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An Experiential and Interactive Education System for Construction Safety Utilizing Virtual and Augmented Reality

The Graduate School

Chung-Ang University

Department of Architectural Engineering

Major in Building Construction Engineering and Management

Le Quang Tuan

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Presented to the Faculties of the Chung-Ang University in

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Abstract

Construction is a very intricate and complicated environment that consists of more than twenty trades with different skilled workers involved in construction process. Furthermore, construction workers are mobilized to work and have a high rate of turnover. This leads to the construction being a high-risk industry making significant contributions to cost overruns and time delays. Although accounting for 7 to 10 percent of global workforce, the construction sector accounts for 30 to 40 percent of occupational fatal accident worldwide. This plague causes many problems related with cost overruns and schedule delays in construction project. In Korea, the characteristics of construction projects and operations are very challenging due to the involvement of numerous partners and companies, the dynamic and constantly changing worksites as well as the increase of multinational workers. The Korean construction industry thus has a higher accident rate than other industries in the territory. Construction safety has become an important issue in Korea and any improvement is likely to be beneficial to society as a whole. Safety education and training are very important in promoting a safe and healthful working environment and making accidents more predictable. However, current pedagogical methods and tools at tertiary level are unable to provide students with real practical safety experiences. This is partially due to the lack of consideration for the construction safety education as a high priority. As such, very few studies have focused on the safety education at the tertiary institution level. In addition, the construction education programmes that do consider site safety issues utilize teaching strategies, which have been criticized for being

inactive, boring and insufficiently motivating. As a result, many graduates enter the construction industry with inadequate construction safety experience and knowledge.

With this regard, this dissertation proposes an experiential and interactive education system for construction safety, which utilizes the state-of-the-art of advanced information and communication technologies (ICTs) to develop students' safety cognition, improve behavioural attitudes and enhance safety education process. The system incorporates the advancements of mobile technology, Virtual Reality (VR) and Augmented Reality (AR) with proactive experiential and interactive learning, which link safety theory and real practices in order to provide construction students with practical safety experiences. In the study, a mobile based VR and AR system for interactive and experiential construction safety education is proposed including three modules. Firstly, Safety Knowledge Dissemination (SKD) is to focus on teaching and transferring safety knowledge based on accident cases on construction sites via mobile devices. Secondly, Safety Knowledge Reflection (SKR) provides students with an interactive and experiential opportunity to apply safety knowledge from previous module. Lastly, Safety Knowledge Assessment (SKA) is to assess leaners' safety knowledge and ensure them acquiring sufficient experience to enter the construction industry. The system prototype is developed with real safety case studies and implemented in real classes to identify its benefits and limitations. Then, the qualitative evaluation is implemented to appraise the system by interviewing and discussing with undergraduate construction management students, lecturers (from the department of Architectural Engineering at Chung-Ang University) and safety managers (from Doosan E&C and Hyundai E&C in South Korea). Furthermore,

a comparison of cognitive workload and learning outcome between traditional methods and the mobile system is executed in order to conduct an objective evaluation. The results indicate that this new approach is capable of improving construction safety education in various ways. The proposed system provides new pedagogical platforms that enhance the safety knowledge of construction students. This improvement will increase the graduates' reaction to accident and potential hazard when they enter the construction industry; eventually reduces the chances of construction accidents. Through this, overall safety improvement purpose can be recognized.

Key words: Construction safety & health, Construction Accident & Hazard, Social Network, Virtual & Augmented Reality, Mobile Computing, Experiential & Interactive Learning, Game-based Learning

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List of Abbreviations

BIM – Building Information Modelling

ACE – Architecture, Construction and Engineering

AR – Augmented Reality

VR – Virtual Reality

KOSHA – Korea Occupational Safety and Health Agency

OSHA – Occupational Safety and Health Administration

ICT – Information Communication Technology

SNS – Social Network System

SNSS – Safety Social Network System

SKD – Safety Knowledge Dissemination

SKR – Safety Knowledge Reflection

SKA – Safety Knowledge Assessment

PPE – Personal Protective Equipment

QR – Quick Response Code

GUI – Graphic User Interface

1. Introduction

This chapter presents a brief overview of the context under which the research was conducted. Background information regarding this study is provided in order to establish research objectives and scope. Consequently, the methodology and expected contributions are discussed. Finally, the structure of the dissertation is outlined.

1.1. Research Background

Construction industry is known as the most hazardous industry, which includes more than twenty trades with different skilled workers involved in construction process (Dzeng et al., 2016). Construction accidents occur repeatedly and inevitably during construction project. According to Occupational Safety and Health Administration (OSHA), 31 percent of all fatalities occur in the construction industry although construction sector accounts for 7 to 10 percent industrial workforce (Reese and Eidson, 2006). The high number of fatalities and accidents that continue to cause many problems related with cost overruns and time delays. In spite of the attention given to construction site injuries and fatalities, the incidence rate of accidents in construction is reported to double the industrial average (Rowlinson, 2004). Construction accidents have caused total loss of 7.9 – 15 percent of the total costs for new non-residential projects and the compensation costs for workers injuries account around 3.6 of the total project cost (Chun, 2011).

The Korea construction industry including large machines and equipment, workers from different countries with different skills and practices, and a constantly changing work site, creates a very intricate and dynamic working environment that presents a high rate of injuries and fatalities. The accident and death rates per thousand construction worker are respectively 7.5 and 2.9 that represents 18.6% of accidents and 24.4% of fatalities of all industries (Poon et al., 2008). According to Ministry of Employment and Labor, (2012) the Korea accident rate in construction industry is high in comparison to other industries and occupational injuries increased in construction sector even with decreasing in other sectors, as illustrated in Fig. 1-1 and 1-2. An accident causing an injury to a worker who requires more than 3 days absence from work, which is a large amount and costly in term of time delay, reduced income and lost profits of construction projects. Construction safety is thus a critical issue in Korea that need to be improved.

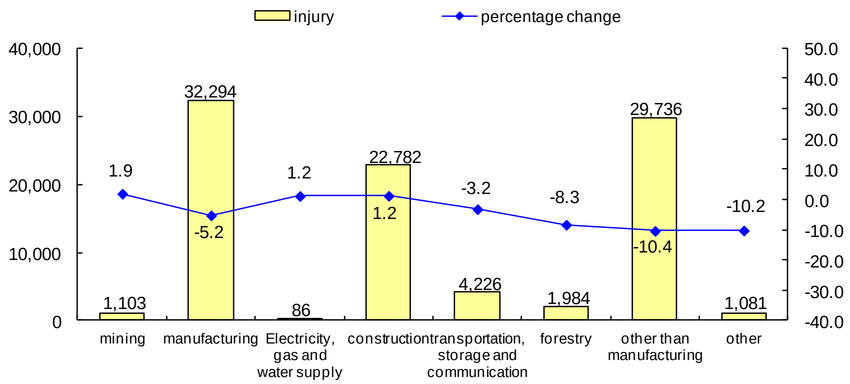


Fig. 1-1 Occupational injuries in Korea (2011)

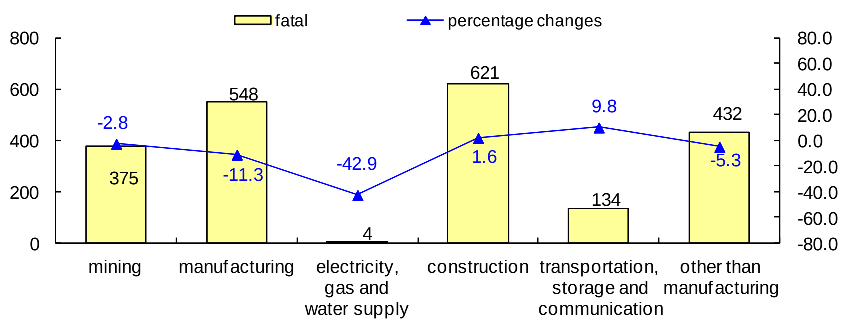


Fig. 1-2 Fatal occupational injuries in Korea (2011)

Safety education plays a crucial role in promoting safe and healthy construction work environment. Petersen et al., (2008) stated that an improvement in the health and safety requires an adequate education in health and safety risk management for future construction engineers and workers (students) at the academic level. Furthermore, integrating the practice and management of safety in construction classes can greatly encourage students' attitudinal changes to occupational health matters and enhance their safety behaviour and then, significantly promote a safety and health during construction process (Hinze and Godfrey, 2006b). As pointed out by Kozlovska and Strukova, (2013) education programs play a significant role in improving employees' safety awareness and behaviours and, then prevent construction accidents proactively. Effective and efficient safety education & training programmes have the potential to improve safety performance and prevent accident occurrence by making latent hazards more predictable (Li and Poon, 2013). However, current pedagogical methods and tools at tertiary level are unable to provide construction students with hands-on knowledge and real experience. In addition, Saleh and Pendley, (2012) observed that current safety education systems are limited in effectiveness, not reaching their target audiences or not being conducted at a scale commensurate with their importance. Interviewing students and civil engineers revealed that traditional classroom-based lecture method does not supply sufficient safety knowledge for performance in construction sites. On the other hand, at the tertiary institution level, construction curricula and courses vary in their approaches to safety education; with some programmes including safety topics in their curricula or others not. Moreover, majority of education programs have been passive, boring and insufficiently motivating. The teaching tools in construction education are unable to sufficiently deliver and present complex details, realistic scenarios and construction problems that cannot enhance leaning. Furthermore, the concept of health and safety risk is usually skipped in construction courses due to the lack of support from the construction departments. Graduates therefore enter the construction industry with inadequate construction safety knowledge and experience, and thus, they are more likely to perform hazardous actions that may results in injuries and fatalities. Regarding this issue, it is necessary to: 1) share and publish more case studies on safety and health topic through websites as part of construction education programmes; 2) integrate safety information and experience into construction method education at academic level; 3) develop an innovative construction safety education for experiential and interactive learning that can motive construction students' safety attitudes and cognitions and improve safety educational process.

Recently, advanced Information Communication Technologies (ICTs) have been applied and proved beneficial in diverse disciplines. The social network sites are web-based services that allow an individual to construct a profile, articulate a list of other users that they share a connection with, view and traverse their list of connections, exchange information, and communicate with other users (Boyd and Ellison, 2007a). Social networking platform is a powerful tool to engage, motivate user to share, update and manage information (Eysenbach, 2008), and plays an important role in exchanging resources among partners which have been applied in many diversified areas (Kim et al., 2011). Social network can create a good environment for safety information and knowledge retrieval in the construction education. Furthermore, visualization technologies such as BIM, VR, AR and mobile computing have revolutionarily changed the construction industry. The use of these technologies has given great opportunities that can improve our industry. BIM is a digital representation of the facilities' physical and functional characteristics (States, 2008) whilst VR is a technology that allows users to explore 3D interactive environment in real time. Both BIM and VR are used to provide leaners with interactive learning experiences through real-time computer generated imagery. Lin et al., (2011) emphasized that VR games provide a comprehensive and immersive training environment, which would bring new opportunities to safety teaching and learning processes. AR overlapping 3D objectives in real world can enhance traditional educational experiences by supporting perception of spatially-related content and enabling discovery-based learning (Behzadan and Kamat, 2013). As presented by Wang et al., (2013), integrating BIM with AR enabled to the physical context of construction activities to be visualized in real-time. In addition, the state-of-the-art of the mobile computing technology can conveniently provide students with contextual learning experiences which make information more accessible, delivery more efficient and personal (El-Hussein and Cronje, 2010). Mobile technology encourages exploration of supplementary course topics, makes courses more interesting, provides additional learning motivation and delivers educational experiences that would otherwise be difficult (Ally, 2009). The use of VR, AR and mobile computing in higher education can support quicker information access, improve communication, content collaboration and situated learning (Gikas and Grant, 2013). From this point of view, adapting these advanced ICTs can contribute to addressing the aforementioned stringent challenges of the construction industry and support experiential and interactive construction safety education.

1.2. Research objectives

This dissertation aims to develop an experiential and interactive education system for construction safety by applying and combining alternative advanced ICTs. The research focuses on motivating and engaging construction management students in order to develop their safety knowledge, behaviour and awareness as well as hazard identification capabilities. Advanced ICTs including social network, BIM, VR, AR and mobile computing are used to provide the novel methods for construction safety learning process. This study greatly improves the traditional and typical education by enabling students to conveniently share safety data, visually access safety information and interactively acquire safety knowledge. Through this, students' safety cognition and long-term memory can be developed; and, then the future construction engineers with adequate safety knowledge and experience can perform safely and healthily in construction site. The five primary objectives of this dissertation are as follows:

- To determine the importance of safety education at tertiary level that proactively prevents construction accidents, enhance safety performance and improves the project productivity.
- To emphasize advantages and benefits of the advanced ICTs (SNS, BIM, VR, AR and mobile computing) that can provide students with real safety experiences.
- To establish social network education channel in order to assist users to exchange, communicate, present and share as well as refine safety information conveniently and easily. Then, this information is retrieved to develop the 3D virtual safety education content.

- To integrate safety into construction methods education course through interactive VR to ensure that all construction students receive adequate and sufficient safety knowledge to enter the construction industry.
- To develop a mobile computing based VR and AR system for experiential construction safety education that significantly increase students' engagement and motivation to learn about safety masters and enable improvably access to construction safety information and then, enhance construction safety performance.

1.3. Research scope

This goal of this research is to contribute to the realm of using advanced ICTs for improving experiential and interactive construction safety education as its target. However, the 'use of advanced ICTs for construction safety education' term is too broad. Regarding this, the author limits the dissertation scope by focusing on developing a safety program as supplementary class as part of building construction materials and methods course at department of architectural engineering, Chung-Ang University. In addition, the advanced ICTs including social network, BIM, VR, AR and mobile computing are adapted and applied as main technique channels throughout the research in order achieve the objectives. The learning theories using in this dissertation consist of game based learning, problem based learning, learning by doing, interactive learning and cognitive learning that are detailed in literature section. More specific, the detail scope of this research is determined as follows:

- To investigate the current state of construction safety education, including a review of safety problems, accident rates in Korea, the importance of safety education and its principle issues.

- To examine the recent advanced ICTs (social network, BIM, VR, AR and mobile computing) applications in construction and education and determine the benefits that can be applied for construction safety discipline.
- To utilize social networking to collect, store, refine and reuse safety information at institutional level.
- To develop a mobile based VR and AR system in order to improve construction safety education.
- To validate the system through case studies derived from common real on-site accidents and conduct with undergraduate students and lecturers at Chung-Ang University, Seoul, Korea.
- To orient the future development of these approaches towards the safety on-site training tools through discussing with field safety managers from Doosan E&C and Hyundai E&C in South Korea.

1.4. Research methodology

The overall methodology of this research is shown in Fig. 1-3. A five-step process was deployed in developing an experiential and interactive education system for construction safety. Firstly, a literature review is carried out and interviews are conducted with students and lectures in order to assess the current state of construction safety and education issues at tertiary level. Safety problems are analysed to confirm the need for safety awareness improvement and hazard identification capabilities in construction industry. Based on this reviews and analyses, the important role of construction safety education is identified. Consequently, investigating recent issues in construction safety education to emphasize the necessity for improving safety pedagogical methods at institutional level. These motivate the development of an experiential and interactive education system for construction safety. Education contents and methods relevant to the Korea construction industry are acquired through reviewing current advanced ICTs in construction and education as well as innovative learning theories in diverse disciplines. Particularly, within ICTs, VR & AR is considered as a new and innovative approach for construction safety education by shifting from "Listen, and I will forget. See, and I may remember" towards "Practice, and I will understand". The vison of aligning teaching & learning strategies including spatial and situation awareness, stimulation of motivation towards safety education, hazard identification and recognition and safety attitude and behaviour is examined in order to ensure the potential benefits of the new approach.

From this point of view, an experiential and interactive education system for construction safety is developed including three stages. These are: 1) A social network model for collecting, refining, storing and sharing construction safety knowledge; 2) The development of VR and AR education contents for construction safety education; 3) A mobile-based VR and AR system for interactive and experiential construction safety education. The system prototype is then applied for safety education in real classes (Building Construction and Management course at department of architectural engineering, Chung-Ang University) in order to address the system's limitations and advantages. Subsequently, the effectiveness of the mobile-based VR and AR are verified through subjective, objective and heuristics evaluations. Subjective assessment is conducted by surveying participants (students and educators). Objective evaluation is achieved through cognitive workload observation and learning outcome measurement. Then, the useability evaluation is implemented for improving the GUI of the mobile system by interviewing professors and safety experts. Lastly, the conclusion will conduct the potential advantages and limitations of the research as far as carry out the future trends.

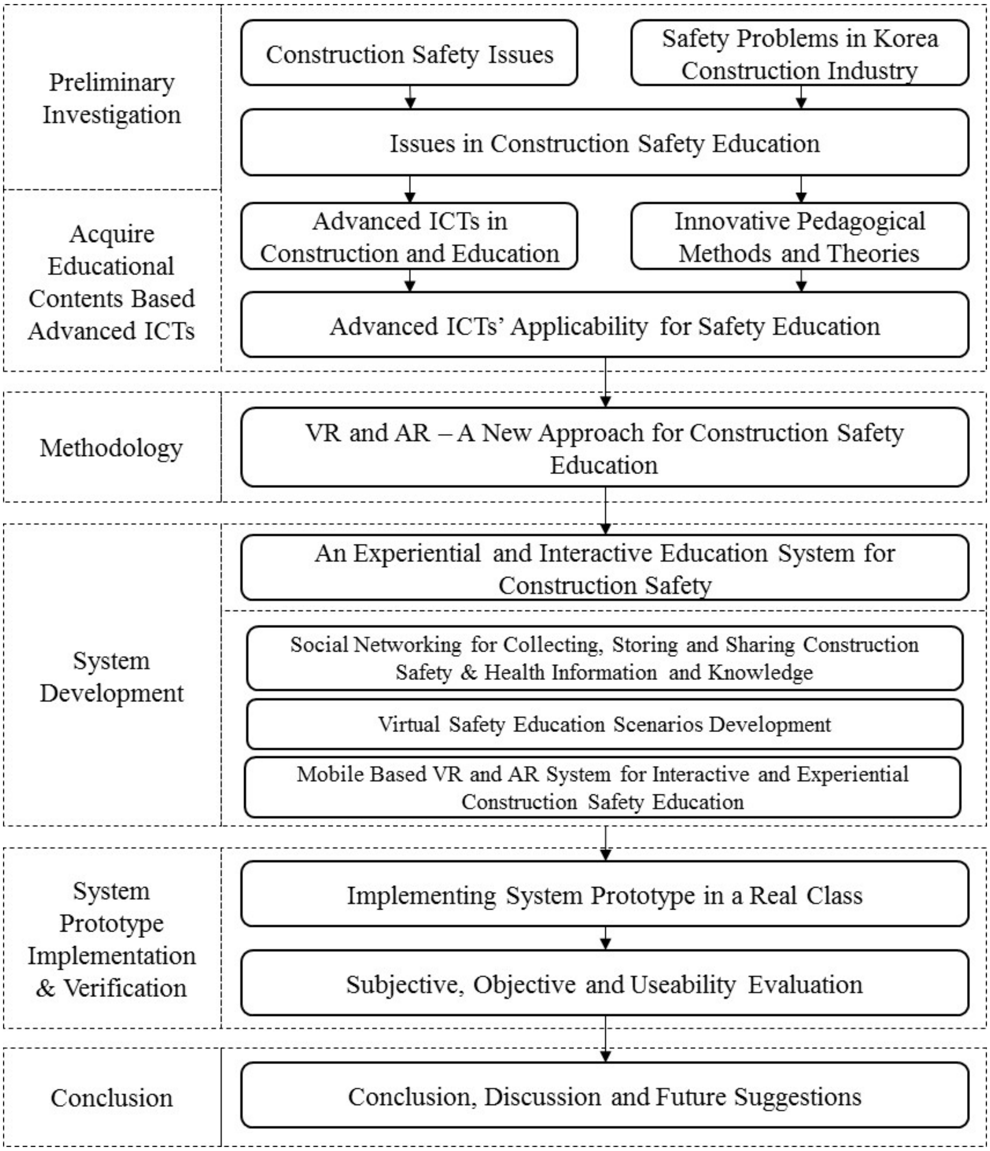


Fig. 1-3 Research Methodology Framework

1.5. Research contribution

Inadequate attention has been paid to construction safety education at institutional level. Furthermore, there are few construction curricula including safety courses, which is considered a low priority or delivered using ineffective educational methods. Additionally, current construction safety education has limited effectiveness, not reaching target audiences, tending to be passive, boring and not sufficiently motivating for students, and not being conducted at a scale commensurate with its importance. The contribution of this research is to develop an experiential and interactive education system for construction safety by utilizing advanced VR, AR and mobile computing, which provides students a good opportunity to learn about on-site construction safety masters in a safe and controlled environment; then, develop students' safety recognition, awareness and long-tern safety memory. These safety knowledge and experiences would prepare learners to prevent the occupational hazards and risks encountered on real construction sites, without any detrimental consequences in real life when they enter the construction industry. As such, this study would support and assist in producing competent, skilled and safety conscious future construction engineers and workers. Through this, construction injuries and accidents could be proactively prevented and safety performance could be enhanced, and then, the productivity improvement can be realized.

1.6. Dissertation structure

This dissertation is organized into eight chapters including:

Chapter 1: Introduction

This chapter introduces the research background, identifies the research problems and defines the research objectives, scope and methodology framework as well as provides an overview of the entire study.

Chapter 2: Literature review

This chapter investigates relevant studies acquired through an in-depth literature review. The review assesses the current state of construction safety and education; recent advanced ICTs including social networking, BIM, VR, AR and mobile computing in construction and various disciplines. The use of advanced ICTs is highlighted to indicate new approaches whereby the research objectives can be achieved. The chapter is concluded with remarks pointing out gaps in literature and the necessity of improving experiential and interactive construction safety education through the proposed system.

Chapter 3: VR and AR – A New Approach for Construction Safety Education

This chapter emphasizes an important role of VR and AR technologies for construction education and suggests VR and AR as a new approach for safety education. This approach shifts from an inactive educational method towards an experiential and interactive pedagogical method. The learning and teaching strategies focus on four aspects including spatial & situation awareness, stimulation of motivation towards safety education, hazard identification & recognition, and safety attitude & behaviour were conducted in order to ensure graduates to acquire sufficient knowledge and perform safely when entering the construction industry. The new approach 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 21st century. From this point of view, the direction of the dissertation is figured out. This chapter is a backbone and plays a critical role that directs for the whole dissertation.

Chapter 4: A social network model for collecting, refining and storing construction safety and health knowledge

This chapter introduces a new data collection and refinement titled a social network for collecting, refining and storing construction safety & health knowledge (SNSS), which utilizes state-of-the-art of semantic wiki and ontology construction technologies for better collection, communication and representation for construction safety information. The SNSS consisted of three modules – a safety information module, a safety knowledge module and a safety dissemination module – to support students to store, share, monitor, manage and retrieve safety information easily. This SNSS was demonstrated by a real case study and evaluate by a series of interviews with learners, educator and safety managers. The main aim of this chapter is to collect, refine and store safety information in order to design and develop the construction safety education contents. This is an initial and indispensable step for the system development.

Chapter 5: The development of VR and AR pedagogical contents for construction safety education

In this chapter, VR and AR educational scenarios are developed using safety information that were collected and refined from SNS system in chapter 4. The case scenarios are selected based on the common potential hazards on construction sites including: seven falling accidents, a fire hazard, a concrete work, a temporary work hazard and a struck-by hazard cases. Then, the simulation and encoding processes for creating virtual safety models are described in detail. After that, these models are converted to the animated VR and AR scenarios that are close to the reality of construction site will use for education purposes. This is a main step for developing an experiential and interactive education system for construction safety.

Chapter 6: A mobile based VR and AR system for experiential and interactive construction safety education

In this chapter, an innovative pedagogical tool, namely a mobile based VR and AR system for experiential and interactive construction safety education is introduced. The system aims to assist students and instructors in the process of construction safety education by providing a sufficient interaction and visual aid in effectively identifying construction hazard, acquiring safety knowledge and developing safety cognition. Firstly, the system framework is proposed including three modules: Safety Knowledge Dissemination (SKD), Safety Knowledge Reflection (SKR) and Safety Knowledge Assessment (SKA). In order to support three modules, the system architecture is figured out. Afterward, the system prototype was developed and then; implemented in real classes at department of architectural engineering, Chung-Ang University, Seoul, South Korea.

Chapter 7: Evaluation and Result

This chapter focuses on assessing the effectiveness of the mobile-based system. After implementing in the real classes, subjective evaluation would be implemented through surveys. This served as a preliminary formative assessment, focusing on identifying learners' initial responses to the system and checking whether modifications to the mobile-based instructional approach are required. Then, objective evaluation is conducted through a comparison of NASA Task Load Index cognitive workload and learning outcomes between traditional methods and mobile-based approach. Lastly, useability evaluation is used for supporting quantitative results and accounting for construction safety experts' experiences about GUI.

Chapter 8: Conclusion

This chapter reviews the dissertation's objective and presents the research contributions and limitations. Furthermore, the future trend of the study would be discussed.

2. Literature Review

An extensive literature investigates safety issues, advanced ICTs in construction and education in order to provide background knowledge related to the research topic. This chapter present a brief understanding of construction safety, social network, visualization technology (BIM, Virtual Reality and Augmented Reality) and mobile computing. Thereafter, need for developing an experiential education system for construction safety is identified.

2.1. Construction safety issues

The construction industry plays a major role in both global economic and society, accounting for 10 percent of the worlds' gross domestic product (GDP) (Raheem and Hinze, 2014). Construction and engineering contributes $8.7 trillion for global market and accounts for 12.2 percent of the world's economic output (Oxford Economics, 2013). Despite the significant economical contributions, the construction industry has been associated with the high rate of injuries and accidents. Even though accounting for around 7 percent of global employment, construction sector constitutes approximately 30 percent of the occupational accidents of the whole industry (Murie, 2007). There are at least 60,000 fatal accidents in the construction industry around the world each year (International Labour Organization, 2005). As such, construction is considered as the most hazardous industry, causing numerous causalities and property losses in every country around the world.

Nowadays, construction has become more complex and changeable due to many factors including frequent work rotations, exposure to weather conditions, high proportions of temporary workers and multinational employees as well as the expanding size and complexity of projects (Rozenfeld et al., 2010; Skibniewski, 2014). Construction workers are from the low level of education and lack of complete skills for the activities on site. As such, in the construction industry, there are many accidental deaths and serious injuries. Despite considerable reduction efforts in the number and rate of injury over the last 20 years, construction still remains a high risk industry. Construction injuries and fatalities occur repetitively and inevitably as well as on a regular basis during projects causing many problems related to cost overruns and time delays (Le et al., 2014). According to Health and Safety Executive (HSE) (2013), about 39 fatal injuries and 3700 occupational cancer cases to workers arise each year that accounted for 27 percent of fatal injuries and 10 percent of major injuries of the whole industry although construction sector employed 5 percent of the Britain employees . In the US, the most developed country, the construction fatal rate was 9.4 per 100,000 full-time equivalent workers and the rate of nonfatal injuries and illnesses resulting in a day was 1.5 per 100 workers in 2010. In Australia (2015), the fatality rate is 3.29 fatalities per 100,000 workers, which is nearly twice the average national fatality rate (Safe Work Australia, 2015). Furthermore, as illustrated in table 2-1, the accidents and fatalities rate is high as well in the construction industry of developed countries (South Korea, US, UK, Hong Kong, Singapore and Australia) (KOSIS, 2015; OSHA 2015; Safety Work Australia, 2015; WSH Singapore, 2015). Additionally, in spite of the attention paid to safety, the construction industry still represents high fatality rate as shown in Fig. 2-1 (USA, UK, China, Japan, Canada, Hong Kong, Singapore and Korea) (Institute, 2014; KOSIS, 2015). The Korean construction industry reported the highest fatal occupational injuries that accounted for 29.4 and 26.6 percent of all industries in 2011 and 2012, respectively (Labor, 2012). A number of construction accidents are 23,669 cases that account 26.3 percent of all industries in 2014. In 2014, there are 486 deaths on Korean construction sites.

Table 2-1. Construction accidents and deaths statistics in 2014

Country	Construction Workforce (Million)	Accidents	Fatalities	Fatality Rate (per 100,000)	Construction/ All Industry (Fatality)
South Korea	3.2 (8.9 %)	23,669	486	15	26.3%
US	9.8 (7%)	82,000	847	13.9	20.5%
UK	2.1 (6%)	69,000	35	1.9	24.5%
Hong Kong	0.098 (2.5%)	3467	20	12	19.6%
Singapore	1.1 (4.6%)	12,200	33	3.6	21%
Australia	1.05 (9.1%)	51,792	43	3	15%

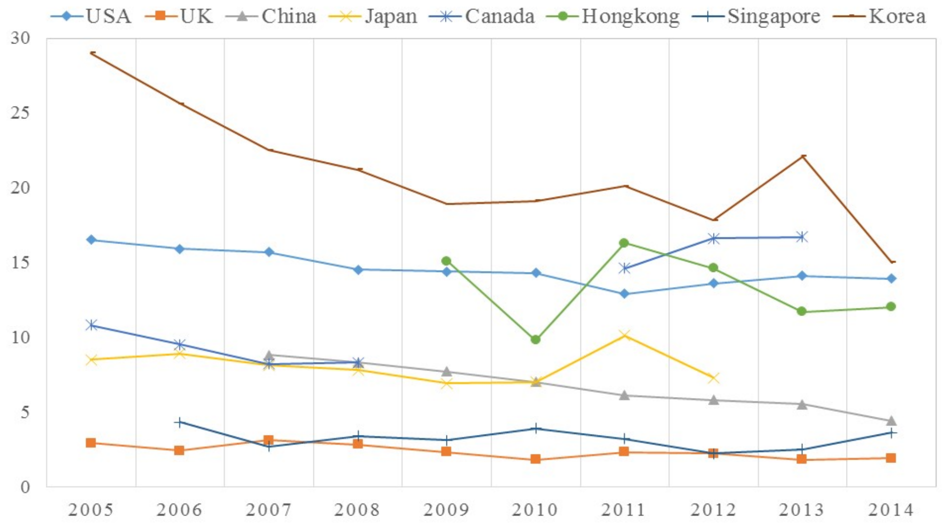


Fig. 2-1 Fatality rate in construction

The real accidents could be dramatically higher than above statistical reports due to a large number of unreported near-miss accidents. The high rate accident has caused many problems involving not only the huge economic and human losses but also the detrimental social welfare effects. The cost of accidents is therefore discussed in following section in order to emphasize the important role of safety in our industry.

2.2. Construction accident costs

Construction accidents incur various losses to the workers and their family, employers as well as society. Accidents and their corresponding damages cause a large amount of problems related to poor productivity and property, time delays and decreased moral that can negatively affect the construction companies' profit and reputation. This plague also brings about other repercussions including the social costs entailed as a result of disabilities and the financial burden attributable to early retirement (Carbonari et al., 2011). The accident costs are confined to the financial costs, which can be expressed in term of direct and indirect costs. The direct costs that are obvious include medical costs, indemnity payments for injuries, public liability claims, repair and replacement expenditures, etc. Whilst the costs to train and compensate a replacement worker, investigate the accident and implement corrective action and relate to schedule delays, added administrative time, lower morale, increased absenteeism and so on, are very difficult to recognize and quantify which were defined as the indirect costs (OHSA, 2013). Estimates of indirect costs as a proportion of direct costs have ranged from 1:1 to more than 20:1 (Davies and Teasdale, 1999). In other words, construction accident costs are more expensive than people realize. In addition, the construction accident cost rates are higher than the average of all industries. Despite estimating 5.2

percent of all private industry employment in 2002, construction sector accounted for 15 percent of all industry injury costs (Waehrer et al., 2007). This leads construction industry to become a disproportionately costly industry. According to Waehrer et al., (2007), the total costs of occupational accidents were estimated at $11.5 billion and the average cost per case of nonfatal or fatal injury was $27,000 in the United States construction industry (Zalk et al., 2011). Furthermore, in UK, injuries and new cases of ill health in construction cost society over £1.1 billion a year (Health and Safety Executive, 2014). Yoon et al., (2013) reviewed that the cost for the construction companies from work-based accidents was 8.5 percent of the project tender price Yoon et al., (2013). In Australia, the cost of workplace injury and illness in construction for 2008-09 financial year is $6.4 billion accounting 10.6 percent of the total industry cost (Safe Work Australia, 2012) . Furthermore, analysis of the incident data showed that million working days are lost due to incapacity at work and 30 percent construction workers have musculoskeletal disorders and back pain that were not calculated. Accident expenses are obviously a hindrance to the development of not only the industry in particular but also the economy in general. The high costs of construction accidents have been regarded as an encouraging and motivating factor to improve safety performance.

2.3. Necessity of construction safety education and training at tertiary level

Comprehensively improving safety remains one of the greatest challenges facing the construction industry today. Construction accidents occur for various reasons; however, one underlying causes related to deficiencies in safety awareness and perception due to lack of basic safety knowledge and practical experience. Li et al., (2015) identified unsafe worker behaviour causes 80% of all accidents on construction sites. In addition, Choudhry and Fang, (2008) and Tam et al., (2004) indicated that construction workers were involved in unsafety behaviours and awareness because of bad safety attitudes and psychology. In other words, good safety attitudes, behaviours and perceptions are essential for construction workers and engineers to avoid accidents on construction sites. Positive and mature safety awareness is fundamental and critical for enhancing construction safety performance (Fang and Wu, 2013). These safety awareness and culture can be achieved through training and education. Cheng and Wu, (2013) emphasized enhancing safety education can ensure occupational safety in the construction industry. Safety learning and training improves behavioural attitudes towards safety and makes accidents more predictable. Kozlovska and Strukova, (2013) stated that university safety education increases construction risk awareness and enhances safety compliance in the construction industry. This can help to develop the knowledge and skills needed to understand the occupational hazards and safe procedures (OSHA, 2001). Furthermore, safety learning not only provides safety knowledge and skill but also serves as a way to socialize the safety and health culture in the construction industry. Currently, at the industry level, typical safety programmes are delivered through on-site workshops. Some of these include mentoring programs and use buddy systems to help orient new employees. However, a large proportion of these training programs have proven ineffective in sufficiently preparing workers and graduates for the work site. Obviously, due to the complexity, expanding size and time constraint of construction projects, new employees cannot easily gain adequate safety knowledge and experience through these on/off site tools to develop their safety culture for the safe performance on construction sites. These emphasize the importance of steady and long-term safety training and education to future construction engineers and workers. This means that students (future engineers and workers) need to become more knowledgeable about on-site safety & health rules and understand how knowledge, skills, and attitudes promoting utilization of safety science in advanced of entering the construction sites. It is therefore critical that the university need to focus on construction site safety education and training at tertiary level (Gambatese, 2003).

2.4. Current state of construction safety education and training

Safety training and education at institutional level have been proven to significantly improve safety performance on construction jobsites. Through safety education and training, future construction engineers and workers can become more aware and knowledgeable of potential site hazards and appropriate mitigation measures. Effective safety education provides sufficient knowledge, which helps to reduce and prevent injuries and fatal accidents on construction sites. This safety knowledge is commonly obtained thorough safety toolbox meetings, specialized training programs (on or off sites), apprenticeship programs, safety courses in universities, and through on the job experience.

Nowadays, majority of safety training programs take place on construction sites, making use of educational presentations, video clips and quizzes (Cherrett et al., 2009). A variety of training and education methods such as lectures, conferences, films, seminars and discussions can be used to provide workers and students with detail information about site risks and hazards, as well as safety behaviour and practices (Odusami et al., 2007). However, employees (workers and students) typically play a passive role in these programs, hence finding them boring and insufficiently engaging. In many cases, these programs are ineffective and inefficient because they do not motive trade workers, project personnel and graduates enough to learn about safety and health matters. Furthermore, training programs and pedagogical tools are usually delivered over relatively short time frames (ranging from a day to few days) which have limited potential to influence long-term worker behaviour and perception. Lucas et al., (2008), emphasized that knowledge acquired from typical training methods, without reflection and application may be quickly forgotten and the learning potential of the training lost. For safety training and education to be effective in improving on-site safety performance, training and pedagogic programs must ensure that project personnel, graduates and workers develop fully cognition of site safety and hazards (Topf, 2000). Without this, any safety system is ineffective and unsuccessful in enhancing site safety performance.

It is also necessary that future estimators, construction managers, project managers, supervisors and other project personnel involved in supervisory and managerial roles acquire an understanding of construction site safety. Even though they may not perform actual fieldworks, their safety knowledge and interactions with workers and other site personnel have a significant influence on jobsites. Carpenter et al., (2004), suggested that construction personnel, engineers and architectures should have an adequate safety & health knowledge in their academic studies. Tertiary safety education provides an opportunity to prepare future project personnel, engineers and workers for the construction jobsite and it can be used to supplement on-site training (Gambatese, 2003). Safety education and training at institutional level has substantial benefits to improve safety performance on construction jobsites

(Lin et al., 2011). It offers a passport to healthy and safe work in construction sites. Some construction management programs already incorporate safety education into their curricula; however, it is not generally considered a high priority (Jaeger and Adair, 2012). Safety subject has not been paid attention in universities; consequently, students enter the construction sites with insufficient safety knowledge and often perform unsafe actions. Most institutional safety programs, which consider safety matters in isolation with real construction activities or do not effectively represent the dynamic sequencing of safety procedures. These education programs tend to focus on a critical examination of safety problems rather than transfer right safety knowledge to students. Furthermore, there has been less attention to incorporating culture of safety content into the education of construction professionals. Petersen et al., (2008), reviewed that the concept of health and safety had not been sufficiently accepted and integrated into courses due to a lack of support from the construction departments and cohesion among academic staff.

A further limitation of construction education is limited students' engagement and motivation. Moreover, due to the nature of construction activities, safety training and education has to take place in (hands-off) off-site environments, where learners can only listen and watch without actively participating (Akeem et al., 2015). Interviews with educators and safety experts revealed that construction safety courses typically use two dimensional images and videos to represent site environments. Videos are partially effective in assisting students in visualizing complex construction tasks, methods and environment. However, students cannot interact with the video environment, they thus play a passive role in their learning and cannot perceive and obtain job hazard and risk information. Teizer et al., (2013) revealed that conventional teacher-student classroom settings were ineffective to engage and motivate students to access health and safety knowledge. As stated by Cherrett et al., (2009), traditional lecture based courses fail to recreate the dynamic realities of managing on site, and therefore do not sufficiently support deeper cognitive learning. Although safety education is important in promoting safe and healthy construction work environments, current pedagogical methods and tools at tertiary level are unable to provide students with adequate and hands-on safety knowledge and experience. In other words, engineering education institutions face the challenges of creating pedagogical tools that enable future engineers to meet on-site health and safety requirements. There is therefore a real need to develop an effective experiential safety education system at tertiary level that can improve students' motivation and engagement in order to achieve the education goals.

2.5. Advanced ICTs in Construction and Education

Recently, advanced ICTs have been applied and proven the beneficial in various disciplines. ICTs can improve the educational access process, strengthen the relevance of learning concepts, raise educational quality and make teaching and learning more engaging, active and motivating by connecting to real life. As stated by Behzadan and Kamat, (2011), advanced ICTs 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. Computer, information and visualization technologies have been advocated to provide support for construction safety education (Guo et al., 2012). It was evident that the capabilities of ICTs used in construction education have been constantly growing and evolving. From this point of view, this section investigates the use of advanced ICTs (including semantic wiki, ontology, social network analysis, BIM, VR, AR and mobile computing) in construction and education in order to motivate the establishment of the research objectives.

2.5.1. Social Networking

2.5.1.1. Semantic Wiki

Unlike some content management systems, wiki websites offer sharable environment that allow visitors to easily add, remove, edit, and change available content in a collaborative manner without using any complex commands or learning programming language (Mills, 2007). West and West, (2009) have found in their review that Wiki could support dynamic online communication where wiki customers could write, discuss, comment, edit and evaluate information. Furthermore, wiki system are used for many different purposes such as database for research and writing, information management, collaborative tool for documents needed to update frequently due to the free expandable collection of interlink web pages or storing and modifying information functions (Sofia Pereira and Soares, 2007). Buffa et al., (2008) proposed sweet Wiki that took the advantages of the wiki and the semantic web technologies to provide information to user actively. Sweet Wiki is not only formalized and reused information based on semantic searching and navigation but also support knowledge relationships between searching keywords and the results through semantic tagging. Obviously, semantic wiki technique would be meaningful in information sharing and knowledge exchange.

2.5.1.2. Ontology Application

An ontology is a representation model which defines concepts, attributes and relations with explicit specifications that could solve the problems of ambiguity in knowledge sharing and reuse (Shih et al., 2011). According to Rezgui, (2006) ontology plays a critical role in proposing knowledge environment and providing a semantic referential to ensure relevance, accuracy, and complete of information. Lima et al., (2005) suggested e-COGNOS that applied ontology as the main feature of platform provided a formal representation of knowledge domain with an effective means. Reusable ontology is thus more important for information integration, knowledge-level interoperation, and knowledge base development (Farquhar et al., 1997). Tudorache and Noy, (2007) developed Protégé system as an open-source platform that provides a growing user community with a suite of tools to construct domain model and knowledge based applications with ontologies. The Protégé system enables users to not only establish and populate ontologies included a set of classes organized in a subsumption hierarchy to represent a domain's salient concepts and their properties and relationships but also build ontologies for the semantic web consisted of description of classes, properties and their instances. Lu et al., (2015) developed ontology-based knowledge modeling namely, CSCOntology that can effectively support construction safety checking processes. In summary, ontology is potential powerful tool to facilitate knowledge sharing, reusing and knowledge acquisition.

2.5.1.3. Social Network Analysis (SNA)

Because of the computer science development, social networking has become very popular and opened a new era where communication and information sharing among people become easier and faster than ever. Social networks are increasingly attracting the attention of both academia and industry by their convenience and affordances. The value of SNA has been verified through various applications and domains such as Facebook, YouTube, LinkedIn, etc. Millions of people use social networking sites to connect, share, communicate their interests as well as integrate social network into their daily practice (boyd and Ellison, 2007b). Social networking is potentially powerful tool to engage, motivate user to share, store, update and manage information (Eysenbach, 2008); and plays important role in exchanging resources among partners which have been applied in many diversified area (Kim et al., 2011). Moreover, Richter and Dawley, (2009) emphasized social networks as great tool in the teaching and learning process while Hu and Racherla, (2008), claimed that social networking is an effective diagnostic method to analysis the nature and pattern of relationships between particular domains.

In construction, the integrated classical project management concepts and social network science theory (Chinowsky et al., 2008) or the using social network as strategic tool for managing construction project (Ling and Li, 2012) has brought abundant efficiencies in construction project management. Social network systems evidently provide a great amount of useful information with lowest effort in term of cost (Kim et al., 2011) as well as a systematic and meaning data by mapping and analyzing relationships among users (Racherla and Hu, 2010). As shown by Alsamadani et al., (2012), social network analysis (SNA) was utilized to: 1) qualify the level of safety communication within small and medium-sized construction crews; 2) model the communication patterns and trends within these crews; and 3) analyse the characteristics of high and low safety performance crews with regard to safety communication on construction worksites. Furthermore, SNA models have been adapted and used to increase collaboration and classification within construction organizations and enhance the project team performance (Chinowsky et al., 2010). There are 389 overseas project executed by Korean firms over last two decades involving collaboration network with the SNA approach (Park et al., 2011). Zhang and El-Diraby, (2012) developed a construction communication portal based social networking to classify and link engineers to roles, processes, and work items and also coordinate information and knowledge flow in the ACE industry.

At educational level, online social networking platform have offered great communication channels for students to exchange, share, store, update and manage information and knowledge. SNA has become more common in professional, educational and scholarly settings in colleges and universities. According to Ajjan and Hartshorne, (2008) the ease of use, usefulness and compatibility of social network can improve students' interaction, learning and satisfaction. The social network sites can be used to establish a series of academic links and to foster cooperation and collaboration in the higher education classroom. Veletsianos and Kimmons, (2013), have found in their review that scholars have adopted the social network to: 1) share information, resources and media relating to the educational lessons; 2) request supports from and offer suggestions to other scholars; 3) motivate learners' commentary and participation; 4) enhance students' learning engagement; and 5) network and make connections with others.

Nowadays, the SNA approach has been received attention within the social sciences, economics and engineering industries as well as tertiary education. Extending this idea, utilizing the state-of-the-art of SNA for better communication and representation is a necessity both in construction education in general and in safety education in specific. In spite of providing the conduit for users to engagingly share their knowledge and experiences and communicate with others, SNA seems chaotic due to no predefined index, no knowledge managers and no structure. This causes some problems related with data repository and knowledge management. Previous literature review indicates that semantic wiki and ontology can potentially play a key role to facilitate a hierarchical view of information and knowledge management. Therefore, the integration of semantic wiki and ontology with social network would bring a powerful and strong tool in sharing, storing, retrieving and reusing huge dynamic information as well as managing complex knowledge.

2.5.2. Visualization technology

2.5.2.1. Building Information Modeling (BIM)

The concept of BIM emerged in the early 2000s. However, there is no standard definition for BIM. In order to comprehensively understand about BIM, various definition for BIM given by different professionals and organizations are listed as table 2-2:

Table 2-2. BIM definition

Organization	BIM definition
Autodesk (Autodesk, 2008)	BIM is an intelligent model-based process that provides insight to help you plan, design, construct and manage buildings and infrastructure
US National BIM standard (States, 2008)	BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decision-makings during the life cycle; defined as existing from earliest conception to demolition process.

Bentley (Bentley, 2009)	BIM is a new way of approaching the design and documentation of building projects - Building - the entire lifecycle of the building is considered (design/ build/ operations) - Information - all information about the building and its lifecycle is included - Modeling - defining and simulating the building, its delivery, and operation using integrated tools
Tekla (Company, 2009)	BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition.
Nemestschek Allplan (Allplan, 2013)	BIM is a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows. BIM describes the process and method of creating and maintaining a digital data model in the form of a virtual, three dimensional building.
BuildingSMART (BuildingSmart, 2009)	BIM is a digital representation of physical and functional characteristics of a facility. A building information modeling is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition process.

In general, BIM has great potentials to improve construction productivity by providing the 3D digital representation of physical and functional characteristics of construction project. During last decade, numerous of studies adapting BIM were published in different educational and industrial settings. BIM was widely used to assist designers, engineers and practitioners by enhancing visualization, communication, collaboration and integration with other technologies for construction improvement (Eastman et al., 2011). For instance, BIM-based application ensures timely inspection (Chen and Luo, 2014), visualizes a whole construction process to support decision-making (Kiviniemi, 2011), education & training (Joannides et al., 2012) and cost estimation (Lawrence et al., 2014), etc. Succar, (2009) and Ku and Taiebat, (2011), also pointed out that leverage of BIM can reduce the project cost, time and construction industry fragmentation as well as improve the productivity, quality and environmental sustainability. BIMSmart mentioned that "BIM helps us to identify and mitigate risk, maximise opportunities and hence, increase project delivery certainty". Jung and Joo, (2011), investigated main benefits and current variables of BIM implementation, and conclude that BIM is considered as a promising tool for the future of the construction industry.

Particularly, numerous studies have indicated significantly possibilities for improving construction safety using BIM tools (Zhang and Hu, 2011; Zhou et al., 2012). Zhang et al., (2015); Zhang et al., (2013) developed the BIM based safety rule checking system that can automatically detect and identify potential hazards, then suggest corresponding preventive methods and measures during construction planning phase. The 4D structural information based BIM system suggested by Hu and Zhang, (2011); Zhang and Hu, (2011), which proposed a new approach for conflict and safety analysis during construction provided significant reference supports that can enhance building safety including: 1) a unique information source for various applications; 2) representation for construction procedure and any changes; 3) the potential analysis and management; and 4) 4D space-time site model and collision detectionIn an attempt to reduce hazards. Riaz et al., (2014) implemented the integration BIM with sensor technology to provide improved visualization for effective monitoring of confined spaces on construction sites. It can be concluded that BIM can be a potential tool for safety improvement.

In construction education, BIM can be applied as a learning tool that can support project teams in familiarizing with construction tasks in a safety environment (Lu et al., 2012). Construction students can effectively acquire necessary skills through a real-life practice simulation model of BIM, instead of going to real construction sites. Some studies have advocated that civil engineering education should use BIM in the curricula (Sacks and Barak, 2010; Salin et al., 2014; Yan, 2010). Peterson et al., (2011) developed the BIM based project management tools support teachers to design more realistic project based class assignments that can help students to obtain real construction experience easily and conveniently. This research illustrates that the integration of BIM-based project management into university curricula has significantly increased construction students' project management skills and abilities. Furthermore, a research has conducted the use of BIM and game simulation for the development of on-site safety education and training tools (Park and Kim, 2013). Hedges and Denzer, (2008) found that BIM promotes clearly defined roles in the group-based classroom management approach of team learning, which encourages students pursue deeper explorations into structural engineering.

Even though the widespread adoption of BIM in construction, the utilization of BIM in safety education is considerably low. Consequently, very few studies have considered how BIM can be used to improve the effectiveness and efficiency of construction safety education. Hence, this motivates the potential use of BIM for enhancing safety & health education at tertiary level within the research scope.

2.5.2.2. Virtual reality (VR)

Virtual reality (VR) which has emerged and been applied in construction management several decades is a technology that allows users explore 3D interactive environments in real time (Sampaio et al., 2010). VR is used to provide interactive learning experiences through real time computer generated imagery. As pointed out by Koskela et al., (2005) virtual environments effectively compliment traditional higher education. VR technologies have been extensively utilized successfully applied for training professionals in high-risk occupations such as pilots, surgeons and nuclear power plant operations.

Several studies have considered VR as a tool to compliment traditional construction education. Messner et al., (2003) used 4D CAD and VR to supplement construction through an immersive project display. Perdomo et al., (2005) addressed the impact of 3D visualization and its advantages over traditional construction approaches. Price et al., (2008) considered a unique approach, utilizing interactive videos for teaching safety and health pertaining to street traffic engineering. Sampaio et al., (2010) explored the potential and applicability of 3D modelling and visualization technology in architectural, engineering and construction education. Lin et al., (2011) conducted a pilot study of a 3D game environment for construction safety education at institutional level. The game enabled university students to assume the role of a safety inspector and walk through the construction site to identify potential hazards. Abulrub et al., (2011) considered using 3D photorealistic virtual environments based on CAD, laser scanning and photogrammetry data sources for engineering education. Their study found that VR encouraged active participation and amplified student interactions. Furthermore, Li et al., (2012) developed a new safety assessment method, namely 4D interactive safety assessment, which used virtual scenarios in educating, training and assessing construction workers. The system presented workers with 3D virtual risk scenarios relating to their project and range of possible for selection. Dickinson et al., (2011) developed a serious game focusing on teaching trench safety & health. Students were capable of interacting and experiencing with the game by walking freely through 3D environments.

Additionally, social VR, which provides an online multiuser and collaboration simulation, role-playing learning and real-time teaching plays an important role in promoting higher education. According to Abdellatif, (2008) social VR could effectively affect the way student access knowledge by supporting distance learning which reaches a wide audience and enables independence of place and time at lower cost compared to traditional approach. Merrick et al., (2011) stated that social VR is an innovative platform that can support human-human collaboration and human-computer co-creativity in construction. In addition, social VR not only provided students with the experiential learning but also enhanced collaborative information and knowledge sharing (Ku and Mahabaleshwarkar, 2011). Messinger et al., (2009) emphasized that the social VR environments offer a new opportunity for teaching and training by providing rich real-time form of social and economic interactions with abundant applications and subsequent implications. Furthermore, collaborative VR influenced the way people do their work and communicate as well as brought about new opportunities on learning and teaching processes (Cheong, 2010). There are several social VR environments to available for the public including There (2003) , Worlds (2003), Second Life (SL) (2003) that could support experiential learning very well. The most prominent application of 3D virtual worlds is SL, which provides a place to connect many people to explore knowledge, and gain practical experiences as well. SL developed by Linden lab has much greater potentials both in terms of teaching and learning on construction safety & health (Jamaludin et al., 2009). Collaborative VR of SL is excellent tool, providing a rich communication, virtual collaboration, and 3D content that allows students to interact with each other and with virtual environment using enactive role-play avatars (Andreas et al., 2010; Hoobs et al., 2006). Moreover, Arain and Burkle, (2011), indicated that virtual world of SL can improve quality of understanding of real life issues in construction project management. It is conduced that social VR provides students with an experiential and spatial learning within 3D interactive virtual environment.

The integration of BIM and VR enables to provide students and trainees with a high realistic condition of construction sites within an immersive virtual environment. Rüppel and Schatz, (2010), considered using BIM based virtual training environment for fire-fighters. Wang et al., (2014), developed the BIM based virtual environment to address several key issues for building management. Their study integrated BIM with serious game based VR that provided timely two-way information flow and its applications during the emergency and allowed users to conveniently and simply enhance evacuation awareness. From this point of view, VR in conjunction with BIM would be a powerful tool that can improve architecture and the built environment as well as construction safety (Brouchoud, 2014).

2.5.2.3. Augmented reality (AR)

Augmented Reality (AR) is a technology where the additional information generated by a computer is inserted into the users' view of a real world scene (Wang and Schnabel, 2008). According to Azuma, (1997), AR was defined as a system identified by three characteristics: 1) combining the real and the virtual; 2) being interactive in real time and; 3) being registered in 3D. AR supplements the real world with relevant synthetic data, allowing real and digital objects to coexist in an augmented space that enables real time interaction between the users, real objects and virtual contents (Siltanen, 2012). AR enhances the visualization and increase users' comprehension.

Current research has shown that AR has the great potential to contribute how the site manager, construction worker, etc. can interact and experience their surrounding environment. Numerous studies have developed AR based applications to supplement the traditional construction and improve the productivity. Wang and Dunston, (2006) found that the spatial cognition benefits of AR CAD against the benchmark of the cognition cost involved in using only the viewing functionalities in standard AutoCAD. In interior design, AR enables users to effectively evaluate how virtual furniture overlap and fit in the room (Eck, 2012; Urbanist, 2014). AR system was employed to cooperatively assist a reinforcement bar arrangement (Yabuki and Li, 2007). Talmaki et al., (2010), used AR to provide the operator with virtual positions and layouts of underground infrastructure that can mitigated undesired damages and accidents. The VTT AR research team considered AR for virtualizing the complex components of New Hotel project during planning phase (Siltanen, 2012). Can, (2012) developed a mobile based AR + BIM to support real-time communication in order to improve the efficiency and safety of field personal in the Crossrail project, UK. Park et al., (2013), explored the potentials of using BIM, AR and ontology to enable proactive reduction of the defect occurrence during construction process that could greatly improve current defect management practice in construction industry. A new approach integrating AR with photogrammetry and augmented virtuality was implemented by Hou et al (2014) to enhance facility management for the Liquefied Natural Gas (LNG) project (Hou et al., 2014). Kwon et al., (2014) combined AR with BIM and image-matching for automatic error and omission detection that could effectively improve current manual based defect management process at construction sites.

The potential benefits of AR have also been considered in education and training. As a learning tool, AR supports constructivist and discovery based learning; enable students to take control of their own learning process. According to Yuen et al., (2011) AR tools can: 1) engage and motivate students to explore learning lessons as well as stimulate their creativity; 2) develop authentic educational environment to enhance collaboration between leaners and educators; and 3) improve experiential learning through virtual objects overlapping real environment. Shirazi and Behzadan, (2013b), developed a mobile AR based learning system in classroom settings. They found that AR motivates students to: 1) enhance the contents of their textbooks with multimedia and virtual objects and; 2) interact with context-aware simulated animations. As observed by Behzadan et al., (2011), a collaborative AR based modelling environment assisted students develop a comprehensive understanding of construction equipment, processes and operational safety. An innovative approach utilized AR marker-book for heavy construction equipment education (Behzadan and Kamat, 2012). Vassigh et al., (2014), used

AR for collaborative learning in building sciences that could promote conceptual thinking and improve learning in ACE students. In assembly training, Wang and Dunston, (2007), developed an AR based training system in which a novice heavy equipment operator was trained in a real worksite environment populated with virtual materials and instructions. AR provided practitioners with a higher level of immersion and interaction with spatial awareness that could significantly facilitate piping assembly (Hou et al., 2013). AR's possibilities for construction are endless. Future technological developments will enable greater opportunities for AR in ACE (Abboud, 2014).

Despite these advantages and potentials, limited research efforts have been directed towards using AR to support and enhance the construction safety education. This dissertation thus considers AR as a powerful tool in order to improve construction safety education.

2.5.3. Mobile computing

Over the past few years, mobile devices are rapidly becoming mainstream in today's world due to their immediacy, adaptability and cost effectiveness (Yang et al., 2013). The advent of mobile computing (MC) has recently garnered substantial interest in various disciplines. Many researches and educators from institution perspective have recognized the potentially pervasive and ubiquitous nature of mobile technology. Facer et al., (2004), identified MC as a potentially powerful tool in supporting the development of learning communities offering interactive & experiential learning and promoting the development of meta-level thinking skills. Mobile devices help students easily and conveniently access course content and interact with teachers and other colleagues. As stated by Cobcroft et al., (2006), mobile learning addresses students' requirements for flexibility and ubiquity and engages them in creative, collaborative, critical and communicative activity. The features of mobile devices are four fold (Cheon et al., 2012; Churchill et al., 2012):

- Portability: ability to move a device within a learning environment or to different locations with ease
- Versatility: ability to find, gather and respond to real or simulated data
- Connectivity: ability to access a variety of information anytime and anywhere
- Interactivity: ability for information exchanging, sharing, managing and collaborating between users

Based on these features, MC devices which have become ubiquitous in colleges and universities, would motivate and engage learners with constant connectivity, foster collaborative and authentic learning and enable interactive and experiential learning (Gikas and Grant, 2013). A huge amount of research efforts have applied MC and proven its advantages in higher education. Noguera et al., (2013), developed a novel anatomy application for mobile device to provide students with interactive 3D visualizations of imaging. This mobile application is a promising and attractive tool for studying anatomy and manual therapy to enhance learning outcomes at tertiary level. A mobile-assisted reading system was implemented by Lin, (2014) to improve language learners' linguistic proficiency and abilities. Sandberg et al., (2011), proposed the mobile technology could improve the English learning for primary school students.

In construction, mobile and pervasive computing has been considered as a potential tool to improve our industry productivity. Consequently, numerous studies have conducted how MC has led to new ways for engineers and constructors to carry out their operations. Chen and Kamara, (2011), suggested a framework for using MC for information management on construction sites. Anumba and Wang, (2012), presented a comprehensive reference volume to the state-of-the-art in mobile and pervasive computing in construction. Other prominent studies include, Park et al., (2013) and Kwon et al., (2014), who developed a mobile defect management system, and Park and Kim, (2013) proposing a site safety management system utilizing mobile AR for locating and registering on-site risks. Anumba et al., (2012), integrated mobile technology with semantic web to support context-aware information and services in the construction sector. Mobile computing based on-site construction management system implemented by Kim et al., (2013) provided engineers with site monitoring, task management and real-time information sharing that improved the existing management processes as well as construction productivity. Williams et al., (2014), combined mobile AR with BIM to develop an innovative method that allowed ACEO practitioners to easily access their data and BIM models within mobile AR environment.

Extending this idea, numerous researches have been directed towards using MC in an attempt to enhance the construction education. Many efforts have pointed out the benefits of mobile technology to support construction learning and teaching process. As stated by Valk et al., (2010), MC learning could meet the needs of students and improve access to education as well as promote the new opening learning and serve society better. Fuertes et al., (2008) suggested mobile leaning in a real-word construction engineering scenario to provide basic knowledge of health and safety risks to students. The implementation of Ipad in the “Hands-on” construction materials and methods facilitated the communication between learners and instructors, increased understanding of construction safety and enhanced problem-solving skills for students (Cline and Davis, 2013). Shirazi and Behzadan, (2013b), incorporated mobile context-aware visual simulation in construction engineering and management education. This mobile approach was considered as an effective educational platform that could improve the quality of education and training in engineering and science (Le et al., 2015b). Redondo et al., (2014), conducted the educational research focusing on the use of mobile learning in the field of Architecture and Building Construction. They concluded that the mobile learning system motivated and engaged students for better understanding for architectural knowledge that could be effective in learning processes as a complement to conventional training. Therefore, it seems that mobile learning plays a critical role in conducting safety education activities.

2.6. Need for integrating advance ICTs with experiential learning for safety education

The "cone of experience" theory developed by Dale, (1954) is a model that incorporates several theories related to instructional design and learning process. Fig. 2-2 illustrates the cone that rates for various methods of teaching. The further progressing down the cone, the greater learning and the more knowledge are retained. The least effective method at the top involves learning from reading and hearing whilst the most effective methods at bottom derives from real and direct purposeful experiences. Learning by doing was known as an interactive and experiential learning to result in up to 90% knowledge retention. In the context of design and education engineering, this theory presents a new concept how education can be designed and delivered. Through this theory, successful pedagogical tools are defined as those can provide an effectively interactive and experiential learning environment where students play an active role to obtain the knowledge and practical experience. In other words, the higher of level of interactive and experiential of education system, the more knowledge we can gain. Particularly, for the construction safety education, an experiential and interactive education plays a very important role to ensure graduates enter the construction industry with adequate safety knowledge and sufficient safety awareness.

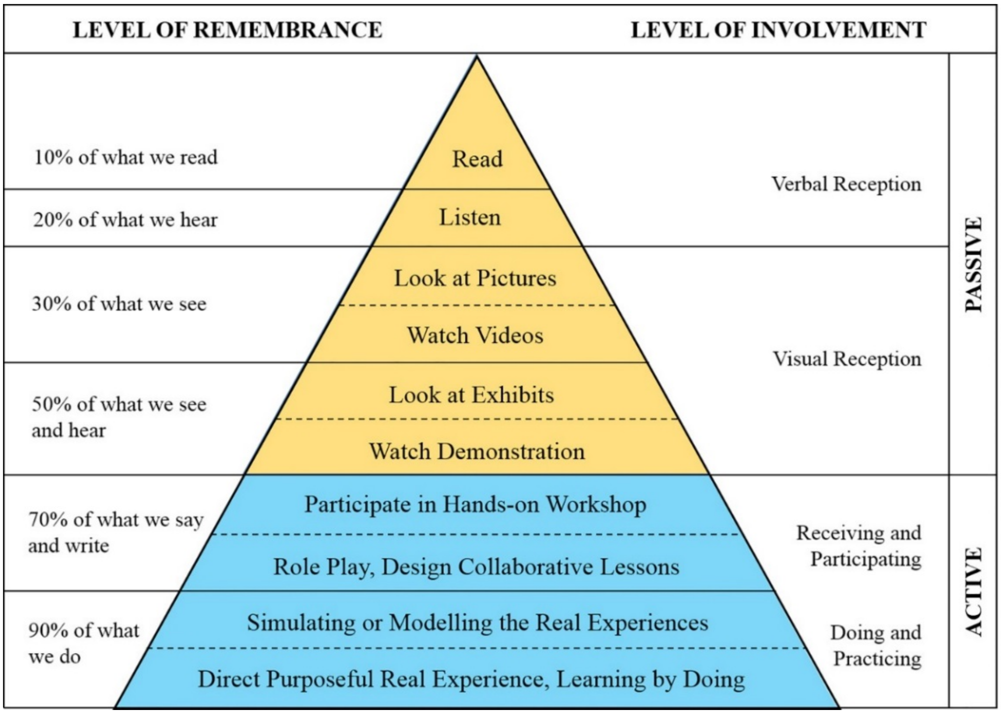


Fig. 2-2 Dale’s cone of experience (Dale, 1954)

As illustrated in Fig. 2-3, Zappa, (2012) examined a few technologies that could play an important role over next 30 years. This info-graphic depicts a map of education technology through 2040 that emphasize how technology will change education. Next five years, Gamification and Open of Information are main issues where teaching and learning is going to be social. These two trends showed that disseminating the information outside the physical silos of schools and classroom and offering feedback and assessment anywhere could help students acquire knowledge conveniently. Over next 20 years, Digitized Classrooms, Disintermediation, Tangible Computing and Virtual/ Physical Studios are critical technologies for education that allow students cope with a perpetually changing world. Specially, the visualization, one of a main channel of technologies, attempts to organize a serial of emerging technologies that are likely influence education in the upcoming decades. The visualization would offer a novel pedagogical method that provides learners with practical knowledge and closed-to-reality experience. As such, virtualization teaching and learning models using mobile platform tend to replace traditional education methods. Consequently, the open and mobile visual platforms obviously become promising tools at the current as well as for the future education.

With regard to construction education, the integrating advance ICTs such as social network, visualization (BIM, VR, AR) and mobile computing into interactive and experiential learning would obviously make a new powerful potential tool that could help students acquire necessary knowledge and practical experience in creative way. Therefore, the dissertation is directed towards developing an experiential and interactive education system for construction safety by utilizing the advancements of visualization technology and mobile computing

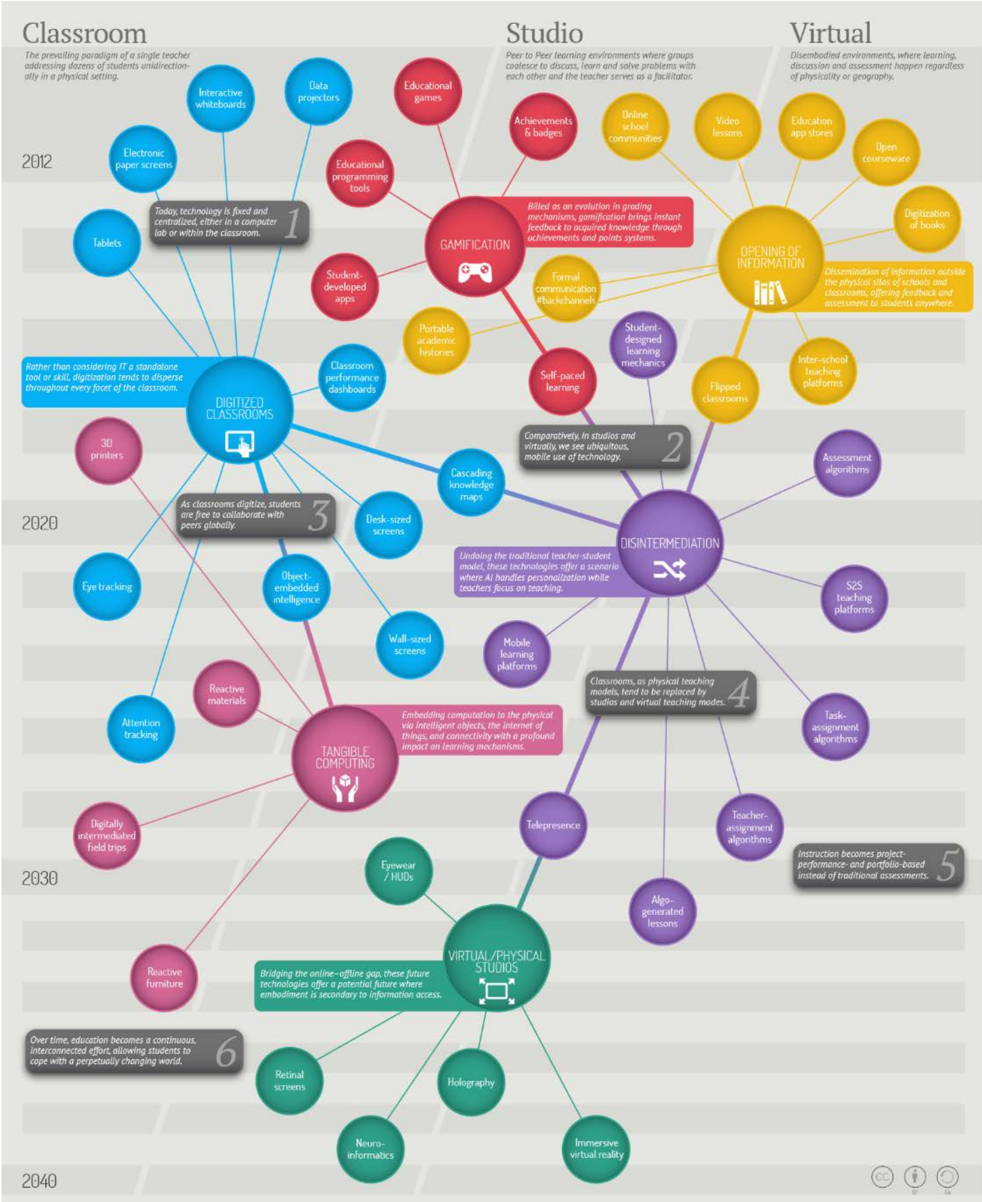


Fig. 2-3 Envisioning the future of education technology (Zappa, 2012)

2.7. Learning terminology classification

In order to present the research more clearly, some terminologies including interactive learning, experiential learning, problem-based learning, learning by doing and cognitive learning are defined as follows.

- Interactive learning: is a pedagogical approach that incorporates SNS and wireless networks, smartphones, etc. into course design and delivery (Wikipedia, 2014).
- Experiential learning: As stated by Kolb, (1984) 'Experiential learning is the process whereby knowledge is created through the transformation of experience'. In other words, knowledge is obtained through direct experiences.
- Problem-based learning (PBL): is an instructional method of hands-on and active learning in which students learn through facilitated real-world problems (Hmelo-Silver, 2004). PBL is part of experiential learning.
- Learning by doing (cased-based learning): is an approach where students gain the knowledge or skills through direct experience (Wu et al., 2012). This approach allows students to take greater responsibility and a more active role in learning process.
- Cognitive learning: is a process of acquiring knowledge and understanding through thought, experience and senses (Lucas and Thabet, 2008).

2.8. Summary

Lack of experience and knowledge on safety is found to be a major root cause of construction errors and unsafe work performances causing serious injuries and accidents. As such, safety education at tertiary level has become more important to the day-to-day construction industry. Construction students are required to comprehensively understand the fundamentals of jobsite safety. Promoting safety education and preparing the future workforce for healthier and safer work environment is obviously a critical goal among other highest priorities in construction. However, current pedagogical methods for construction safety are not considered as high priority and lack of interactive and experiential learning. Very few universities incorporate safety programmes into their construction curriculum; and if have, the safety courses tend to be passive, boring and insufficient motivating for learners. Students could not well obtain and build up safety knowledge during education process. Then, graduates enter the construction sites with inadequate safety knowledge experience and may perform unsafe acts causing accidents and injuries.

The literature review reveals that researches have explored the potentials of SNS, BIM, VR, AR and MC in construction and various disciplines. According to the NMC Horizon Report (Consortium, 2011; Consortium and Initiative, 2012), advanced ICTs such as SNS, VR, AR and MC are likely to assist educators in meeting educational objectives more than traditional lectures alone as conducted currently in construction. Nevertheless, few studies have focused on their potentials in construction safety education. Behzadan et al., (2011), emphasized the use of VR and AR techniques for teaching can effectively deliver construction equipment, process and operational safety knowledge to students. Additionally, Lin et al., (2011), conducted a pilot study assessing the potentials of an interactive safety inspector game based on VR. Aside from these studies, barely any research has adopted SNS, BIM, VR, AR, and MC or considered combining these technologies as learning tools to support tertiary construction safety education. Construction safety seems to lack of some powerful pedagogical tools that can help to achieve the educational objectives.

With this regard, this dissertation develops an interactive and experiential education system for construction safety by utilizing mobile computing based VR and AR, which facilitates education process and bridges the gap between real construction sites and the classroom. The system incorporates VR, AR and mobile computing advancements with an innovative proactive experiential learning approach, which link safety theory with practical experience. In this system, a novel safety pedagogical tool is implemented as shown in Fig. 2-4 including four steps. These are: 1) A social network model for sharing construction safety and health knowledge; 2) The VR and AR education content development; 3) A mobile-based VR and AR for construction safety education, and; 4) The system assessment. Firstly, a social network model is developed as a communication channel in which students and teachers can share, exchange and manage construction safety information and knowledge by using social network analysis, semantic wiki and ontology technologies. Consequently, safety information will be reused to develop VR and AR pedagogical scenarios for an interactive and experiential safety education. Next, the virtual safety contents from previous approach are retrieved to propose a mobile-based VR and AR for construction safety course that allow learner interact with immersive virtual environment to acquire practical safety experiences. This provides students and teachers with a great opportunity to access 3D safety information and knowledge anytime and anywhere. The effectiveness of the system is assessed by using subjective, objective and heuristics evaluation. The study demonstrates the mobile system partially motives and inspires students to acquire and gain the sufficient safety & health knowledge before entering construction sites.

The detail of the research is described in flowing charters. The major difference between the proposed approach in this study and the conventional methods is that the educational process shares and retrieves safety information through SNS as well as overlaps and visualizes knowledge through mobile-based BIM, VR and AR. Students are able to easily and conveniently understand and obtain safety knowledge without the ambiguity often encountered with traditional materials. Before entering to develop the system, next chapter completely reviews VR and AR for construction education and proposes a new approach utilizing VR and AR that shift safety education from "Listen and I will forget. See, and I may remember" to "Practice, and I understand".

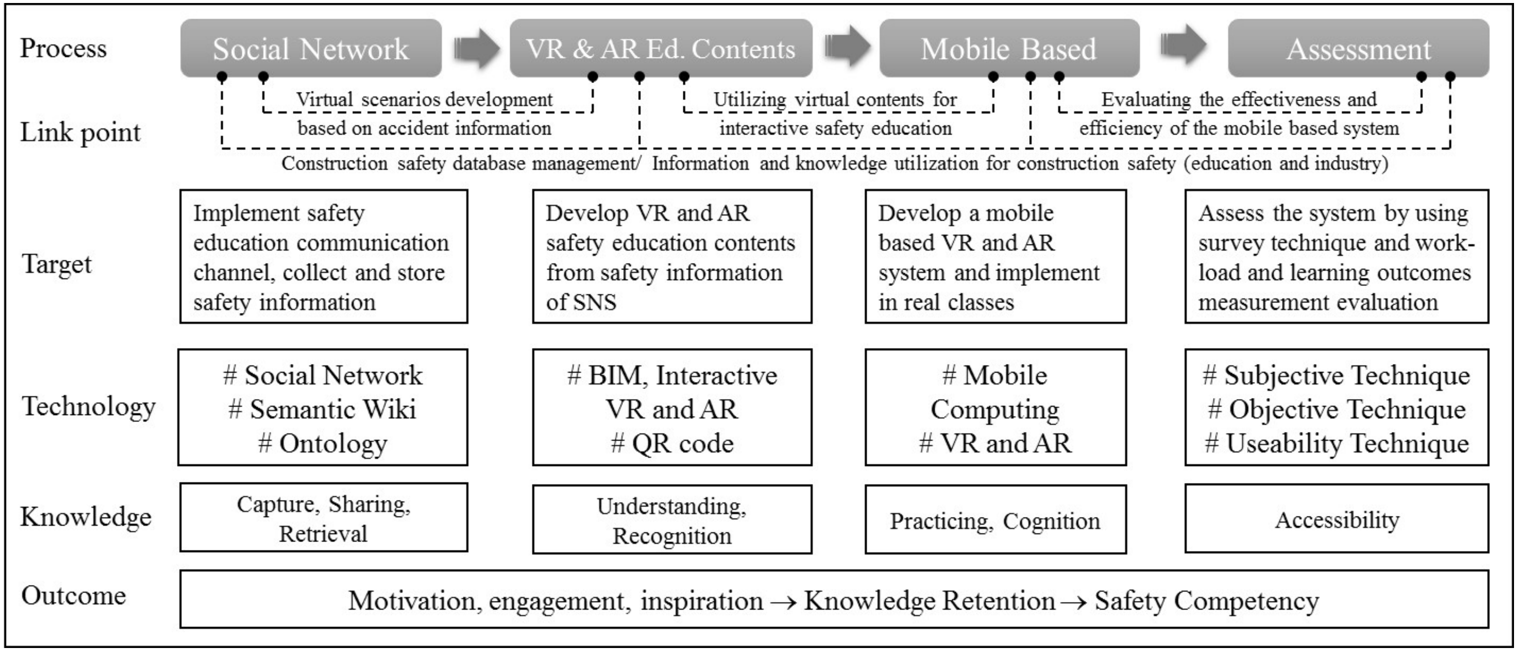


Fig. 2-4 An experiential and interactive education system for construction safety

3. Virtual Reality and Augmented Reality – A New Approach in Construction Safety Education

Safety is paramount for construction industry throughout the world. Human errors which contribute to more than half of construction accidents, could be proactively prevented by 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 constructions safety education. This chapter presents a new approach in construction safety education by utilizing VR and AR as the direction for the dissertation. The vison aligning teaching & learning strategies are examined in order to ensure the potential benefits of the new method. This approach shifts safety education towards “Listen and I will forget. See, and I may remember” to “Practice, and I understand”.

3.1. 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 (Zhao, 2014). 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 (Gambatese, 2003). Le and Park, (2012) emphasized that safety education at the tertiary level is one of the effective ways to enhance the graduates’ safety awareness. Also, interactive pedagogical programs offer higher level of competency and comprehension for obtaining knowledge, effectively transfer practical experience and enhance leaners’ learning outcome (Zhao and Lucas, 2014). As such, the 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 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 Technologies (ICTs) based learning. ICTs allow learners to have a support that facilitates the social-communication, visual aids, interaction and learning-by-doing. In term of construction safety education – the subject emphasizes much on the identification, analysis and control of work hazards as well as interpretation of safety regulation – ITCs have been becoming more and more important to transfer safety knowledge to learners. ITCs could assist students in developing and maintaining a high safety competency and practical skill level. Beyond this logic, Virtual Reality (VR) and Augmented Reality (AR) can 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 enable to practically experience on construction sites by interacting with virtual environment via mobile device touchscreen. Although, the advantages of VR and AR have been proven in construction education, very few studies have focused on the safety education at tertiary level.

This chapter presents a new construction safety education approach that utilizes Virtual Reality (VR) and Augmented Reality (AR). It includes two stages: 1) developing a vision; and 2) Carrying out the strategies for construction safety education; in order to direct for the dissertation. This new approach will not only prepare future construction personnel with safety competency but also make them more creative and ready for challenges of the current complicated construction projects.

3.2. Safety Information Transfer Issues at Tertiary Level

The effectiveness of safety information transfer from education programs allows leaners to become aware of on-site dangerous occurs 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. 3-1, 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 occur 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 the information loss between real data and educational information.

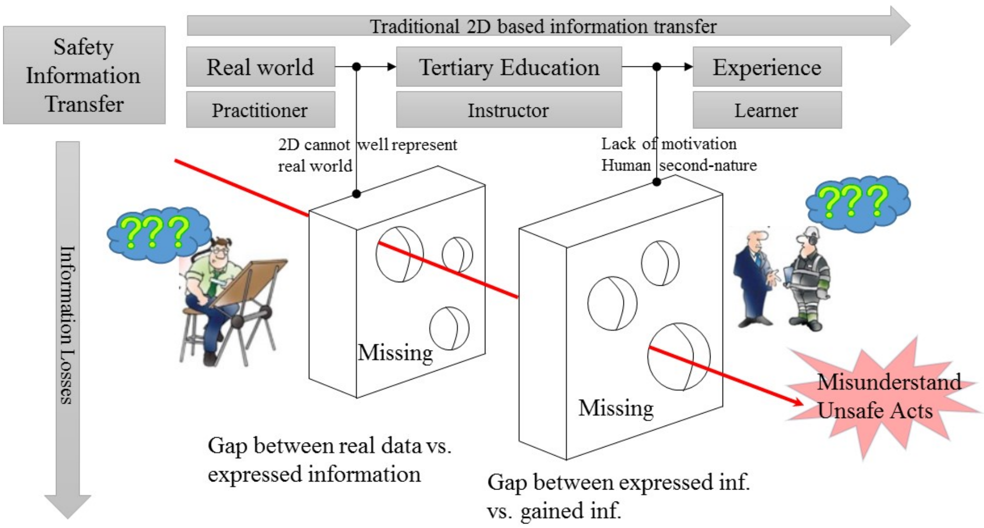


Fig. 3-1 Safety Information Transfer in Traditional Education

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 of 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.

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 and a lack of practical skills would perform unsafe procedures to meet the productivity demands (Chen et al., 2013). There is a big gap between the safety skills students acquire from schools with what the construction industry actually requires. 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.

3.3. 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 (Pour Rahimian et al., 2014). As such, the amount of necessary knowledge transfer to students has been huger and much more. Moreover, 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., (2015a) 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 (Kolb and Kolb, 2005). Particularly, regarding construction safety, learning outcomes in terms of safety knowledge retention and long-term memory have become critical factors to assure the 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 proactive 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 the 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.

3.4. An Innovative Approach in Construction Safety Education Utilizing Virtual & Augmented Reality

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. According to Glatter, (2015) VR is poised to be a new medium for medical education and dissemination of information. Furthermore, AR adding virtual contents to the physical real world has potential to offer a highly realistic situated learning experience and enhance leaners' psychomotor skills and understanding of complex causality in the medical area (Kamphuis et al., 2014). Particularly, Pour Rahimian et al., (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. 3-2, 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 represent 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 education 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.

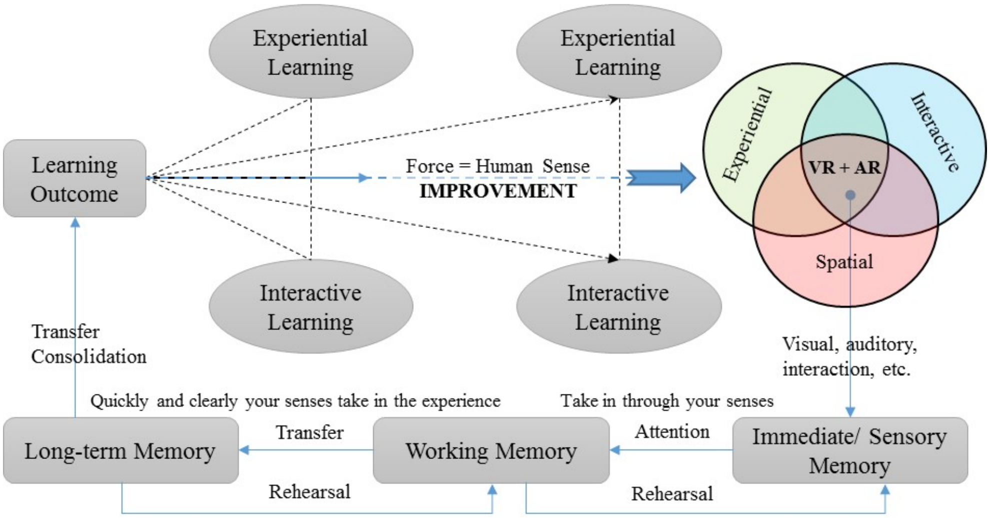


Fig. 3-2 The relationship between learning outcome and VR & AR technologies

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 (Pantelidis, 2010; Wu et al., 2013). Messner et al., (2003) 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., (2015c) 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), 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.

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 and gaining about different types of safety knowledge. As stated by Bhoir and Esmaeili, (2015), 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 provide students with higher quality education with long-lasting impacts (Shirazi and Behzadan, 2013a). 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 a new 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-centred; 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 and innovative approach encompasses all approaches 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 to a proactive (experiential and interactive) approach, from "Listen and I will forget. See, and I may remember" to "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 approach in construction safety education. However, it is important to explore how the use of VR/AR could be aligned with instructional and learning approaches in order to achieve the safety education objectives. As such, following section presents the main learning and teaching strategies for construction safety.

3.5. Learning and Teaching Approaches

3.5.1. 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) 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) 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 (Fonseca et al., 2015).

3.5.2. Stimulation of Motivation towards Safety Education

Students' engagement is a critical factor 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 of 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., (2011) 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), 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.

3.5.3. 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 approaches 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), 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., (2015a) allow 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.

3.5.4. Safety Attitude and Behaviour

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 (Hinze and Godfrey, 2006a). 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 the real experiences and acquire the safety competency by practicing virtual construction activities (Le et al., 2015c). Hou et al., (2015), 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. The VR/AR technology provides an interactive and experiential learning environment where students can practice construction tasks in order to gain the healthy attitudes and develop the safety behaviour. 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.

3.5.5. Implementation Strategy

Previous sections present the analyses and discussions on four implementation strategy aspects of using VR and AR for construction safety education. This section overall introduces the main aim of the dissertation that incorporates four aforementioned approaches through developing an interactive and experiential VR and AR education system. Fig. 3-3 depicts the implementation strategy for the study. Safety data and information are refined and covered to express knowledge through the VR and AR system. The system based on four criteria: spatial and situation awareness, safety attitude and behaviour, hazard identification and recognition, and stimulation of motivation towards safety education would transfer this express knowledge to students in order to help them to achieve safety competency. Leaners go through four steps including exploration (explore in immersive VR and AR environment), enjoyment (enjoy in VR and AR gaming, learning by doing), acquisition (acquire the necessary safety knowledge, long-term memory) and wisdom (perform safely when entering the construction industry).

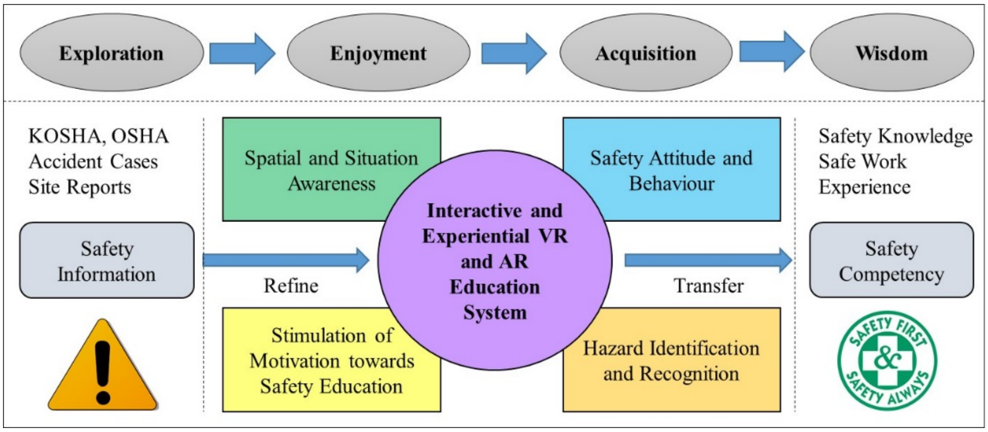


Fig. 3-3 Four aspects of Implementation strategy

3.6. Direct for the Dissertation

What and how do students learn construction safety in VR&AR environment? Via VR&AR environments, leaners can virtually manipulate, interact, experience a variety of learning objects and models, and acquire safety knowledge and practical skills. VR and AR mobile application allows students to quickly organize, search and evaluate safety data and information as well as effectively reflect this information through role-playing and authentic learning. Specially, VR and AR will bring a new revolution in construction safety education that can ensure graduates to gain sufficient safety knowledge and perform safely when entering in construction industry. In order to assess the value of this new and innovative approach, this section introduces the comprehensive development process of mobile-based VR and AR system for construction safety education. This whole process enables to effectively transfer hazard precursor, accident causes and safety information into education points in a mobile based VR and AR environment for leaners to practice.

As illustrated in Fig. 3-4, the dissertation structure includes four steps: safety information collection & education content design, VR & AR scenarios development, mobile-based VR & AR framework, and safety education & training application. Firstly, the social networking method would collect, refine and transfer accident data to safety information and store them in order to reuse and retrieve for education purposes. By integrating social network with ontology and semantic wiki, this approach creates a communication channel that allows users to share, search and update safety accident data and safety information easily and conveniently. Secondly, the information from first step is retrieved to create 3D safety educational and training scenarios for construction students. BIM and VR tools would simulate the 3D models and then, these models are encoded to develop the education features. Thirdly, an experiential and interactive education framework for construction safety is proposed by utilizing mobile-based VR and AR. The learning and teaching process would be explained such as how to use mobile-based approach for learning and teaching, what instructors and students should do, what kind of test leaners have to answer, etc. Lastly, the mobile-based prototype derived from VR & AR scenarios and the framework is developed and implemented with undergraduate students at Chung-Ang University. Students could experientially interact with instructors and lecture materials in order to effectively gain construction safety knowledge.

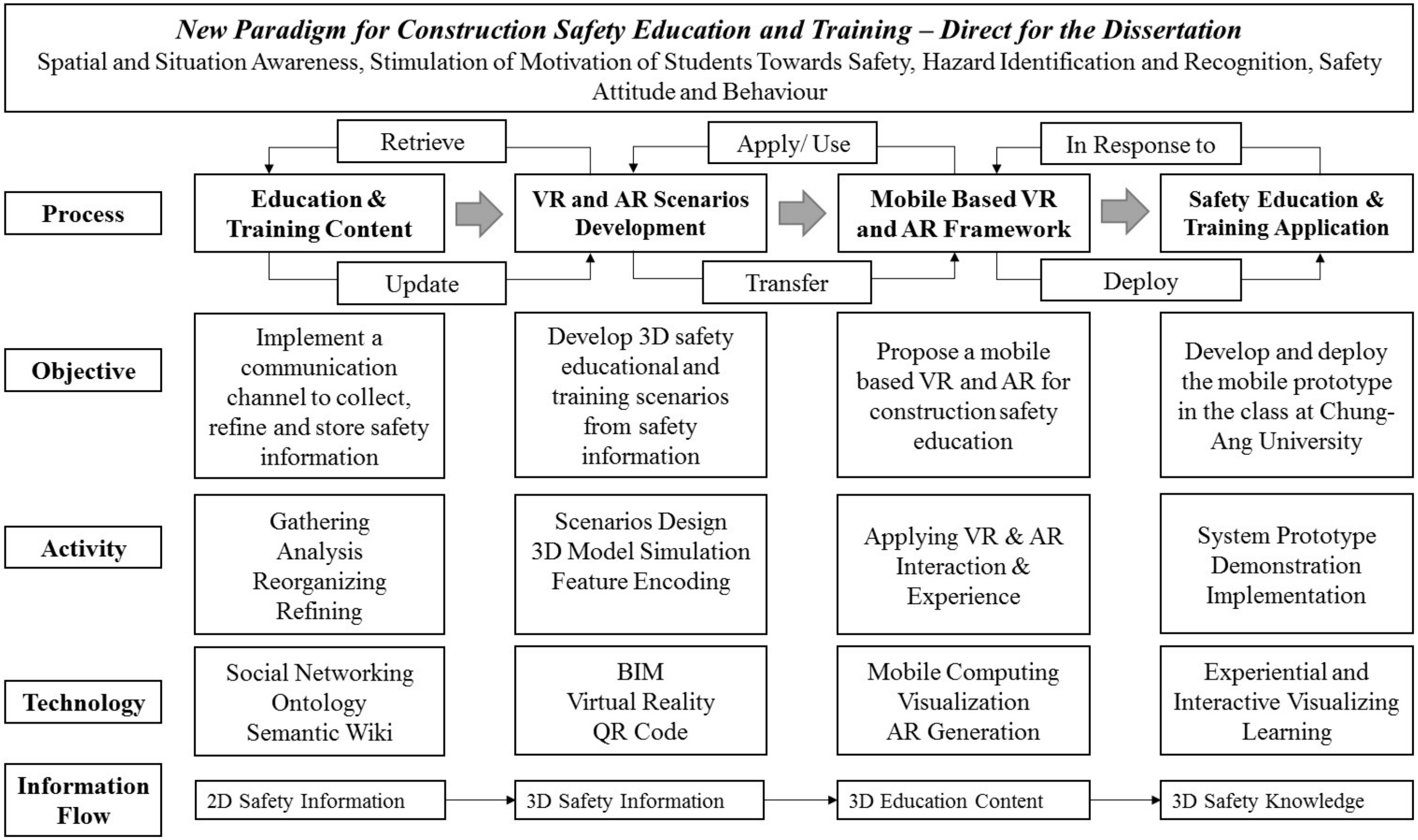


Fig. 3-4 Direct for the Dissertation

3.7. Summary

There are several methods to improve construction safety education such as on the-job training, mock-ups learning, and the use of VR & AR environment. However, due to the dangerous nature of construction sites, the on-the-job site and mock-ups learning cannot allow students to fully practice hazard-related tasks and experience construction consequences in the real world. In addition, these learning methods are costly and limit a number of students. Hence, the effectiveness of these pedagogical types is limited. In contrast, VR and AR based approach is considered as a powerful tool that can overcome the aforementioned limitations by providing learners an experiential and interactive environment. As such, this chapter presents a new approach in construction safety education – VR and AR – shifting from "Listen, and I will forget. See, and I may remember" towards "Practice, and I will understand". This new approach constitutes the philosophy of this dissertation by identifying the potential benefits of VR & AR and figuring out the learning and teaching strategies for construction safety. Through this, the dissertation structure is established including four stages:1) education & training contents to collect refine and store safety information; 2) VR & AR scenarios development to simulate 3D safety education models from information in previous stage; 3) mobile based VR and AR approach to develop the framework of using mobile based VR and AR for safety education; and 4) Mobile application implementation stage to deploy the new pedagogical method at department of architectural engineering, Chung-Ang University, Seoul, Korea. Following chapters explain in detail the dissertation.

4. A social networking for collecting, storing and sharing construction safety knowledge

This chapter describes the use of social network to collect safety data and convert them to safety knowledge in order to store, share safety & health knowledge, and retrieve safety information for the development of 3D educational contents. The Semantic Wiki and Ontology were used to integrate with social network to classify common construction accidents and to allow students and teachers conveniently to discuss, diagnose and figure out root causes, prevention methods of these accidents. The social network approach is considered as a key component in addressing and improving safety communication issues. Furthermore, through this approach, construction safety database would be established and updated constantly. The right safety information would be provided to right leaners at the right time. This is an initialization stage to develop a 3D virtual reality experiential education system for construction safety.

4.1. Framework of Social Network System for Collecting and Refining Safety and Health Information

The effective safety information collection and management are becoming more important to reduce dangerous occurrence of accidents as well as hazards and risks in the construction industry. However, the communication, capture and collection of the safety information are often fragmented and difficult to manage. As such, the main purpose of this chapter is to develop a social network system in order to not only establish a safety database for educational purpose but also enhance information sharing and knowledge exchange through a social communication channel at tertiary education. The key benefit of a social network system is that it does not require the authority expert as intermediary, which allows teachers and students to more direct access of data and information. As illustrated in Fig. 4-1, the disintermediation process properties of SNSS mobilizes and utilizes expert domains to take over the role of the intermediary and to help users to attain accurate safety information and knowledge. The SNSS is a broker between user and information, which enables the individual to play an active role in perception rather than just passively receiving impression from surroundings. Through this disintermediation process, the safety data are transferred to information using wiki editing, tagging, browsing, and linking, and the safety information is changed to the safety knowledge using ontology tagging and wiki editing. Then the safety knowledge will be available in the website for the use of specific safety knowledge including retrieving information for 3D safety models development.

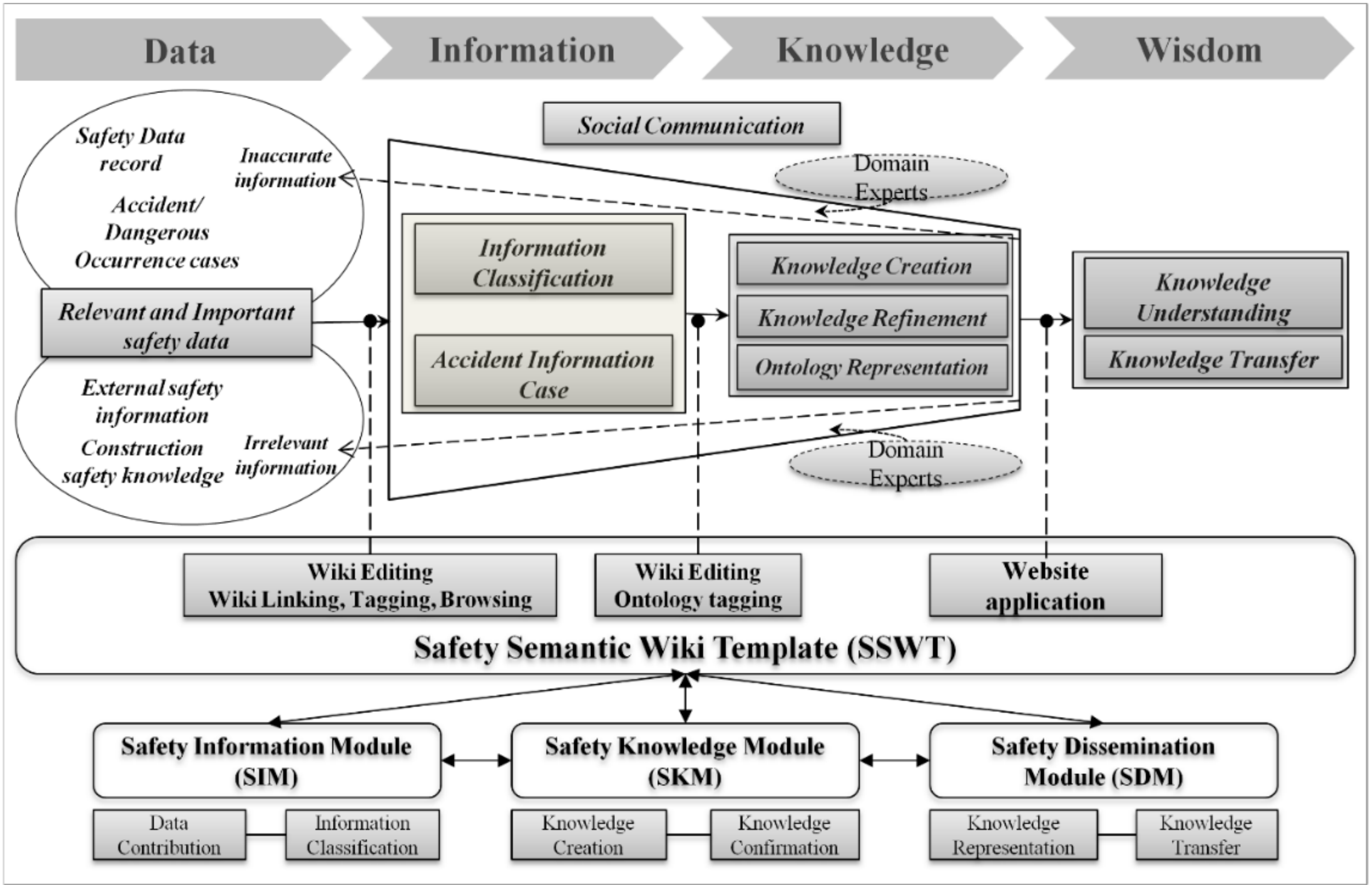


Fig. 4-1 The disintermediation process of SNSS

Unlike some knowledge management systems, the SNSS is structured under a semantic Wiki system as a bridge to link the following three modules: safety information module (SIM), safety knowledge module (SKM), and safety dissemination module (SDM), as illustrated in Fig. 7. The Safety Semantic Wiki Template (SSWT) is a backbone of the SNSS that is designed to support a flexible environment for information collection, knowledge creation and dissemination on construction safety. The SIM would convey relevant and important accident data to safety information by using the Wiki techniques of SSWT. By utilizing social experts, the SKM refines the comments on safe information for safety knowledge achievement and ontology representation. The SDM where safety knowledge would present on the web-based as social website to share and disseminate safety information and knowledge. The SSNS system would offer a user-friendly approach to those involved in creating a good sharing and communication environment that help users find the right safety knowledge at the right time.

4.2. SNSS Technique Definition

Before describing deeply about SNSS system, some key functions that incorporated in the SSNS framework would be specified:

1. Tagging-Linking-Browsing: This is the common technique that has been applied in social network web 2.0 to enhance the annotation of information [2]. In the SNSS, this technique allows users to place tags, link to published information, and browse their own data on the SNSS's database and user profile. Furthermore, users could be able to select tags from safety ontology library of SNSS to classify the safety information and knowledge. Going beyond that,

social tagging-linking-browsing is used for information discovery, sharing, and navigation as well as information extraction.

2. Commenting: This approach allows users to share their opinions and experiences about the accident information, hazard causes and prevention method by writing comments on the SNSS without any computer science background. The peer review in commenting function would enrich the SNSS contents. It is noted that users could incorporate social tagging-linking-browsing in commenting function to annotate their comments.

3. Editing: Users can add supplementary ideas or correct errors in original safety information by using editing function. The editing process often begins with the author's idea for the work itself, continuing as a collaboration between the author and the editor as the work is created [25]. As such, the editing function would mobilize and utilize social experts to collaboratively work together that can improve SNSS's safety database both of quantity and quality.

4. Voting: This technique allows users to rate the comments on accident cases to refine safety information by using like, dislike, or neutral functions in SNSS. Through the peer rating, users are able to agree or disagree with other users' comments or ontology tagging not only to reject the wrong safety information but also confirm the good safety knowledge. Voting process in SNSS would help to achieve the best safety knowledge to deliver to users.

5. Grouping: Similar to general social network sites, this approach via users' profile can gather users that had same interest, major, job, etc, into groups. It allows users to manage and monitor the safety information and knowledge following their needs easily. Furthermore, users are able to connect with their

friends or make new friends conveniently that create the good environment for safety knowledge sharing and exchange.

4.3. Safety Semantic Wiki Template

The Safety Semantic Wiki Template (SSWT) is designed under the collaboration between semantic wiki web and construction safety ontology technologies that allows visitors to share safety information and knowledge as well as to classify them easily and conveniently without any computer background. Firstly, the semantic Wiki web provides an elegance and flexible form of safety knowledge, which users can add, comment, remove, and edit its content via web browser. The SSWT pages are directly edited by all users, and allow them to create new topic pages as required. Similar to Wikipedia, the SSWT page creates a knowledge network through tagging, linking, and browsing. Secondly, the safety ontology provides the safety classification framework that presents the correlation of safety information and their corresponding significance. The ontology applied in the SSWT constructs conceptual maps of safety information based on Protégé [21] in order to provide an effective safety catalogue for reference to users as they perform information search and contribution. Fig.4-2 delineates the safety catalogue ontology that is connected with a comprehensive SSWT. The functions of sharing and reusing of ontology enable users to search, identify and manage text safety information easily and accurately. With taken advantages of semantic Wiki and ontology, the SSWT provides open safety platform for its users to contribute, share, evaluate, and synthesize their safety knowledge. Furthermore, the SSWT supports safety knowledge management in term of knowledge accessing and extraction.

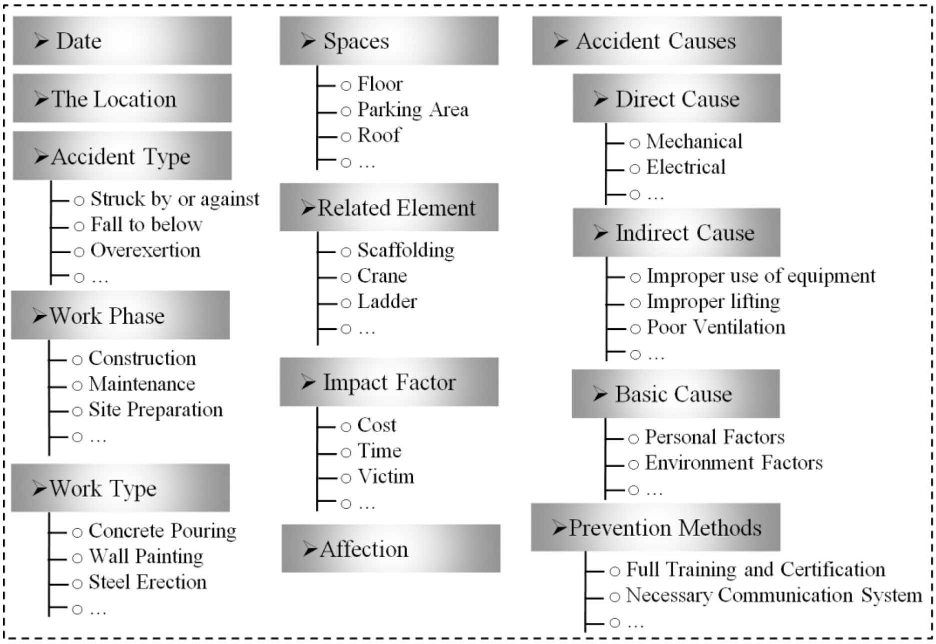


Fig. 4-2 Safety Catalogue

As noticed in Fig. 4-3, there are two main sections that are information and knowledge of construction safety in the SSWT. Firstly, in the section of construction safety information, the visitor will contribute to upload cases of accident, unsafe situation or hazard by describing such as what kind of hazard, how accident happens, and so on. Similar to other social network pages, they can use dynamic editing and semantic resources by tagging in order to create better description of unsafe phenomenon. Secondly, domain experts take part in analysing the uploaded accident information to suggest accident causes and prevention method in the construction knowledge section. It is noted that this knowledge section of SSWT would support three main functions of bringing the best result: 1) Discussion forum where experts can easily and collaboratively insert their expertise to analysis accident or dangerous case; 2) Safety voting and confirmation for expert evaluation to attain the best knowledge; 3) Ontology representation to categorize construction safety information and knowledge.

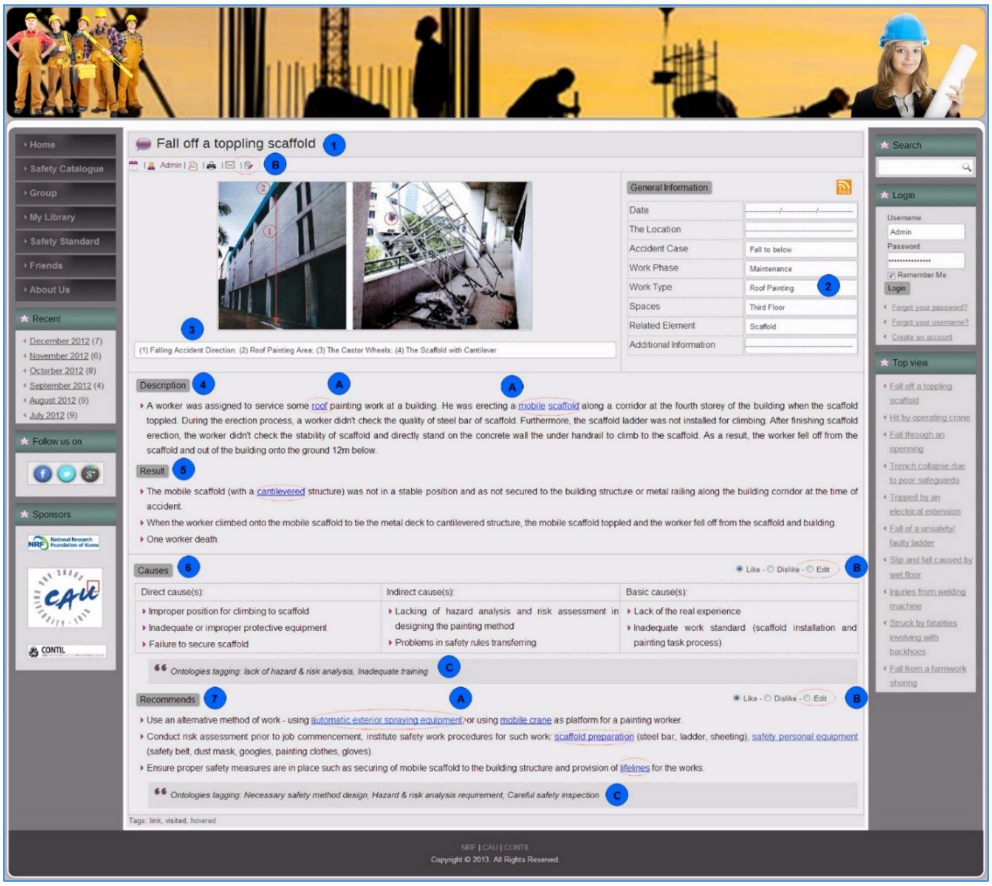


Fig. 4-3 A Sample Case of SSWT

(A) Wiki Tagging; (B) Wiki Editing; (C) Ontologies Tagging

(This case study is extracted from "Falls from Height - Case Studies Construction Industry", Workplace Safety and Health Council, Lee Tzu Yang, 2008 [28])

4.4. Safety Information Module

The safety information module (SIM) is the fundamental module of SNSS that is devised for construction engineers/participants to share accident and dangerous occurrence data. The known accident data and its relative information would be input step by step in the SSWT, which include: (1) Accident case name and location; (2) Specific accident data such as work phase, hazard type and case, spaces, as well as related accident element; (3) File attach to upload visual information such as accident case picture or video for better understanding of accident; (4) Description section to depict detail accident process and also level of damage of accident case; (5) Result section to figure out the real situation after the accident happened (refer to the top portion of Fig. 3). With these collaborative safety data contribution and classification of the SSWT, an active user engaged community can be created. It should be noted that the SSWT, similar to wiki pages, would support functions of editing (B) and semantic tagging-browsing-linking (A) (C) to participants for ambiguous terminology explanation and data supplement without any computer science skill (refer to the middle portion of Fig. 3). Through the process of uploading and supplementing data in the SIM, the safety data are transferred into safety information and are ready for information analysis to convert it into safety knowledge.

The top and middle portion of Fig. 4-3 exemplified the safety information module through a ‘Fall off a topping scaffold’ real accident case. The general information including (1) accident case: fall to below, (2) work phase: maintenance, (3) work type: roof painting, (4) spaces: third floor, (5) related element: scaffold, (6) file attach: falling direction and accident scene pictures, would classify not only to help users easily read and organize accident information but also allow to manage and store information effectively. The falling case sequence was continuously detailed step by step. A worker who was assigned a roof painting task, erected a mobile scaffold along a corridor at fourth storey. During the erection process, he didn't check the quality of steel bar of scaffold. Furthermore, the scaffold ladder was not installed for climbing. After finishing scaffold erection, the worker didn't check the stability of scaffold and directly stand on the handrail to climb to the scaffold. The scaffold collapsed and result was one worker death. This falling scenarios showed that the safety information module creates a good environment to share and present accident data and also store and manage safety information effectively and efficiently.

4.5. Safety Knowledge Module

In the Safety Knowledge Module (SKM), the accident information are analyzed and refined through the contribution of domain experts. Fig. 4-4 illustrates the refining process that is a main core of SKM. The SSWT provides the knowledge contribution forum for experts to add their expertises by clicking the editing button icons (B) in cause (6) and recommendation (7) sections (refer to the bottom portion of Fig. 4-3). By leveraging on state-of-the-art of social network system, the SNSS supports users an easy and convenient environment to share their experiences about the causes and prevention method of accident phenomenon by commenting ideas and uploading evident documents. After this expertise contribution activity is finished, all analytical accident causes and recommendation ideas would be refined to achieve best result through voting process by domain experts. In the voting process, domain experts give rating points by inserting "like" or "dislike" or "neural" opinions to each idea via voting tool of SSWT in predefined time. At the end of pre-defined time, the idea acquires highest score voting, is the credible knowledge.

The information of ‘fall off a topping scaffold case study’ would be converted to safety knowledge as illustrated in the bottom portion of Fig. 4-3. Seven users (lecturers) joined in analysing and refining the falling accident case. From the accident information in the top and middle portion of Fig. 4-3, users would comment their ideas on accident causes and prevention methods. Based on the editing and voting functions, this falling accident causes were defined following direct, indirect, and basic cause. The causes in three catalogue were arranged from top to bottom following voting score (high priority in direct cause is improper position for climbing to the scaffold, in indirect cause is lack of hazard analysis and risk assessment in designing the painting method, in basic cause is lack of real experience). Moreover, the prevention method has a best score in this case study, is to use an alternative painting method – using automatic exterior wall spraying equipment or using mobile crane. There is no doubt that the semantic Wiki and ontology technologies provide users with powerful tool to acquire the good safety knowledge.

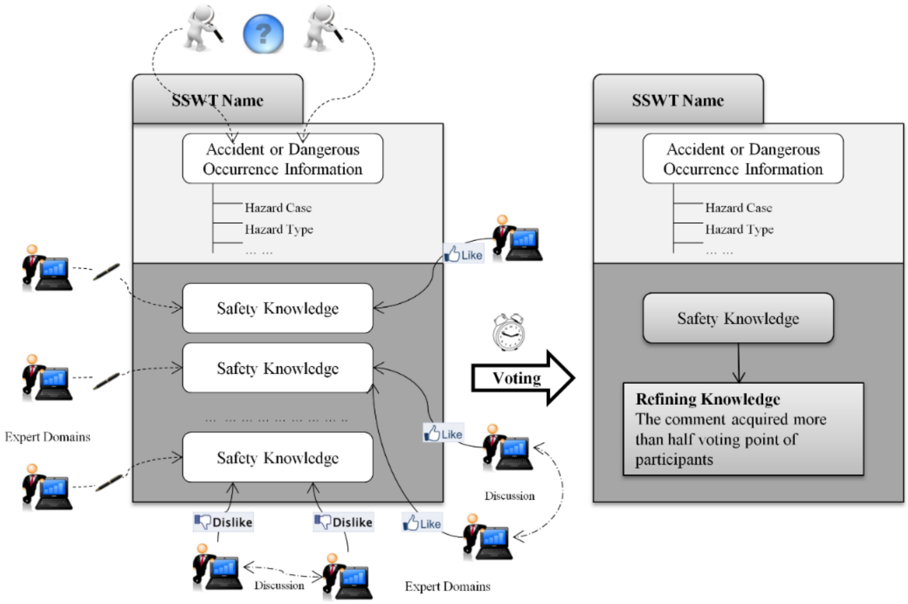


Fig. 4-4 Construction Safety Knowledge Analyzing and Refining

After safety knowledge is confirmed, the whole knowledge in the SSWT would be converted into ontology classes, as illustrated in Fig. 4-5. Via ontology library of SNSS, domain experts would execute ontology tagging and verification for the knowledge sharing and reuse. The ontology library of SNSS has been built based on the theory of Collaborative Protégé [21] that supports collaborative ontology editing and voting to allow expert participants not only to extract ontology class from library but also to contribute to define new ontology classes onto ontology library. Particularly, in case of accident cause and recommendation knowledge, there could be more than one ontology classes be tagged based on the different theories of construction industry. In the SNSS, users can play an active role in establishing safety information and knowledge in the form of systematic and automatic procedure.

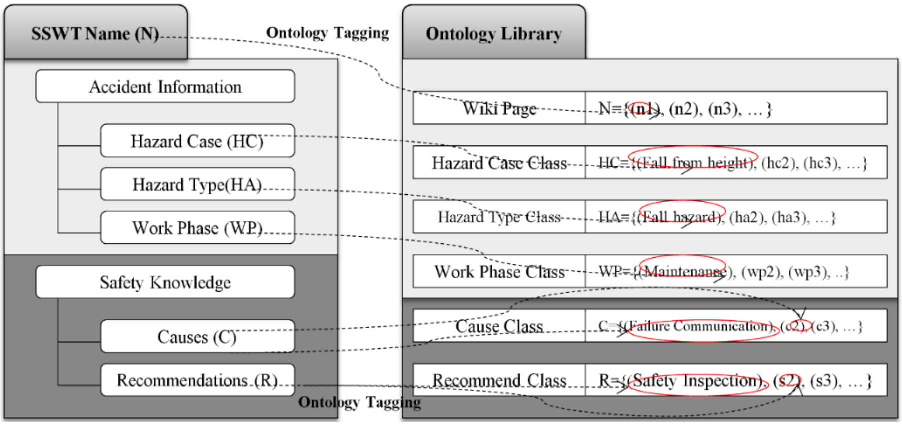


Fig. 4-5 Ontology Converted Information and Knowledge

4. 6. Safety Dissemination Module

The safety dissemination module (SDM) of SNSS consists of the following three layers: Interface Layer to implement, Management Layer to create knowledge from user input, and Data Layer to store the input data from users, as illustrated in Fig. 4-6. The Interface Layer including searching engine, SSWT pages and social services allows users to interact with website to create safety knowledge based on the semantic wiki web and ontology applications. The Management Layer includes three parts to support the system management: 1) SSWT Management creates and modifies the safety knowledge in wiki pages as well as supports domain experts to accumulate knowledge and to construct ontology classes; 2) Ontology Management provides ontology class name list and new ontology class creation; and 3) Refining Engine allows users to discuss and score the knowledge. The score of knowledge is stored in the data layer for knowledge refinement. The Data Layer consists of Database Storage and Safety Ontology Library. Ontology Library is encoded based on Protégé [21] that is the cornerstone to support knowledge classification framework of the Database Storage. The SDM clearly illustrates the interaction between social network with semantic wiki and ontology. The social network technology provides the platform for users to share, represent accident data and also exchange and evaluate the information with others while semantic wiki and ontology techniques support hierarchical safety catalogue to classify and structure the safety information. The social network controls the information accessibility and user interaction, plays an important role in management and interface layer. Ontology and semantic wiki would manage the safety knowledge and the relationship between the information. The integration of social network with ontology and semantic wiki in the proposed system would enhance information retrieval and knowledge management in terms of access and extraction.

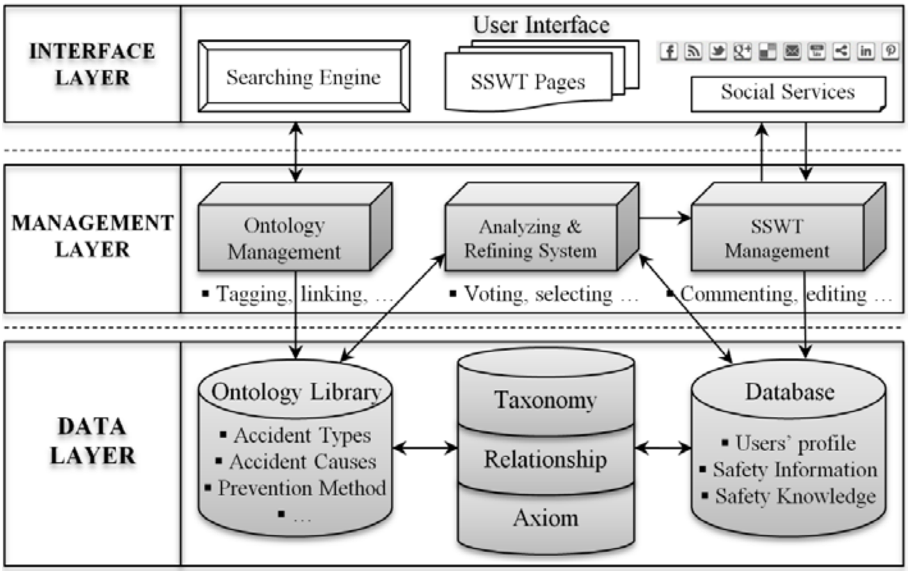


Fig. 4-6 Dissemination Module Technical Architecture

In the dissemination module, some key functions has been specified as follow: (1) Profile: This approach allows users to define and maintain their profile including user's name, kind of job, study area, working place, and so on; (2) Safety information and knowledge sharing: SNSS's users can upload accident knowledge & experience and comment or vote to other user's information via SSWT if they are willing to share; (3) Group Tool: Due to the user's profile, the system would automatically match relevant safety information with user's job, major, etc to provide them valuable safety catalogues; (4) Navigation tool: it is used for ontology tree as safety categorization and for searching safety knowledge. And also typical website interfaces are provided for managing information share and knowledge exchange. This feature of SDM would attract many people to take part in for the creation of qualitative and quantitative safety knowledge in the SNSS.

4.7. SNS evaluation

The system has been tested with a real accident scenario in order to figure out the potential applicability and limitations of the SNSS. In addition, the system practicability and applicability have been appraised and evaluated through interviews. The interviewees were divided into four groups: student, lecturer, safety manager, and site supervisor. The evaluation criteria were identified as following: 1) ease of use: how well users can interact with the SNSS, 2) information sharing: focus on the impact of users towards safety information exchange and sharing, 3) communication: consider whether the SNS motivate users to communicate with each other and; 4) knowledge refinement: access how useful and helpful safety information collected from the system is used for the education purpose (Park and Kim, 2013). The summary of interview result is shown in Table 4-1 and Fig. 4-7.

Table 4-1. Summary of interview result

Average SNSS rating 1 – Useless, 2 – Ineffective, 3 – Normal, 4 – Effective, 5 - High Effective				
	Ease of Use	Information Sharing	Communication	Knowledge Refinement
Lecturers (7)	3.88	3.95	3.23	3.67
Construction Students (12)	4.02	3.74	3.44	3.88
Safety Managers (5)	3.52	3.98	3.06	3.56
Site Supervisors (4)	3.3	3.03	2.98	3.38

Fig. 4-7 Interview Results

As shown in table 4-1 and Fig. 4-7, the higher ease of use (3.68/5) and information sharing (3.67/5) indicated that users felt easy to use the SNSS to share the safety information. They found that the mobile-based SNSS could be accessed anytime and anywhere that motives them to share more hazard and accident cases and then, can promote the effectiveness of the safety information collection and refinement. Moreover, they mentioned that the ontology and semantic tag functions of the SNSS help them quickly add the information on the template. The SNS system also provides the safety otology catalogue that allows users to access and classify as well as refine safety information easily and conveniently.

The results indicate that the interviewees generally agreed that the proposed SNSS has great potential to create a good environment for construction safety knowledge retrieval in the construction industry. The SNSS is applicable in construction academic and commercial area, and could support information sharing, knowledge representation in storing and managing construction safety data. The results can be explained through the effectiveness of semantic wiki and ontology, and integration with social network techniques towards knowledge management.

However, the interviewees also expressed that they were unfamiliar with the communication platform and it is difficult to use for chatting and talking. This represents the lower score of communication criteria. Particularly, safety engineers stated that the construction sites having accidents usually hide this information due to the negative effects on companies' reputations. As such, on-site accident information is always kept in confidential and then, very difficult to access and share on the SNSS. This is a challenge, which should be considered. Furthermore, it should be noted that some limitations of the system were found: 1) the pre-defined time for knowledge voting creates some difficulties for users to join in the safety contribution and confirmation process;

and 2) the knowledge transfer procedure sometimes encountered problems due to the abuse of semantic resources tagging, linking and ontology tagging for knowledge sharing and reusing.

The use of SNSS, in contrast with traditional safety information management system, provides a new communication platform for managers, workers, owners, etc. The users can not only get the right information that they need in timely manner but also share, exchange and store their safety experiences through connecting with SNSS. By utilizing this system, users can improve their safety knowledge and effective decision-making.

4.8. Summary

This chapter presents one of data collection and refinement methods namely, a social network system for coordinating, collecting and sharing construction safety and health information and knowledge, which are focused on combining unique features of semantic wiki web and ontology to create more effective and efficient representation and communication tool. The core of the proposed SNSS is the SSWT that allows users conveniently and cooperatively contribute, refine, and retrieve knowledge linking three modules - information, knowledge and dissemination module. A prototype system was developed and tested with a real accident case scenario. Through the recommendation via interviews with some field safety managers, it is confirmed that the SNSS could greatly enhance the current practices and communication problems of construction safety knowledge as well as effectively collect and refine safety information. However, there are still some limitations such as the pre-defined time or the abuse of semantic tagging and ontology tagging that will be further examined in the future research. In addition, some research efforts would be directed toward the combination of social network and virtual technique for establishing the good knowledge-sharing environment as well as developing the construction safety training or education tool. In short, this chapter aims to collect and refine safety information in order to design the safety education contents via SNS. As such, in next chapter, this safety information collected from the social networking would be retrieved to develop the 3D virtual educational content.

5. The Development of Virtual and Augmented Reality Pedagogical Contents for Construction Safety Education

This chapter aims to develop VR and AR educational contents by using safety information collection and analysis from chapter 4. The transfer process from the accident case analysis in the social networking to 3D models and the simulated and encoded procedures are described.

5.1. Introduction

Information transfer is a critical factor for the success of a safety education and training program. However, traditional education based classroom and lecture cannot present real accident information and safety content well. As such, this chapter introduces the development of VR and AR educational contents for construction safety education. The safety knowledge collected and refined from social networking in chapter 4 would transfer to 3D models through simulation techniques. The contents are selected based on the common potential on-site hazards. Given the identification of typical virtual scenarios, there are four vital points including the hazard and dangerous occurrence awareness, the suitable personal protective equipment (PPE), the safe approach working at height and the effective communication. The VR & AR scenario development is the initial step to achieve the learning and teaching strategies: spatial and situation awareness, stimulation of motivation towards safety education, hazard identification and recognition and safety attitude and behaviour.

In order to develop the VR & AR scenarios, several steps are required. Initially, accident cases from the social network system, construction methods textbooks and Korea Occupational Safety and Health Agency (KOSHA) training documents are analysed and incorporated. Based on the analysis, a suitable hazards classification is determined for the education lessons. A trade-oriented work breakdown is utilized, based on the KOSHA safety evaluation standard, and the fundamentals of building construction textbook (Allen and Iano, 2013). Subsequently, safety rules, regulations, hazards and accident cases are matched with analogous textbook sections. Afterwards, the virtual scenarios are developed. These virtual scenarios are embedded to generate the AR educational contents.

Following sections explained in detail the VR and AR development process.

5.2. Virtual Content Development Process

Prior to commencing the 3D modelling simulation, the safety information from social networking is classified and rearranged as follows: 1) Where do construction accidents happen; 2) Who involves in construction accidents, who are responsible for these accidents; 3) When do the accidents occur; 4) How construction accident process happens; and 5) What are the accident causes and prevention methods. Based on this information, the modelling process consists of two stages: 3D object models and 3D construction environment. The 3D objects include virtual building, construction equipment (crane, elevator), materials, temporary structures, PPE components, etc. And, the virtual environments comprise design of construction site conditions, weather layouts and relative sounds. Majority of 3D contents are created using Autodesk Revit 2013, Blender and Sketch-up - open source computer graphics software products with features including 3D modelling simulation, UV unwrapping (3D modelling process of making a 2D image representation of a 3D model), texturing, rigging, animation and a built in game engine. Afterwards, these models are lighted, embedded animation and added physical characteristics in order to make education contents more realistic. Colours were assigned and realistic textures were added to building components and elements. Ambient occlusion shadows were designed, calculated and added to material textures. Consequently, lighting was set up for the site scene. Construction worker models were also created for the virtual animation and safety game scenarios. Armature was created for worker characters, and through rigging, realistic and natural character movement and interaction were enabled. The characters were animated and the view of the 3D virtual environment was changed by animating the camera based on a key frame method. This feature would allow leaners to easily understand accident precursor, sequences, causes and prevention methods. Consequently, real-time scene optimization, virtual interaction characters and environment integration are executed to complete VR educational scenarios development. Through this, construction students can improve the spatial awareness and hazard recognition as well as their safety attitudes. All 3D contents and properties are converted to Game Engine and published as an iOS application (the detail system architecture of the app will be described in the chapter 6). Lastly, the VR models are embedded in construction textbooks to develop AR scenarios for safety education. The purpose of AR scenarios is to increase the interaction between students with instructors and with lecture materials.

5.3. Education Interface Design

The education application interface is designed to help not only students to interact with safety lessons easily but also instructors to deliver safety knowledge to leaners conveniently. The interface is to display educational scenarios, which are broken down into a series of functions, such as:

- Load the 3D education and training contents to leaners' mobile screen
- Display the 3D safety lessons; see the accident case animation; play the safety game
- Response users input when they interact with the lessons
- Real world data acquisition
- Overlap 3D safety information (PPE, equipment, real videos, etc.) to the real world
- Track the users' performance and response timely as well as data record

5.4. VR & AR Scenarios Development

5.4.1. Introduction of Case Scenarios

The field accident cases were selected for virtual scenarios based on the common potential hazards from site reports. Reese and Eidson, (2006) indicated that falls are the number one accident in construction site, accounting for approximately 30% of construction fatalities. Workers' errors and misjudgements affect their actions at work, leading to injuries. Improving safety awareness through investigating potential falling hazards within virtual environment can proactively reduce accidents. From this point of view, the authors developed virtual education contents related to falling cases: a dangerous floor opening, working without the ceiling protection, etc. In addition to the falling cases, several scenarios involving the inappropriate use of PPE are also developed.

Working on scaffold is one of task that accident is easy to happen due to unsafe site conditions and insufficient safety education. Workers working on scaffolding usually neglect safety rules by not wearing safety belt, and not checking scaffold conditions, etc. The authors use a case ‘exterior glass installation on scaffolding’ as individual safety game scenario in the system prototype. Learners via avatars would practice to install glasses using scaffold to recognize potential hazards in virtual environment.

Concrete work is one of the most common tasks, playing an indispensable role in modern building, design and construction. According to OSHA and ILO construction OS&H , there are many accidents in concrete pouring work due to lack of PPE or inappropriate PPE such as eyes and skin irritation from exposure to cement dust. As such, a ‘pouring concrete for columns’ case is developed to demonstrate the importance of protective wear in conjunction with pertinent concrete construction methods.

Temporary works are defined as engineering solutions used to support or protect existing structures or permanent works during construction processes. In order to prevent accident, it requires workers to completely understand the installation process, type of temporary works, fall protection and so on. An error in this task can contribute to causing serious accidents. Hence, delivering safety knowledge on temporary work to students is needed. The ‘formwork panel transferring for a cured concrete column’ case is simulated for students to navigate the virtual construction site and identify the hazards.

Struck-by accidents in machine operation is one of common accident, accounting about 22% of construction accident (Reese and Eidson, 2006). This is due to communication failure between two or more workers in complex and dynamic construction working environment. ‘An I steel column installation activity’ was selected as group safety game scenario. This case requested three students via their avatars to cooperatively install the steel column by using a crane in virtual construction site. Through executing the cooperative construction activity process within social VR environment, students would not only achieve the safety knowledge by recognizing the potential dangerous occurrences but also improve their collaborative working skills.

5.4.2. Virtual Scenarios Development

5.4.2.1. Virtual construction site

Construction site models are the prerequisites for the development of VR and AR education environment. Virtual construction site consists of eight stories steel structure building, one tower crane and other facilities. Autodesk Revit 2013 is in charge of simulating virtual building (Fig. 5-1). Virtual crane is created by Google 8.2, and others 3D facilities are developed using Autodesk Maya 2012 (Fig. 5-2). It is noted that all models are imported in game engine and encoded for the mobile application development.

Fig. 5-1 Virtual building created by Revit Architecture 2013

Fig. 5-2 Virtual Crane Created by Sketch-up 8.6.2

5.4.2.2. Falling hazard scenarios

The designed scenarios are based on the falling accident data analysed from the social networking in previous chapter. These include seven falling scenarios that are detailed in A*ppendix I – virtual safety education scenarios*

As illustrates in Fig. 5-3, a dangerous occurrence from elevator opening is a typical educational content for safety education that includes:

a) Situation: Two workers transferred construction materials to the fifth floor. For their work convenience, they removed the fences around the elevator opening, but they forgot to fit up them again. In the evening, three workers poured concrete on the fifth floor, one of the workers was close the elevator opening. As moving forward to sharpen concrete surface, he stepped towards the unguarded opening, fell 16m, and landed on the steel basement elevator. He died from fatal head and bones broken.

b) Avatar: Three workers work on the fifth floor near the elevator opening

c) Time: At night time in dim conditions

d) Place: The elevator opening at the fifth floor

e) Main elements: Safety barriers, pouring concrete equipment

f) Activities: Transfer construction materials, pouring concrete

g) Safety Standard:

- *Where employees are exposed to falling 6 feet (1.8 meters) or more from an unprotected side or edge, the employer must select either a guardrail system, safety net system, or personal fall arrest system to protect the worker.* Quotation from OSHA 1926.501(b)(1)

- *Personal fall arrest systems, covers, or guardrail systems must be erected around holes that are more than 6 feet (1.8 meters) above lower level.* Quotation from OSHA 1926.501(b)(4)

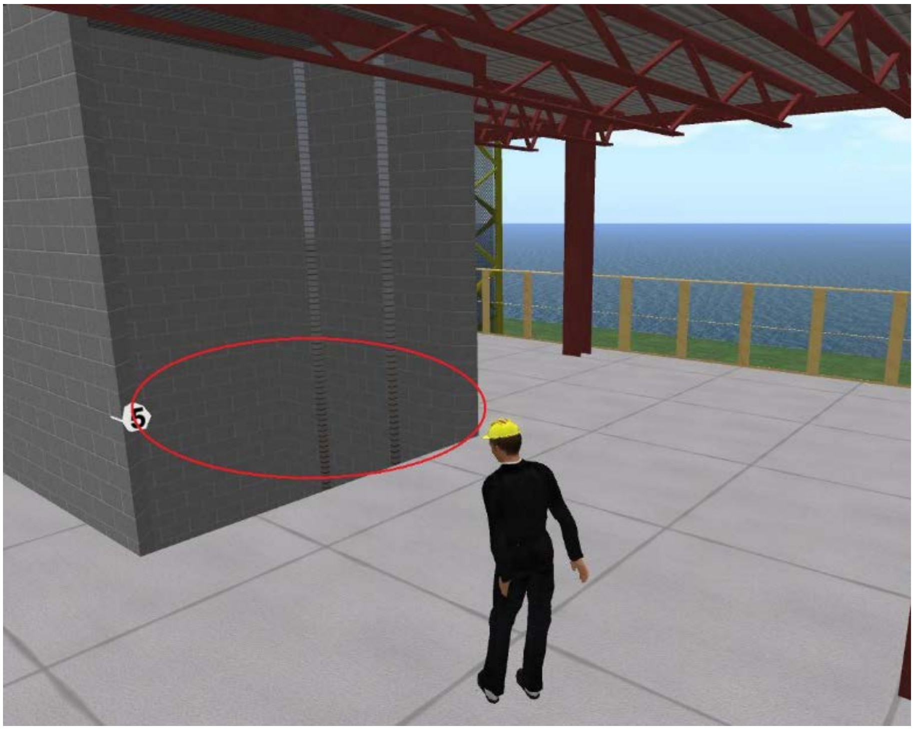


Fig. 5-3 A dangerous elevator opening

5.4.2.3. Fire hazard scenario

In the construction industry, the fire can cause serious accidents that make many losses including cost overruns and time delays. As such, the author selects the fire hazard scenarios in order to demonstrate the small error of a worker could cause a serious accident. In this case, the worker had a mistake during the electric pipe installation on the sixth floor (Fig. 5-4). The pipe was put in a wrong position and an inspection did not detect it. After 2 years operation, there was a floor maintenance. Two workers drilled the floor to install a new pipe. However, due to the error during the construction phase, the workers drilled through the electric pipe, and then the short circuit was happened. As a result, the fire was bloomed and the workers died from the explosion and the house was damage.

This scenario demonstrates that accidents can happen anytime, anywhere and workers' error can cause accidents not only to themselves but also to their colleges. Two young workers and one experience worker are simulated as characters. The wrong pipe installation time reflected the late afternoon when the worker feels hasty and wants to finish his work as soon as possible. The maintenance process is at the early morning. Main elements in this scenario include steel bars, electric pipes and electric boxes. Also, pipe installation and drilling task are main activities in the virtual scenarios. The safety standard for this case is OSHA 1926.150.

- *The employer will be responsible for the development of a fire protection program to be followed throughout all phases of the construction and demolition work, and he shall provide for the firefighting equipment as specified in this subpart. As fire hazards occur, there shall be no delay in providing the necessary equipment.* Quotation from OSHA 1926.150(a)(1)
- *Access to all available firefighting equipment will be maintained at all times. All firefighting equipment, provided by the employer, shall be conspicuously located. All firefighting equipment will be periodically inspected and maintained in operating condition. Defective equipment will be immediately replaced.* Quotation from OSHA 1926.150(a)(2),(3),(4)

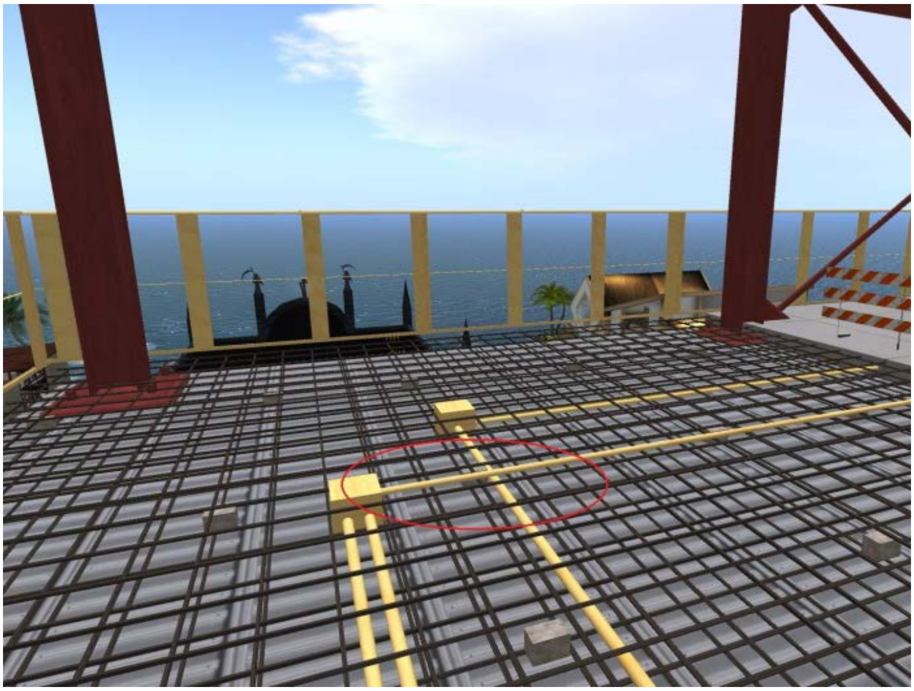


Fig. 5-4 Electric pipe defect causing the fire accident

5.4.2.4. Concrete Works Scenario

a) Concrete work was chosen since it is one of the most commonly used building materials, playing an indispensable role in modern building, design and construction. This scenario portrays labourers pouring concrete for columns on the sixth floor. Two workers executed the concrete work in the late morning. Once the formwork has been nailed down around rebar, one worker stood on the scaffold and poured the concrete into the formwork around rebar while another inspected this process (Fig. 5-5). Both workers did not wear PPE (goggles, gloves, etc.). During the pouring work, the concrete sandstone flied into the workers' eyes and the cement dust adhered in their hands and bodies. As a result, they got the eyesight problems and skin irritation. The workers' health has been negatively affected and their productivities decreased. This case has partially proved how the PPE is important.

b) Avatar: Two workers are simulated as characters

c) Time: In the late morning (around 11:40 – 11:50 AM)

d) Place: At the center columns on the sixth floor

e) Main elements: scaffold, formwork, concrete, PPE

f) Activities: Pouring and vibrating the concrete

g) Safety Standard:

- *Eye and face protection shall be provided when machines or operations present potential eye or face injury.* Quotation from OSHA 1926.102(a)(1)
- *Eye and face protective equipment shall meet the requirements of ANSI Z87.1-1968.* Quotation from OSHA 1926.102(a)(2)
- *Head protective equipment (helmets) shall be worn in areas where there is a possible danger of head injuries from impact, flying or falling objects, or electrical shock and burns.* Quotation from OSHA 1926.100(a)
- *The employer is responsible for requiring the wearing of appropriate personal protective equipment in all operations where there is an exposure to hazardous conditions or where the need is indicated for using such equipment to reduce the hazard to the employees.* Quotation from OSHA 1926.28(a) and 1926.95(a)(b)(c)

Fig. 5-5 Concrete work

5.4.2.5. Temporary Works Scenario

a) Every construction task includes temporary works and many jobsites injuries and fatalities involve work on temporary structures. This scenario illustrates the falling accident that involves the column formwork transferring on the seventh floor (Fig. 5-6). For pouring column concrete, two workers carried and installed the formworks around the column rebar. Along the moving path, there is a protected opening, an electric cable and brick lying around. One side of the opening was covered by the tape. Before transferring the formwork, the workers did not clean the path. The workers were close the opening and one worker encountered the brick and stepped towards the opening. He fell down the tape-guard opening. He fell 24 meters and landed on the concrete basement floor. He died instantly from his injuries. The temporary work scenario reflects the ability of workers in recognizing potential hazards on the construction sites.

b) Avatar: Two workers are simulated as characters

c) Time: In the afternoon (around 13:40 – 13:50)

d) Place: The elevator opening on the seventh floor

e) Main elements: formwork, brick, electric cable, guardrail

f) Activities: Transfer and install formworks for the cure column

g) Safety Standard:

- *Guardrail systems shall be surfaced so as to prevent injury to an employee, with a strength to withstand at least 200 pounds (90 kilograms), the minimum requirement applied in any outward or downward direction, at any point along the top edge.* Quotation from OSHA 1926.502(b)(3) and (6)
- *Form and scrap lumber with protruding nails and all other debris shall be kept clear from all work areas.* Quotation from OSHA 1926.25(a)
- *Combustible scrap and debris shall be removed at regular intervals.* Quotation from OSHA 1926.25(b)

Fig. 5-6 Temporary work

5.4.2.6. Struck-by Hazard due to the Failure Communication Scenario

a) The failure communication among workers causes abundant construction accidents making signification contributions on cost overruns and schedule delays. Struck-by accident is one of prevalent cases, is chosen to demonstrate the communication problem. This accident case was demonstrated through an I steel column installation executed by three workers (Fig. 5-7). In the installation process, two China workers stood on a scaffold on the eighth floor and another from Korea controlled a tower crane. They communicated through walkie-talkies. The crane controller lift the I column and move it to the position following the guidance of the two workers standing on the scaffold. When the column was close to the right position, the two works tried to locate and connected the column with the column system. Due to the failure communication among the workers, the crane controller moved the column to right side instead of left side. As a result, the column stuck by the workers standing on the scaffold. They fell 27 meters and died immediately from their injuries.

b) Avatar: Two workers and a toward crane controller are simulated as characters

c) Time: In the afternoon (around 16:40 – 17:00)

d) Place: Near the edge of the eighth floor

e) Main elements: scaffold, an I column, toward crane

f) Activities: Transfer and install an I steel column into the column system

g) Safety Standard:

- Quotation from OSHA 1926.601(b)(4)(i),(ii) and 602(a)(9)(i), (ii): *No employer shall use any motor vehicle, earthmoving, or compacting equipment having an obstructed view to rear unless:*
    - *The vehicle has a reverse signal alarm distinguishable from surrounding noise level or*
    - *The vehicle is backed up only when an observer signals that it is safe to do so*

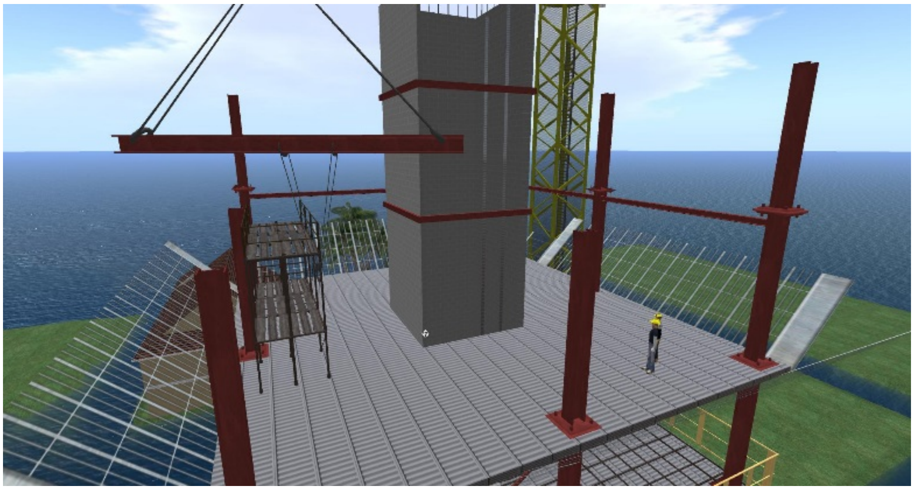


Fig. 5-7 Struck-by hazard due to the failure communication

5.4.3. AR scenario Development

5.4.3.1. Hardware Setup

The hardware setup of the AR scenario development is depicted in Fig. 5-8.

Fig. 5-8 AR Hardware Setup

a) Tracking webcam: The webcam used is a Microsoft LifeCam, which allows a High Definition (HD) view. The webcam would track the predefined paper markers in order to overlap the virtual content onto the textbooks. As such, students can access the animated guidance anytime and then, they can acquire safety knowledge effectively.

b) Paper-based markers: Makers are generated and calibrated by using the BuildAR Pro and ARToolkit. There are two type of marker: Image-based maker (slower and utilized more system resources but provide a number of distinct features) and black square ARToolkit maker (faster and utilized fewer system resources but more strict rules regarding maker appearance).

c) Software Setup: The AR scenarios are developed based on BuildAR Pro, AR Media Plugin and iOS AR program. These programs allow reading several multimedia and 3D files such as avi, mp4, 3ds, blend, etc. The virtual contents can be directly imported into AR interface via the attached AR of these programs and the contents can be recognized through the predefined markers.

d) IPhone and iPad: These mobile devices are set up to read 3D educational contents in order to support students during the learning process. Augment – 3D AR application is used to access the education scenarios in the mobile devices.

5.4.3.2. AR implementation

The purpose of AR scenarios development aims to overlap the virtual graphics /data onto real world objects and textbooks in order to improve students' perceptions on safety issues. Firstly, the camera data is prepared by using the API in the iOS devices. Afterwards, the makers/ tags or data location (markerless – through magnetic, accelerometer and rotation sensors of mobiles) are set up to determine where to place the augmentation data. Next, all aforementioned VR scenarios would be added to overlay the makers or markerless position through the camera. For example, fig. 5-9 illustrates the AR scenario development that the left side shows the marker and the right side demonstrates the virtual building overlapping onto the maker. It is noted that the AR data are stored in the SQL and connected up to a web service using CML parsing.

Fig. 5-9 AR scenario development (left – Marker, right – a AR scenario)

5.5. Summary

This chapter presents the development of VR and AR scenarios for construction safety education. Seven falling, one concrete work, one temporary work and one struck-by scenarios are simulated to close the reality based on the information from previous chapter. Each scenario represents one major hazard event and a few potential dangerous occurrences in order to show how dangerous and complex the construction industry is. These scenarios also are encoded to allow users to interact with the visualization environment through PC or mobile devices. This is the initial cornerstone step for developing an interactive and experiential education system for construction safety. Following chapter will comprehensively explain the details of the mobile based VR and AR system.

6. A Mobile Based Virtual and Augmented Reality System for Experiential and Interactive Construction Safety Education

6.1. Framework for Using Mobile Based VR and AR for Interactive and Experiential Construction Safety Education

The aim of this chapter is to develop a mobile-based VR and AR for improving the safety performance of construction students. The mobile-based system provides information about hazard precursor and pathogen, accident sequences, causes and prevention method in 3D form by using the educational contents from chapter 5. Students can acquire safety knowledge through interactive role-playing, collaborative learning and immersive interaction in the mobile virtual environment.

In order to achieve the research object, a system prototype has been developed reflecting the typical safety education process, comprising of three modules as illustrated in Fig. 6-1. Firstly, Safety Knowledge Dissemination (SKD) represents a traditional inactive approach, which typical involves educators delivering safety lectures to students. Next, safety information from previous module would be reflected in an active approach by allowing learners via their mobile devices to identify hazards and reflect on safety knowledge in Safety Knowledge Reflection (SKR). Finally, Safety Knowledge Assessment (SKA) represents a proactive approach in which students via the avatars in their mobile devices practice construction activities in order to ensure them obtained the required knowledge and practical experiences. The mobile based

VR and AR system would stimulate students' interest, engagement and motivation as well as creativity by allowing them to practice within the virtual education environment, which assists in obtaining a better understanding of construction safety & health.

The major difference between the proposed approach in this study and the conventional methods is that the educational process overlaps and visualizes construction safety information through mobile based VR + AR. Students are able to easily understand and obtain safety knowledge without the ambiguity often encountered with traditional textbooks. The mobile based VR and AR system assists leaners to access safety information anytime and anywhere that enhance learners' motivations towards safety education. Students are encouraged and inspired to be self-learning with safety lessons through the VR and AR system. Furthermore, leaners can not only understand the insight causes of accidents and hazard prevention methods but also to identify safety risks inherited during construction process; and then develop the safety competency. The system aims to achieve this goal by providing mobile-based visualization information, easy communication and flexible interaction, collaborative spaces, and immersive and experiential environment.

The next sections thoroughly discuss the details of the system.

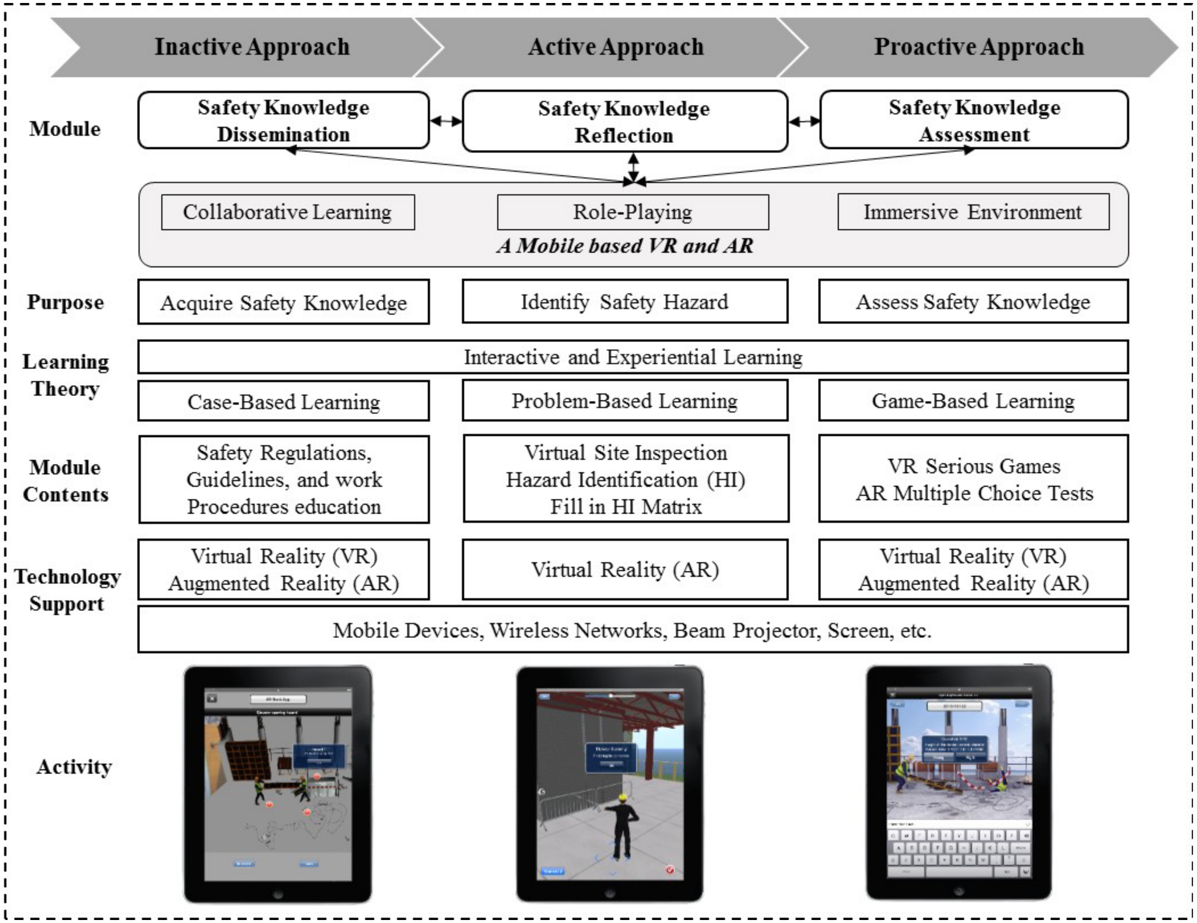


Fig. 6-1 A framework for using mobile based AR and VR for construction safety education

6.2. Safety Knowledge Dissemination

The SKD focuses on teaching and transferring safety knowledge based on accident cases, as shown in Fig. 6-2. Through the cases, educators introduce safety regulations, guidelines and safe work procedure by using VR and AR contents. Since the study was carried out in South Korea, the Korean Occupational Safety and Health Agency (KOSHA) rules and regulations and KOSHA's Standard Risk Evaluation Model were utilized. These KOSHA regulations were then compared to the Occupational Safety and Health Agency (OSHA) regulations in order to ensure that the system is internationally relevant. The risk evaluation model was appropriate for this study, as it highlights hazard points from previous accident cases. The SKD module is initiated with a case-based learning approach, whereby learners play an active role in brainstorming and get to see how safety regulations and guidelines tie in with safety performance in real construction. In this approach, VR animations are utilized to illustrate construction site scenarios, allowing students to clearly visualize the site environments from the accident cases. In addition, AR is used to access virtual objects and scenarios via fusion markers. Students are expected to develop a comprehensive understanding of safety regulations based on accident cases. After the lecture, students are expected to be aware and knowledgeable of the hazards associated with the types of construction work considered during the lecture.

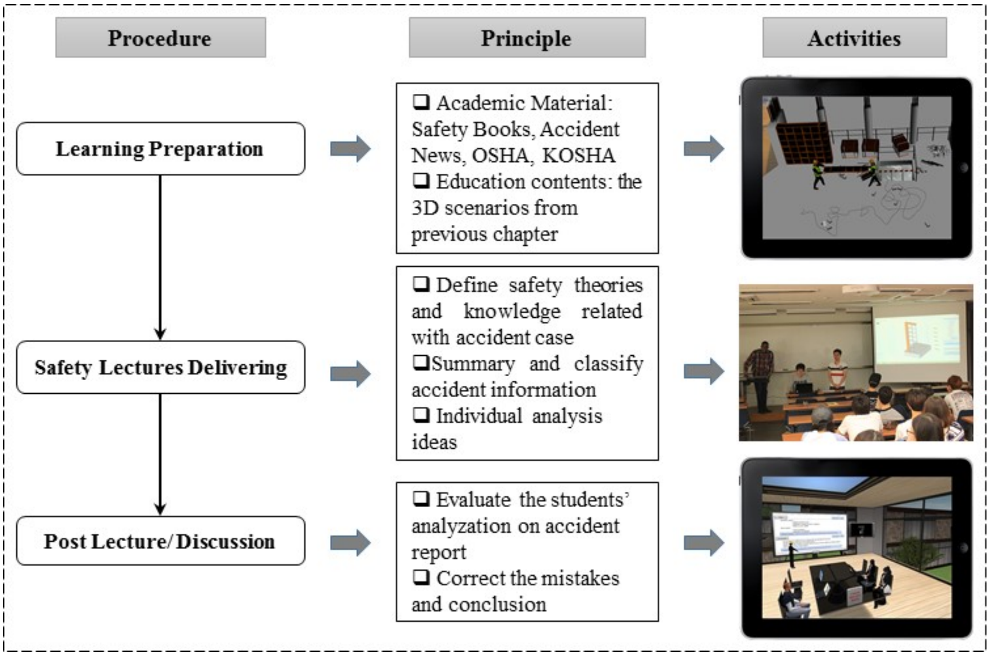


Fig. 6-2 Safety Knowledge Dissemination

In this module, the educators would help students to perceive safety knowledge by allowing them to learn common construction hazards and accidents through visualization form. The knowledge from this SKD is applied in two subsequent modules.

6.3. Safety Knowledge Reflection

The SKR provides students with an experiential opportunity to apply the safety knowledge acquired in the previous module, as shown in Fig. 6-3. Students are required to inspect an immersive virtual construction site in order to identify potential hazards. Firstly, visualization education contents are loaded and implemented for safety inspection task by the lectures. Afterward, students log into their accounts and select the SKR bar to access virtual scenarios in the mobile devices. Then, via avatars, users navigate and inspect a virtual environment to identify the hazards and unsafe conditions. After identifying the hazards, students practice correcting unsafe conditions. During the process, regardless of whether students correctly identify and rectify hazards or not, safety instructions from related photos and videos would be presented to improve students' cognition of safety risks. Furthermore, students practice filling in a hazard identification matrix in their personal mobile devices. Through this practical approach, students are expected to acquire safety knowledge, which would be retained in their long-term memory. In this module, VR plays a crucial role to facilitate interactive learning that reflects safety issues resembling those encountered in real on-site construction. Student's hazard inspection process would be recorded for reviewing again. This module will establish not only hazard identification ability but also safety knowledge through practical experience within mobile virtual environments.

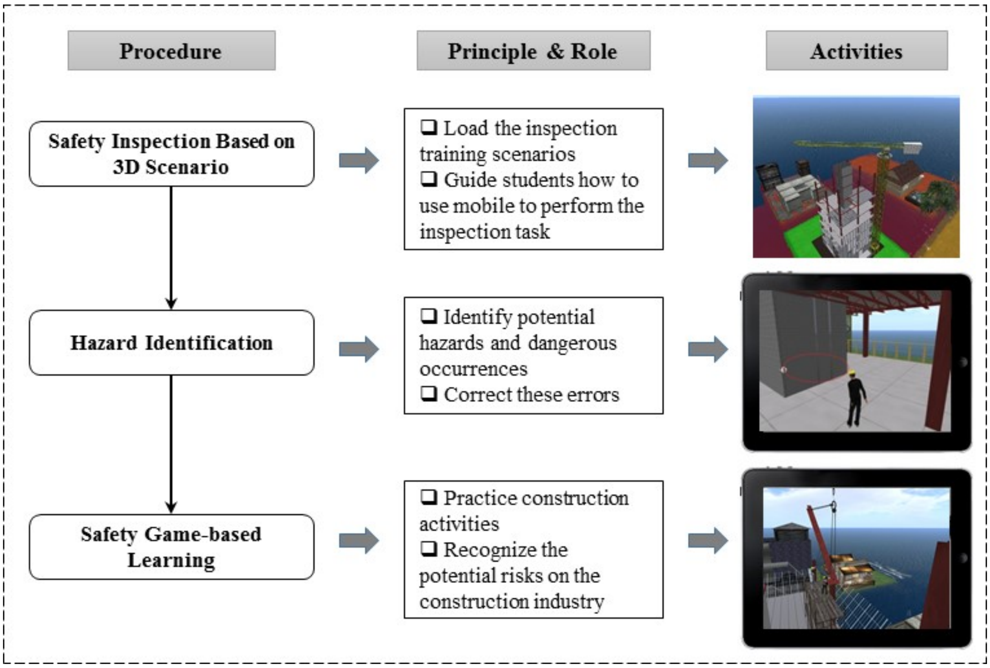


Fig. 6-3 Safety Knowledge Reflection

In the SKR module, leaners can play an active role in enhancing safety knowledge and awareness in form of inspection process. In addition, this feature would assist students to understand the accident scenarios comprehensively.

6.4. Safety Knowledge Assessment

Lastly, the SKA's fundamental purpose is to assess learners' safety knowledge, as shown in Fig. 6-4. This is carried out through the use of a VR serious game in which students identify hazards and determine appropriate hazard mitigation and response strategies. The game has been designed for students to pre-experience safety risks virtually prior to entering the construction site, by which the capability of students is examined in term of risk recognition and safety behaviour. During the game, students would investigate animations that include unsafe factors causing construction accidents. Then, they have to answer questions regarding how to handle the site risks in VR animations and fix into the Job Safety Analysis matrix table through their mobile devices. The game would range from easy level to difficult level and continue to run until users answer correctly. Furthermore, AR multiple-choice tests would assess students' application of safety rules pertaining to specific safety topics such as personal protective equipment, and safety when working with electrical equipment. Through this, lecturers can evaluate students' safety knowledge and provide feedback and comments accordingly. This approach ensures that construction graduates acquire adequate safety experience and knowledge to meet the safety demands of the modern construction industry.

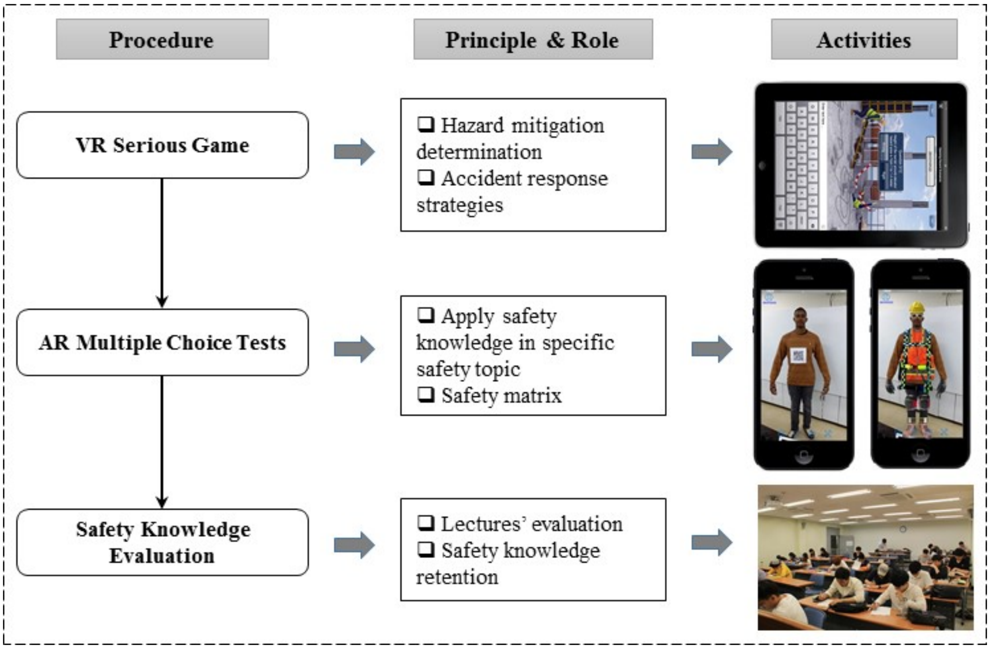


Fig. 6-4 Safety knowledge Assessment

In summary, the SKA module would assess safety knowledge, which students gain from previous section. It enables linking the knowledge with real experience that can improve learners' safety performances when entering the construction industry.

6.5. System Architecture

In order to support three modules, the system architecture for using mobile based VR + AR for experiential construction safety education is designed consisting of the following three layers: interface layer, management layer, and data layer, as shown as Fig. 6-5. The interface layer includes a safety lesson page, search engine, and 3D gaming, etc. allowing learners to study and reflect on safety knowledge through mobile devices. The management layer includes four components to support the system management: 1) safety lesson management tier which allows lecturers to control safety contents from safety database to deliver to students; 2) Next, the safety assessment management tier which manages how students interact with the VR, AR and game-based tests and scenarios, allowing students to reflect their safety knowledge through 3D game and test, and evaluates student's performance; 3) The ontology management tier is responsible for classifying safety information into groups such as work type, work phase, spaces, etc. ; 4) Recommendation management tier which is in charge of providing right safety information to right student. For example, in a fall into open area accident case, a structural engineering student would be interested in the capacity of opening barrier while the design student would want to know whether the barrier is appropriately designed and installed at right position. Based on the majors, interests and other data from users' profiles, the system automatically recommends the information that users need. Finally, the data layer consists of three databases namely: the visualization database with VR and AR scenarios; the safety information database with safety regulations and accident cases; and the user's profile database. The MySQL-Sever is in charge of storing the databases including visualization, safety information and user's profile data. The Xcode and iOS Software Development Kit were used to develop and manage the mobile application and link with database in MySQL-Sever. Furthermore, Revit Architecture 2013 and Blender 2.68 are utilized for simulating the VR scenarios. Lastly, the mobile AR contents are developed using BuildAR pro 2 – commercial program. The initial mobile system development was based on the iOS platform because its Xcode Integrated Development Environment (IDE) is fast, powerful and easy to use. Future studies will consider the extensibility of the system to the Android platform.

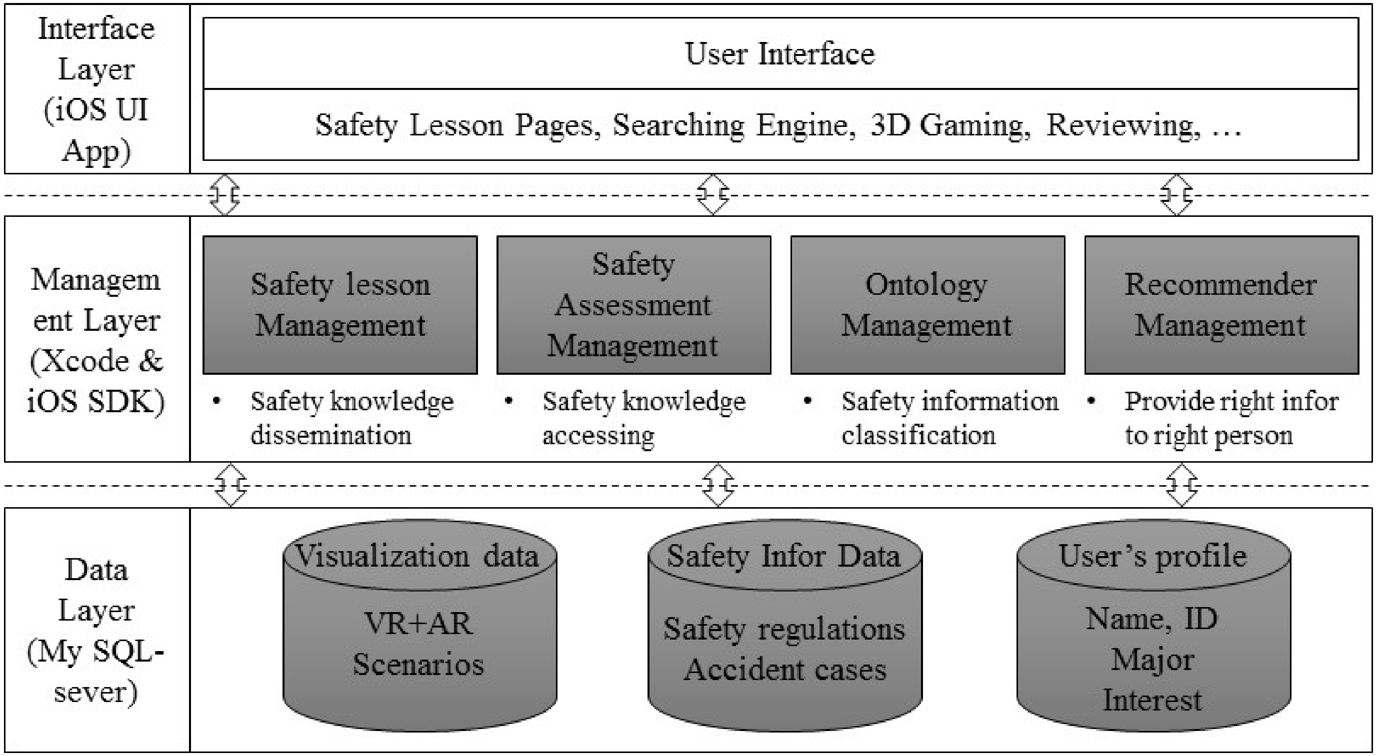


Fig. 6-5 System Architecture for using mobile based VR+AR

6.6. Implementation

Prior to commencing the SKD lecture, the educator introduces PPE and their vital role in establishing on-site safety. Students are encouraged the play an active role and the lecturer distributes AR markers to the class. These are then attached to a student's body, and when other students point their smart devices at the marker, a visualization of PPE is overlapped on the student's body (Fig. 6-6). Through this engaging approach, students can effectively acquire safety knowledge relating to PPE.

Fig. 6-6 Using AR for PPE education

The learners were also taught about PPE related to concrete work since it plays an indispensable role in modern building and construction. Through AR fusion markers embedded in lecture notes, learners used mobile devices to access virtual animations portraying labourers pouring concrete for columns. Fig. 6-7 illustrates the ideal situation, whereby workers have the appropriate PPE. The focal point of the mobile based VR+AR in this process is teaching students about common hazards and the importance of protective wear (such as glasses, long sleeve shirts and gloves) in conjunction with the relevant KOSHA and OSHA safety regulations and standards.

Fig. 6-7 Workers pouring concrete with appropriate PPE

Next, seven falling accident scenarios were delivered to learners, with each one focusing on a specific area of a virtual construction site. The scenarios disseminate safety knowledge pertaining to fall hazards. Through smart devices and AR codes embedded in lesson notes, students accessed a virtual animation to obtain safety knowledge. As seen in Fig. 6-8, the site scenario displays two workers carrying a formwork panel away from a cured concrete column. Along the laborers walk path, there is a partially protected opening, an electric cable and bricks lying around. As the result of these conditions, one worker falls into the opening. Based on this animation, the teacher would explain the causes of the accident such as inadequate fall protection, messy site; and corrective measures according to OSHA 1910.23(a) regulation.

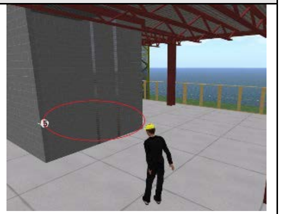
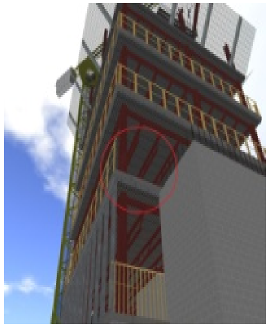
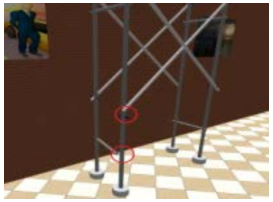
Fig. 6-8 Falling into an opening while carrying formwork panel

After the lecture, students experientially reflected on their safety knowledge in a mobile virtual environment. Students used avatars to navigate and inspect the hazards and safety risks within the virtual construction site. Initially, the lecturer would explain the site inspection task and how to use the mobile device to navigate and inspect the virtual site (Fig. 6-9). Also, after the inspection task, the lecturer would explain the appropriate hazard mitigation methods to students using an overhead projector.

Fig. 6-9 Explaining site navigation and corrective hazard mitigation measures using mobile device and projector

After the guideline, learners were required to investigate the whole virtual building to identify the seven falling hazards (Table 6-1). Subsequently, students corrected the unsafe situations in the virtual environment. Fig. 6-10 depicts the hazard inspection process, with a student using his avatar to navigate the 5th floor of the virtual building. Using a smart device, he identifies the absence of an elevator shaft barrier. The application enables the user to input identified safety risks into a hazard identification matrix. Consequently, the learner clicks on the corrective tool on the right side of the mobile interface. This allows him to mitigate the hazard by adding temporary barriers.

Table 6-1. Educational Scenarios

Number	Accident Title	Hazard	Safety Information	Screen
1	Fall into elevator opening (story 5)	While moving material using the elevator, the workers removed the fences around the opening and they forgot fit up them again	- Protective barrier type - The position and dimension barrier covering opening (OSHA 1926.501)	
2	Fall from height to below (story 3)	The workers detached the exterior cover wood barrier to install aluminium frame and glass. Although the installation task was not finished, the worker did not set up the protection in work area	- Spacing between vertical members of protection barrier - Temporary railing standard (height, space) (OSHA 1926.500(b), 501(b))	
3	Fall due to the scaffold collapse (front of building)	The lack of pin connection between two bottom bars in scaffold because of workers' carelessness during the installation	- Scaffold type, dimension, material - Installation method (OSHA 1926.451)	

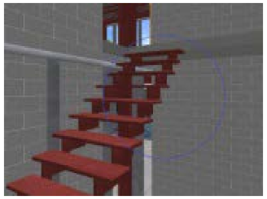
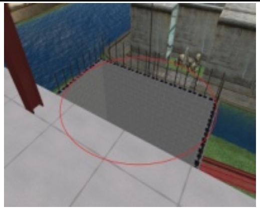
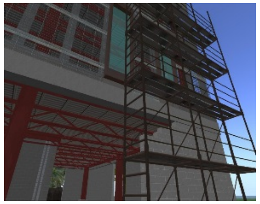
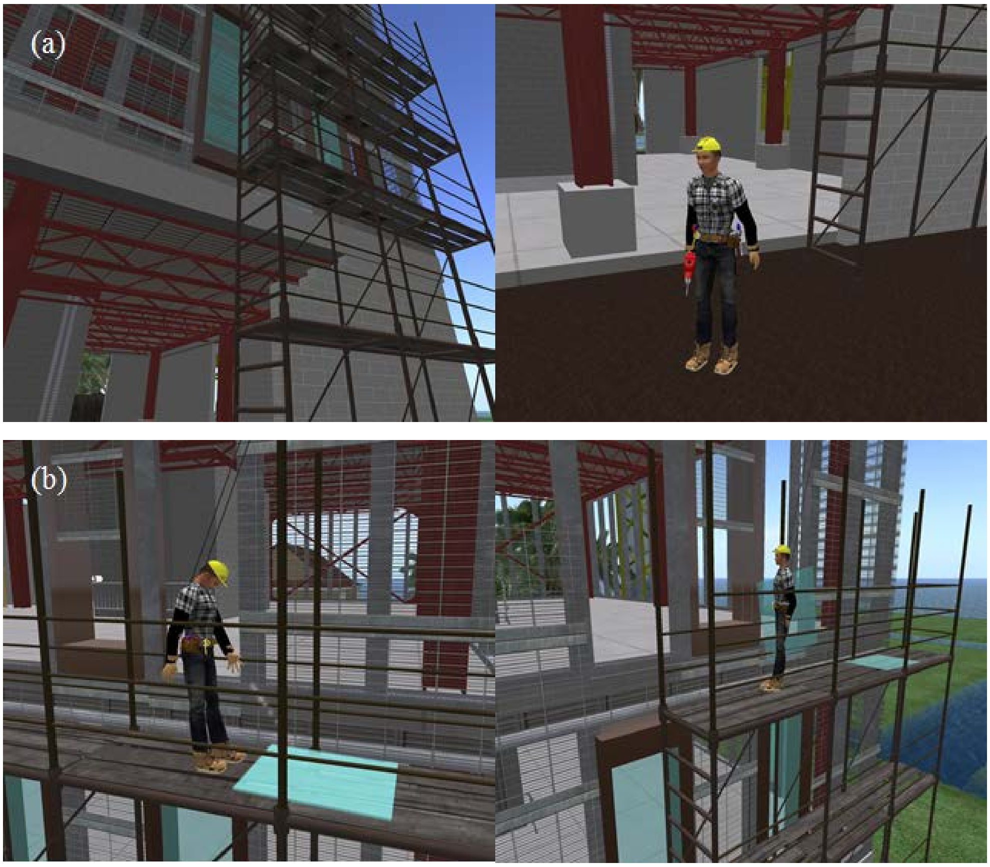
4	Fall from stair (stair from story 3 to story 4)	After finishing an exit stair from story 3 to story 4, the worker didn't fit up temporary handrail protection	- Stairway railings and guards rule (handrail height, material, etc.) (OSHA 1926.1051, 1052)	
5	Fall into stair opening (story 4)	While waiting to pour concrete for the cover wall of stairway, the worker did not install protection fences around the hole	- Covering formwork for stair hole (formwork area, material, etc.) (OSHA 1926.501)	
6	Fall from scaffold to below (story 7)	Missing protective horizontal beam on the scaffold due discomfort when working on scaffolding	- Scaffold type, dimension, material - Installation method (OSHA 1926.451)	
7	Fall from scaffold during exterior wall installation on 2nd floor	The worker felt from scaffold during a curtain wall installation due to lack of scaffold guardrail system	- Scaffold safety rules - Fall protection (OSHA 1926.451)	

Fig. 6-10 Hazard Inspection Process

Subsequently, the students via avatars would individually practice construction activities within the collaborative VR environment to recognize the on-site potential hazards. The installation process of exterior glasses at third story was selected to demonstrate the individual training game scenario. In this case, the trainee via his avatar stood at the scaffold to install exterior glasses on the 3rd story. Before executing installation activity, the trainee must equip his avatar with the safety outfit, safety belt and check the scaffold working condition (Fig. 6-11(a)). This step helps students to review knowledge on personal safety equipment lesson. Then, the trainee via the avatar would step-by-step practice the glass installation process under the guidelines from the professor. Firstly, the student lifted up the glass and put it in right position within the glass frame (Fig. 6-11(b)). This step provided the student with potential risks and safety knowledge on manual load lifting and moving on scaffold. Secondly, the trainee installed the screws and glued to fix the glass frame with the steel frame (Fig. 6-11(c)). Student could understand the installation process and working on scaffold's rules through interactive role-play in this step. Finally, the student checked the glass again and released from the scaffold. During the game process, the prompt notification of hints would be sent to trainees when safety problems or errors occurred. Hence, the trainee could effectively understand potential risks and acquire safety knowledge that are involved in the installation sequence.



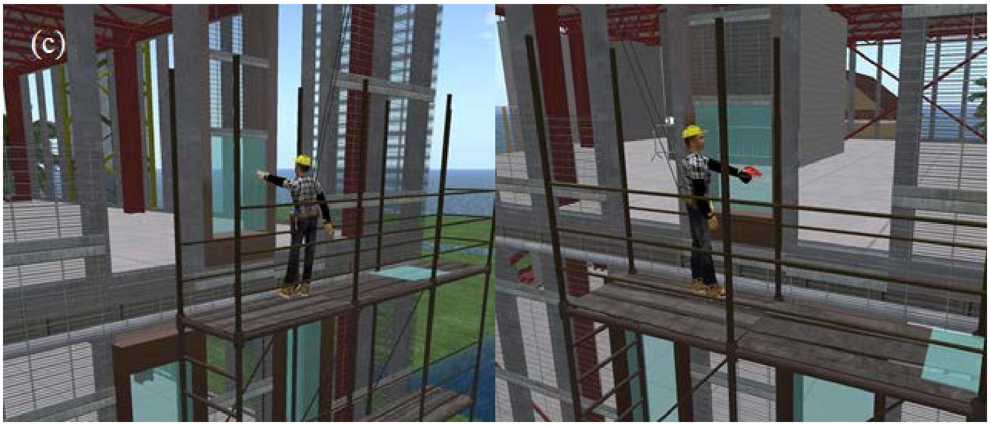
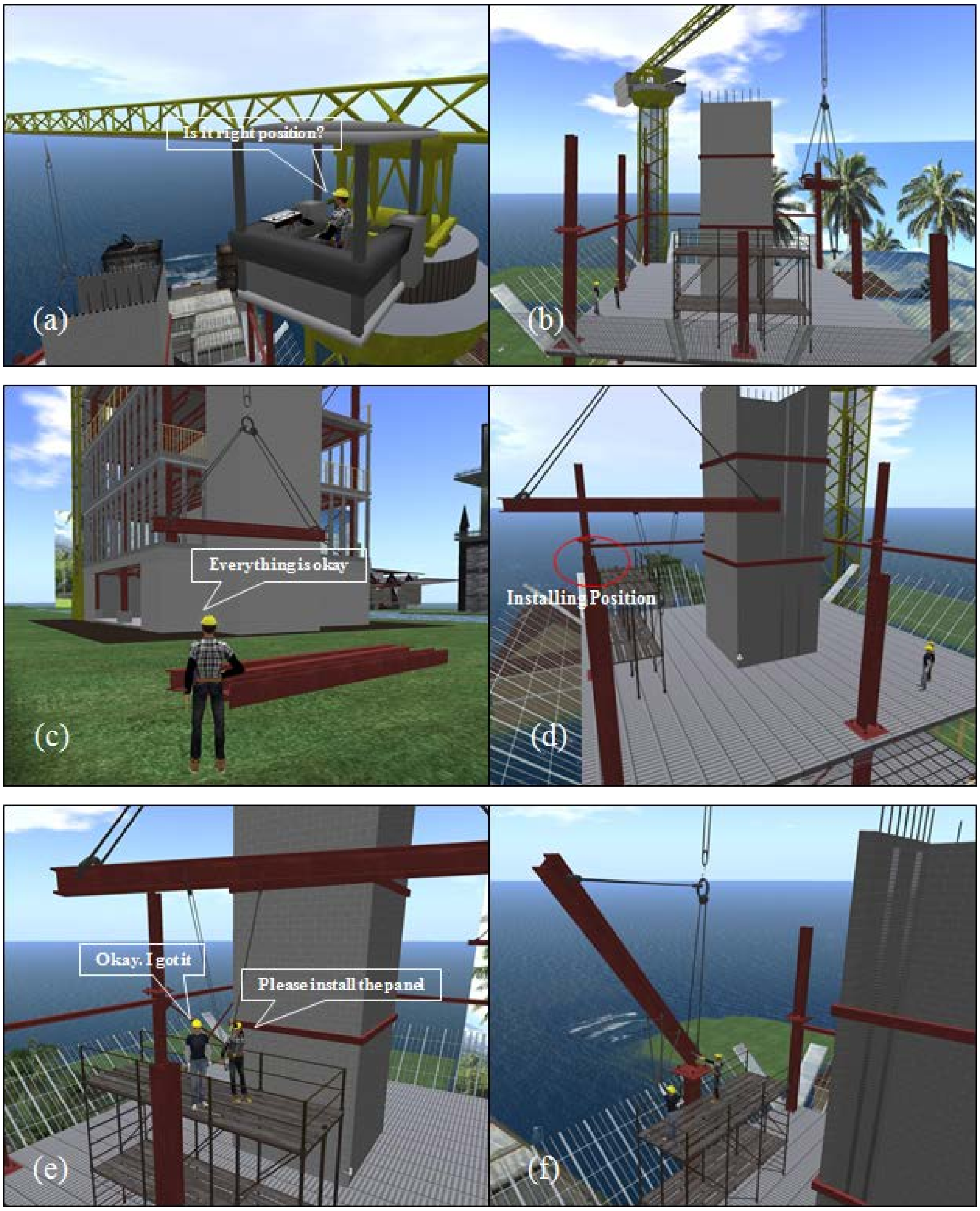


Fig. 6-11 Exterior Glass Installation Sequence; (a) Checking and Preparation; (b) Glass Lifting and Transferring; (c) Glass Installation

In order to emphasize the importance of the communication for construction safety, the I steel column installation on 8th story of the virtual building would be chosen to delineate the group game scenario. Three students through their avatars synchronously cooperated to execute this task by utilizing the audio and virtual reality technologies. This case focused on the collaborative working involved in connecting an I steel column with the steel frame system at 8th story by using the tower crane. The potential risks related with struck-by accident would be mirrored during this game process. To perform this task, student A via the avatar (SA) controlled the crane to lift an I column to its installation location, and student B and C using their avatars (SB and SC) stood on the scaffold on the eighth story of virtual building to locate, install, and fix the I column in its' right position within the 3D virtual environment. Fig. 6-12(a) and (b) show the perspective from SA and (SB, SC), respectively.


Is it right position?
(a)
(b)
Everything is okay
(c)
Installing Position
(d)
Okay. I got it
Please install the panel
(e)
(f)

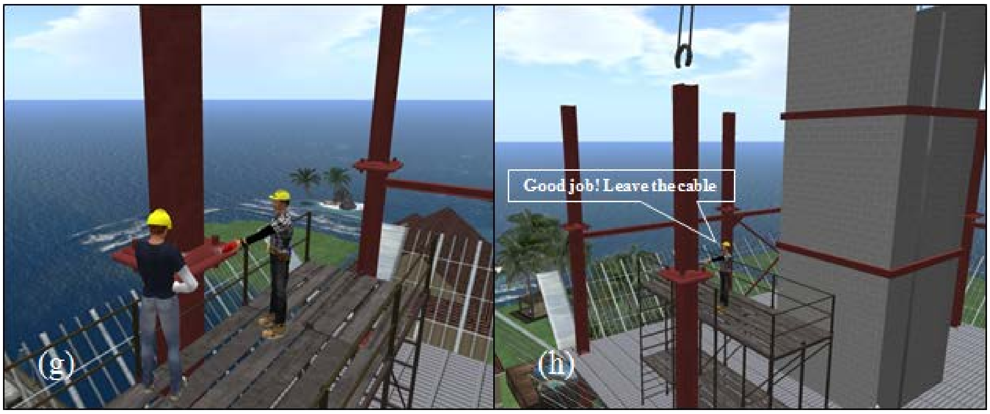
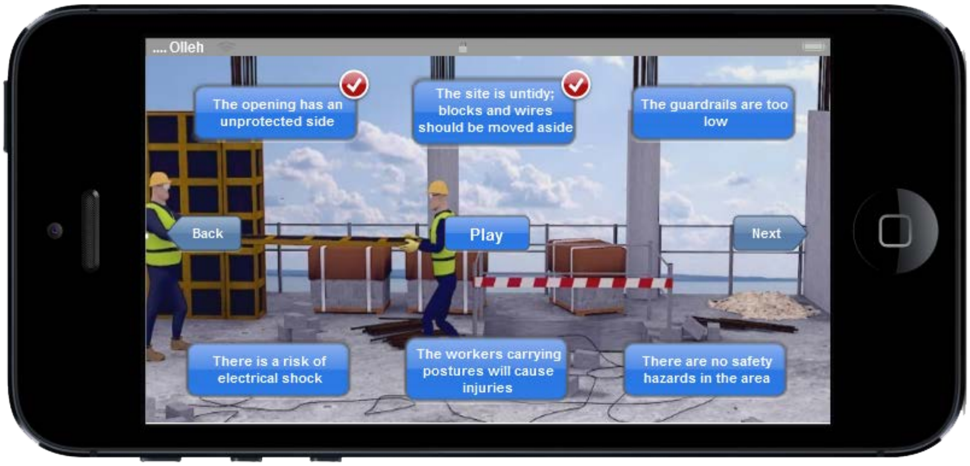


Fig. 6-12 (a) (b) Perspective of SA and (SB, SC); (c) Lifting an I column from steel yard; (d) Reaching the installation position; (e) Locating an I column; (f) Placing an I column; (g) Installing crews; (h) Checking

Firstly, SA controlling the tower crane lifted and moved an I column from the steelyard to reach the installation position through the audio communication with SB and SC (Fig. 6-12(c), (d)). This step required the good communication between the crane controller and guilders. When the I column was close to the correct position, SB and SC standing on the scaffold would collaboratively locate, align and connect the I column with the column connection panel. Fig. 6-12(e) and 6-12(f) show the adjustment process to place the column in correct position. During this step, students recognized that the struck-by accident could easily happen due to the failure communication. Finally, they screwed four bolts to fix the column with the steel frame system and released the crane cable (Fig. 6-12(g), (h)). Fig. 6-12(g) illustrates the fixing the column by screwing, while Fig. 11h delineated the checking process. It is noted that the pop-up notification would be sent to trainees for any safety problem occurrence by the professor. Students conveniently recognize potential risks for experiential safety learning during the collaboration activity.

Finally, teachers have to assess the safety knowledge and hazard recognition capabilities of students. Its' purpose is to ensure that construction students have the ability to apply their safety knowledge to realistic construction sites. Learners are evaluated with a novel approach using VR and AR based theory and multiple option questions, whereby students can view various simulations of construction site equipment and processes. This approach enables construction students to visualize the context clearly for questions being considered, whereas such scenarios would typically be described using text and depicted with pictures traditionally. Visual learners would be disadvantaged with such approaches. Fig 6-13 (a) portrays the QR scanning application mobile interface, which enables leaners to scan QR codes through their mobile device cameras. In addition, they may scan QR codes, which have been saved in their mobile devices through photo scan option. A history of recently scanned QR codes and recently accessed website pages is also available. Fig. 6-13 (b) demonstrates the options that pop up after students click on a virtual site component with the touch-screen function of their mobile device. A red tick mark appears next to options that have been selected on the game-assessment interface. In this scenario, the correct options that should be chosen are (1) the opening has an unprotected side; and (2) the site is untidy; blocks and wires should be moved aside. Fig. 6-13 (c) shows a sample theory question relating to PPE during the concrete pouring process, while Fig. 6-13 (d) illustrates an optional question involving elevator opening accidents and appropriate barrier height based on OSHA 1900.23(a) regulations. Students would access these questions by pointing their smart devices at fusion markers embedded in their test papers. The tests range from easy to difficult level, and students individual scores are computed automatically in the user profile database which only the lecturer can access. Students may retry the hazard identification test, and if the educator deems it necessary, a detail explanation of the hazards in the scenario may be provided. Furthermore, students are required to state the solution of the hazard as part of the hazard-response activity. Lastly, based on the test results, the system will automatically recommend types of safety knowledge that students should focus on based their profile.



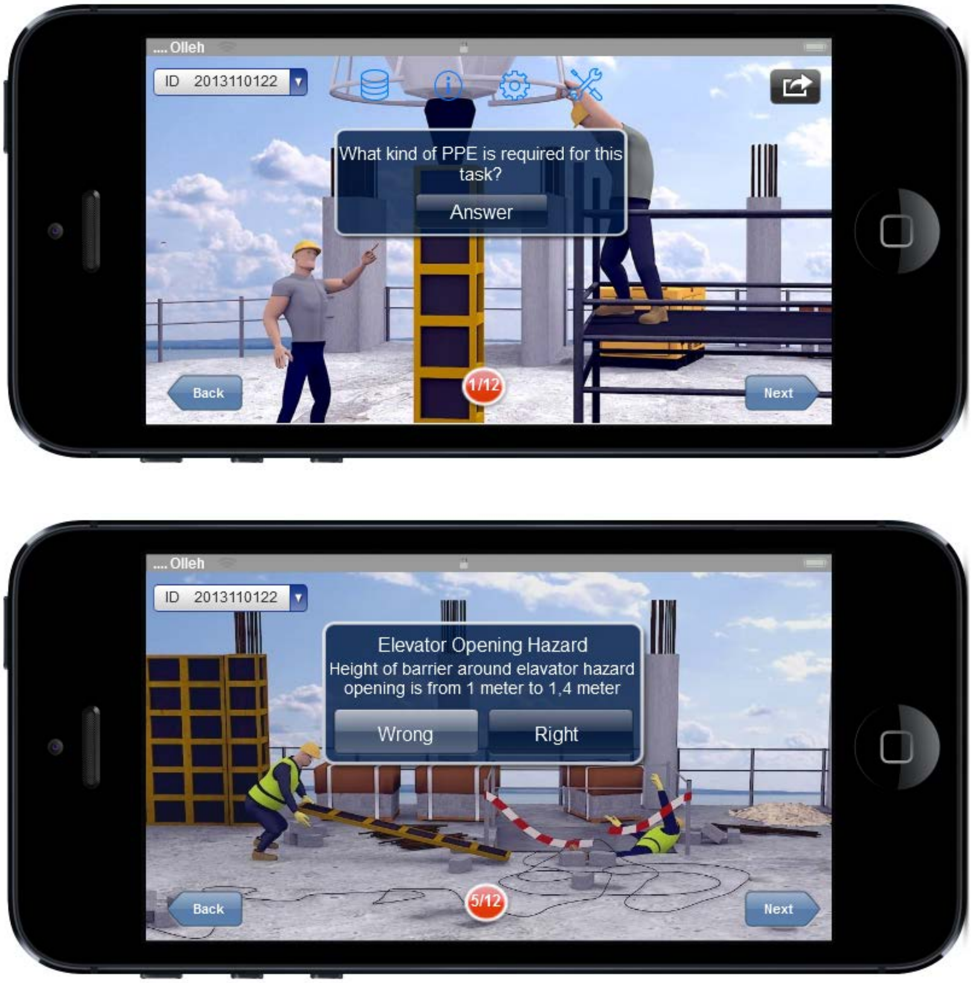


Fig. 6-13 Game assessment (a) QR scanning application mobile interface; (b) Virtual game scenario; (c) Selecting options in hazard inspection game; (d) pop-up after accident occurs

6.7. Summary

This chapter describes the development and implementation processes of the mobile-based VR and AR for construction safety learning and teaching in order to enhance safety performance of construction students. Three modules

– Safety Knowledge Dissemination (SKD), Safety Knowledge Reflection (SKR) and Safety Knowledge Assessment (SKA) – and the system architecture are introduced, and then the prototype is applied in a real class at Department of Architectural Engineering, Chung-Ang University in order to evaluate the system's limitations and advantages. The results and analysis is explained in next chapter.

7. Evaluation and Result

The mobile based VR and AR for interactive and experiential construction safety education seems to be a powerful tool that can improve construction safety learning and teaching process. As such, the system must be verified to prove its effectiveness and identify the limitations and advantages for future development. This chapter introduces the system evaluation and results including experiment design, prototyping technique and data collection and analysis strategies. For the implementation of the experiment, undergraduate students from department of architectural engineering, Chung-Ang University, Seoul, Korea were measured by subjective methods, such as questionnaire, in spring semester 2014 as well as objective methods, such as test performance observation in spring semester 2015. Furthermore, the interviews with safety engineers from Doosan E&C and Hyundai E&C were developed in order to assess the participatory process and main features of the mobile-based system. Finally, a statistics model was created and analysed to compare the VR and AR approach with the traditional education approach. The results from the assessment conduct that the system effectively facilitates experiential learning and provides adequate levels of interaction to transfer safety knowledge to learners. Following sections are explained the evaluation process in detail.

7.1. Evaluation framework

In order to determine the benefits and limitations of the mobile-based VR+AR system, the evaluation scheme depicted in Fig. 7-1 was deployed including three steps: subjective, objective and useability evaluation.

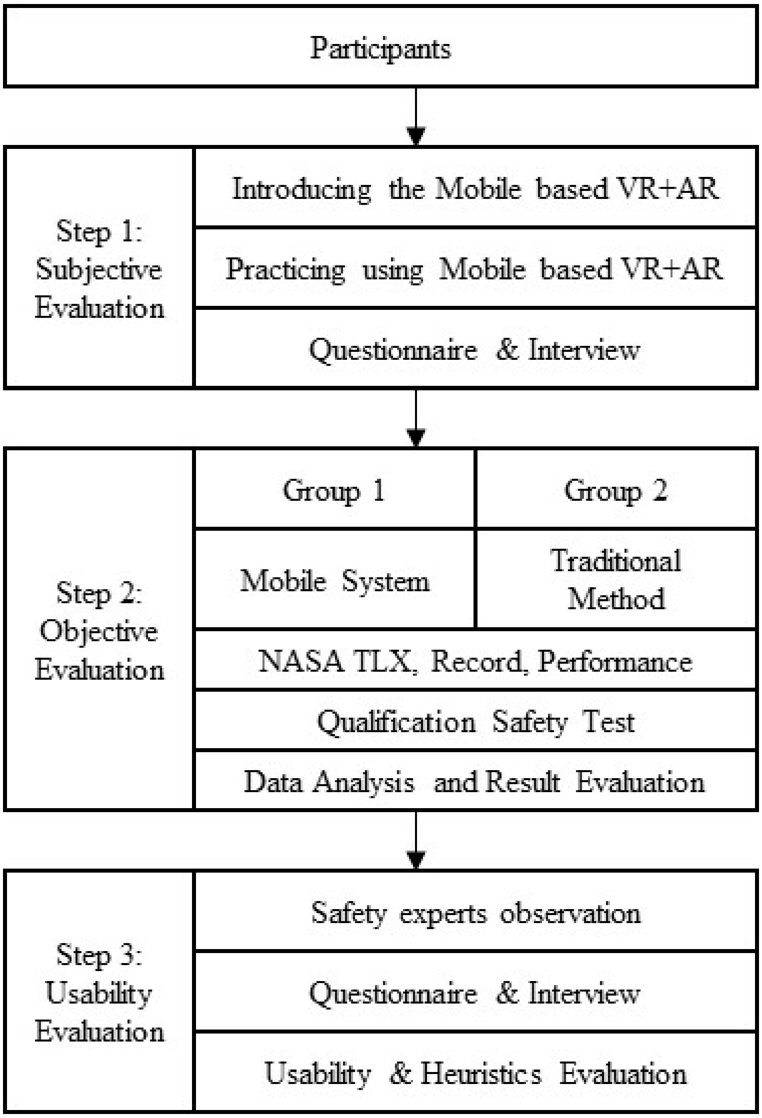


Fig. 7-1 System evaluation process

In step 1 - subjective method, 29 construction management students attempt using the mobile based VR+AR system. The safety lesson was delivered as part of a supplementary course for an undergraduate building construction class. The lecturer spent 50 minutes teaching the class using the system. After a short break, students participated in system trials and interviews for usability evaluation within 90 minutes. The five criteria which were evaluated as following: 1) ease of use, visual output (sensory), which assessed how well participants senses were utilized during interactions with the mobile based VR+AR system; 2) Safety Cognition (cognitive), to focus on how well the system support engagement; 3) Safety Memory (affective), which focused on the emotional impact of the student towards safety knowledge retention; and 4) Safety accessibility (active), which considered the expected level of user attachment towards the mobile based VR + AR (Dustin, 2010). Following the classroom deployment of the mobile-based VR + AR system, feedback was also acquired from educators and a safety manager.

Step 2, namely objective method, comprises of 30 construction management students divided into 2 groups – group A and B. A construction safety course is delivered to group A using the mobile-based VR and AR system, while group B learns about construction safety through the traditional method (university classroom based lecture). After finishing the construction safety course, two groups would participate in a safety qualification test. The test questions would be extracted from the KOSHA and OSHA library. The test contents include hazards from KOSHA animations and questions relating to KOSHA standards. Then, participants performance observations (score, time, NASA task load index) are analysed in term of cognitive workload by using statistical and mathematical theories. Finally, the prototype system evaluation is conducted based on analysis results.

Finally, in step 3, useability evaluation is employed by observers during the learning process in order to modify User Interface (UI) to improve learning activities. Three lecturers (from Chung-Ang University), two safety engineering (from Doosan E&C and Hyundai E&C) were interviewed to assess the system's usability and construct good human-computer interface in the future.

7.2. Evaluation Result

7.2.1. Subjective Evaluation

In spring semester 2014, system trials, interview questionnaires and discussions were conducted with 29 4th year undergraduate construction management students, 3 lecturers (from the department of Architectural Engineering at Chung-Ang University), and a safety manager (from Doosan E&C in South Korea) in order to appraise and evaluate mobile based VR+AR system for experiential construction safety education. Fig. 7-2 illustrates the system classroom implementation within 120 minutes. The interview questions and students responses based on 5-point Likert scale (1 – Useless, 2 – Ineffective, 3 – Normal, 4 – Effective, 5 – High Effective) are illustrated in table 7-1 and Fig. 7-3. These advantages were perceived in terms of the systems: 1) ease of use, 2) level of visual output (sensory), which assessed how well participants' senses were utilized during interactions with the mobile-based system; 3) Safety cognition (cognitive), to focus on how well the mobile-based system supports engagement and the potential to improve students' safety cognition 4) safety memory (affective) and 5) safety accessibility.

Fig. 7-2 The system implementation in the real class

Table 7-1. Summary of questionnaire and interview result

Issues	Mean	Results
1. Ease of Use (Sensory)		
Did you feel comfortable when interacting with the screen of the mobile system?	4.2	Very comfortable Very high score illustrates that users felt comfortable when using the mobile interface for learning.
Did you find the system easy to use?	3.8	Neutral It seems that users can easily familiarize themselves with using the smart device to operate the system.
2. Visual output (Sensory)		
How real do the VR and AR contents appear on mobile devices?	3.7	High The virtual contents reflects close-to-reality with real construction site, which impressed the users.
Is the information provided in the system clear?	3.5	Clear The system provides users with adequate safety information via its constituent modules.
Did the system reflect practical construction experience?	3.6	Normal The virtual scenarios satisfied the educational purpose; however, some scenarios seemed not to reflect practical experiences.
3. Safety Cognition (Cognitive)		
Was the safety content of the system helpful in safety cognition?	3.8	Helpful Users felt that the safety content can provides them with a good cognition on how important of construction safety is.

Did you believe the system could improve hazard recognition in a real construction site?	3.2	Neutral It seems that the VR and AR contents of the system can support users to identify potential hazards in real construction site
4. Safety Memory (Affective)		
Did you think the system could enhance your safety memory?	3.6	Satisfied The interactive and experiential features of the mobile VR+AR system engaged and motivated students to remember safety lessons.
Do you expect the mobile-based VR+AR system affect your long-term memory?	3.2	Normal The neutral rating implies that experiential learning through mobile-based VR+AR could support long-term memory; however, further testing of long-term memory testing is necessary.
5. Safety Accessibility (Active)		
Did you think the system enhance construction safety education effectively?	3.7	Effective The mobile system was interesting and captivating and could improve construction safety & health education.
Do you think the mobile-based VR+AR system is more beneficial than tradition whiteboard based lecture?	3.1	Neutral Users felt that the system was a somewhat helpful and useful in comparison with the traditional whiteboard based lecture; however, it is necessary to use mathematical method to further evaluate the system and its classroom suitability
1 - Useless; 2 - Ineffective; 3 - Normal; 4 - Effective; 5 - High Effective		

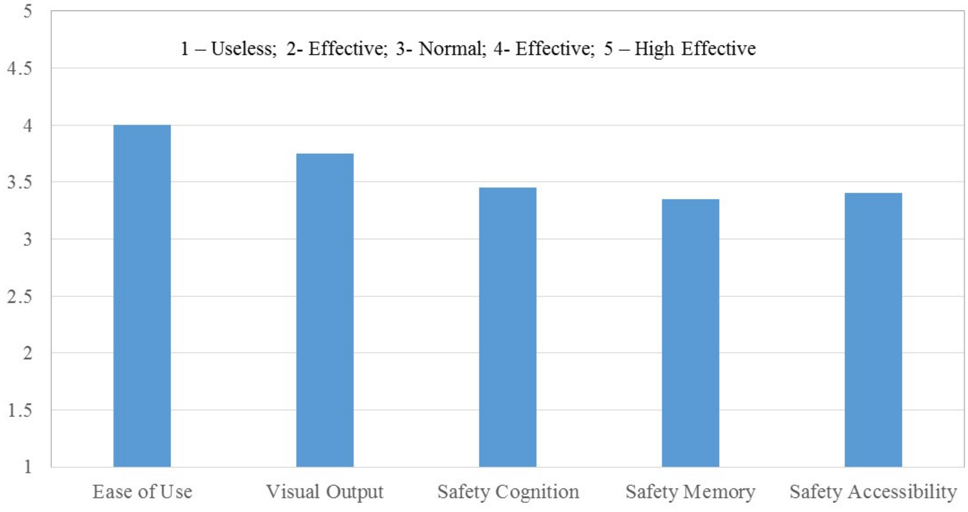


Fig. 7-3 The system effectiveness evaluation result

Student participants recognized many advantages with mobile-based VR + AR assisted learning. Students felt positive and comfortable about using their mobile devices to access hazard information through augmented virtual contents overlapping their textbooks in the classroom. Also, learners found the SKR and SKA modules captivating, motivating, and easy to operate through mobile avatars. Students mentioned that the system was user friendly, and course content based on VR and AR scenarios were easy to follow by using mobile device. Mobile based system also useful to help them to improve their learning independence. Learners who used mobile devices with larger screens (such as iPads) were observed to enjoy using the system more than those with smaller screens (iPhone). Nonetheless, both larger and smaller mobile device screens afforded improved virtual environment perception for more contextualized learning. However, a few learners using smaller screen devices expressed the opinion that virtual navigation was difficult to control at certain points. Students also felt that the system provides them with a good opportunity to develop their hazard recognition capabilities. They used their mobile devices to interact with safety VR and AR contents; and then stated that the interactive and experiential features of the system engaged them to significantly remember safety lesson. Finally, students considered that mobile based VR+AR was somewhat helpful and useful in comparison with the traditional whiteboard based lecture.

Educators stated that the virtual contents had sufficient sensory fidelity to reflect a realistic construction site. Educators also agreed that the systems' SKD and SKR modules allowed for sufficient interaction to engage students in acquiring safety knowledge and developing safety cognition. Furthermore, the SKA VR games and AR multiple choice test helped educators to comprehensively assess students' knowledge on PPE, on-site safety procedures, hazard identification, etc. Majority of lecturers recognized the great potential of the mobile VR + AR safety system to effectively transfer safety knowledge to construction students, however they also pointed out that faculty readiness and support would play a crucial role in incorporating the system into current syllabi. Educators also raised concerns that mobile devices could be a distraction to learners in the classroom. However, during the system trial, students stated that the devices were not distracting. In addition, the development of VR and AR system contents was considered time consuming and laborious. When working with 2 lecturers, the scenario creation process ranged from 3 to 5 days per model. Furthermore, some educators mentioned that anti-technology instructors are a future barrier, which should be considered. Lastly, a safety manager recognized the potential of the systems' virtual site inspection and hazard identification tasks to be adopted in the construction site for safety training. However, he observed that a few scenarios (such as the staircase falling scenario in no. 4 of table 1) did not adequately reflect the realistic construction site. To address this, he recommended the utilization of Building Information Modelling (BIM) from real construction projects. Through this, the content development workload and time consumed would be significantly reduced.

Preliminary results confirm that the proposed mobile-based VR + AR system can assist students and educators in the process of construction safety education. Interviewees generally agreed that the system would significantly improve the construction safety performance and outcomes. As illustrated in step 2 of Fig. 9, a more objective evaluation through a performance based comparison and qualification safety test will be completed in next section.

7.2.2. Objective Evaluation

For more quantitative and rigorous assessment, the objective evaluation including a test performance observation and a statistical analysis is developed and implemented. This test was performed in spring semester 2015 with 30 undergraduate students from Department of Architectural Engineering, Chung-Ang University, Seoul, Korea. It is noted that the authors implement the computer based the education concept in real construction classes instead of using the mobile-based system. The computer-based system represents the same education features of the VR and AR system. The method is believed to demonstrate the same result when using mobile-based system. Firstly, the students were separated into two groups A and B. The traditional education and mobile methods were utilized to deliver construction knowledge to group A and B, respectively. Group A were taught about safety lessons mainly based on whiteboard, projectors and verbal based the lecturer (Fig. 7-4). The participants of group B were given an introduction and overview of the game process (Fig. 7-5). The mobile system was applied to integrate falling and struck-by hazards with construction methods and materials course in the department computer room. The hazard lessons were delivered as part of a supplementary course for undergraduate classes. An educator spent 90 minutes teaching for each group using the game system and traditional method.

Fig. 7-4 Traditional education method

Fig. 7-5 The system classroom implementation

Afterwards, all students of group A and B would review the safety lessons within 20 minutes. Group A's participants use a textbook and paper-based lecture materials while group B's students via VR and AR mobile-assisted a textbook review the lecture. Then, they would fill out a 20-point Likert scale of NASA Task Load Index (TLX) (Hart, 2006) (Fig. 7-6) to evaluate the cognitive workload of each educational method. NASA TLX developed by the Human Performance Group at NASA's Ames Research Center is a multidimensional assessment tool that rates perceive workload in order to assess the mobile-based system's effectiveness and students' performance (For more detail, please refer the A*ppendix III – NASA Task Load Index*). The NASA TLX has been applied in various fields involving the evaluation of visual and/or auditory displays, vocal and/or manual input devices, and virtual/augmented vision. This evaluation approach is based on weight average of ratings on six subscales: 1) metal demand: how much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? 2) Physical Demand: How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brick, slack or strenuous, restful or laborious? 3) Temporal demand: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? 4) Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals? 5) Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance? 6) Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

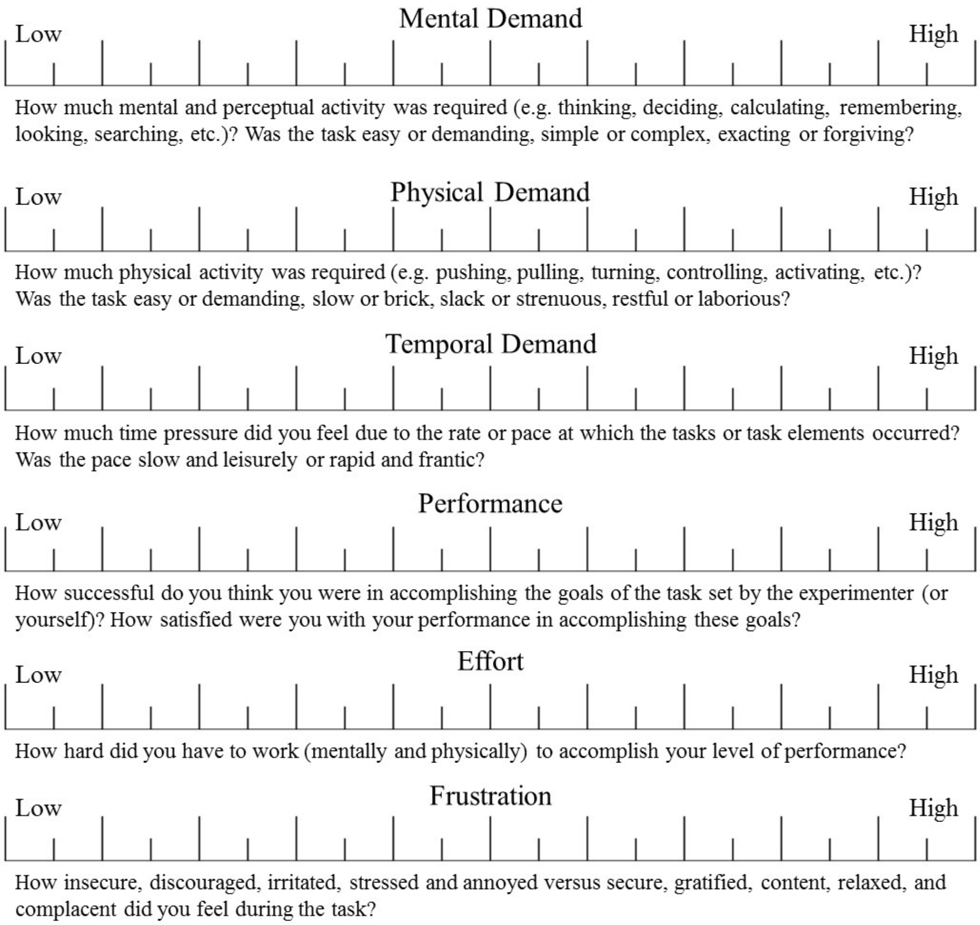


Fig. 7-6 NASA Task Load Index (Hart, 2006)

Fig. 7-7 indicates the rating results of NASA-TLX Scores for each item for evaluating cognitive workload of two approaches. Mobile-based system produced an average score of 9.66, lower than the score of 13.32 in the traditional method. The initially results depict that students using mobile based VR and AR place less cognitive workload then using traditional method. Table 7-2 illustrates the statistical results for each NASA TLX factor in detail. For metal demand, the significant coefficient is zero less than 0.05 that represents hypothesis: the mental demand is different between two approaches. In other words, the use of the tradition-based education method underwent higher mental stress than those using mobile-based VR and AR. Furthermore, higher frustration and physical demand were in accordance with the longer understanding time about safety lessons when participating whiteboards and lectures based learning (frustration score: 13.53/20 for traditional approach and for 8.2/20 mobile-based; physical score: 17.87/20 for traditional approach and for 12.07/20 mobile-based). However, for the temporal demand and performance factors, the significant levels (0.069 and 0.058) are greater than 0.05, indicates that the subjects using mobile based VR and AR were satisfied with their performance during safety reviewing process, an opinion equal to the students using textbook based lecture materials.

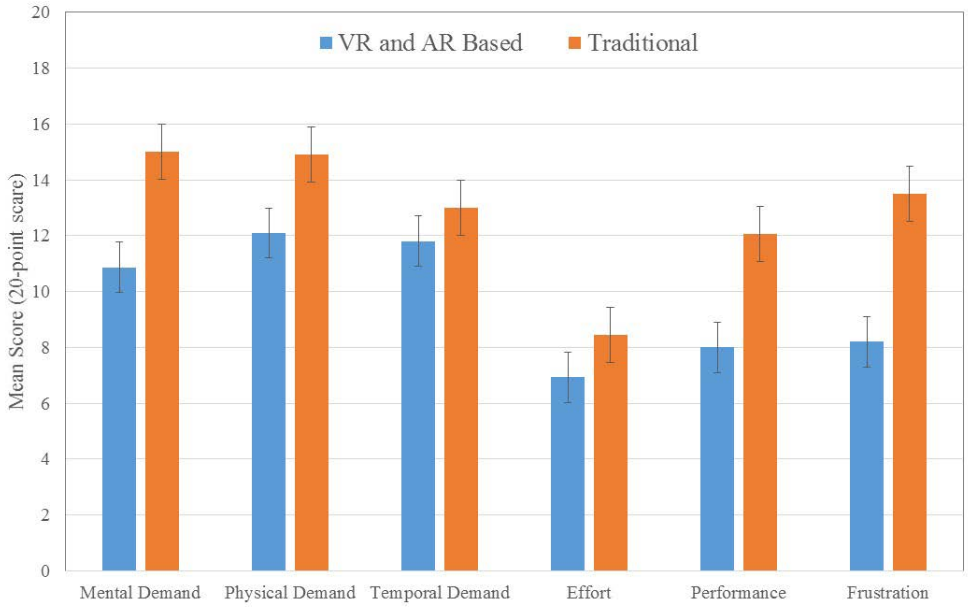


Fig. 7-7 NASA Task Load Index Mean Score

Table 7-2. Statistical results for each NASA Task Load Index factor

Factor	Method	No. of Students	Mean	Std. Deviation	F-value	P value	Significant
Mental Demand	VR & AR based	15	10.87	2.74	1.028	.000	Significant
	Traditional	15	15	2.27			
Physical Demand	VR & AR based	15	12.07	2.12	0.971	.001	Significant
	Traditional	15	17.87	1.96			
Temporal Demand	VR & AR based	15	11.8	1.59	0.938	.069	Insignificant
	Traditional	15	13	1.6			
Performance	VR & AR based	15	6.93	1.98	0.464	.058	Insignificant
	Traditional	15	8.47	2.26			
Effort	VR & AR based	15	8.07	2.6	0.579	.000	Significant
	Traditional	15	12.06	2.05			
Frustration	VR & AR based	15	8.2	1.74	0.169	.000	Significant
	Traditional	15	13.53	2.26			

Finally, a paper-based examination related to teaching topics (19 questions, score 100 – Refer to *Appendix IV – Paper Based Examination*) was implemented for all 30 students and a statistical model was developed in order to compare the score results between two approaches (Fig. 7-8). The independent T-test method is selected with hypothesises: Null hypothesis – the score test results from both educational methods are same, alternate hypothesis – the score test results from two educational methods are significantly different. The score data were analysed with 5% significant level using SPSS statistics 22. Table 7-3 presents the statistical results of the test scores of two educational approaches. The mean value and standard deviation of the test score from traditional and mobile-based methods are: Mobile-based (87.33 and 9.98) and traditional approach (80.47 and 7.95). The p value is 0.046 smaller than 0.05 (significant level) that conduct to reject the null hypothesis. Furthermore, the mobile-based system's mean value is higher than the traditional approach's, and therefore, it concludes that the new approach is more significant than traditional method. In other words, students participating the class using mobile-based system had higher score than those who joining the traditional class based on whiteboard lectures. This objective evaluation partially proves that VR and AR based approach can improve construction education process and help leaners to effectively acquire safety knowledge.

Fig. 7-8 Paper-Based Test

Table 7-3. Statistical Results of T-test for the paper examination

Education Method	No. of Students	Mean	St. Deviation	F value	p value	Significant
VR & AR Approach	15	87.33	9.98	0.439	0.046	Significant
Traditional Approach	15	80.47	7.95			

7.2.3. Usability Evaluation

For assessing the system usability, a post-experiment evaluation by interviewing two construction experts (from Doosan and Hyundai E&C) and three professors (from Chung-Ang University) was implemented (Fig. 7-9). The evaluation technique is mainly referred from Molich and Nielsen, (1990) and Nielsen, (1994) that came up with five criteria including clarity of instruction status, system guideline, user control and freedom (comfort), easy to learn and pleasant to use (interactivity) and engagement and motivation (Refer to *Appendix V – Comparison of use of VR and AR system with traditional whiteboard based lecture*). As illustrated in Fig. 7-10, safety engineers and lecturers agreed that instructions for use the system and guidelines for safety lessons are visible and easily retrievable whenever appropriate. They describe they system as “straightforward” and barely encountered any difficulties in comparison to traditional education approach. Nevertheless, mobile device screen size has to be considered in according with virtual content graphic application. Even though the mobile usually are used for self-directed informal learning, safety experts commented that the mobile based VR and AR would fit well into formal academic learning in not only safety but also construction methods and materials.

Fig. 7-9 Interview with a safety expert

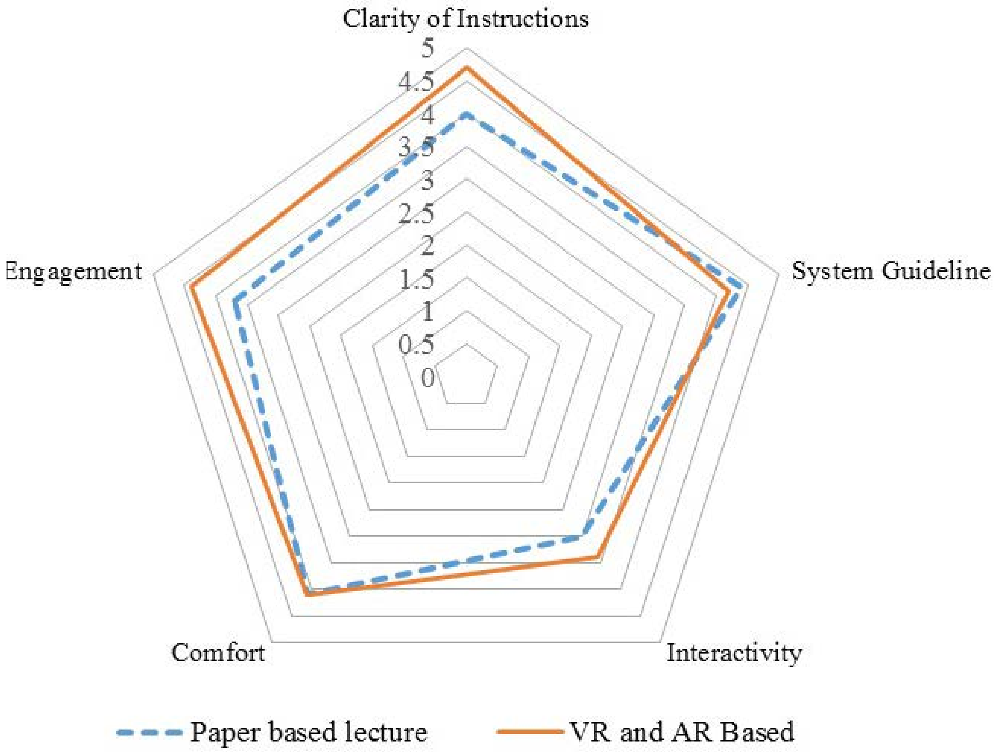


Fig. 7-10 Usability Evaluation

Furthermore, construction experts and professors commented that:

a) The mobile-based provides sufficient interactions capable of anatomize and construct a building object. Professors replied that students seem to be immersed in the new system. They also mentioned that they expected the unique concept to enhance the learning experience. Some educators who experienced with BIM based class mention that in comparison to BIM, the system is easier and more comfortable to operate for delivering construction knowledge. By interactively manipulating BIM and VR models, the mobile-based transfers knowledge to construction students more effectively and efficiently. However, some experts raised concerns that the development of mobile-based scenarios would be time consuming and costly. Moreover, collaboration is limited due to students focusing on operating virtual models.

b) The construction industry experts agreed potential of the new system to improve construction education. They mentioned that the system provides an interactive and experiential learning environment that motivates learners to gain the knowledge and partially enhances knowledge retention. Moreover, they strongly recommended further studies considering the application of the mobile based VR and AR in the construction site, to improve communication, train workers and reduce the occurrence of rework.

7.3. Summary

This chapter depicts the evaluation of the mobile-based VR and AR system including three steps: subjective evaluation, objective evaluation and usability evaluation. Subjective step is mainly focusing on interviewing students about four criteria: sensory, cognitive, affective and active. In objective step, cognitive workload is assessed through a survey and learning outcomes are measured and compared between the traditional and mobile-based methods. Lastly, the useability of the system is conducted by safety engineers and professors. The evaluation results dedicates that the mobile system affords visual and experiential learning and supports interactivity between leaners. In addition, mobile-based virtual and augmented reality has been observed to provide adequate sensory fidelity to deliver compelling safety learning experiences to students. The objective assessment partially demonstrates that the mobile based VR and AR system can improve the safety knowledge transfer process and help leaners to acquire construction experiences effectively. Then, construction students can perform safely when entering the construction industry. However, at this point, the study has been done subjective and preliminary objective evaluation, the more quantitative and rigorous assessment will be implemented based on task performance analysis and long-term learning outcome measurements.

8. Conclusion

This chapter reviews the achievements of the research objectives. Then, the conclusions and contributions of the research are discussed. Finally, some possibilities of future researches are outlined.

8.1. Review of Objectives

This dissertation was set out to explore the Virtual Reality (VR) and Augmented Reality (AR) for construction safety education. The main objective of the research was to develop the experiential and interactive education system for construction safety by utilizing mobile technology-based VR and AR, as well as assess the effectiveness of the system in facilitating effective and efficient educational process and effective learning performance of students involved in safety education. According to research methodology, the following major sub-objectives have been solved and achieved:

1) To understand the need of safety education at tertiary level for safety performance improvement in the construction industry and

2) To explore the VR and AR technologies as a new approach that shifts safety education from ‘Listen, and I will forget. See, and I may remember’ towards ‘Practice, and I understand’

3) To emphasize the potential benefits of mobile devices that can support to VR and AR technologies for construction safety education

4) To implement a social network system for collecting, storing and sharing safety information & knowledge in order to develop the virtual scenarios for the main system

5) To develop a mobile based VR and AR system that allow students to interactively and experientially acquire construction safety knowledge

6) To demonstrate and evaluate the education system by observing the cognitive workload and comparing learning outcomes between the convention education methods and the new approach

8.2. Contributions and Conclusions

Based on the formulated methodology, the prototype system called mobile-based VR and AR for construction safety education was successfully developed. The key features of the proposed system focus on four aspects: spatial & situation awareness, safety attitude & behaviour, hazard identification & recognition, and stimulation of motivation towards safety education in order to create an experiential and interactive environment in which students can easily and effectively acquire safety knowledge and then, perform safely when entering the construction industry. Virtual contents of the system have been simulated close-to-reality construction site that motive and inspire leaners acquiring safety knowledge and developing safety cognition.

The research shows that the approach of using VR and AR and the developed mobile application based VR and AR were feasible to deliver safety knowledge and construction experience to students. The prototype was implemented and evaluated in the real classes. The results illustrated a positive effect on cognition facilitations and learning outcomes when using the new approach. Specially, this dissertation has shown that:

1) The review of ICTs in order to emphasize:

- The VR and AR could play a significant role for experiential and interactive education on construction safety
- SNS could be a powerful tool for collecting and sharing safety information
- Mobile devices provide learner with a great educational opportunity to access VR and AR safety contents and interact with instructors and other students anytime and anywhere

2) Designing and developing virtual education scenarios that are close-to-the reality from the safety information collected from SNS.

3) Developing the mobile based VR and AR framework, which consists of three modules: SKD, SKR and SKA for interactive and experiential construction safety education.

4) Prototyping the system in the laboratory scale with these virtual education scenarios derived from real accident cases. Testing the prototype with students from department of Architectural Engineering, Chung-Ang University, Seoul, South Korea

5) Qualitatively and quantitatively validating that the mobile-based system can be used as an effective safety education approach. The verification results partially demonstrate that students using the proposed system undergo lower cognitive workload and acquire higher learning outcome than those using conventional methods. The new approach can improve construction safety education process and help learners acquire safety knowledge effectively and efficiently. Through this, graduates can perform safely when entering the construction industry.

6) Implementing heuristic usability evaluation for the mobile based VR and AR. Improving suggestions for enhancing future use of the system

The study provides an empirical impetus for improvements in using mobile-based VR and AR for educating construction students about safety. In particular, it is suggested from the results that VR and AR system could be used in guiding construction workers for safety training where training productivity and effectiveness can be enhanced. These findings can be generalized in not only safety education but also a wide range of construction academia as well as construction practices such as worker training, construction assembly, etc.

8.3. Discussions

The limitations of the mobile-based VR and AR system were found through the prototype implementation and evaluation in the real class at department of architectural engineering, Chung-Ang University, Seoul, Korea. These are: 1) the time-consuming development of VR and AR education scenarios, 2) the lack of long-term memory evaluation for the VR and AR system.

For one visualization education scenario, it takes around 2 days for development. It would require much time to create all the VR and AR contents covering the safety courses. As such, it is important to establish a link between universities and construction companies in which companies would provide universities with visualization models and safety information for education and universities can generate the required safety competency students in the labour market. In addition, long-term memory measurement requires evaluating students after 6 months learning. However, one education course in the semester is only 4 months. This causes difficulties for long-term memory evaluation. This requires one-year safety course for construction students in universities.

Besides the technical challenges, educators and leaners spent extra efforts with using mobile devices and anti-technology instructors are barriers, which should be considered. It is important that teachers develop new competencies related to apply a VR and AR technology for safety courses.

8.4. Recommendations for future work

The research have investigated the fundamental principles of using mobile computing, VR and AR for improving construction safety education. The author is currently in process of developing a VR and AR system utilizing Hub of Immersive Visualization and E-learning (HIVE) for both safety education and training (Fig. 8-1). Additionally, the more quantitative and rigorous assessment based on full-scale workload measurement and long-term curve evaluation will be implemented.

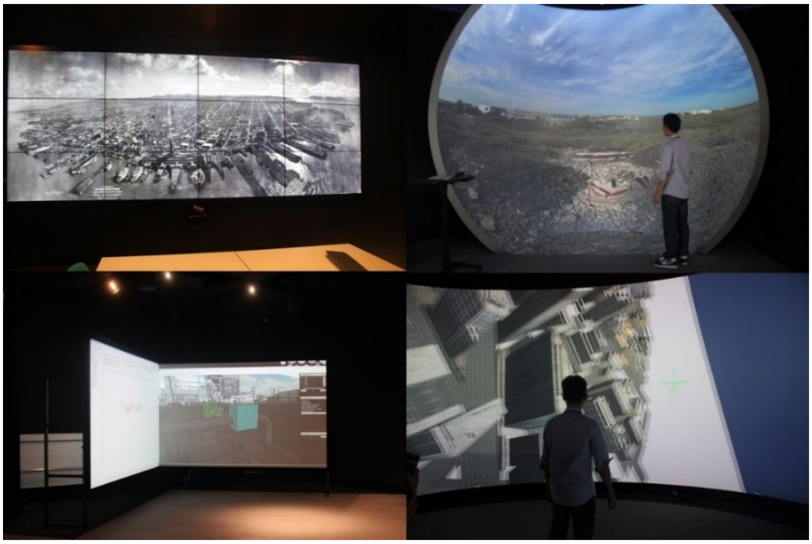


Fig. 8-1 Interaction with HIVE

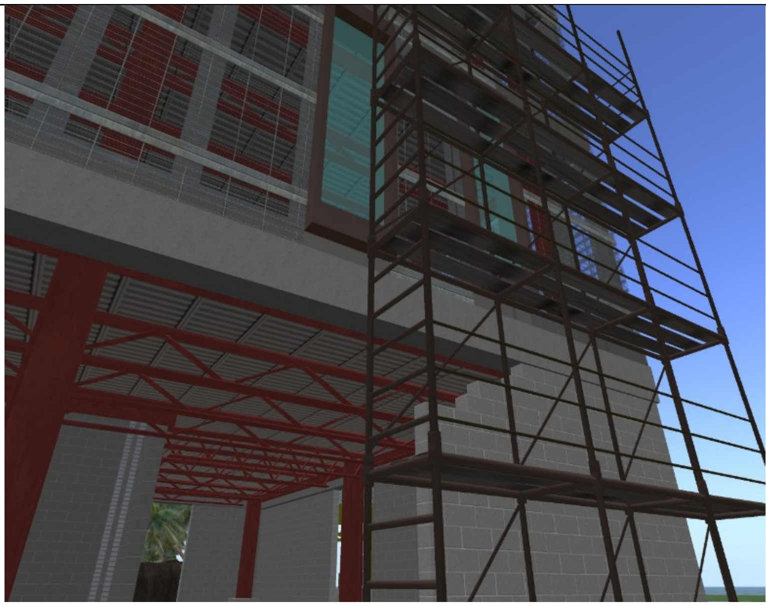
Future oriented research can implement some of following needs and applications:

1) To solve the time-consuming of scenario development of the system by integrating and reuse real BIM models from real construction projects. To integrate the VR and AR educational scenarios into real construction schedules in order to develop an active safety-training program.

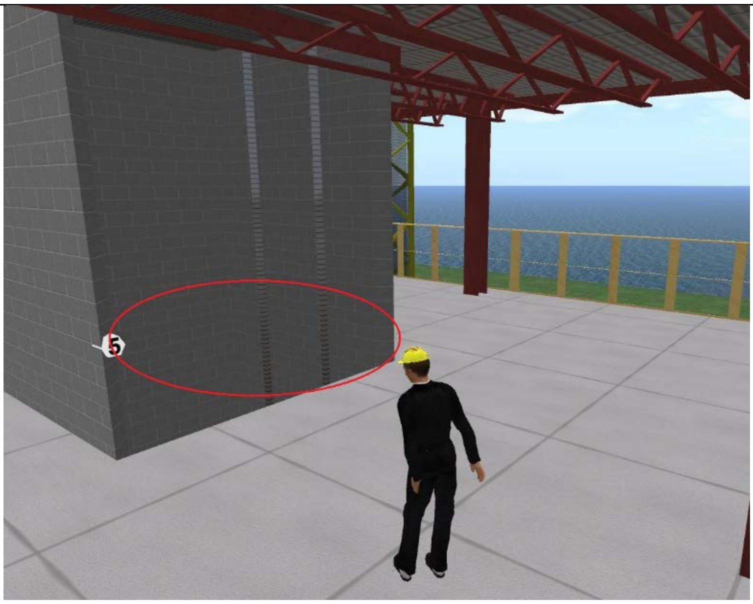
2) To lead to the implementation of the mobile based VR and AR system into real construction project as a training tool. The real improvement in safety performance and productivity with the mobile app can be then measured and quantified with construction site activities in real projects.

3) To implement the system utilizing wearable devices (e.g. wireless Head Mount Devices (HMD), Google Glass, etc.) will enable safety training and education more reality and effective. The use of heat rate and temporary sensors as well as tracking technology during training process for analysing human behaviour to develop effective training/ education strategies is also a good topic.

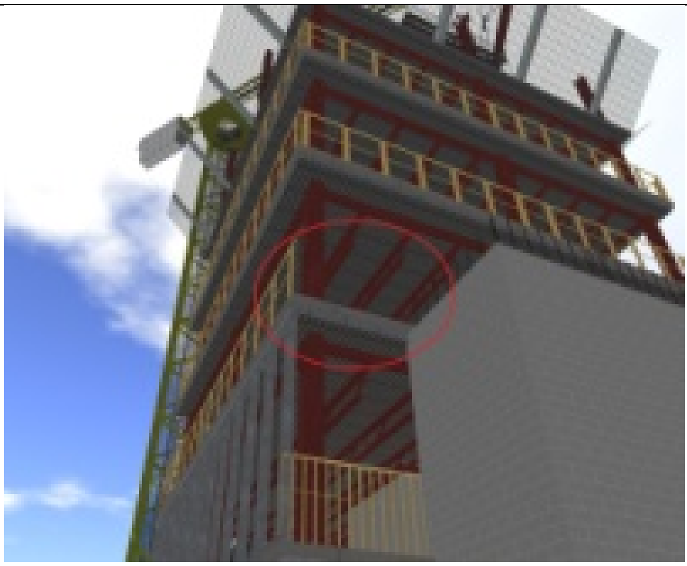
Appendix I. Virtual Safety Education Scenarios

Name	Falling during exterior curtain wall installation
Activities	Frame the curtain wall into building façade
Place	In front of building (building façade) at the third floor of the building
Time	Sunny day with a strong wind
Main safety Elements	Personal arrest system, PPE, scaffold
Situation	During the exterior curtain wall installation, a worker stood on the pole scaffold to perform his work. Although the worker was protected by a personal arrest system, there is no guardrail covering the scaffold. When transferring a curtain wall panel to its position, the worker slipped off the edge of the scaffold and fell down. The personal arrest system protected him to avoid a serious accident. However, his head was struck-by the exterior wall and as the result, he stayed at a hospital for a week.
Photo	
Avatar	A young male worker is modelled to install exterior curtain wall

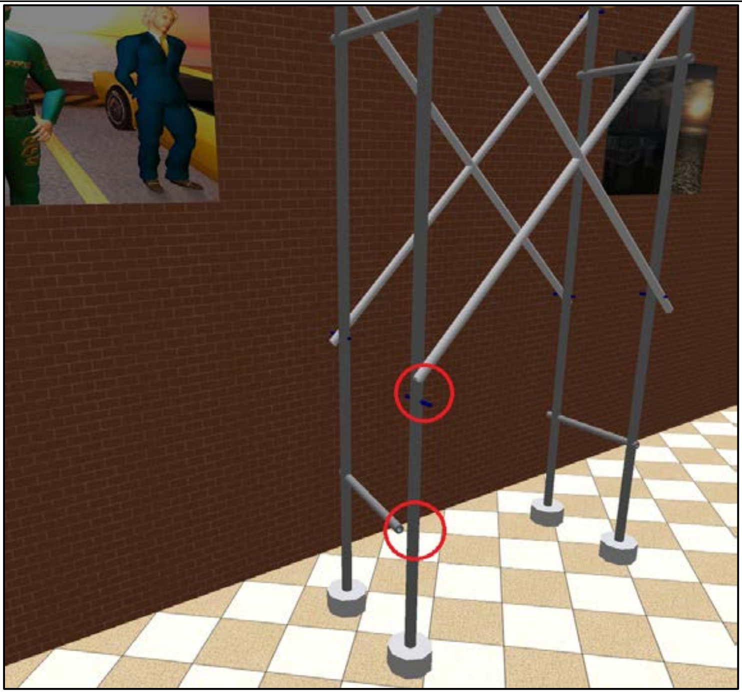
Safety Standard	Scaffolds: Fall protection *(guardrail systems and personal fall arrest systems*) must be provided for each employee on a scaffold more than 10 feet (3.1 meters) above a lower level. Quotation from OSHA 1926.451(g)(1) Scaffold, Guardrail: Guardrail shall be installed along all open sides and ends and before the scaffold is released for use by employees other than the erection and dismantling crews. Guardrail are not required on the front edge of a platform is less than 14 inches (36 centimetres) from the face of the work. When plastering and lathing is being done the distance is 18 inches (46 centimetres) or less from the front edge. When outrigger scaffolds are attached to supported scaffolds the distance is 3 inches (8 centimetres) or less from the front edge of the outrigger. Quotation from OSHA 1926.451(b)(3) and (b)(4) Each employee on a single-point or two-point adjustable suspension scaffold shall be protected by both a personal fall arrest system and guardrail system. Quotation from OSHA 1926.451(g)(1)(ii)

Name	A dangerous elevator opening
Activities	Transfer construction materials, pouring concrete
Place	The elevator opening at the fifth floor
Time	Sunny day with a strong wind
Main safety Elements	Safety barriers, pouring concrete equipment
Situation	Two workers transferred construction materials to the fifth floor. For their work convenience, they removed the fences around the elevator opening, but they forgot to fit up them again. In the evening, three workers poured concrete on the fifth floor, one of the workers was close the elevator opening. As moving forward to sharpen concrete surface, he stepped towards the unguarded opening, fell 16m, and landed on the steel basement elevator. He died from fatal head and bones broken.
Photo	
Avatar	Three workers work on the fifth floor near the elevator opening
Safety Standard	Where employees are exposed to falling 6 feet (1.8 meters) or more from an unprotected side or edge, the employer must select either a guardrail system, safety net system, or

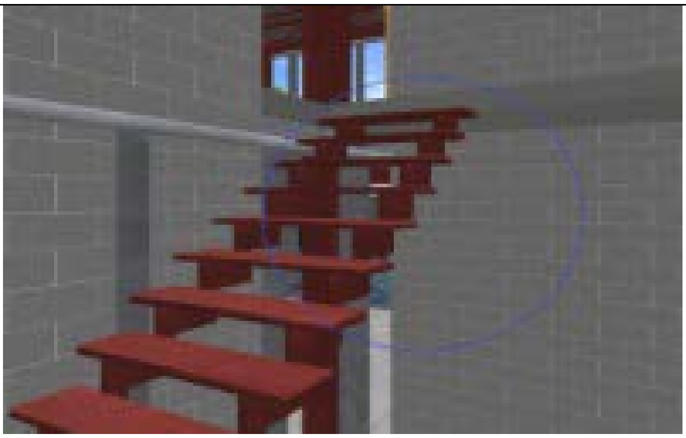
	personal fall arrest system to protect the worker. Quotation from OSHA 1926.501(b)(1) Personal fall arrest systems, covers, or guardrail systems must be erected around holes that are more than 6 feet (1.8 meters) above lower level. Quotation from OSHA 1926.501(b)(4)

Name	A dangerous floor opening
Activities	Transfer wood fences, punch nails in the wood fence to install the safety barrier system
Place	The edge of the sixth floor
Time	In the afternoon after the lunch time
Main safety Elements	Safety barriers, wood fences, nail guns, safety arrest system
Situation	Two workers installed safety barriers covering the eight-story building on the sixth floor. They did not wear any personal fall protection. The workers used nail guns to install wood fences into a safety barrier system. One of them was close to the edge of the floor. As he reaching to pick up another wood fence, he lost his balance. He slipped off the edge of the floor. He fell more than 18m and landed on the basement below. He therefore died from his internal injuries.
Photo	
Avatar	One apprentice and one worker are simulated as characters
Safety Standard	"Unprotected sides and edges." Each employee on a walking/working surface (horizontal and vertical surface) with an unprotected side or edge, which is 6 feet (1.8 m) or more above a lower level shall be protected from falling by

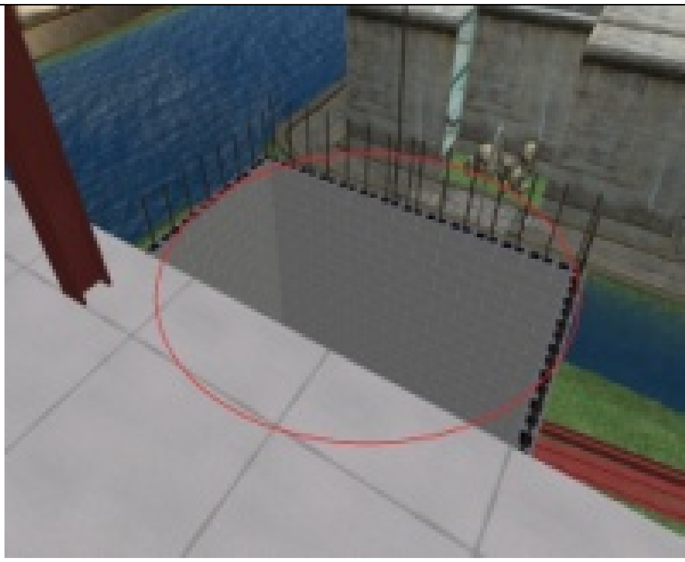
	the use of guardrail systems, safety net systems, or personal fall arrest systems. Quotation from OSHA 1926.501(b)(1) Personal fall arrest systems, covers, or guardrail systems must be erected around holes that are more than 6 feet (1.8 meters) above lower level. Quotation from OSHA 1926.501(b)(4)

Name	An accident due to the instability of the scaffold
Activities	Clean the windows and maintain the window frames
Place	The basement floor
Time	In the early morning (at the beginning work-time)
Main safety Elements	Scaffold, steel bars, safety arrest system
Situation	In order to maintain and clean the wall windows, a worker installed a scaffold to execute this task. However, due to the dynamic mobility of construction workforce, the worker was moved to another construction site. A new worker was assigned to continue the maintenance task. Before starting the task, the new worker did not check the scaffold conditions. He stood on the scaffold and performed this task. During the maintenance process, the scaffold was collapsed and the worker fell and landed on the floor below. As a result, his arm was broken, his head got injuries and he stayed in the hospital for two weeks.
Photo	
Avatar	One young worker is modelled as a character

Safety Standard	Scaffold erections and dismantlers: A competent person shall determine the feasibility for safe access and fall protection for employees erecting and dismantling supported scaffolds. Quotation from OSHA 1926.451(e) and (g)(2) Erecting and using a scaffold must be followed OSHA FS 3759 (2014) Scaffolds and scaffold components shall be inspected for visible defects by a competent person before each work shift, and after any occurrence, which could affect a scaffold's structural integrity. Quotation from OSHA 1926.451(f)(3) Training workers in scaffold safety following OSHA 3722

Name	A dangerous occurrence due to lack of the stair guardrails
Activities	Carry a formwork panel
Place	The emergency stairs from the third floor to the fourth floor
Time	In the late afternoon
Main safety Elements	Stairs, formwork panels
Situation	After finishing the emergency stairs from the third floor to the fourth floor, workers did not fix up the stairs with temporary handrail protection. In the next day, two workers carried a formwork panel using the stairs. Due to the time constraint, the workers tried to finish their job quickly. When moving from the third floor to fourth floor, the workers reached two-stair for one-step. As a result, the workers lost the balance and fell through the stairs. The workers' legs were broken and their body got internal injuries.
Photo	
Avatar	Two workers are modelled as characters
Safety Standard	Where there is one point of access between levels, it must be kept clear to permit free passage by workers. If free passage becomes restricted, a second point of access must be provided and used. Quotation from OSHA 1926.1051(a)(3) Stairways have four or more rises, or rising more than 30 inches in height (76.2 centimetres), which is less, must have at least one handrail. A stairrail also must be installed along

	each unprotected side or edge. When the top edge of a stairrail system also serves as a handrail, the height of the top edge must not more than 37 inches (93.9 centimetres) nor less than 36 inches (91.4 centimetres) from upper surface of the stairrail to the surface of the tread in line with face of riser at forward edge of tread. Quotation from OSHA 1926.1052(c)(1)(i) through (ii)

Name	A hazard stair opening
Activities	Clean trashes, arrange equipment
Place	Near the stairs opening on the fifth floor
Time	In the late afternoon
Main safety Elements	Stairs opening, carpet
Situation	After installing steel bars for pouring concrete for the cover wall of stairs, workers forgot to install the guardrail protection covering the hole on the fifth floor. In the next two days, three workers performed construction activities such as cleaning trashes, arranging equipment, etc. on fifth floor. One of them was close to the opening and did not wear any the fall protection. During the working process, he moved forward to attach the completed carpet and he lost his foot. He fell 18m and landed on the ground. He hence died from fatal head.
Photo	
Avatar	Three workers are modelled as characters
Safety Standard	Personal fall arrest systems, covers, or guardrail systems must be erected around holes that are more than 6 feet (1.8 meters) above lower level. Quotation from OSHA 1926.501(b)(4)

Name	A dangerous occurrence from unsafe scaffold
Activities	Weld and fix the panel into the steel column system
Place	Near the edge of the eighth floor
Time	In the morning (around 11:30 – 11:50 AM)
Main safety Elements	Mobile scaffold, steel panel, steel column
Situation	A worker welded the panels connecting two steel columns on the eighth floor of the building. He stood on a scaffold that was placed near the edge of the eighth floor. A co-worker was also on the scaffold installing bolts into the panels. One side of the scaffold had no guardrail. The workers did not wear any fall protection. While standing on the scaffold, he took the panel from his co-worker, overreached to one side and slipped off the scaffold. Then, he fell and landed on the eighth floor. He finally stayed in hospital in two weeks due to the head injuries.
Photo	
Avatar	Two workers are simulated as characters
Safety Standard	A competent person shall determine the feasibility for safe access and fall protection for employees erecting and

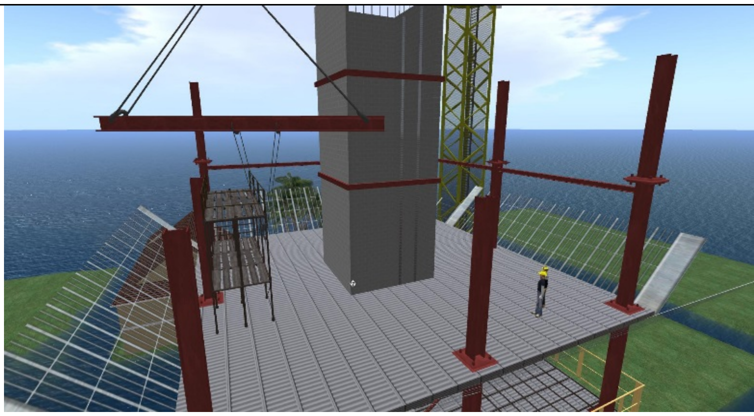
	dismantling supported scaffolds. Quotation from OSHA 1926.451(e) and (g)(2) Fall protection (guardrail systems and personal fall arrest systems) must be provided for each employee on a scaffold more than 10 feet (3.1 meters) above a lower level. Quotation from OSHA 1926.451(g)(1) Support scaffold footings shall be level and capable of supporting the loaded scaffold. The legs, poles, frames and uprights shall bear on base plates and mudsills. Quotation from OSHA 1926.451(c)(2) Each employee more than 10 feet above a lower level shall be protected from falls or by guardrails or a fall arrest system, except those on single-point and two point adjustable suspension scaffolds. Quotation from OSHA 1926.451(g)(1)

Name	Concrete works
Activities	Pouring and vibrating the concrete
Place	At the centre columns on the sixth floor
Time	In the late morning (around 11:40 – 11:50 AM)
Main safety Elements	scaffold, formwork, concrete, PPE
Situation	This scenario portrays labourers pouring concrete for columns on the sixth floor. Two workers executed the concrete work in the late morning. Once the formwork has been nailed down around rebar, one worker stood on the scaffold and poured the concrete into the formwork around rebar while another inspected this process. Both workers did not wear PPE (goggles, gloves, etc.). During the pouring work, the concrete sandstone flied into the workers' eyes and the cement dust adhered in their hands and bodies. As a result, they got the eyesight problems and skin irritation. The workers' health has been negatively affected and their productivities decreased. This case has partially proved how the PPE is important.
Photo	
Avatar	Two workers are simulated as characters

Safety Standard	Eye and face protection shall be provided when machines or operations present potential eye or face injury. Quotation from OSHA 1926.102(a)(1) Eye and face protective equipment shall meet the requirements of ANSI Z87.1-1968. Quotation from OSHA 1926.102(a)(2) Head protective equipment (helmets) shall be worn in areas where there is a possible danger of head injuries from impact, flying or falling objects, or electrical shock and burns. Quotation from OSHA 1926.100(a) The employer is responsible for requiring the wearing of appropriate personal protective equipment in all operations where there is an exposure to hazardous conditions or where the need is indicated for using such equipment to reduce the hazard to the employees. Quotation from OSHA 1926.28(a) and 1926.95(a)(b)(c)

Name	Temporary works
Activities	Transfer and install formworks for the cure column
Place	The elevator opening on the seventh floor
Time	In the afternoon (around 13:40 – 13:50)
Main safety Elements	Formwork, brick, electric cable, guardrail
Situation	This scenario illustrates the falling accident that involves the column formwork transferring on the seventh floor. For pouring column concrete, two workers carried and installed the formworks around the column rebar. Along the moving path, there is a protected opening, an electric cable and brick lying around. One side of the opening was covered by the tape. Before transferring the formwork, the workers did not clean the path. The workers were close the opening and one worker encountered the brick and stepped towards the opening. He fell down the tape-guard opening. He fell 24 meters and landed on the concrete basement floor. He died instantly from his injuries. The temporary work scenario reflects the ability of workers in recognizing potential hazards on the construction sites.
Photo	
Avatar	Two workers are simulated as characters

Safety Standard	Guardrail systems shall be surfaced so as to prevent injury to an employee, with a strength to withstand at least 200 pounds (90 kilograms), the minimum requirement applied in any outward or downward direction, at any point along the top edge. Quotation from OSHA 1926.502(b)(3) and (6) Form and scrap lumber with protruding nails and all other debris shall be kept clear from all work areas. Quotation from OSHA 1926.25(a) Combustible scrap and debris shall be removed at regular intervals. Quotation from OSHA 1926.25(b)

Name	Struck-by accident due to failure communication
Activities	Transfer and install an I steel column into the column system
Place	Near the edge of the eighth floor
Time	In the afternoon (around 16:40 – 17:00)
Main safety Elements	scaffold, an I column, toward crane
Situation	Struck-by accident is one of prevalent cases, is chosen to demonstrate the communication problem. This accident case was demonstrated through an I steel column installation executed by three workers. In the installation process, two China workers stood on a scaffold on the eighth floor and another from Korea controlled a tower crane. They communicated through walkie-talkies. The crane controller lift the I column and move it to the position following the guidance of the two workers standing on the scaffold. When the column was close to the right position, the two works tried to locate and connected the column with the column system. Due to the failure communication among the workers, the crane controller moved the column to right side instead of left side. As a result, the column stuck by the workers standing on the scaffold. They fell 27 meters and died immediately from their injuries.
Photo	
Avatar	Two workers and a toward crane controller are simulated as characters

Safety Standard	No employer shall use any motor vehicle, earthmoving, or compacting equipment having an obstructed view to rear unless: - The vehicle has a reverse signal alarm distinguishable from surrounding noise level or - The vehicle is backed up only when an observer signals that it is safe to do so Quotation from OSHA 1926.601(b)(4)(i),(ii) and 602(a)(9)(i), (ii)

Appendix II – Questionnaire for Subjective Evaluation

Student name ***ID***

Experience Questionnaire: Please rate the following on a scale from 1 to 5

1 - Useless; 2 - Ineffective; 3 - Normal; 4 - Effective; 5 - High Effective

1. Did you feel comfortable when interacting with the screen of the mobile system?

	1	2	3	4	5
Mobile based VR and AR					

2. Did you find the system easy to use?

	1	2	3	4	5
Mobile based VR and AR					

3. How real do the VR and AR contents appear on mobile devices?

	1	2	3	4	5
Mobile based VR and AR					

4. Is the information provided in the system clear?

	1	2	3	4	5
Mobile based VR and AR					

5. Did the system reflect practical construction experience?

	1	2	3	4	5
Mobile based VR and AR					

6. Was the safety content of the system helpful in safety cognition?

	1	2	3	4	5
Mobile based VR and AR					

7. Did you believe the system could improve hazard recognition in a real construction site?

	1	2	3	4	5
Mobile based VR and AR					

8. Did you think the system could enhance your safety memory?

	1	2	3	4	5
Mobile based VR and AR					

9. Do you expect the mobile-based VR+AR system affect your long-term memory?

	1	2	3	4	5
Mobile based VR and AR					

10. Did you think the system enhance construction safety education effectively?

	1	2	3	4	5
Mobile based VR and AR					

11. Do you think the mobile-based VR+AR system is more beneficial than tradition whiteboard based lecture?

	1	2	3	4	5
Mobile based VR and AR					

Appendix III - NASA Task Load Index

Evaluating the use of the mobile based VR and AR system and traditional method (1 – very low, 20 – very high)

Student name ***ID***

Mental Demand

Low High

How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the take easy or demanding, simple or complex, exacting or forgiving?

Physical Demand

Low High

How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brick, slack or strenuous, restful or laborious?

Temporal Demand

Low High

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

Low High

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Effort

Low High

How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration

Low High

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Appendix IV: Paper Based Examination

Student name ***ID***

Questionnaire:

1. What kinds of accidents are when installing exterior curtainwalls from inside building?

A) Falling from height B) Struck-by C) Electrocution

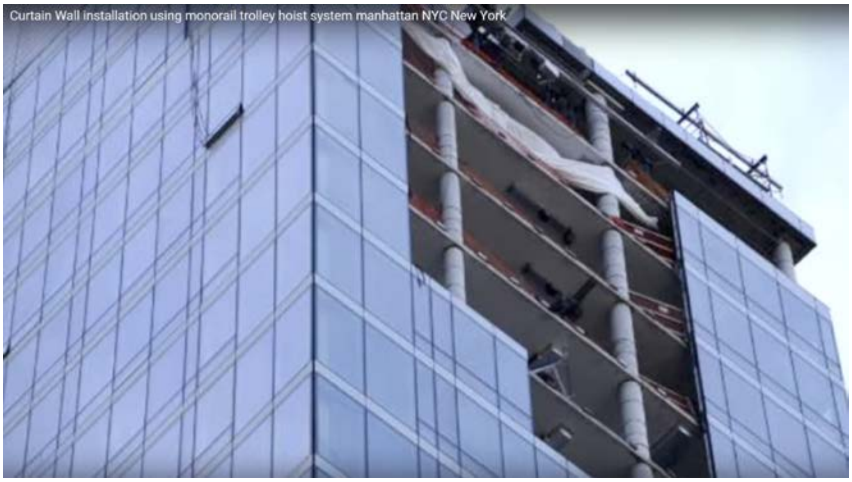
2. Which Personal Protective Equipment is necessary when applying sealant to finish a curtain wall?

A) Safety Glasses B) Gloves C) Safety glasses and gloves

3. This picture illustrates workers installing a curtain wall from inside the building. What kind of safety facilities are necessary to prevent falls?

A) Safety glasses and gloves B) Falling arrest system

C) Helmet D) Scaffold



4. There are two methods to install a curtain wall: from inside and from outside. Which method is more dangerous?

A) Outside B) Inside C) Same

5. The standard requires a guardrail system, safety net system, or personal fall arrest system for workers on a working surface with an unprotected or edge, which is 1.5 meters or more above a lower level.

A) True B) False

6. One who identifies existing and predictable hazards in the working conditions is called:

A) A site supervisor B) A Safety engineer C) Both A and B

7. The construction standard requires protecting an employee on scaffold for a height above:

A) 1.2 meters B) 1.8 meters C) 3 meters

8. How wide does the work area need to be on scaffolding?

A) 25 centimetres B) 45 centimetres C) 60 centimetres

9. How minimum high should the top of the guardrail on a scaffold be when working at height?

A) 800 centimetres B) 950 centimetres C) 1.1 meters

10. What kind of hazards is in the following picture?

A) Electrocution B) Falling C) Both A and B

11. A visual safety inspection must be inspected by a competent person before each work

A) True B) False

12. Each employee on a single-point or two-point adjustable suspension scaffold shall be protected by:

A) Fall arrest system B) Guardrails

C) Fall arrest system or guardrails D) Fall arrest system and guardrails

13. Each employee on a walking/working surface 1.8 m or more above a lower level where leading edges are under construction, but who is not engaged in the leading edge work, shall be protected from falling by:

A) Guardrails B) Fall arrest system

C) Safety net D) Guardrails or fall arrest system

E) Guardrails or fall arrest system or safety net

14. This picture illustrates the worker who works at height without fall protection. What kind of safety facility are the most suitable to prevent fall?

A) Fall arrest system B) Guardrail/ Work platforms

C) Scaffold

15 – 16. The following picture demonstrates the pouring concrete work

15. What kind of accident can happen?

Write your answer:

16. What kinds of safety facilities are necessary to prevent the accident?

Write your answer:

17 – 18 – 19. *The picture below describes the case of falling during the scaffold dismasting. The bamboo scaffold of a building under construction had been partially dismantled. To prevent the bamboo members of the scaffold from getting loose and falling down during the holiday, a team of scaffolders tied up first. Even getting the working at height training from the foremen, in the course of their work, one of the workers lost his balance and plunged to his death onto the platform.*

17. What are the causes of this accident?

Cause of accident	*Right*	*Wrong*
The safety harness was not attached to the independent line		
There was no suitable working platform		
Safety dismantling procedures were not provided		
The worker overstretched his body from the working platform		
A safety system for scaffold dismantling was not provided		
The worker drink alcohol before work		

18. What should workers do to prevent the accident? Briefly describe

Write your answer;

19. The role of the foremen to prevent the accident. Briefly describe

Write your answer:

The picture in question 3 is from the source: *"Curtain-wall-installation-using-monorail-trolley-hoist-system-manhattan-nyc-new-york"*

The picture in question 10 is extracted from the author's research article

The picture in question 15 – 16 is from the source: *"http://beodom.com/en/news/entries/amadeo-2-1st-floor-slab-and-installation-of-avi-thermokorb"*

The case scenario in question 17 – 18 – 19 is referred from: *brief analysis of site accident cases* published by Occupational Safety and Health Branch Labour Department

Appendix V – Comparison of use of VR and AR system with traditional whiteboard based lecture

Questionnaire: Rate the following on a scale from 1 to 5

1 - Useless; 2 - Ineffective; 3 - Normal; 4 - Effective; 5 - High Effective

1. How was the clarity of instruction of two methods?

	1	2	3	4	5
Mobile based VR and AR					
Traditional Method					

2. How was the guideline of two methods?

	1	2	3	4	5
Mobile based VR and AR					
Traditional Method					

3. How interactive did you acquire during the education lesson of two methods?

	1	2	3	4	5
Mobile based VR and AR					
Traditional Method					

4. How comfortable did you feel when participating two methods?

	1	2	3	4	5
Mobile based VR and AR					

Traditional Method					

5. How engage did you think you were involved in two methods?

	1	2	3	4	5
Mobile based VR and AR					
Traditional Method					

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VR 과 AR 기반 상호 보완 건설 안전교육 시스템

국문초록

건설업은 다양한 분야에 종사하는 전문 인력이 투입되어 복잡한 프로세스로 이루어지며, 타 산업에 비하여 높은 이직률을 보여주고 있다. 이로 인해 건설 프로젝트는 불필요한 비용이 낭비되거나 공기가 지연되는 등 다양한 문제점이 나타나고 있는 실정이다. 건설 산업에 종사하는 노동자의 비율을 살펴보면, 세계적으로 약 7~10% 정도를 차지하고 있지만, 이 중 약 30~40%에 해당하는 건설 관련 노동자들이 안전 재해를 경험한 것으로 분석된 바 있다. 이와 같은 안전 재해는 건설 프로젝트의 비용 낭비, 공기 지연 등의 문제점을 초래하는 주요 원인 중 하나이다. 특히, 국내 건설업의 측면에서 살펴보면, 수많은 기업들은 파트너링 형태로 공사를 수행하거나 다수의 다국적 노동자들을 고용하는 등 끊임없는 변화가 이루어지고 있기 때문에 타 산업에 비하여 상대적으로 높은 안전 재해율을 나타내고 있다. 따라서 안전 재해는 건설 산업뿐만 아니라 사회적으로 점차 중요한 이슈가 되고 있으며, 이에 사고 위험을 사전에 인지하여 안전하고 쾌적한 작업환경을 제공하기 위한 방안의 일환으로 안전 교육의 중요성도 높아지고 있는 추세이다. 그러나 기존의 안전 교육 방식은 대부분 교육의 우선순위를 고려하지 않아 학생들이 직접 느끼고 체험해 볼 수 있는 경험 위주의 상호보완적인 안전교육의 실시는 미비하다.

이로 인해 일부 학생들은 단순히 기관에서 실시하는 전형적인 교육 방식의 안전교육에 의존하여 학습하고 있다. 이와 같은 교육방식은 프로그램 자체가 학생들의 동기나 흥미를 유발하기 어렵기 때문에 학생들의 능동적인 참여를 유발하지 못하며, 안전 교육을 이수하더라도 실무 현장에 적합한 안전 지식이나 경험은 여전히 부족한 것으로 분석된다. 이를 개선하기 위해 본 연구에서는 안전 교육에 대한 학생들의 의식이나 태도를 함양하고 전통적인 방식의 안전 교육 프로그램을 향상시키기 위해 ICT 기술을 융합한 경험 중심의 상호 보완적인 건설 안전교육 시스템을 제안하고자 한다. 본 연구의 시스템은 모바일 기술(Mobile Technology), 가상현실(Virtual Reality), 증강현실(Augmented Reality) 등의 ICT 기술을 융합하여 실제 프로젝트를 기반으로 건설 안전에 대한 이론 지식을 제공하기 때문에 학생들은 경험 중심의 이론학습이 가능하다. 본 연구의 시스템 구성은 총 3 가지의 모듈로 구성되어 있다. 첫째, 안전 지식 공유(Safety Knowledge Dissemination, SKD)는 모바일 장비를 통해 건설 현장에서 안전 사고 사례나 관련 지식 및 정보를 편리하게 전송 및 공유하는 모듈이다. 둘째, 안전 지식 반영(Safety Knowledge Reflection, SKR)은 학생들이 이전 단계의 안전 관련 지식이나 정보를 통해 경험 중심의 학습을 할 수 있는 모듈이다. 셋째, 안전 지식 평가(Safety Knowledge Assessment, SKA)는 학생들이 경험 중심으로 학습한 안전 지식, 정보, 내용을 직접 건설 현장에 적용하여 평가하는 모듈이다. 본 연구에서는 시스템의 건설 현장의 사고 사례를 적용하여

프로토타입을 구현하였으며, 이를 바탕으로 정량적인 평가를 실시하였다. 이를 위해 중앙대학교 건축학부의 강사와 두산 건설, 현대 건설에 종사하는 안전 관리자를 교육자로 초빙하였으며, 학생들을 피교육자로 섭외하여 학생들의 학업 성취도를 평가하였다. 또한, 본 연구에서는 객관적인 평가 결과를 도출하기 위해서 평가 대상을 2 그룹으로 분류하여 기존의 교육방식과 본 연구의 시스템을 각각 적용하여 그 결과를 서로 비교, 분석하였다. 그 결과 본 연구의 시스템은 기존의 건설 안전 교육 방식을 개선하기 위해서 다양한 시각으로 접근하였으며, 학생들의 안전 지식의 교육 수준을 향상시킬 수 있는 유용한 대안으로 나타났다. 또한, 이는 학생들이 건설 현장에서 발생할 수 있는 잠재적인 안전 사고의 위험요소를 쉽게 파악할 수 있어 향후 건설 산업에서 발생하는 안전 사고의 비율을 효과적으로 감소 시킬 수 있을 것으로 기대된다.

키워드: 건설 안전, 건설 안전재해, 소셜 네트워크, 가상현실, 증강현실, 모바일 컴퓨팅, 경험 중심의 상호 보완적인 교육방식, 게임 기반 교육

Dedication

My father and mother,

Le Quang Thich and Nguyen Thi Doa

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