative to each other. The VR system provides feedback on the constructed detail. The feedback appears in the form of overlaid information representing performance as both numeric values such as U-Value (heat transfer indicator) or fire rating and constructability deficiencies extracted from BIM constraint and conflict detection.

6.3.3 Module 03: Detailing (Problem Solving)

In the problem-solving level, the user meets multiple technical problems building a construction detail. The clues to solve those problems have been reviewed through the previous two modules. The solution might need an extra component or a certain tool to be achieved. In this case, the user employs the material objects or tools he/she has collected previously during the walkthrough module. Once the student solves a problem, another with higher complexity appears. This happens recursively until a certain number of construction details are resolved. Figure 3 shows a flowchart of the user scenario moving from one module to another.

6.4 Main Considerations

During implementation of curricular-unit prototypes, many aspects related to BIM, VR technology, learning styles, and game mechanics should be considered, such as:

- Edutainment: the balance between game-like environment and the learning atmosphere is intended to avoid putting the student under the stress of game challenges that may block his/her willingness to read or try out.

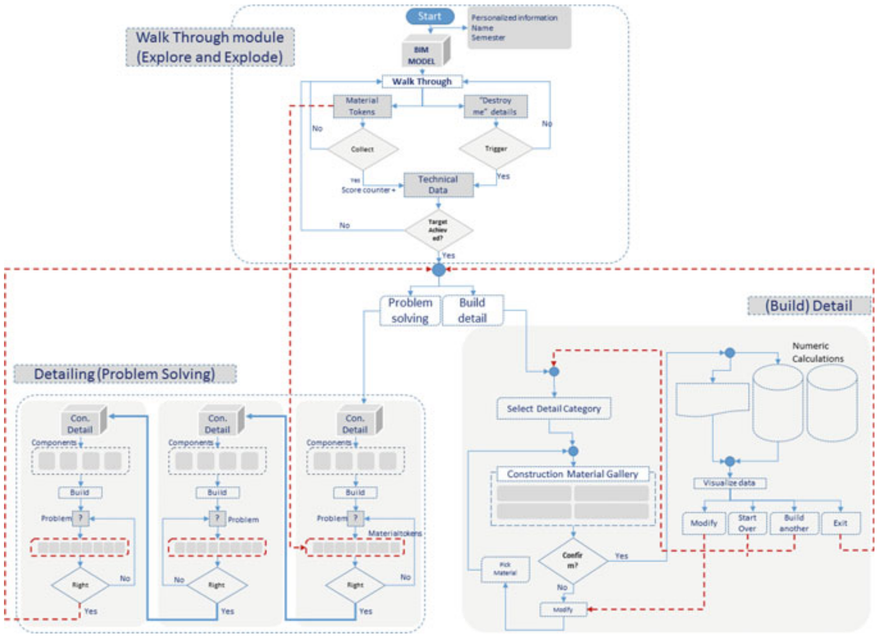

Fig. 3 VRConDet user scenario

- Avoid repetitive challenges to keep the student alert and always thinking about his/her cognitive input to avoid any mechanical actions.
- Consider virtual reality constraints and potentials trying to overcome constraints (such as field of view (FOV), teleportation, and VR sickness).
- Environment, interaction, UI, and objects physical behavior are not forced to look real. For example, environment can sometimes disappear to focus on certain function detached from its context. However, user interaction is meant to be intuitive and consistent in all modules.

7 Limitations

VRConDet as a main stream in construction education has a few challenges: for example, preparing teaching materials with a different approach following BIM is time-consuming. Besides, due to hardware limitation, VR headset is single-player equipment, this does not support multiuser decisions which may enhance the learning experience. Furthermore, and as long as it is new to construction educators to integrate such technology, proper training should be provided to them.

As long as BIM has a huge volume of data behind the scene, mobile-based VR—with a limited data storage capacity—is not suitable to run such an application unless a reduced version is developed. As mentioned earlier in this paper, VRConDet, as computer-assisted learning (CAL) tool, is not supposed to replace the traditional teaching; it is mainly concerned with supporting and enhancing the learning experience and filling the gap between academia and industry.

8 Conclusions

Building construction education requires the agreement between academia and industry to allow students to learn from real projects' BIM database documentation. This would be a huge source of information which enriches both the learning process and the outcome. According to literature, virtual reality is an effective and motivating educational medium that enhances the students learning experience and learning outcomes in various disciplines. BIM-integrated virtual construction site, as a concept, is expected to be widely applied in the very near future to be a main stream in AEC education, as well as in industry as a decision support system for project and construction management. In this respect, integrated virtual construction site bridges the gap between industry and academia by facilitating more experiential learning and bringing real construction projects to the classroom. Adopting a new technology naturally implies adapted ways of teaching and course materials. This will require strong agreement between academia and industry to employ real projects' documentation in the educational process. In this essence, endeavors of capacity building on the scale of universities and architecture and construction firms are expected to be increased fostering the up-to-date technology.

This research paper introduces the first phase of VRConDet which is a computer-assisted learning (CAL) conceptual framework for construction detailing that aims to enhance the learning experience and learning outcomes for construction education within architecture curricula. VRConDet builds on the VR technology as a medium and Building Information Modeling (BIM) as a source of technical information following aspects of adult's active learning and gamification of learning materials. The paper strictly focuses on VRConDet system architecture and module design that will feed in the second phase of developing and validating a prototype environment and interface covering a vertical spectrum of learning outcomes of construction courses.

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