Virtual Reality and Augmented Reality – A New Approach for Construction Safety Education

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

Abstract: Safety is paramount for construction industry throughout the world. Human errors which contribute to more than half of construction accidents, could be proactively prevented through effective education and training methods. Although Virtual Reality (VR) and Augmented Reality (AR) have gained much attention in various disciplines, few studies applied them for construction safety education. This research presents a new approach in construction safety education by utilizing VR and AR. The vision of aligning teaching & learning strategies is examined in order to ensure the potential benefits of the new method. This innovative approach shifts safety education from "Listen, and I will forget. See, and I may remember" towards "Practice, and I understand".

Keywords: Virtual Reality, Augmented Reality, Construction Safety Education, Experiential & Interactive Learning

I. INTRODUCTION

Human errors cause more than half of workplace accidents in construction industry. During construction activities, people do not consciously think about following safety procedures due to their nature and then pose a hazard to health and safety [1]. In an effort to improve safety performance, education and training are believed to be an effective approach to promote a safe and healthy working environment and making hazards more predictable [2]. Le and Park [3] (2012), emphasized that safety education at the tertiary level is one of the effective ways to enhance graduates' safety awareness. Also, interactive pedagogical programs offer higher level of competency and comprehension for obtaining knowledge, effectively transfer practical experience and enhance learning outcomes [4]. As such, effective education programs could prepare future construction engineers and workers for safety experiences that they both routinely and infrequently encounter on construction sites.

Safety education has existed for many years; however, most up-to-date educational tools in term of paper-based handouts, slide shows and video tapes do not represent construction accident precursors, sequences, causes and prevention methods well enough. These cannot simulate real-life hazards into education contents and in doing so do not allow learners completely understand how dangerous real on-site conditions and situations are as well as how important it is to follow safety regulations on construction sites. Furthermore, universities did not pay attention to the safety subject in comparison with others or deliver safety knowledge separated with construction process that makes construction safety education not effective. As a result, there is a significant information transfer loss during the safety knowledge delivering process and learners have less motivation and engagement to obtain construction knowledge. Students cannot therefore gain sufficient safety knowledge at tertiary level, and then they can perform errors and unsafe actions when entering the construction industry.

Engineering education is changing, with its focus shifting from traditional classroom based learning to Information Communication Technology (ICT) based learning. ICTs allow learners to have a support that facilitates social-communication, visual aids, interaction and learning-by-doing. In term of construction safety education – the subject emphasizes the identification, analysis and control of work hazards as well as interpretation of safety regulation – ICTs have been becoming more and more important to transfer safety knowledge to learners. ITCs could assist students in developing and maintaining high safety competency and practical skill level. Beyond this logic, Virtual Reality (VR) and Augmented Reality (AR) become an innovative method to promote the safety education effectiveness. VR and AR based education has been applied and succeeded in various disciplines such as safety procedure in surgical education, soldier training in military, construction assembly, mine safety training, civil engineering education, etc. In the construction industry, VR and AR approaches provide flexible and interactive learning environments in which the student is the centre. Mobile VR and AR technology allows learners to access learning lessons anytime and anywhere. Users are able to practically experience the construction site by interacting with virtual environments via mobile device touchscreen. Although, the advantages of VR and AR have been proven in construction education, very few studies have focused on safety education at the tertiary level.

This study presents a new construction safety education approach that utilizes Virtual Reality (VR) and Augmented Reality (AR). It includes two stages: 1) develop a vision; and 2) figure out the strategies for construction safety education using VR and AR. This new method will not only prepare future construction personnel with safety competency but also make them more creative and ready for challenges of the current

[1] Ph.D. Candidate, Department of Architectural Engineering, Chung-Ang University, Seoul, South Korea. Email: lequangtuan2009@gmail.com
[2] Professor, Department of Architectural Engineering, Chung-Ang University, Seoul, South Korea. Email: cpark@cau.ac.kr (*Corresponding Author)

complicated construction projects.

II. Safety Information Issues at Tertiary Level

The effectiveness of safety information transfer from education programs allows leaners to become aware of on-site dangerous occurrences, and proactively prevents construction accidents. However, current pedagogical tools for construction safety do not represent all aspects of accidents and safety procedures well and result in information losses. As illustrated in Fig. 1, there are two big gaps causing information losses when delivering safety knowledge to leaners. The first loss involved in the gap during transferring information process from real hazard information to educational contents. In the real world, construction safety & health includes dangerous occurrence information, hazard precursor, accident information, sequences, causes, prevention methods, cost overruns, etc. It therefore requires more visual aids to effectively illustrate safety information. However, 2D content-based traditional education cannot represent enough safety information from the real construction industry. This causes information loss between real data and educational information.

A further information loss is due to the limited student engagement and motivation when delivering safety knowledge at classes. Because of the nature of construction work, safety education has to take place in hands-off off-site in where learners only listen and watch without actively participating. Traditional education methods based on slide show, handouts and video hardly present the safety information. Students typically play a passive role during the conventional education, and hence, they feel bored and lack motivation. As such, safety information is lost during the transfer process from educational information to delivered knowledge. Particularly, in comparison to other subjects such as schedule, cost, quality, etc. safety issue seems to be paid less attention due to the human second nature. They usually consider the safety subject as a supplementary course and are not engaging in obtaining safety knowledge. As a result, students misunderstand safety regulations or quickly forget safety information after the lectures, then enter construction industry with insufficient safety knowledge and perform unsafe acts.

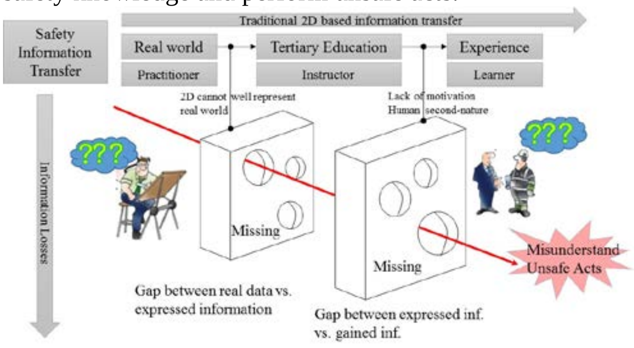

Fig. 1 Safety Information Transfer in Traditional Education

There is no doubt that the conventional education programs would limit the effectiveness of safety information perception. Learners could not play active role during the safety course and fully understand safety lectures as well as remember the knowledge for a long time. Consequently, future construction personnel with inadequate hazard recognition capabilities and a lack of practical skills would perform unsafe procedures to meet the productivity demands [5]. This causes many on-site problems related to construction accidents and defects making significant contributions to cost overruns and schedule delays. Therefore, it requires the development of a new safety education system that can deliver safety knowledge effectively and assist students in long-term memory.

III. Experiential and Interactive Learning in Engineering Education

Due to the more complex and expanding size of the projects, engineers are required to be more creative, practical and intelligent in order to address the current challenges in construction industry [6]. As such, the amount of necessary knowledge transfer to students has become huger and much more. And, the education has become more and more important to prepare the future of engineering. Graduates (future engineers and workers) need to be educated on how to develop feasible and patentable solutions in the dynamic and complicated construction industry in order to improve the productivity and proactively prevent construction accidents. However, the information-transfer losses in conventional methods do not allow engineering students to obtain sufficient knowledge and experience to develop the competency for construction job-site works.

Experiential and interactive learning have been main parts of the engineering education and training for many years and can improve education process by partially reducing the aforementioned information-transfer loss problems. This learning concept would motivate and inspire students to concentrate on the lessons and obtain the knowledge. So far, many studies have proved that active, interactive and experiential pedagogical methods lead to a better comprehension of education material and improve information transfer process. Le et al., (2015) [7] stated that active and interactive learning approaches contrasting to the traditional lecture where students passively receive information from the instructor would engage and motivate students in learning process that can improve leaners' long-term memory and education outcome as well. Furthermore, the experiential learning could enhance students' metacognitive abilities and their capacity to apply new acquired skills and knowledge to real-life [8]. Particularly, regarding construction safety, learning outcomes in terms of safety knowledge retention and long-term memory have become critical factors to assure safe and healthy workplace on construction sites. As such, effective pedagogical methods on safety at tertiary level have to equip future construction personnel with sufficient safety knowledge to proactively prevent accidents on construction sites. Interactive and experiential learning would present a great opportunity for students to acquire the necessary safety knowledge and develop their safety competency.

In terms of construction safety, successful education tools can be defined as those that will create an effective experiential and interactive teaching-learning environment in which learners can play an active role to gain knowledge and practical experience. Building upon this, the study emphasizes the potential of the advanced ICTs for engineering education, and particularly proposes to apply Virtual Reality (VR) & Augmented Reality (AR) as an innovative method for construction safety education.

IV. Virtual Reality and Augmented Reality – A New Approach for Construction Safety Education

Over past few years, the use of VR and AR in education can be considered as one of the natural evolutions of computer/ mobile based learning. VR is a computer based 3D artificial environment that is created by simulating the physical real world while AR is a technology that superimposes a 3D VR model on the real world. Rahimian et al., [6] (2014) stated that visualization technology (such as VR and AR) can prevent tacit knowledge loss and miscommunication among various parties from different disciplines and in so doing improve education process in AEC professionals.

As illustrated in Fig. 2, the education outcomes including the long-term memory, users' attitude and physical skills are based on the level of experiential and interactive learning. The more learning by doing and interaction learning contents have the more effectiveness the education achieves. In this respect, the VR+AR based educational method is considered as a positive force to pull up more experiential and interactive learning. VR and AR contents providing visual & auditory information (3D models, animation, 3D VR overlapping on the real objects etc.) would create a natural close-to-reality experiential and interactive environment where learners could easily to store the information as a sensory memory. Then, the sensory memory would be taken in through learner's senses in order to develop the working memory. Finally, learners via interactive and experiential visualization could retrieve the information and deeply understand the lessons and their senses would take in the experience quickly and clearly. On the other hand, working memory would transfer to long-term memory effectively by using VR + AR education tools. The VR and AR technologies make the lessons more realistic and attractive and thus motivate and engage students to learn and memorize the knowledge and eventually help to deduce the gaps of information losses. As a result, learning outcome would be consolidated and enhanced greatly and significantly.

VR and AR have been widely used in many areas such as medicine, military, aerospace and so on. The introduction of these technologies is changing the traditional ways of education and training in the construction industry. VR and AR have been applied and proven beneficial in construction education recently. They have potentials to lead, motive, encourage and excite learners to learn new things [9, 10]. John et al. (2003), [11] implemented 4D CAD to visualize construction sequences in order to enhance construction education and help students quickly gain experience. As noted by Le et al. (2014), [12] VR games reinforce cognitive skills and emphasize learning by doing, collaboration, reflection and frequent feedback among students and teachers. Furthermore, the interactive AR tool developed by Behzadan et al. (2011) [13], would help leaners to attain a comprehensive understanding of construction equipment, processes and operational safety. These visualization technologies allow students to be the centre of the learning processes and provide great opportunities to engage students in acquiring construction knowledge.

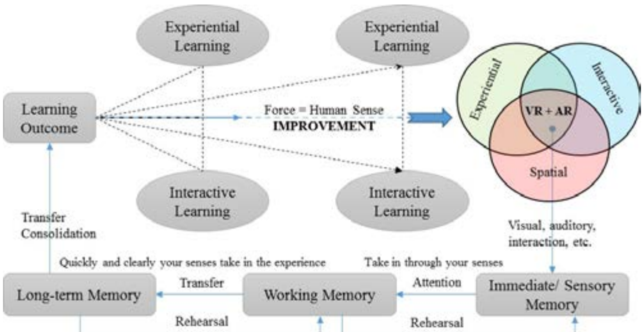

Fig. 2 The relationship between learning outcome and VR & AR technologies

In construction safety perspective, a main concept is the acquisition of competencies that allow graduates develop a safe-work environment and solutions for any challenge in the construction industry. Safety education has become more important now and construction students need to develop new ways of thinking about safety or in other words, the construction safety education is in fact need of reauthorization. In this ICT era, it seems that the VR and AR are crucial in changing the ways of learning and teaching on safety issues. The potential benefits of these technologies help learners to change the common thinking about safety issues (not just a supplementary course in construction), motivate and attract them to obtain safety knowledge through abundant interactive and experiential learning and assist them to perform safely after entering construction industry. As such, within this study, VR and AR are considered as a new approach in construction safety education. These technologies have an essential role in transmitting different types of safety knowledge. As stated by Bhoir and Esmaeili (2015) [14], VR environment brings a new way of teaching tech-savvy students and can revolutionize the safety training and education of the future workforce. Additionally, the context-aware AR application by superimposing 3D virtual models over the real life would support educators to more effectively deliver construction knowledge while providing students with higher quality education with long-lasting impacts [15]. Particularly, VR/AR and its potentials to adapt and link with various innovative technologies (e.g. mobile devices, wearable computing) have been gaining enormous momentum and considering as an innovative approach for construction industry in general and for safety education in specific. In this context, the main effects of VR and AR based education for construction safety are as follows: 1) learning is student-centered; 2) Interaction between students with VR environment and 3D objects overlapped into real-world scenes; 3) task compatibility, multi-user collaboration at the same time and learning by doing; and 4) leaners' of presence, immediacy and immersion. This new approach encompasses all methods that can improve learning & teaching in construction safety rather than just simple focusing on white board, 2D drawing, slides and video-based lectures, which has been the cornerstone of the traditional education method. The construction safety education will be shifted from an inactive approach towards a proactive (experiential and interactive) approach, from "Listen, and I will forget. See, and I may remember" towards "Practice, and I understand".

The compelling features and affordances mentioned above illustrate the great potentials and opportunities of VR and AR that is considered as a new and innovative approach in construction safety education. However, it is important to explore how the use of VR/AR could be aligned with instructional and learning methods in order to achieve the safety education objectives. As such, following section presents the main learning and teaching strategies for construction safety.

V. Learning and Teaching Strategies

A. Spatial and Situation Awareness

Spatial and situation awareness is the ability to understand the construction equipment and activities in term of assessing location, recognizing element shape and identifying workers' safety and health problems. Increasing students' spatial and situation awareness can improve their capacity to respond to hazards and perform safely at the job-site when they enter construction industry. With regard to safety education, the interaction within VR and AR based education environment can provide students with the relationship among virtual objects and spatial location that activates their perception of real working situation and environment and then, lead to the better understanding of safety issues. Fang et al. (2014) [16], developed an as-built interactive VR system which is provided close-to-real experience for crane operation training. This approach enhanced trainees' spatial awareness and increased real-time communication. Moreover, as stated by Hou and Wang (2010) [17], by incorporating virtual objects into real-world scenes, AR can assist users to develop the nature of attention to work spatially and enhance spatial and situation cognition. Mobile based VR & AR methods can be a new tool with particular attention paid to the user experience for improving spatial skills [18].

B. Stimulation of Motivation towards Safety Education

Students' engagement and motivation are critical factors to improve the learning process. Particularly, the construction safety subject emphasizes much on the hazard precursor, accident sequences, causes and safe work procedures, risk analysis, etc., motivating students to learn safety masters has become more important in order to achieve the educational target. In the present ICT society, VR/AR is considered as a powerful tool that provides an interactive and experiential learning environment where leaners are the centre. This characteristic would inspire students to acquire the required safety knowledge and share safety information with others. Dickinson et al. [19] (2010) acknowledged this potential by developing a VR game for trench safety education. This game enhances the engagement of students and provides an innovative medium for hands-on activities as well as assesses the long-term safety knowledge retention of leaners. Additionally, Park and Kim (2013) [20], has considered the use of BIM and AR for development of the educational and training tool in order to enhance not only construction management process but also the motivation and interest of workers for safety training.

C. Hazard Identification and Recognition

Hazard identification is the foundation of construction education and training programs. Improving construction students' hazard prediction ability is essential to prevent accidents and mitigate risks proactively. Hence, enhancing hazard recognition and risk perception skills of graduates is one of the most important goals of safety education at tertiary level. Currently, VR and AR approach can be applied through game-based or problem-based methods that include a series of hazard scenarios allowing leaners to explore construction risks and dangerous occurrences within augmented visualization environment. This technology also provides an active and interactive virtual space in which students can collaboratively learn safety issues in order to enhance hazard identification skills. Lin et al. (2011) [21], conducted a pilot study of a 3D game environment in which students play the role of safety inspectors for construction hazard recognition and assessment. The mobile game developed by Le et al. [7] (2015), allows learners not only to investigate potential accidents within VR environment but also inspect safety problems related to personal protection equipment (PPE) of workers through superimposing virtual PPE objectives on a real human body.

D. Safety Attitude and Behavior

Safety attitudes are essential for graduates to contribute to enhancing safe behaviour and avoid on-site accidents when they enter to the construction industry. The academic level has a serious obligation to promote and foster the attitudes of learners so that safety performance can be enhanced. Therefore, construction safety training and education should clearly delineate various parties' roles on construction sites and emphasize their responsibility for construction safety [22]. The safety attitudes can be developed through the role-playing of inspectors, workers, safety designers and so on within VR/AR environments. Students can gain real experiences and acquire the safety competency by practicing virtual construction activities [12]. Hou et al. [23] (2013), stated that using AR technology could reduce the human errors and increase the productivity as well as improve the trainees' attitudes towards safety during piping assembly process. VR/AR technology provides an interactive and experiential learning environment where students can practice construction tasks in order to gain healthy attitudes and develop the safety behavior. In addition, integrating accident information and safety knowledge into construction methods through interactive VR/AR can offer an innovative medium for improving graduates' safety competency and establishing leaners' responsibility for construction safety & health.

VI. Discussion

Although using VR & AR for teaching and learning is considered as a promising tool, some shortcomings including technology challenges, human factors and financial constraints which should be discussed. Firstly, lack of computer knowledge makes students and teachers unwilling to effectively incorporate technology in their safety courses, then can somewhat affect to educational processes negatively. The development of VR & AR contents is time-consuming and requires the special skills and extra efforts of instructors. Secondly, learners may face frustrations and challenges with using mobile based VR and AR. Furthermore, resistance to change when using innovative technology based education methods is still problematic. Lastly, the development of mobile based VR and AR for construction safety education will need the investment of more time and money. As such, the Return of Investment (RoI) on the capital must be considered carefully.

VII. Conclusion

The study presents a new approach in construction safety education – VR and AR – which shifts from an inactive educational method towards an experiential and interactive pedagogical method. The learning and teaching strategies including spatial & situation awareness, stimulation of motivation towards safety education, hazard identification & recognition, and safety attitude & behavior were conducted in order to ensure graduates to acquire sufficient knowledge and perform safely when entering the construction industry. The new method will not only offer an opportunity to change the traditional education of construction safety but also make students more creative and ready for the challenges in construction area in the 21^{st} century. However, existing obstacles for the risk-averse construction industry include technological challenges, human factors and financial constraints which should be addressed in the future.

Acknowledgement

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

References

[1] D. Zhao, Mobile Virtual Reality — An Approach for Safety Management, 2014.

[2] J. A. Gambatese, "Safety emphasis in university engineering and construction programs," International e-Journal of construction, pp. 1-12, 14 May 2003.

[3] Q. T. Le and C. S. Park, "Construction safety education model based on second life," in Teaching, Assessment and Learning for Engineering (TALE), 2012 IEEE International Conference, Hong Kong, 2012, pp. H2C-1-H2C-5.

[4] D. Zhao and J. Lucas, "Virtual reality simulation for construction safety promotion," International Journal of Injury Control and Safety Promotion, vol. 22, pp. 57-67, 2015/01/02 2014.

[5] A. Chen, M. Golparvar-Fard, and B. Kleiner, "SAVES: A safety training augmented virtuality environment for construction hazard recognition and severity identification," CONVR 2013, pp. 373-384, 2013.

[6] F. Pour Rahimian, T. Arciszewski, and J. Goulding, "Successful education for AEC professionals: case study of applying immersive game-like virtual reality interfaces," Visualization in Engineering, vol. 2, p. 4, 2014.

[7] Q. T. Le, A. Pedro, C. R. Lim, H. T. Park, C. S. Park, and H. K. Kim, "A Framework for Using Mobile Based Virtual Reality and Augmented Reality for Experiential Construction Safety Education," International Journal of Engineering Education, vol. 31, pp. 713-725, 2015.

[8] A. Y. Kolb and D. A. Kolb, "Learning styles and learning spaces: Enhancing experiential learning in higher education," Academy of management learning & education, vol. 4, pp. 193-212, 2005.

[9] V. S. Pantelidis, "Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality," Themes in Science and Technology Education, vol. 2, pp. pp. 59-70, 2010.

[10] H.-K. Wu, S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang, "Current status, opportunities and challenges of augmented reality in education," Computers & Education, vol. 62, pp. 41-49, 2013.

[11] J. I. Messner, S. C. Yerrapathruni, A. J. Baratta, and V. E. Whisker, "Using virtual reality to improve construction engineering education," in American Society for Engineering Education Annual Conference & Exposition, 2003.

[12] Q. T. Le, A. Pedro, and C. S. Park, "A Social Virtual Reality Based Construction Safety Education System for Experiential Learning," Journal of Intelligent & Robotic Systems, pp. 1-20, 2014/09/21 2014.

[13] A. H. Behzadan, A. Iqbal, and V. R. Kamat, "A collaborative augmented reality based modeling environment for construction engineering and management education," in Simulation Conference (WSC), Proceedings of the 2011 Winter, 2011, pp. 3568-3576.

[14] S. Bhoir and B. Esmaeili, "State-of-the-Art Review of Virtual Reality Environment Applications in Construction Safety," Proceeding of the AEI conference 2015.

[15] A. Shirazi and A. Behzadan, "Assessing the Pedagogical Value of Augmented Reality-Based Learning in Construction Engineering," in Proceedings of the 13th International Conference on Construction Applications of Virtual Reality (CONVR), London, UK, 2013.

[16] Y. Fang, J. Teizer, and E. Marks, "A Framework for Developing an As-built Virtual Environment to Advance Training of Crane Operators," in Construction Research Congress 2014-Construction in a Global Network, 2014, pp. 31-40.

[17] L. Hou and X. Wang, "Using augmented reality to cognitively facilitate product assembly process," 2010.

[18] D. Fonseca, E. Redondo, S. Villagrasa, and X. Canaleta, "Assessment of Augmented Visualization Methods in Multimedia Engineering Education," International Journal of Engineering Education, vol. 31, pp. 736-750, 2015.

[19] J. K. Dickinson, P. Woodard, R. Canas, S. Ahamed, and D. Lockston, "Game-based trench safety education: development and lessons learned," J. Inf. Technol. Constr, vol. 16, pp. 119-133, 2011.

[20] C.-S. Park and H.-J. Kim, "A framework for construction safety management and visualization system," Automation in Construction, vol. 33, pp. 95-103, 2013.

[21] K.-Y. Lin, J. W. Son, and E. M. Rojas, "A pilot study of a 3D game environment for construction safety education," Journal of Information Technology in Construction, vol. 16, pp. 69-84, 2011.

[22] J. Hinze and R. Godfrey, "Student Attitudes about Construction Safety," Global Unity for Safety and Health in Construction in CIB W99 international conference, 2006, pp. 233-240.

[23] L. Hou, X. Wang, and M. Truijens, "Using Augmented Reality to Facilitate Piping Assembly: An Experiment-Based Evaluation," Journal of Computing in Civil Engineering, vol. 29, p. 05014007, 2015.