The 6th International Conference on Construction Engineering and Project Management (ICCEPM 2015)
Oct. 11 (Sun) ~ 14 (Wed) 2015 • Paradise Hotel Busan • Busan, Korea
www.iccepm2015.org

Visualization Based Building Anatomy Model for Construction Safety Education

Hai Chien Pham[1], Quang Tuan Le[2], Akeem Pedro[3] and Chan Sik Park[4]*

Abstract: Safety education at the tertiary level prepares students to enter construction industry with adequate safety knowledge; then accidents can be prevented proactively. However, safety subject has not been paid adequate attention in universities and most institutional safety programs consider safety matters in isolation. Meanwhile, anatomical theory in the medicine field has been successfully adopted and proved potential advantageous in various scientific disciplines. With this regard, this study proposes a visualization based Building Anatomy Model (BAM) for construction safety education, which utilizes the anatomical theory in order to improve student's safety knowledge and practical skill. This BAM consists of two modules: 1) Knowledge Acquisition Module (KAM) aims to deliver safety knowledge to students through building anatomy models; 2) Practical Experience Module (PEM) where students safely perform construction activities by using the system to improve safety skill. The system trial is validated with virtual scenarios derived from real accidents cases. This study emphasizes the visualization based building anatomy model would be a powerful pedagogical method to provide effectively safety knowledge and practical skill for students, as a result, safety competence of students would be enhanced.

Keywords: Visualization, Building anatomy model, construction safety education

I. INTRODUCTION

Construction is one of the most dangerous industries where accidents occur repeatedly causing many problems related to cost overruns and time delays. Human errors cause more than half of workplace accidents in construction industry [1]. Moreover, Garrett et.al. (2009) pointed out that human error has been considered as a key factor for up to 80% of occupational accidents [2]. As such, safety education has become more important nowadays. However, attention has not been paid to safety subjects in universities and most institutional safety programs consider safety matters in isolation or do not effectively represent the dynamic sequence of safety procedures [3]. Consequently, students enter construction sites with insufficient safety knowledge an often perform unsafe actions. Furthermore, an important limitation of safety education is lack of the student's engagement and motivation because it takes place in hands-off off-site environment. Therefore, it is necessary to improve construction safety education.

Visualization technologies such as Building Information Modeling (BIM) and Virtual Reality (VR) have been applied and proven beneficial in various disciplines. Despite prominent advantages, the use of VR/BIM in construction safety education is limited [3]. Universities currently lack strategies and capabilities to effectively incorporate BIM into existing or future curricula. Moreover, current BIM applications for safety education have focused on technical-push instead of considering educational contents and delivering necessary knowledge to learners. Thus, there is a real need to develop an effective safety pedagogical tool to enhance safety education.

A key obstacle in safety education for engineering students, who lack practical knowledge, is due to the complex construction works. Similarly, the medical discipline also faced this issue several decades ago. Meanwhile, anatomy involving in the dissection and prosection of cadavers can facilitate medical students with experiential learning [4]. As stated by Winkelmann, medical pedagogy effectively delivers knowledge of human anatomy to students through cadaver dissection [5]. The nature of cadaver dissection and prosection engages and motivates students, providing great benefits for anatomy education. Furthermore, the similarity between the human body and construction building [6] and successful adoption of anatomical theory in various scientific disciplines proved potential advantages of providing concrete experience to construction students. As such, the application of anatomy theory is considered as a powerful pedagogical method to provide concrete knowledge and practical skill (e.g. hazard identification, situation awareness, etc.) for students in construction safety education at tertiary level.

In response to this need, this paper proposes the visualization based building anatomy model (BAM) for construction safety education. The BAM utilizes state-of-the-art of anatomy concept and visualization technology to improve student's safety knowledge and practical skill through interactive and experiential learning. The scope of this paper focuses on students in construction safety education at tertiary level. This BAM consists of two modules: Knowledge Acquisition Module (KAM) in which safety information is disseminated by professor through safety lesson and 3D anatomy models and Practical Experience Module (PEM) where students would

[1] Ph.D. Candidate, Department of Architectural Engineering, Chung-Ang University, Seoul, Korea, e-mail address: phamhaichien@gmail.com
[2] Ph.D. Candidate, Department of Architectural Engineering, Chung-Ang University, Seoul, Korea, e-mail address: lequangtuan2009@gmail.com
[3] Ph.D. Candidate, Department of Architectural Engineering, Chung-Ang University, Seoul, Korea, e-mail address: lanrepedro3@gmail.com
[4] Professor, Department of Architectural Engineering, Chung-Ang University, Seoul, Korea, e-mail address: cpark@cau.ac.kr (*Corresponding Author)

experience as a safety manager to inspect construction hazards and assemble temporary structures or safety facilities to eliminate these hazards. The BAM trial is developed and validated with virtual scenarios derived from real accident cases. The results reveal that the virtualization based building anatomy model would be a powerful pedagogical method to provide effectively safety knowledge and practical skill for students; as a result, safety competence of students is enhanced.

II. Literature Review

2.1 Safety issues in the construction education

Construction safety education at the tertiary level plays a crucial role in improving construction safety at jobsite. This is because safety education prepares students to enter construction industry with adequate safety knowledge; then accidents can be prevented proactively. Furthermore, Tam et al. proved that poor safety awareness of top management and project managers are key factors affecting safety performance [7]. Thus, it would be worthy to recognise that a good construction safety education at tertiary level is a solid foundation to enhance the safety awareness of managers afterwards.

However, current construction safety education is usually a low priority [8]. Moreover, few universities establish the construction management program including safety education in their curricula [9]. In other words, it is the fact that safety subject has not been paid attention in universities.

A further limitation of safety education is lack of student engagement and motivation because the safety training and education takes place in hands-off off-site environment. Learners have inactively listened and watched what the lectures educate without any interaction. Consequently, students feel bored, restless, disruptive and disengaged, and then they have impacted negatively on colleagues, lecturers, and schools [10]. As a result, graduates enter the construction industry with insufficient safety knowledge.

As discussed above, there is an imperative need to develop an efficient and effective method for improving current construction safety education. The following section discusses about how to apply an approach that has been successful in medical education for hundreds of years [11] in terms of construction safety education.

2.2 Anatomy in construction education

Anatomy in medical science, which involves a similar pedagogical objective, has effectively dealt with related issues but through different approaches. Medical schools deliver essential knowledge to learners not only through lectures, but also through real experiences with virtual cadaver dissection. Through interactive and experiential learning based VR cadaver dissection, medical pedagogy effectively delivers knowledge of the human anatomy to students. And, the medical area itself has developed a successful anatomy learning theory for decades.

Barbara (2010) stated that there are the close resemblances between the human body and the construction building [6]. For example, the skeletal system of the human body resembles the structural frame of building in order to keep them straight and upright. The circulation system in the human body, which is responsible for circulating blood and nutrients, is similar to the plumbing and mechanical system in the building for transporting water, waste, heat and air conditioning. As such, due to this similarity, the anatomy concept is considered as a new way to improve construction safety. The following section reviews the current visualization technologies in safety education in order to emphasize the need to integrate the anatomy concept with Virtual Reality for our industry.

2.3 Visualization in construction safety education

Visualization has benefited the education area thanks to the effective interaction, motivation and engagement afforded between teachers and students. At least to some extent, BIM and VR are remarkable visualization technologies nowadays. VR which emerged several decades ago is a technology that allows users to explore 3D interactive environments in real time [12]. From this perspective, the features of BIM and VR are capable of providing students engaging, self-motivating and immersive contents, which would induce experiential learning [13]. However, barely any research has adopted VR as learning tools to support tertiary construction safety education. Furthermore, existing VR systems in construction education have been of a 'VR or BIM technical push' nature without considering teaching strategies in offering concrete experience and supporting sufficient safety knowledge. Hence, incorporating VR with a good education strategy such the anatomy concept can be a worthy solution for construction safety.

2.4 Need for visualization based building anatomy model

Construction safety education provides a vital opportunity for students to obtain their knowledge and to improve their core competencies. However, as construction projects become increasingly complex, the traditional teaching methods are no longer advantageous to students [13]. Moreover, current safety education lacks motivation and engagement of student during the lessons. Previous research indicates that even though VR has been used and found beneficial in many education areas, there are few VR applications in construction safety education and most of them have focused on technology aspects, not on the teaching strategy. Therefore, this study addresses this shortcoming by proposing a visualization based building anatomy model which integrates the anatomy concept with VR for experiential construction safety education. It is ascertained the powerful tool to reform current pedagogic modality because: (1) anatomy would help students easily understand many complex construction structures; (2) the visualization technologies can potentially play a key role in overcoming current educational barriers (e.g. motivation, engagement, etc.) to achieve effective learning outcomes

III. Building Anatomy Model for Construction Safety

The aim of the visualization based Building Anatomy Model (BAM) is to enhance safety knowledge retention and practical skill (e.g. hazard identification, situation awareness) of students through experiential learning. BAM enables interaction with 3D models and concurrent access to multimedia resources including text, images, animations, video, and sound.

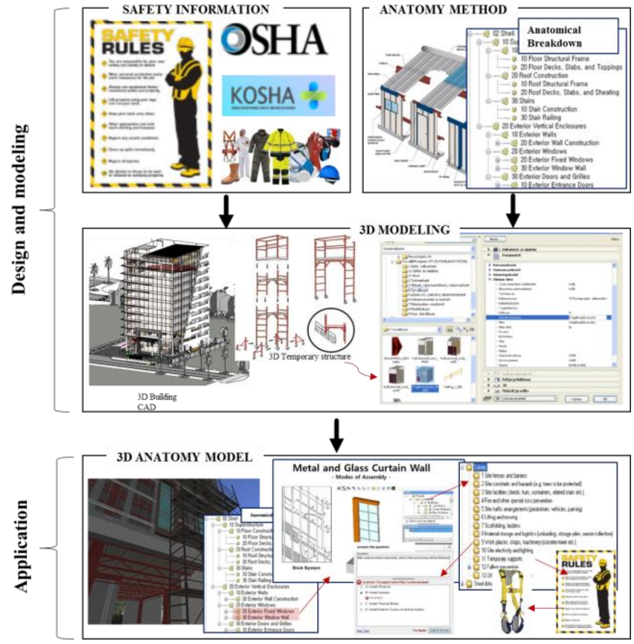

Fig. 1. Visualization based BAM development

As illustrated in Fig 1, there are two key phases in creating BAM. In a design and modelling phase, 3D models of building are simulated based on Computer-Aid Drawing (CAD) engine (e.g. Revit Architecture, AutoCAD, etc.) in order to create virtual construction sites for learning. Moreover, simulation of 3D temporary structures and safety facilities is designed to assist learners to eliminate potential hazards when interacting with virtual construction environment. All 3D models are classified based on anatomical breakdown for the safety educational purpose. After that, safety information such as safety standards, rules, instructions of PPEs and other safety multimedia resources (e.g. text-based lecture, images, videos, sounds, etc.) are integrated with 3D models in application phase to develop BAM for safety educational purpose.

After developing BAM, the learning-teaching process would be implemented consisting of Knowledge Acquisition Module (KAM) and Practical Experience Module (PEM), as shown in Fig. 2. The purpose of KAM is to enhance safety knowledge retention, while PEM is designed for learners to improve their practical skill in virtual environment and then to enhance safety competence of learners. The functions of each module are detailed in the following sections.

3.1 Knowledge acquisition module

Firstly, the professor introduces a safety lesson and relevant practical accidents to students through BAM. In this introduction, professor also points out hazard precursor and pathogen, accident sequence, especially emphasises causes and prevention methods in order to help students clearly understand safety matters in practice.

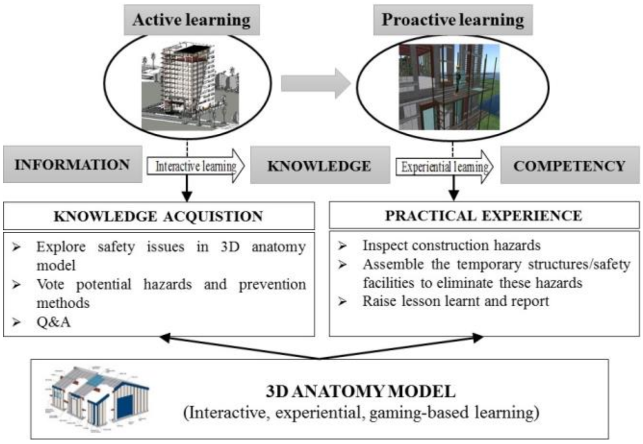

Fig. 2 Framework for Building anatomy system

Secondly, the professor instructs students on how to explore and access safety information in BAM. Professor then assigns an accident case in a virtual building to students for analysing safety issues. After that, by using their own account in the system, students are required to identify accident case information including accident type, location, and other specific data related to accident such as work phase, hazard type. Through the system, students can raise their opinions and then vote for potential hazards. In order to clearly understand the accident case and proactively prevent construction accident in practice, students then analyse prevention methods. Moreover, during discussion and analysis, students simultaneously answer questions related to accidents in order to assure learners thoroughly understand the lesson. All information about student's performance as well as professor's conclusion is stored in system for evaluating student's knowledge acquisition.

3.2 Practical Experience Module

Initially, students are required to anatomize virtual building in order to inspect construction hazards by using designed tools in the BAM. In particular, students need to decide what prevention methods would be applied and select appropriate safety facilities (e.g. PPEs, fence, safety net, cover, etc.) from a library of the system to eliminate these hazards. Depending on a detailed level of safety facilities designed in BAM development, learners in some cases have to use an assemble/dissemble tool to attach/detach some safety components into a completed safety facility before putting them in the right place in

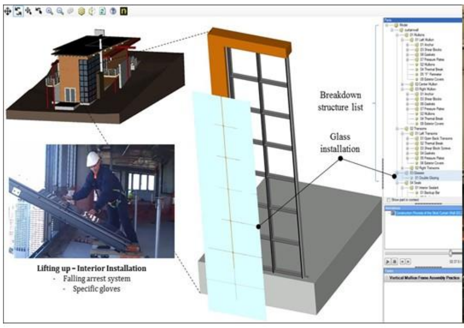

Fig. 3a Knowledge Acquisition

Fig. 3b Practical Experience

Fig. 3c Test-Performance Evaluation

BAM to avoid accidents. Finally, students report lesson learnt from anatomy of virtual building for their examination. Based on system, students submit results of anatomy of virtual building for examination to professor. Thereafter, professor evaluates student' examination and corrects mistakes.

By interacting with virtual building in KAM, safety knowledge retention of students would be enhanced due to their motivation engagement. Moreover, practical experience in PEM is necessary to improve student's skill as a safety manager in real construction site.

IV. CASE STUDY AND EVALUATION

The anatomy prototype derived from real hazards and accidents during curtain wall installation was developed in order to determine the system advantages and limitations. The MySQL-Sever is in charge of storing anatomy database including safety lessons, visualization models and students' profiles. Revit Architecture 2014 was used to simulate 3D models. These models were imported into Okino PolyTrans 64 and then, converted to NGrain producer environment according to anatomy classification in order to establish the anatomy prototype. Lastly, the prototype was encoded to support educational activities which could enhance learner-instructor-model interaction and create an embedding question and answer game for assessing students' knowledge.

The prototype was implemented and conducted with 31 under-students at the department of architectural engineering, Chung-Ang University, Seoul, South Korea. The students participated in a 3-hour lecture with the support of anatomy system to obtain safety knowledge and practical experience.

Initially, in the KAM module, teachers deliver safety knowledge related to falling, struck-by and electrical shock hazards to students. Following the anatomy concept in the medical field, safety lessons including accident precursors, pathogens, sequences and prevention. These contents are integrated into construction methods of curtain wall installation would be transferred to learners by using 'pro-section', detach, real images and videos embedded in 3D objects, etc. features of the anatomy prototype. As shown in Fig. 3a, the instructor demonstrates the falling accident and prevention method when installing the curtain wall into the frame. Normally, students think that falling accident usually occurs for external installation of the curtain wall (a worker stands on a scaffold outside the building and installs a curtain wall). However, in reality, installing the curtain wall from inside a high-rise building is more dangerous and causes more hazards than exterior process. During the installation process, a worker slowly lifts up the curtain wall with the support of a crane to place it in to the right position. There is no safety barrier cover the work area and hence, any error in falling arrest system or misunderstanding communication between the installation worker and a crane controller would cause an accident. Furthermore, the direct contact between the worker's hands with metal of curtain wall frame could cause the hand injury that requires special gloves during the installation process. Via the anatomy model, teachers would provide specific sequences of installation process and detailed information about each element of the curtain wall as well as hazards according to the installation process in order to help students comprehensively understand root causes of falling accidents and their prevention methods.

After the lecture is delivered by educators, students would themselves manipulate the model to gain safety competency in the PEM (Fig. 3b). They could detach and view the detail information of each element and structure of the curtain wall as well as execute the curtain wall assembly and installation activities. During this process, an alarm would warn the leaners for any dangerous occurrences. The safety information incorporated with the elements would help learners acquire safety knowledge in a proactive way. When they explore the assembly of a curtain wall, there are some elements required the welding task. Electrical shock and injury due welding without goggles would emphasize how dangerous the curtain wall assembly is. In particular, during this step, students had to identify potential hazards and safe-work methods involved in the curtain wall work. For example, for the exterior filling up of the curtain wall, students recognize that the stability of scaffolds is a crucial factor to assert safe-work. As such, checking the stability of scaffolds and falling arrest systems are high priority during external installation. Lastly, students are required to answer questions in the installation practicing process. For instance, when they perform the fixing glass task using sealant, the question is 'which Personal Protective Equipment is necessary when applying sealant to finish a curtain wall'. All manipulation processes and question & answer game were recorded for assessing the students' knowledge retention.

In order to address the model limitations and benefits, subjective and objective evaluations were implemented. Subjective evaluation was conducted by interviewing students on five criteria: 1) Clarity of instructions; 2) Interactive and experiential learning with the anatomy model; 3) Ease of use; 4) Motivation and engagement; and 5) Cognitive skills. These criteria were refined from Le et.al. [13], Witmer & Singer [14], Reis et al., [15], Hanna & Richards [16] and Chertoff [17]. Fig. 4 shows the system effectiveness evaluation results. Leaners stated that the highly engaging process of the system would allow them to formulate their own learning objectives and give them more control over their learning. Participants agreed that the model was simple, intuitive, easy to follow and engaging (clarify of instructions: 4.3/5; ease of use: 4.4/5). They felt very interested, comfortable and active when exploring this model by themselves. In particular, some instructors mentioned that this pedagogical tool has the equilibrium between safety contents and VR technology and more effective in comparison to other BIM based safety education systems that have just focused on technique-push. This model well represents the term 'Visualization based Building Anatomy' by applying Virtual Reality for construction safety following the anatomy education concept. They also commented that the system may even replace traditional classroom based lecture in the future.

For objective evaluation, the measurement of test-performance via T-test is implemented between 2 groups - one group (15 students) was educated by using traditional method, another (16 students) by using anatomy method (Fig. 3c). After 3-hour lecture, 2 groups would answer 16 questions related to safety issues and hazards during the curtain wall installation process. The result showed that the group using anatomy tool has higher score than the group using traditional 2D method. It concludes that the anatomy tool would help students to obtain better academic results than traditional method. However, the prototype was developed with several safety scenarios that were only sufficient for a preliminary assessment. In the future, the full-scale system will be developed and more quantitative and rigorous assessment will be performed.

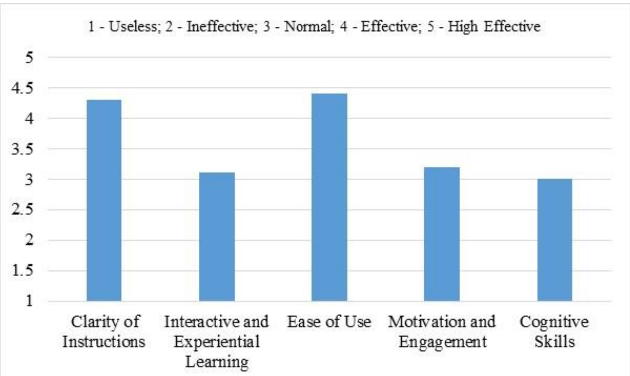

Fig. 4 The evaluation result

II. CONCLUSION

This study presents a visualization based building anatomy model, which integrates virtual reality and anatomy concept to improve construction safety education. A prototype is developed and preliminary results suggest that the proposed model will be effective in enhance students' knowledge retention and learning & teaching process on construction safety issues. For the future work, the anatomy model in conjunction with Augmented Reality (AR) for construction education will be considered.

ACKNOWLEDGEMENT

This research was partially supported by National Research Foundation of Korea (NRF) grant funded by the Korea Government (MEST) (No. 2013R1A1A2062181).

REFERENCES

[1] Zhao, D. and J. Lucas, Virtual reality simulation for construction safety promotion. International Journal of Injury Control and Safety Promotion, 2014. 22(1): p. 57-67.
[2] Garrett, J.W. and J. Teizer, Human Factors Analysis Classification System Relating to Human Error Awareness Taxonomy in Construction Safety. Journal of Construction Engineering and Management-Asce, 2009. 135(8): p. 754-763.
[3] Le, Q.T., A. Pedro, and C.S. Park, A Social Virtual Reality Based Construction Safety Education System for Experiential Learning. Journal of Intelligent & Robotic Systems, 2014: p. 1-20.
[4] Sugand, K., P. Abrahams, and A. Khurana, The anatomy of anatomy: A review for its modernization. Anatomical Sciences Education, 2010. 3(2): p. 83-93.
[5] Winkelmann, A., Anatomical dissection as a teaching method in medical school: a review of the evidence. Medical Education, 2007. 41(1): p. 15-22.
[6] Jackson, B.J., Construction management jumpstart. 2006: John Wiley & Sons.
[7] Tam, C.M., S.X. Zeng, and Z.M. Deng, Identifying elements of poor construction safety management in China. Safety Science, 2004. 42(7): p. 569-586.
[8] Jaeger, M. and D. Adair. Construction safety simulations and students' perception of stress. in SEFI 40th annual conference. 2012. Thessaloniki, Greece.
[9] Rowlinson, S., Construction safety management systems. 1st ed. 2004, London and New York: Spon Press. 179.
[10] Parsons, J. and L. Taylor, Student Engagement: What Do We Know and what Should We Do? 2011: University of Alberta.
[11] Turney, B., Anatomy in a modern medical curriculum. Annals of the Royal College of Surgeons of England, 2007. 89(2): p. 104.
[12] Sampaio, A., Henriques, P., Martins, O. Virtual Reality technology used in civil engineering education, Open Virtual Reality Journal 2 (2010) 18-25.
[13] LE, Q.T., et al., A Framework for Using Mobile Based Virtual Reality and Augmented Reality for Experiential Construction Safety Education. 2015.
[14] B. G. Witmer and M. J. Singer, Measuring presence in virtual environments: A presence questionnaire, Presence: Teleoperators and virtual environments, vol. 7, 1998, pp. 225-240.
[15] R. Reis, P. Escudeio, and B. Fonseca, Assessment model for educational collaborative virtual environments, in Computer Science & Education (ICCSE), 2012 7th International Conference, 2012, pp. 1555-1559.
[16] N. Hanna and D. Richards, "Evaluation framework for 3D collaborative virtual environments (the core)," in The 18th Pacific Asia Conference on Information Systems (PACIS), Chengdu, China, 2014.
[17] Chertoff, D.B., B. Goldiez, and J.J. LaViola. Virtual Experience Test: A virtual environment evaluation questionnaire. in Virtual Reality Conference (VR), 2010 IEEE. 2010.