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A Virtual World Based Construction Defect Game for Interactive and Experiential Learning*

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In the construction process, defects occur inevitably and repeatedly, making significant contributions to cost overruns and time delays. Many studies have focused on quality education to reduce the reoccurrence of defects. So far, most of them have emphasized the necessity of teaching about defects in construction classes without considering how to take advantage of new technologies such as virtual worlds in order to improve the education process. In recent years, Virtual World (VW) has been successfully applied as a pedagogical tool in the medical field, with applications in nursing training, healthcare education, and other areas. The concept of VW is still new and there are few studies on the topic in the construction discipline. With this regard, this study proposes an online 3D VW platform, which allows students to participate in role-playing, dialogic learning, and social interaction for construction defect education. In this approach, a construction defect game-based learning system using VW platform is developed. The system comprises of the following three modules: (1) A Construction Defect Learning Module (CDL) which delivers lecture based quality information within the virtual environment to teach students about common defects and their prevention methods; (2) A Defect Inspection Game Module (DIG) where students identify and correct defects in a virtual construction site; (3) A Construction Activity Game Module (CAG) which allows students to engage in construction activities within the virtual environment and recognize actions which may lead to defects. The game system is tested with real scenarios in order to address the system's potentials and limitations. The study emphasizes the advantages and benefits of VW that can provide students with the real construction defect experience through learning by doing. Finally, this paper discusses the extensibility of the system to training program for workers in advance of working in construction site.

Keywords: construction defect; virtual world; second life; interactive and experiential learning; construction education

1. Introduction

The modern construction industry is a complex and dynamic environment where various factors are involved and many activities occur simultaneously [1]. Defects are serious problems that occur repeatedly and inevitably in construction projects. Numerous studies have shown that construction defects make a significant contribution to cost overruns and schedule delays. In many cases, defects occur as a result of errors, omissions, and misunderstandings of construction work procedure and quality control [2]. In particular, one of the underlying causes of these issues is lack of knowledge and practical experience in defect prevention and management [3]. As such, construction defect education plays an important role in providing graduates with adequate knowledge to prevent mistakes and defects when entering construction industry. However, Le et al., [4] observed that traditional education methods do not sufficiently equip students with knowledge and practical experience required in the construction field. Therefore, there is a real need to develop an effective pedagogical tool for construction defect education at the tertiary level.

In an effort to improve institutional education, virtual worlds (VW) have been applied and proven beneficial in various disciplines. VW is a computer-based simulated environment that can brings new opportunities to learning and teaching processes [5]. The immersive Virtual environments of VW have been notably effective in improving educational experiences in medical and military fields. Applications of VW such as Second Life (SL) have been used to create realistic problem scenarios where medical practitioners can improve their surgical skills, anaesthesiology skills and cardiovascular techniques [6]. The virtual environment of SL offers opportunities for student interaction, immersive experiences, intense engagement, role-playing and constructivist learning [7]. Many educators have utilized SL in their teaching environments to transform pedagogical practice and enhance students' learning outcome [8]. However, despite the successful adoption of the SL virtual world as a pedagogical tool in various fields, this is not prevalent in the construction industry. Currently, there are limited applications of VW for educational purposes in construction. Furthermore, there is

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limited research and development on VW and its' potential in construction education. It seems that the construction industry is missing out on the educational benefits which VW is offering in other industries.

This research aims to propose a virtual world based construction defect game for interactive and experiential learning in order to assist students in acquiring construction quality knowledge and then, proactively prevent on-site accidents and defects. The proposed system is developed based on the Second Life platform, comprising of three modules, namely: (1) Construction defect learning module (CDL): The focal point of this module is the delivery of a defect case based lecture which gives students an opportunity to learn about common defects and their prevention methods within the virtual environment. (2) Defect inspection game module (DIG): This module gives students an opportunity to identify defects and implement corrective actions in a virtual construction site and finally, (3) Construction activity game module (CAG) where students practice recognizing potential defects by participating in realistic construction activities within a 3D training environment. The system would be evaluated with real scenarios to emphasize the learning by doing advantage that could provide to students with realistic experience. Finally, the extensibility of the proposed system to a virtual game for worker training would be discussed for future research.

2. Research objective and methodology

The main objective of this research is to apply the VW platform for enhancing construction defect education, and improving students' cognitive and spatial skills is considered as a sub-objective. In order to achieve these goals, the study was initiated with a thorough literature review investigating the importance of construction defect education at tertiary level, current education problems and the state-of-the-art of VW. Literature review showed that even though Virtual World has been applied as a powerful pedagogical tool in various disciplines, it is not the case in construction quality education. It motivated the development of a virtual world based construction defect game for experiential learning. A game prototype using the Second Life (SL) platform was developed deriving from two common on-site defects. Afterwards, interviews with educators and students (from department of architectural engineering, Chung-Ang University, Seoul, South Korea) were performed in order to appraise and evaluate advantages and limitations of the proposed system. Furthermore, comparing students' cognitive workload between the text based-lecture methods with the new pedagogical tool was considered by using performance comparison based technique.

3. Literature review

3.1 Construction quality issues and the importance of defect education

Construction productivity tends to show a general pattern of decrease in comparison with that of other industries [9]. Among factors impeding productivity, rework due to construction defects is considered as a no-value adding activity seriously affecting the performance of construction projects, consuming unnecessary costs, time and manpower [3]. A defect is defined as a physical phenomenon, which should be reworked or fixed due to incorrect implementation at the first time. Defects occur repeatedly causing many problems related to cost overruns and time delays. As stated by Mills et al., [10] costs of defects account for 4% of construction contract value. Love, [11] observed that rework contributed to 52% of a project cost growth in Australia. Furthermore, defects can pose a hazard to health and safety. Therefore, it is crucial that construction personnel are capable of preventing construction defects proactively.

Construction defects occur for various reasons such as task omissions, work procedure misunderstandings, etc. One of the root causes of these issues is the lack of fundamental construction defect knowledge [3]. According to Douglas and Ransom [12], lack of academic interest in repair and maintenance is also a major contributing factor to the repeated occurrence of construction defects. In addition, current pedagogical tools have limited effectiveness, and are unable to sufficiently include complex details, realistic scenarios and construction problems that cannot enhance education process [13]. As a result, graduates enter the construction industry with inadequate construction knowledge that can lead to on-site defects. Hence, a defect education and training system that could effectively: improve the acquisition of defect knowledge; support practical experience to prevent rework; and improve on-site construction quality is required [14]. However, it is challenging to develop an educational system that can satisfy this purpose because of the changeable, dynamic working environment and inconsistent machines in construction.

Recently, advanced information communication technologies (ICTs) have been applied and proven beneficial in various disciplines. ICTs can improve access to educational contents, strengthen the relevance of learning concepts, raise educational quality and make teaching and learning more engaging, active and motivating by connecting to real life [15]. As stated by Behzadan and Kamat [16],

advanced ICTs such as visualization technology have significant impacts on construction student achievement, with benefits such as increased instructor-learner interaction, cooperative learning, problem-solving, experiential learning and student inquiry skills. According to the NMC Horizon Report [17], gamification and digital games have been emphasized as a useful pedagogic and motivation tool that can enhance the education process. Game-based learning simulating real construction tasks can increase students' interest and engagement to obtain construction knowledge through teamwork activities, real-world scenarios and problem-based solving [18]. As such, it seems that digital games have positive effects on construction defect education. The following section reviews the advantages of using game-based learning for construction in order to suggest a new educational paradigm for defect education.

3.2 Game based learning for construction education

Michael, [19] defined serious gaming as gaming in which education is the primary goal, rather than entertainment. Game-based learning is a branch of serious games, which has a learning approach that emphasizes engagement, learning by doing, collaboration, reflection, iteration and frequent feedback among students and teachers. Serious gaming can be split into subsets of gaming styles for different types of educational activities. Some of these subsets include strategy games, skill games, training games and simulation games [20]. Effective game-based learning can be used to sustain motivation among students. In addition to this, games allow the formation of social networks, which further enriches learning processes.

Despite many years of research, a lack of motivating and engaging educational contents has remained a major problem in various disciplines [21]. As such, innovative educational approaches using digital games have been applied to the medical, surgical, military and business fields. They have also been applied in creating realistic scenarios where students can practice and develop important skills prior to entering professional industries [22]. Simulation game-based learning has great potential to improve the lifelong learning and performance of new practitioners in the construction industry [23]. Freitas, [22] observed that one of the main perceived limitations of games is large costs required in educational content development. However, contrary to these perceptions, with the emergence of easily accessible software applications, costs are no longer a major deterrent to game-based learning implementation.

According to Howard et al., [20] the use of serious gaming in construction engineering education could offer students supplementary tools which would facilitate student interaction with environments, materials and personnel. This type of set up would give students an opportunity to apply the knowledge they gain from traditional learning in practical scenarios. Some researchers have considered the potential of gaming in construction worker training. A serious game approach would enable trainees to be more engaged to obtain construction knowledge during training sessions [24]. Tepe et al., [25] designed a hazard recognition game for construction safety induction. The use of gaming simulation in the teaching of integrated land use-transportation also enhanced learning achievement by allowing students to explore complex problems within a collaborative teamwork environment [26]. However, to date, only a few studies have considered the potential benefits of gaming and game-based learning specifically in construction defect education. Recently, using game-based learning in virtual world (VW)—3D online environment platform has been considered as a powerful educational approach that can create highly immersive and engaging environments for teaching engineering related materials [27]. From this point of view, this research explores virtual world and game-based learning to provide the simulated virtual environment to teach about construction defects. A literature review of VW and its' suitability for construction defect education is discussed in the subsequent section.

3.3 Virtual World and a new gaming paradigm for construction defect education

Over past few years, VW has advanced and its educational benefits have been realized. Therefore, its' adoption as a pedagogical game tool has continuously increased in various fields, especially in medical area. Educational communities within virtual worlds have been expanding quickly, as more teachers have begun to see the potential virtual environments have to enhance the medical and health learning experiences of their students [28]. The Vital lab at Ohio university developed a VW nutrition game that increases the student's awareness about the health effects of eating fast food and certain traditional ethnic food [29]. This was achieved by allowing students via their avatars to experiment with different foods and eating styles in three simulated restaurants to learn about the health impacts of their choices. The score for the game and the effect health report helped students to make good choices when eating fast food. Additionally, the Virtual Neurological Education Centre (VNEC) in VW created by Hetherington offered an immersive and interactive experience to allow its users to experience neurological disabilities and to

suffer from neurological disorder [30]. The VNEC simulated the real experience in 3D VW environment where people were able to explore common neurological disability symptoms and to receive health information services.

VWs have emerged as a potential pedagogical tool that allows students to interact with 3D environment and each other to gain practical experience. VWs motivate learners and provide a safe and realistic game-based learning environment to facilitate various educational approaches. In VW environments as in computer games, students explore and navigate a virtual environment, and interact with 3D objects via avatars to construct their knowledge effectively [31]. Furthermore, VWs provide learners with a chance to experience real-life situations to enhance their learning through active role-playing in safe and immersive environments [32]. In the construction discipline, the use of VWs has become more common in recent years. Sulbaran and Jones, [33] implemented a VW platform as a training game in order to provide construction students with a realistic experience of construction sequence and resource management. As stated by Anderson et al., [34] incorporating Building Information Modeling (BIM) with VW improved the effectiveness of communication that could reduce coordination latency and meeting duration in construction projects. VW based construction education supports highly flexible, interactive and student-centred learning. Effective construction defect education, demands high social interaction, dialogic studying and active learning. Construction defects involve many sequential activities, which tend to be very difficult to deliver to students through text-based lectures. Despite the existence of VWs over a significant period time, very few studies have considered how VWs can be used to improve the efficiency and effectiveness of construction defect education. VWs are capable of establishing collaborative leaning environments that allows students to learn about construction defects asynchronously and synchronously within virtual environments. VWs can provide interactive and experiential learning within a technological environment that gives learners strong knowledge retention. By allowing students to practice construction activities in virtual environment, VWs would enhance not only construction defect education but also safety and quality issues.

In this context, the main effects of VWs on defect education are as follows:

- Learning is student-centred
- A collaborative space allowing multi-users to work at the same time
- Interaction between students and 3D objects in real-time within virtual environment (Spatial knowledge representation and contextual learning)
- The possibility of development of close-to-reality construction sites
- The development of an interactive and experiential learning environment

In construction engineering education and defect education particularly, a key concept is knowledge acquisition and experience that develops graduates competence to give solutions to problems encountered in future works. Therefore, VW is expected to support students with adequate knowledge and experience through 'learning by doing'. The next section proposes a framework of using VW for interactive and experiential construction defect education.

4. Framework of Virtual World based construction defect game for interactive and experiential learning

The main goal of developing a construction defect game-based learning system using VW platform is to focus on improving construction quality education. This game would address the limitations of the traditional education approach by using the state-of-the-art of active role-playing, real-time experiential learning and collaboration of VW. The system would stimulate students' interests, motivation and inspiration as well as creativity by facilitating learning and practice in a virtual education environment, to obtain a better understanding of construction defects. In order to achieve the research goals, a framework was developed based on virtual world platform including three modules: (1) Construction defect learning module (CDL); (2) Defect inspection game module (DIG); and (3) Construction activity game module (CAC), as shown in Fig. 1.

Firstly, the CDL focuses on delivering construction quality control knowledge based on defect cases. Educators introduce work procedures, common errors and omissions when performing on-site construction tasks, as well as preventive and corrective defect measures and safety guidelines by using audio and video cues within a virtual environment. Initially, the professor who is an expert in failure engineering would teach students about construction failures related to building defects. The lectures include knowledge about common defects, their causes and management methods. With the support of virtual reality, the teaching process could be more effective than ever. Secondly, the professor would split students into groups and give each group a take-home assignment

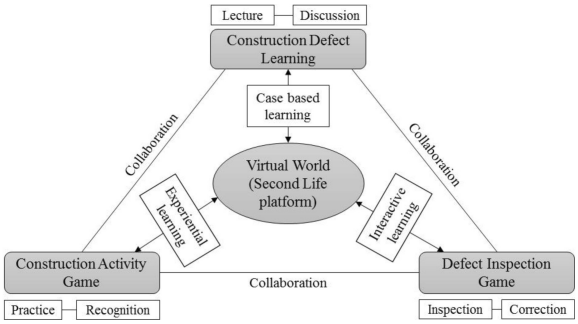

Fig. 1. A virtual world based construction defect game for interactive and experiential learning.

related to the lectures for in-depth learning. The assignments include multiple-choice questions and a question & answer game, which requires students to debate with each other in order to find the best answer. Finally, after discussion, the assignment results would be presented by group leaders for evaluation by the professor. Then, the professor would confirm the results and answer all questions from students about the assignments. Through this approach, students are expected to develop a comprehensive understanding of fundamental quality control and defect management knowledge based on defect cases.

Secondly, the DIG provides students with an interactive opportunity to apply the construction quality knowledge from the previous module. Via motional avatars, students are required to inspect a virtual construction site in an immersive virtual world environment in order to identify common errors, omissions and defects. After that, students have to correct the defects by using the built-in functions of the VW platform, which enable the selection, modification, attaching, detaching and moving of building elements. The DIG would motivate the students to learn about construction defects effectively by providing a captivating environment with realistic scenarios. After the training game, the professor would send training results with recommendations and detailed explanations of the correct construction sequence to students. Through this, learners can acquire in-depth defect knowledge effectively and efficiently. This module facilitates interactive and experiential learning by reflecting defect issues resembling those encountered in real on-site construction. In the DIG, learners could play active roles in establishing defect information and knowledge by inspecting the construction mistakes in the VW environment. These features would not only help students comprehensively understand defect scenarios but also improve their defect analysis skills.

Finally, the CAG represents a proactive approach in which students practice and experience construction activities via avatars in order to recognize potential defects during the construction process within a virtual environment. During the game process, the educator can provide additional information through audio and visual cues. In first step, guidelines about the construction task would be provided by the professor. Through audio communication and the virtual environment of VW, the professor would inform students about what kinds of construction activity they would have to execute and what steps they would have to follow. Secondly, students will use their avatars to participate in the game not only to recognize potential defects but also to obtain practical construction experience and knowledge. It is interesting to note that a notification would be sent by the professor whenever students make mistakes or defects occur. Through this process, students could learn about construction activity sequences. Furthermore, it could enhance their learning experience by providing a realistic and collaborative working environment. Finally, a process video with the professor's recommendation and evaluation would be sent to students for review. This game provides learners with quality control knowledge by incorporating defect information with construction sequences. Through learning by doing, students are motivated and inspired to effectively obtain the knowledge.

5. Analysis of Virtual World and construction defect education: the case study

This section describes the prototype development process to identify the systems educational applicability and the pedagogical validity of its' constituent modules.

5.1 Case scenario introduction and virtual content development

Common defects derived from construction site reports are used to develop virtual scenarios for the system prototype. According to Douglas & Rasom [12], and Cohen [35], window leaks at curtain walls due to faulty installation is one of the most common construction defects. The rework process for this defect typically involves many complicated activities, costs much money and is still a significant problem in both new construction and reconstruction projects. Plumbing defects are also a great inconvenience, bringing water inside the house, with equally serious consequences such as structural damage, etc. Improving students' construction quality knowledge by teaching about critical defects would actively reduce on-site errors and omissions. As such, curtain wall and plumbing

Fig. 2. Construction site model.

defects are selected for VW based construction defect education prototype.

Currently, Second Life (SL) represents the most mature and prevalent online collaborative VW platform being used in education [36]. SL is easy to access, implement, and integrate with external graphic programs, and has a relatively low development cost. Moreover, the multiuser virtual environment of SL would create a number of educational opportunities including game-based learning, experiential learning and cooperative leaning. Hence, this system prototype would be developed using the SL virtual world platform.

For the prototype development, majority of the virtual contents are developed using Revit Architecture 2013 and Blender 2.7—open source modelling simulation tools. The development process begins with modelling an 8-story building under construction and a surrounding site, as illustrated in Fig. 2. Next, all models are imported into virtual environment of SL; then these are scripted by using Linden Scripting Language in order to develop defect education scenarios that are close-to-reality with real construction sites. In addition, an external program integrated with SL is written by C language to support educators to record learners' performances and notify learners during game based learning processes. After virtual contents are created, interactive and experiential defect education is performed as explained in the following section.

5.2 System prototype implementation

Prior to commencing the CDL module, educators introduce common defects related to curtain wall and plumbing installation and their prevention methods via avatars within the virtual environment (Fig. 3); and then students discuss and raise questions based on the defect lectures. Fig. 3 shows the teaching process, which involves an educator teaching about a curtain wall leak defect and its causes to students within the virtual system environment. By using a motional avatar, audio and virtual reality techniques, the teacher explains how the window leak problem is due to faulty installation. Hence, the window installation process requires careful inspection or should be executed by professional installers. The educator also provides learners with instructions and guidelines the curtain wall inspection. This approach represents the traditional method whereby teachers deliver knowledge to students through defect cases. The system supports distance learning by allowing students to stay at home and access the lessons through their personal computers. During the learning and teaching process, virtual reality and audio techniques can help educators easily transfer defect lessons while learners effectively acquire defect knowledge relating to curtain wall and plumbing.

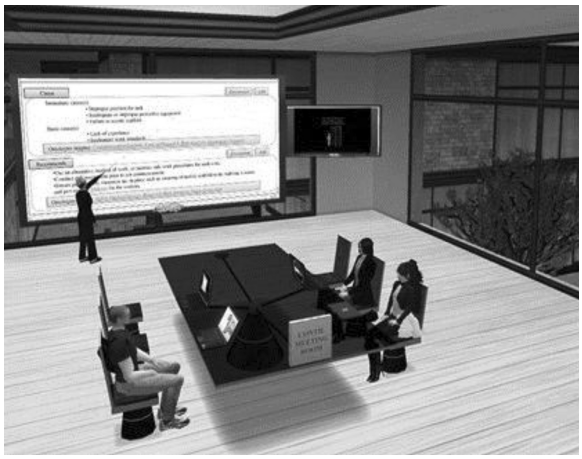

Fig. 3. Virtual education activities within SL.

Next, students reflect their knowledge of construction quality from previous CLD module interactively and experientially in SL virtual environment. Within a 3D environment, students use avatars to inspect on-site errors and mistakes that can cause defects during the construction phase. At first, teachers would explain the inspection task and how to use the SL simulation tool to correct the defect cases. Then, learners via avatars investigate the virtual building to identify construction defects relating to curtain wall and plumbing. They finally correct and verify the defect cases. All education activities would be performed within virtual environment and users could communicate with each other through audio, video and avatar interaction. For example, Fig. 4 illustrates the inspection process, with student using the avatar to navigate the plumbing system in the 6th of the virtual building. The left side shows the plumbing defect involving a

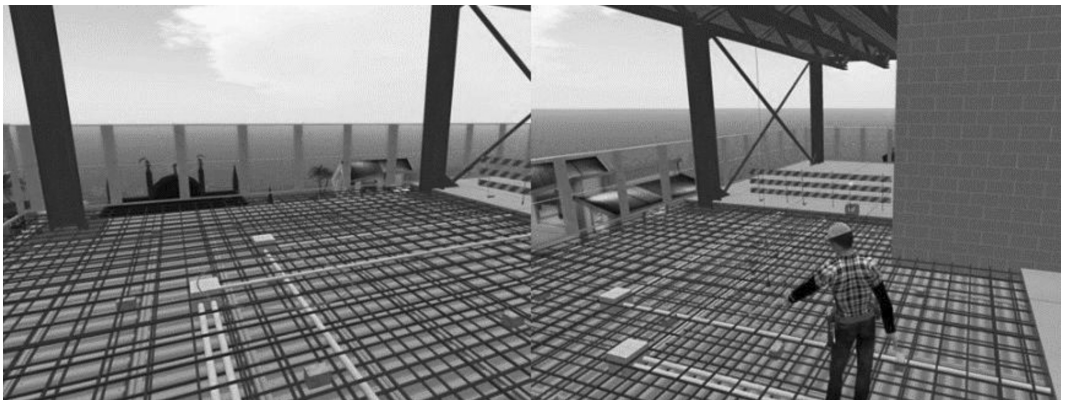

Fig. 4. Defect inspection task.

wrong position of pipe due to worker's error during installation process whist the right demonstrates the student's correction action by reinstalling the pipe to right position. After finishing the corrections, the plumbing installation process would be explained to learners for deeper understanding. Lecturers would explain the pipe position, drain fittings and valve assemblies as well as their functions according to defect management and quality control standard [37]. Based on this interactive and experiential game, the system helps students to effectively gain the construction quality knowledge.

Lastly, using avatars learners perform construction activities as a training game in order to completely acquire knowledge of construction quality and defect management. Students access the training scenarios through their personal computers. SL environment improves learners' spatial and experiential learning by allowing them to interact with 3D virtual objects. Students are required to practice curtain wall and plumbing installation, and then recognize potential defects during the work process. Fig. 5 illustrates the curtain wall installation process, with a student fixing the glass with the frame virtually via an avatar. During this process, trainees realize that rain penetration defects can easily occur due to errors during the glasses and frame fixing process. Along with game training process, lecturers also explain and give guidelines to learners about the installation process. For instance, Fig. 6 shows an explanation of curtain wall structure and the installation process provided by an educator. Thermal break and head type positions and the step-by-step process of their connection are detailed through a guideline video. An external program written using C language supports teachers to conveniently guide trainees during the game process. Through this game, learners can perceive the outcomes of their actions and comprehensively obtain the construction knowledge; and then, construction defects can be reduced proactively.

Fig. 5. Curtain wall installation.

5.3 Evaluation and result

In order to identify the system's advantages and limitations, the prototype was implemented in a 3rd year building construction class with 26 learners from Department of Architectural Engineering, Chung-Ang University, South Korea. The participants were given an introduction and overview of the game process. The system was applied to integrate curtain wall and plumbing defects with construction methods and materials course in the department computer room. The defect lessons were delivered as part of a supplementary course for undergraduate classes. An educator spent 45 minutes teaching the class using the game system. After a 10 minute break, students participated in game trials and then filled out a 5-point Likert scale questionnaire (1—useless; 5—high effective) to evaluate the potential and effects of the system within 120 minutes. The evaluation criteria for the

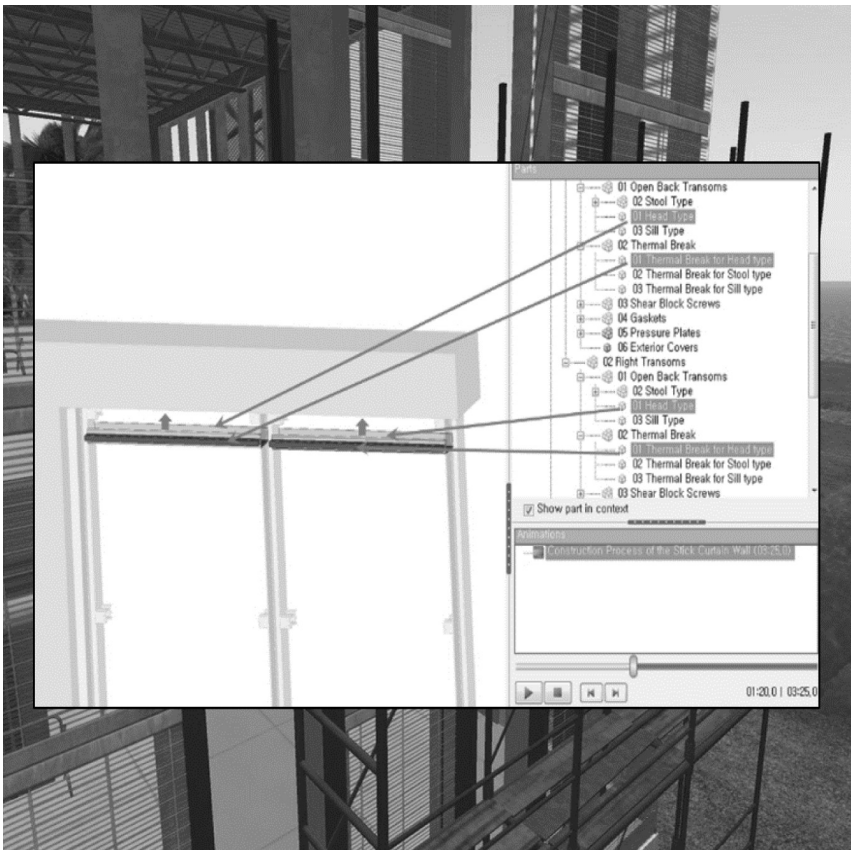

Fig. 6. Curtain wall explanation.

system included the following eight factors: (1) Ease of use: focusing on participants' senses when using the new game system, (2) Interactivity with 3D environment: how well the system support virtual interaction, (3) Spatial and experiential learning: considering the level of realism of the virtual construction site, (4) Motivation and engagement: reflecting how well the system captivated students during the game, (5) Cognitive skills: the capability of understanding the lessons, (6) Defect identification ability: focusing on the systems potential to improve learners' defect inspection competency levels, (7) Defect knowledge transfer: the long term memory impact of the system on the learners towards knowledge retention and (8) Accessibility of defect information: expected level of accessibility of defect information through VW based construction defect education. These criteria were refined from Witmer & Singer [38], Reis et al. [39], Le et al. [1], and Hanna & Richards [40].

As illustrated in Fig. 7, student participants agreed that the system was simple, easy to follow, more interesting, engaging and interactive than traditional paper based lectures. The results show that the main strong points of the system were its ability to promote spatial visualization, experiential learning, motivation and engagement, and improve learners' construction defect identification capabilities. Learners were very comfortable, motivated and felt actively involved when using the game. Students recognized the game system improves defect identification, knowledge transfer and enhances accessibility to defect information. Educators considered the VW based construction defect game capable of illustrating complex detail and realistic construction activities, which could support interactive, active and experiential learning, and then improve outcome perception and education. In comparison to traditional text based lectures, participants stated that the game scenarios resemble situations that students would encounter in real construction sites. Hence, they would feel more competent prior to entering the construction industry. The results also show that the game system is valuable, and has abundant potentials for construction defect education.

Students and teachers emphasized that the system provided practical and hands-on knowledge that could effectively improve quality knowledge retention and develop defect recognition. Learners were highly engaged and immersed in virtual environment of the system. They stayed focused on the defect lectures in VW longer than with text-based methods. Educators were generally pleased with this

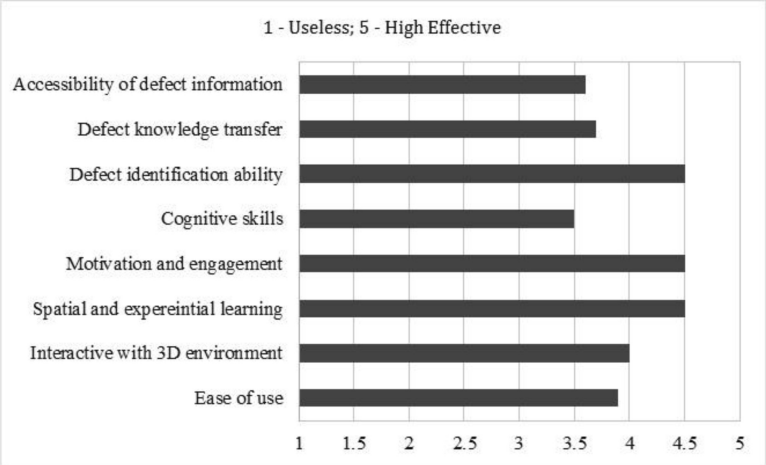

Fig. 7. The system effectiveness evaluation result.

innovative teaching method. They recognized that role-playing, authentic learning and social interaction of VW would help to improve the effectiveness and efficiency of construction defect education. The game system helped learners to address the real-life defects faced in construction sites. Technological features of VW such as the use of avatars, 3D objects importation, external program integration, etc. enabled interactive and experiential learning that can significantly enhance construction defect education. Offering continuous virtual education would motivate students to play an active role in obtaining construction defect knowledge. Hence, through the game system, students can understand construction defects better, while professors can conveniently link theory with practical scenarios and easily transfer knowledge to students.

Participants mentioned that the game provided an effective education method especially for curtain wall and plumbing installation processes. The VW based construction defect education game is cost effective and efficient due to its easy development, convenient access and operation. Interviewees also noted that the system would be suitable for training construction workers, and VW can partially replace hands-on training methods that are usually dangerous and expensive to execute in real life. The system was observed to be highly effective in providing defect knowledge as well as practical experience.

However, educators also raised some concerns about learning with the VW based construction defect game. Lecturers mentioned that using VW when teaching students occasionally proved technically challenging. The game system demands that teachers spend much time to understand the technology and all its functions. Furthermore, communication and peer guidance is limited due to students encountering unfamiliarity with virtual environments. In addition, game scenario preparation took too much time because of the complex scripting required for the real attributes of elements (at least two days for one scenario). Moreover, activities in the developed system do not involve exactly the same durations and interactions as real construction projects. As such, careful collaborative construction procedure simulation is necessary.

6. Conclusion

This research presents a virtual world based construction defect game for interactive and experiential learning, which focuses on improving construction quality education. A prototype is developed and preliminary results suggest that the proposed system will be effective in enhancing access to construction quality information and transferring defect knowledge. Based on the results, the main benefits and limitations of the study are summarized as follows:

(a) The study showed that the VW game has abundant potentials to enhance quality education, learners' defect identification abilities and worker's risk cognition. Furthermore, the proposed system would address the limitations of current construction defect education and greatly improve future construction personnel's competency as well as the abilities to identify problems in complicated working environments. In particular, using the VW system to portray construction processes would support learners in practicing virtual construction activities and in realizing the kinds of potential defects involved in real situations. Then, defects on-site can be prevented proactively.
(b) For the system prototype development, the time consumed in 3D game scenario creation

was considered. Therefore, the combination of a 3D BIM model from a real on-site project with the defect data of the game system is suggested as a solution. This is proposed not only to create and build a game database effectively but also to save training costs and time significantly.

(c) This research completed the preliminary evaluation by using questionnaires. The results confirm that the game system can assist learners and educators in construction defect education as well as significantly improve learning outcomes. Nevertheless, a more objective evaluation through physical performance factors and affective measures must be completed as a part of future research.

In conclusion, this study demonstrates how VWs have great potential in promoting teaching & learning and increasing students' motivation and engagement to learn about construction defects as well as greatly improving learners' quality control competency. For future work, the authors will consider the potential of VW technology in conjunction with BIM and Augmented Reality (AR) for construction education. Furthermore, research efforts will be directed towards developing a Mobile Defect Education Application using the BIM, AR and VW platforms in order to establish an on-site training tool.

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