Research Article

Improving Effectiveness of Safety Training at Construction Worksite Using 3D BIM Simulation

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Construction worker safety and safety training continue to be the main issues in the construction industry. As a means of improving construction worker safety, this study focuses on safety training at an actual construction worksite. In order to promote safety awareness among workers, it is imperative to develop more effective safety training. This study examined safety training as a method of improving construction worker safety, focusing on the effectiveness of the instructional delivery method. Effectiveness pertains to level of understanding of instruction and can be enhanced through improving instructional delivery method. This study aims to examine two different types of safety training methods: (1) the conventional lecture method and (2) innovative method using the 3D Building Information Modeling (BIM) simulation, reflecting the hazard condition of the actual site. An experiment is conducted, in which the two types of training are implemented and assessed through testing trainees' understanding. The workers trained via BIM simulation showed a higher level of understanding than the group of workers who were trained conventionally. Also, a survey was conducted targeting safety managers, in which the workers evaluated lifelike quality of the training, active learning and enjoyment that each of the training methods can promote. This research will provide implications that an innovative method using the virtual reality is more effective than the conventional lecture method.

1. Introduction

Construction work has a high accident frequency and fatality rate compared to other industries, despite a constant attention on safety and accident prevention at the governmental level. Safety accidents in the past have been considered as the construction workers' liability, whereas it is now believed that corporations and society have the responsibilities [1, 2]. In fact, the countries with advanced construction management, e.g., the United States and United Kingdom, regard safety accidents as a critical factor pertaining to the corporations' ability to produce profits in the long term, prioritizing the issue in sustainable construction. There has been a great body of research conducted on safety management with the purpose of reducing accidents in construction sites. Safety training has been regarded as the most important factor in preventing safety accident hazards. For this reason, development and application of improved safety training is strongly called for. The purpose

of this study is to determine the effectiveness of the 3D Building Information Modeling (BIM) simulation as a safety training method. This is performed by comparing its trainees' level of understanding to the understanding achieved from a conventional safety training method. This research is intended to demonstrate the possible advantage of using 3D BIM simulation in safety training and how it could increase trainees' understanding of safety training contents. To achieve this, it is the task of this research to determine if 3D BIM simulation is more effective in improving trainees' understanding of the training contents, compared to the conventional safety training methods through data collected from actual construction workers. Previous studies have demonstrated effectiveness of construction safety education by applying virtual reality (VR), augmented reality (AR), and game engine. However, considering the strain of operating the space and equipment, it is difficult to apply them to the entire on-site, actual worker training, especially to the small and medium-sized

construction sites. This indicates that there is a need for considering realistic methods, applicable to the most sites while maintaining the advantages of the sense of realism and immersion, with the proof of increased educational understanding achieved.

2. Literature Review

2.1. Construction Safety. Considering its nature, the construction industry is constantly exposed to a hazardous environment. Workers who are willing to do the hard, physical labor of construction work are limited, and the need for them to be more technologically advanced than the normal work force further limits the size of the pool of workers. These factors can cause the use of workers who are more prone to accidents because of their lack of training. However, since the evaluation of construction work revolves mainly around the cost of materials and the efficiency of the management, the need for safety management has rarely been recognized. In order to prevent accidents, construction work sites are introducing and applying strict regulations, codes, and a variety of equipment and devices. Nevertheless, construction sites have not actually shown a noticeable decrease in their safety accidents. The U.S. Bureau of Labor Statistics (2017) reported that 47% of all fatal work injuries occurred in the construction industry. This had the highest percentage of all industries in the U.S. Similarly, the Korean Ministry of Employment and Labor announced the industrial fatalities in construction industry was as high as 52.5%, taking up the highest among all fatal work injuries in Korea. The high accident and fatality rate is often attributed to corporations' insufficient focus on prevention, due to the additional expense and work hours required at worksites [2]. Research has indicated, however, that in the long term, accidents and worker fatalities can impair a corporation's profit realization [3–5]. Based on findings that accident prevention and profit realization are mutually compatible and complementary, the construction industry has sought sustainable improvement [6].

It is necessary to trace fundamental causes of accidents in order to prevent safety accidents in the construction industry. Various research studies have been conducted to identify the root causes of accidents. Hinze [7] suggested the distraction theory in which he argued that construction workers being stressed about getting their tasks done could cause them to be distracted, which would result in ignoring the hazards that lead to accidents. McClay [8] suggested three major causes of accidents; hazards by physical condition, human's action, and exceeding functional limitations. Abdelhamid and Everett [9] introduced the Accident Root Cause Tracing Model (ARCTM) and argued that following roots cause safety accidents: (1) failing to recognize unsafe conditions at a work site, (2) deciding to carry on with a work task after the worker realizes that him/herself is working in unsafe conditions, and (3) deciding to act unsafely regardless of existing conditions of working environments. Also, Toole [10] suggested the root causes of construction accidents, including lack of proper training, unsafe work methods and sequencing, not using provided

Personal Protective Equipment (PPE), inappropriate attitude toward safety, and isolated or sudden deviation from prescribed behaviors.

The body of research has commonly pointed out unsafe conditions, unsafe behaviors, and unsafe task methods or sequencing as the causes of safety accidents. These major causes could be prevented by improved safety management. Safety management practice could achieve safer construction environments by modifying and improving the enforcement, accident prevention equipment and techniques, and safety training. In Korea, KOSHA, under the Korea Ministry of Employment and Labor, has provided a set of construction guides/codes for accident prevention and standards for safety education. In addition, KOSHA, has established occupational health and safety standards, provided appropriate trainings, and mana ged the statistical records related to industrial accidents. In accordance with KOSHA standards, all employers in construction workplaces in Korea must conduct a compulsory safety and health education under the industrial safety and health acts: Statutory requirements periodic training (2 hours/month), new employment training (non-construction-related employee: 8 hs/month, construction-related employee 1 h/month), work task changing training (non-construction-related employee 2 hs/month, construction-related employee 1 h), and special safety training for hazardous tasks (non-construction-related employee 16 hs/month, construction-related employee 2 hs/month).

Several researchers, however, have suggested that safety training in the field does not meet the safety training hours regulated by industrial safety and health act. An [11] and Kim [12] conducted an analysis of operating condition of safety training in Korean construction workplaces in which they found some serious problems. Examples include failure to conform to training hour regulation, poor quality of safety training facilities in workplaces of medium and small-sized enterprises, and poor/cursory safety training to avoid violation penalty. The similar is found in the U.S. [13] and Hong Kong [14], as workers expressed dissatisfaction with the effectiveness of safety education and made strong demands for improvements in the traditional education methods.

2.2. Construction Safety Training. The prevention of accidents can be accomplished through the 3E of injury prevention: Engineering, Enforcement, and Education [15]. As such, continuous regulation of and technological application towards accident prevention have been implemented at many construction sites. Nonetheless, an objective and measurable decrease in the accident rate has not been seen. In addition, it was shown in previous research that there can be a failure to overcome the learning abilities due to the lower education levels of construction workers, as well as communication issues with foreign workers [16, 17]. Consequently, improvement of fundamental safety management practices through effective educational training is strongly called for [18, 19]. A large body of research in safety education has focused on the adequate education materials [20–22]. In the same line, Heinrich et al. [23] considered two

factors regarding accidents: (1) direct factors including unsafe physical hazards and (2) indirect factors including insufficient worker education. Of these two types of factors, Heinrich et al. claimed that it would be more effective to focus on the educational aspects by identifying and selecting necessary and sufficient content. Choudhry and Fang [24] pointed out a lack of safety knowledge and awareness as one of the reasons for workers' unsafe behaviors. Toole [10] points out that improper training is a root cause of accidents, drawing from the cases in which lack of adequate training was identified, and the cases in which workers' lack of knowledge in accident preventive measures resulted in their insufficient understanding of sources of potential danger, and consequently, in the increased accidents. These previous studies commonly contend that adequate safety training can contribute to increased proficiency and decreasing occurrence of accidents. However, these studies lack in empirical data and, thus, lack in evidence-based analysis.

Improvement in the quality of safety education training can be achieved through many ways. Examples include promoting trainees' interest, refining the content of the training, and also developing more effective training methods. In addition, effective learning training can take place not only through language but also through observation, experience, and active engagement in real-life situations. Dale's cone of experience [25] claims that stimulating learners' interest can contribute to improved retaining of the instructed contents. Burke et al. [21] examines the previously existing safety education training and accidents. Their findings substantiate that, through active involvement in behavioral modeling rather than through passive learning by lectures and brochures, workers obtained and retained more knowledge, which resulted in a decreased accident rate. Similarly, Li et al. [14] conducted a case study involving visualization of safety training. The study reveals that workers' awareness of the predominant causes of accidents can contribute to preventing accidents. Kang et al. [26] also found that empirical knowledge obtained through 4D visual simulations can prompt an improved task accomplishment over two-dimensional drawings, because the 4D visual simulations required less time and communication and resulted in less inaccuracy.

2.3. 3D Technology for Safety. Building information modeling is a multiple dimensional model concept involving different information such as objects' attributes, scheduling, cost, and regulation across the project stages. BIM has become an innovative and essential management technology to integrate and manage construction projects by collecting and visualizing construction data. Alshawi et al. [27] suggested visualization is one of the core technologies of building information modeling and this feature of BIM offers interactive learning environments for construction trainings. Various research studies indicated that BIM is useful for communications in relation to safety in construction sites [28–30]. On the other hand, such reasons as lack of initiative and sufficient training, hesitation to change current work practice, and indecision to acquire new technology have been found to serve as barriers in adopting BIM in construction industry [31]. Despite the difficulties in implementing BIM's adaption, there is a body of research that has been conducted regarding BIM integration for different goals.

For safer construction environments, many researchers who studied BIM took safety factors into consideration in the stages as early as designing and planning. For example, Hadipriono and Barsoum [32] developed an interactive virtual environmental modeling to be used in site workers' training in regards to the fall hazard from scaffolding. They developed the procedures of scaffolding election and inspection to visually identify hazardous conditions from scaffolding. Sulankivi et al. [33] found that although the temporary structures and heavy equipments cause hazardous zones, which can threaten workers' safety, the 3D description did not include the information regarding the installation process of the temporary structures. They went on to assert the need for such information regarding the installation process of temporary safety structures, including fence and office container, to be reflected on BIM modeling, in order to improve participants' understanding not only of the process of the project but also of the related safety issues. They also created a BIM based site model with 3D object libraries and used the model in locating the possibly risky areas as well as safe walkways in a construction site. Ku and Mills [34] reviewed current design tools for safety that featured hazard recognition, risk assessment, procedure, and visualization; they suggested visualizing construction sites can contribute to helping constructors in early identification of hazards, which can also serve as a safer interaction between constructors and designers. They also indicated that evaluation of the jobsite environment is considered to set a safer construction procedure and thus is required in the design stage. Benjaoran and Bhokha [35] introduced the integrated construction management system including safety management using 4D CAD model throughout the design phase. The integrated system analyzes potential working-at-height hazards and mitigates fall accident risks. Similarly, some researchers applied BIM modeling to structural safety and to the analysis of productivity during their design phase. Lee et al. [36] introduced a formwork layout module using BIM and showed that a system developed by BIM could enable a reduction in workload and work time than 2D-based-drawing. Hu et al. [37] developed a 4D-based structural safety analysis model and evaluated structural conditions for safety during all construction phases. The researcher suggested that 4D simulation could offer designers and engineers a way to predict and prevent threats to safety. In addition to these studies, there is a great body of research regarding using BIM modeling to improve safe training. Ku and Mahabaleshwarkar [38] developed virtual worlds called Second Life Planform for safe training specifically on the scaffolding work and tower crane operation. Their collective building information for building interactive models allowed communication and interaction among the architecture, engineering, and construction in order to enhance construction management and training. In short, this research showed that a tower crane training by

Second Life simulation allowed trainees to avoid collision hazards and to grasp optimal-operational paths.

Various researchers discussed so far proved that visualization and 4D-based design are the core of BIM and a means to improve the communication among all subjects involved in a project, including owners, designers, contractors, and construction workers and, thus, ultimately improve the constructability and optimize the safe job site for workers.

In this respect, safety training through BIM simulation can serve as a virtually created work environment for site workers. Furthermore, as BIM can adapt to distinctive features of individual work environments and tasks, it is expected to be a practical and engaging substitute for existing instructional training methods, which tend to be somewhat too standardized and unified [15, 34]. Clevenger et al. [39] found that using 3D visualization can also increase foreign workers' understanding of training, as 3D visualization can be implemented with reduced text representation of information. Overall, the previous studies have claimed that visualization in safety training could enhance trainees' understanding. However, these studies lack in statistical evidence to substantiate their arguments. The questionnaire survey was used as the standard practice of measuring the effectiveness of alternative safety training methods. However, the questionnaire survey is a subjective measure of trainee interest and participation; therefore, an alternative way to objectively measure the level of learned knowledge is crucial [40]. Therefore, it is necessary to conduct an empirical experiment and demonstrate the statistical validity of the efficacy in visualizing using BIM safety training.

3. Improvement of the Educational Delivery Method: Case Study of Construction Workers

3.1. Conventional Lecture-Type Method. In order to develop the conventional training method for this research, the researcher examined existing training methods used in five major Korean construction firms. It was found that all the five construction firms trained their workers via lectures with videos. For more frequent accident types, their training contents tend to include photographs taken in the real accident situations to arouse the workers' caution. The contents were based on accident cases, with the goal of training the workers regarding the causes of accidents and possible preventions. Therefore, to create a training method similar to theirs, the researcher made lecture slides with photographs, texts, and sounds. Figure 1 shows examples of conventional safety training slides.

3.2. Alternative Training Method. We aimed at devising the most realistic method to be applied to the on-site safety training room using 3D simulation. The method is performed by the utilizing the provided space and equipment in the existing training facilities and by using minimal software and equipment necessary for 3D simulation. However, we focused on maintaining the characteristics of the improved education, including indirect experience and sense of immersion in the site's hazardous factors, in an effort to develop a safety training method not only innovative, but also practical and applicable to the actual construction sites.

BIM enables the three-dimensional virtual construction environment. In this research, the three-dimensional virtual construction environment was created based on the 2D drawings of the high-rise apartments, through Revit® Architecture. Then, through the Explore function in the Navisworks® Manage software program, the 3D information was adapted in creating computer animations explaining the accident hazards and types along with texts or narration.

This research used a few Building Information Modeling tools to develop the BIM safety training. Revit® Architect is a part of Building Information Modeling software, together with Structure and Mechanical, Electrical, and Plumbing (MEP). This Revit® Architect software allows its users to design such basic elements of buildings as walls, slabs, columns, and windows, as well as detailed elements including equipment and day-lighting, all of them in 3 dimensions. The software also allows the users to access building information, as it bears an inbuilt, accumulative database. Revit offers 4D BIM, which is the 3D modeling plus scheduling, and provides the tools to plan construction project stages in the building's lifecycle. The BIM modeling that uses Revit is parametric modeler. Parametric design is a process based on an algorithmic system that enables the expression of parameters by designating the rules among the components of models. A modeling, based on the parametric design, provides an innovative building design, as it clarifies the relationship between users' intention and the result of the design. Navisworks® Manage is a program that reviews and explores 3D designs. Navisworks® Manage allows its users to navigate around 3D models in real-time; this enables coordination, construction simulation, and project analysis for integrated project reviews. Navisworks® Manage has various tools to simulate and optimize scheduling, identifies interferences and clashes, and allows a greater perception into potential problems under construction. In addition, this program has a virtual person, "Avatar," who serves as a viewer and navigates through the designed modeling. Avatar in the human scale can go around the virtual BIM model and helps the viewers to feel and grasp the scale of the spaces, pressure of materials, and the scope of observation, which could not have been known in two-dimensional-based drawings. In other words, Avatar, taking the place of construction workers through virtual reality, enables the construction workers to navigate, identify, and become informed about the hazard factors in the building in which they will work. Figure 2 shows different steps in creating animated BIM safety training.

3.3. Effective Delivery Method for Construction Workers. This study aims to examine the effectiveness of delivery methods between the conventional lecture method and the Building Information Modeling (BIM) simulation targeting construction workers in field. An experiment, in which the two types of training are implemented and assessed through testing trainees' understanding, is conducted. The site

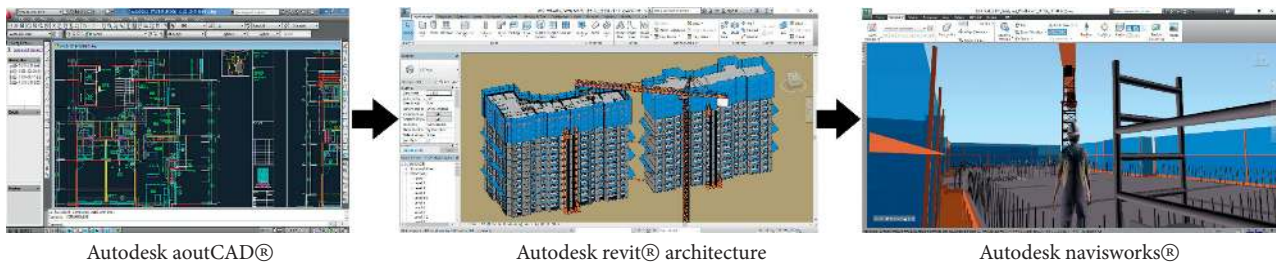Figure 1: Examples of conventional safety training slides.

Figure 2: Different steps in creating animated BIM safety training.

workers trained via BIM simulation showed a higher level of understanding than the group of students who were trained conventionally. Also, researcher analyzed safety training understanding level in consideration of construction workers' individual characteristics; training method, age, education level, and work experience. Research verifies the hypothesis that construction workers' individual characteristics affect safety training understanding level.

3.4. Selection of the Construction Site for Case Study.

3.4. Selection of the Construction Site for Case Study. A construction site in progress was selected for conducting the case study of the site workers. The site workers then participated in the safety trainings and assessments. A high-rise apartment building project (1,390 households, 11 buildings 61,330 m^2 Site area) was selected for this safety training.

3.5. Development of the Educational Delivery Method. The order of training content is consistent with that of the actual work at the site. The content of the training covers, with the concrete examples, the possible safety accidents as well as the preventive measures. Figure 3 represents the 3D remodeled exterior of the worksite. The 3D remodeling enabled the characteristics and actualities of the scene. Table 1 shows examples of 3D modeling scenario reflecting the hazard condition of the actual site and training contents.

4. Experimental Design and Result

4.1. Experimental Design. This study used a behavioral experiment approach rather than adopting survey method because experiments can better measure cause and effect relationships. As an effective instructional delivery method, this study adapted the BIM 3D simulation. The following Figure 4 shows the control group in the experiment, which examining the effectiveness of BIM simulation safety training for apartment construction site workers. This study used the "pretest-posttest control group" design. In this experimental design, the researcher carries out the pretest to all subjects in both groups and measures the degree of change caused as an effect of this treatment. By conducting the pretest, the researcher confirms the homogeneity between/among the groups.
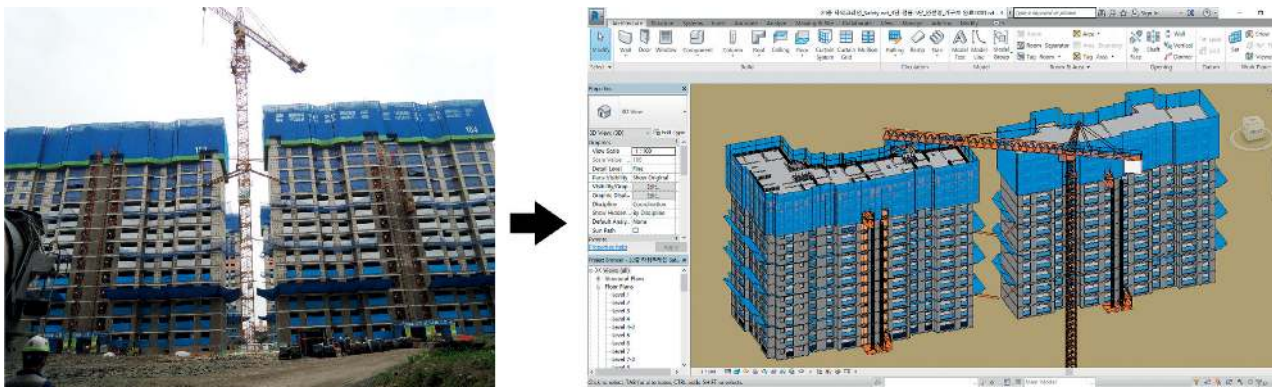
Figure 3: Front view of high-rise apartment buildings and the 3D BIM modeling.

The steps are as in the following:

(1) Randomly assign subjects to the treatment group and control group

(2) Carry out the pretest to all subjects in both groups

(3) Assure that both groups experience the same conditions except for the treatment in the experimental group

(4) Carry out the posttest to all subjects in both groups

(5) Assess the amount of change on the dependent variable's value for each group

4.2. Population. A total of 189 workers have participated in this experiment in four distinct groups because of classroom capacity and work schedule. Each group has 46 to 49. Group A who were trained using BIM was then divided into two groups: the A-1 group included 46 trainees, and the A-2 group included 49 trainees. Group B who were trained using conventional training was then divided into two groups: the A-1 group included 46 trainees, and the A-2 group included 48 trainees. The total number of trainees who yielded valid assessment outcomes was 189. Figure 4 shows process of safety training and the assessment by groups.

4.3. Test Result. This study used a *t*-test analysis to examine whether or not there exists a difference in the mean score between the groups by conventional and innovative safety training.

In this experiment, two groups took BIM simulation safety training, and other two groups took conventional safety training. Therefore, it is necessary to check that there are differences of initial knowledge about safety training among the four groups to accurately measure effect of treatment. Same pretest was conducted on all groups, and the result of pretest shows there is no difference in workers' initial safety knowledge. ($p > 0.05$). Statistics analysis shows more detail information of each group's pre- and posttest scores. Mean values shows there is no difference of means between BIM and CONVENTIONAL groups on pretest and BIM group's mean score is higher than that of the CONVENTIONAL group on posttest (Table 2).
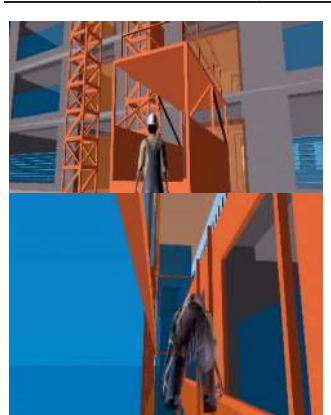
4.4. Analysis of Trainees' Understanding by Workers' Personal Factors. This study also analyzed the relationship between individual workers' personal features and the workers' level of understanding in the training content. In order to examine the relationship, workers' personal features such as their age, educational background, and experience in the field were collected and sorted to analyze whether such features affect the workers' level of understanding in the training content. The trainees from both groups were asked to take the assessment test on the training content to compare their level of understanding. Then the results of the assessment were classified by each group and also by the individual trainees' personal features. This was to decide whether such features affect the workers' level of understanding in the training content and rule out the possibility that only such features decide the assessment results, regardless of the training method. Before the experiment, the researcher collected the participants' personal information mentioned above in two different safety training methods. After the training and assessment were implemented, the participants' scores were compared in terms of the three different factors (workers' personal factors) to determine effectiveness of training methods. According to workers' characteristic, workers' personal factors which are age, educational background, and work experience were measured, and before the experiment began, each factor was categorized into three levels.

In Figure 5, age, educational background, and work experience were categorized into three different levels. *t*-test is conducted if each categorized group's test scores are statistically significant in order to examine the effectiveness of BIM safety training in consideration of each factor. Table 3 shows classification of variables by workers' personal factors; education level, age group, and work experience.

The test score difference between the BIM and conventional groups depending on the participants' education level, age group, and work experience was computed. The significance of the difference between the two groups was then evaluated using *t*-tests at 95% confidence level.

Table 4 shows BIM and conventional training groups' mean by each factor and results of *t*-test on variances by workers' personal factors. As can be seen, the BIM group indicated mean scores in all three factors that are higher than

TABLE 1: Examples of 3D modeling views and training contents.

Examples of 3D modeling views	Training contents
	The 3D simulation demonstrates that a safety platform must be used when alighting from the hoist, as there is a fall hazard due to the opening between the hoist and the floor
	The 3D simulation emphasizes the need to wear helmets to prevent injuries due to falling objects and to wear the safety belts to prevent fall accidents when working in the gangform.
	The 3D simulation informs about the hazard of impalement from protruding ends of steel rebar or concrete form pin and directs the use of PPE and rebars caps in the case of moving to the rooftop through the narrow stair room. The 3D simulation locates the form fixing pins and rebar specific to the stair room in the actual corresponding building, contributing to the worker's identifying the hazards in the exact location
	The 3D simulation shows that there is a fall hazard due to the openings in elevator rooms or the openings for carrying materials and indicates the need of opening cover and warning sign installation. The exact size and location of the openings are reflected in the simulation, demonstrating the precautions in the actual worksite
	The 3D simulation shows that (1) standard safety guardrail must be installed when working at heights greater than 10 feet in form and rebar installation work and that (2) the workers must wear the safety belts to prevent themselves from fall accidents in high place work
	The 3D simulation indicates that working under lifted materials is prohibited in top slab and that the cranes must load the materials in double-legged sling. Also, training reflects the movement radius of the tower crane in actual construction site indicating the precautions in the pertaining area

the conventional group, and the results demonstrate effectiveness in BIM safety training based on worker characteristics. Within the variances, significant differences were found for the factors "Educational Background" in high school level ($t = 2.746$, $p < 0.5$) and middle school level ($t = 2.770$, $p < 0.5$); similarly, for "Age" factor, significant differences between the scores of BIM and conventional training groups were found for 50s' scores ($t = 1.174$, $p < 0.05$) and in 20 and 30s' scores ($t = 2.515$, $p < 0.05$); for "Work Experience" factor, also, significant differences (BIM safety training and conventional training scores) were found

for advanced level ($t = 2.848$, $p < 0.05$), intermediate level ($t = 2.237$, $p < 0.05$), and beginning level ($t = 2.090$, $p < 0.05$). On the other hand, no significant differences were found for the "Age" in 40s' scores ($t = 1.074$, $p > 0.05$) and "Educational Background" in University and college level scores ($t = 1.690$, $p > 0.05$).

5. Relevance of Safety Training Method

5.1. Relevance Evaluation. Sherif and Mekakawi [41] have suggested that computer-based tools in education for
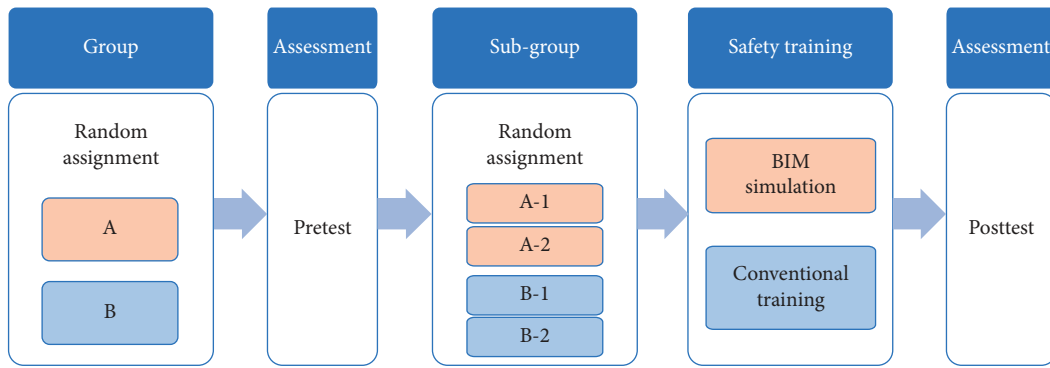
Figure 4: Process of safety training and the assessment by groups.

Table 2: *t*-test result of pretest and posttest of each group.

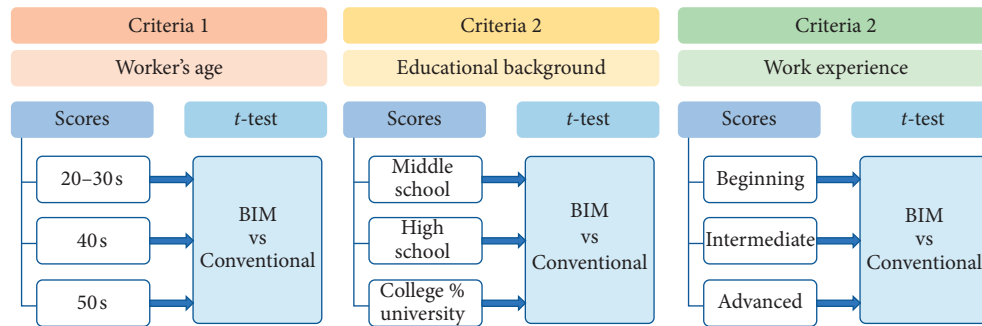|	Pretest			Posttest		
	Conventional	Alternative	Sig.	Conventional	Alternative	Sig.
Total	19.04	20.74	NS	48.14	58.29	0.00
Identification	10.98	9.97	NS	28.82	31.14	0.00
Prevention	8.06	10.77	NS	19.32	27.15	0.00

Note. NS = not significant.

Figure 5: Outline *t*-test of trainees' understanding by workers' personal factors.

Table 3: Classification of variables for workers' personal factors.

Variables	Explanation
Edu_C&U	Person who has a college or university degree
Edu_High	Person with at least a high school diploma or the equivalent
Edu_Mi&El	Person with at least a middle or elementary school diploma or the equivalent
Age_50s	Age over 50 years old
Age_40s	Age from 40 to 49
Age_20 and 30s	Age from 20 to 39
Exp_Adv	Advanced level experienced; person with more than 9 years of working experience in the field
Exp_Int	Intermediate level experience; person with 3 to 8 years of working experience in the field
Exp_Beg	Beginning level experience; person with 0 to 2 years of working experience in the field

decision making in construction engineering should have elements of realism, activism, interaction, uncertainty and novelty, performance evaluation, interface, creativity, enjoyment, and safe learning environment. Based on this, the assessment factors presented in this study to assess the appropriateness of the 3D virtual reality-based safety training method as on-site safety training method are as follows:

(1) V1. Real-life: does the training method realistically reflect the actual site?

This question determines whether the characteristics and environmental factors in the 3D virtual reality-based safety training method are developed with realistic environmental factors and thus provide concrete experiences.

TABLE 4: *t*-test result by workers' factor group.

	Variable	N	Mean	Sig.
Edu_C&U	BIM	33	56.82	0.089
	Conventional	32	49.53	
Edu_High	BIM	47	62.45	0.005
	Conventional	48	51.29	
Edu_Mid	BIM	13	48.33	0.008
	Conventional	18	35.00	
Age_50	BIM	51	55.98	0.003
	Conventional	48	44.69	
Age_40	BIM	33	56.21	0.287
	Conventional	34	51.62	
Age_20 and 30	BIM	11	72.27	0.022
	Conventional	12	52.08	
Exp_Adv	BIM	57	56.05	0.005
	Conventional	55	45.64	
Exp_Int	BIM	18	66.39	0.040
	Conventional	19	51.58	
Exp_Beg	BIM	19	56.05	0.040
	Conventional	20	47.25	

(2) V2. Suitability for on-site training: is the safety training suitable for on-site application?

This question specifies whether the safety training is appropriate for on-site application and delivery in terms of the contents' relevancy and applicability to the particular construction sites.

(3) V3. Active learning: does the teaching material promote the trainees' active participation?

This question pertains to the trainees' participation. It is meant to determine whether the safety training is worker-focused and promotes active participation in obtaining knowledge, as compared to the conventional, one-way trainings.

(4) V4. Enjoyment: does the safety training stimulate the trainees' interest?

This question asks whether the 3D safety training suggested in this study stimulates the trainees' interests and thus engage them in acquiring the new knowledge, compared to the conventional trainings.

5.2. Result of Relevance Evaluation. Each element of the appropriateness evaluation in the survey was divided into safety training based on 3D simulation (A) and conventional lecture training (B); then a qualitative assessment was performed for real-life (V1), suitability for on-site training (V2), active learning (V3), and enjoyment (V4), with the seven-point scale from strongly disagree (1) to strongly agree (7). The survey was responded to by the trainees after the training. The scope of the survey was limited to the managers in charge of safety management at the current construction site, and the survey was conducted on 54 persons in charge and responsible for each construction site of five construction companies. The age of the surveyors is 40.8 years,

TABLE 5: Questionnaire survey data to examine the experimental group.

Variables	Group	Mean	N	Std. deviation	*t* stat	d*f*	Sig.
V1	A	5.42	54	1.28	3.592	53	0.000
	B	4.67	54	1.26			
V2	A	5.35	54	1.02	−0.812	53	0.215
	B	5.39	54	0.96			
V3	A	5.47	54	1.47	4.639	53	0.000
	B	3.91	54	1.22			
V4	A	5.82	54	1.41	12.917	53	0.000
	B	3.58	54	1.15			

and their field experience averages 13 years. The average response for each item in the relevance of safety training materials evaluated by the safety manager was shown in Table 5.

In the opinion of safety managers according to the survey, the results of the survey in terms of suitability for on-site training (V2) showed no statistically significant difference between the two training methods ($p > 0.05$), while the results that real-life (V1), active-learning (V3), and enjoyment (V4) of the 3D visualization safety training method are more appropriate is statistically significant. In particular, enjoyment (V4) of 3D visualization safety training and that of the conventional training showed the most notable difference between the two, among all the other variables.

6. Conclusions and Discussion

This research examines the effectiveness of different safety training methods, 3D simulation and conventional lecture, delivered to workers on site. The site workers trained via virtual environmental simulation using BIM program showed a higher level of understanding than the group of workers who were trained via the conventional lecture approach. The safety training test indicated the statistical significance of the difference in mean of test scores between the two groups. In addition, test scores are statistically examined by workers' personal factors, including age, educational background, and work experience. Significant differences were found for the factors "Age" in 50s' scores and in 20 and 30s' scores, "Educational Background" in high school level and Middle school level, and for "Work Experience" in all levels; advanced level, intermediate level, and beginning level.

The major contribution of this research is that it statistically confirms the effectiveness of visualized safety training by BIM for construction site workers. The previous studies have also claimed that visualization in safety training could enhance trainees' understanding. However, these studies lack statistical evidence to substantiate their arguments. As such, the authors of this study conducted an empirical experiment and through statistics analysis clearly demonstrate the statistical validity of the effectiveness in visualizing safety training. Hence, this statistical validity holds significant applicability to generalize the outcomes of this study.

This research attempted to examine the effectiveness of different methods of training based on the contents. In this

process, the present research was able to compare the effectiveness of each method, conventional and alternative, using BIM.

The assessment in the experiment was in the data form of multiple choice and short answer items and was implemented immediately after the training. Because of the short time between knowledge transfer and assessment, it is possible that this assessment tested the trainees' short-term understanding. Future study may be needed corroborating the current findings of this research while examining the long term understanding of workers as well. Researchers including Wilkins [13] and Li et al. [14] drew attention to the trainees' dissatisfaction with the existing methods of safety training and have clearly presented the need for improvement in the methods. Safety training methods using 3D simulation were shown to be easily feasible and applicable to construction workers and to have distinct advantages over conventional methods. In addition, the results of safety training tests in this study also verified the effectiveness of training by the characteristics of workers. Besides, taking into the age of the trainees (early 20s) in the study on the improvement of safety training effectiveness [42], this study indicates that the improved safety training can be applied to a wide range of workers age-wise, thus workers of various ages can participate in the training. The innovational method of safety training is also found to be effective in the context of various educational and experiential backgrounds.

The trainees in other studies on the safety training utilizing the AR/VR and gamming engines were able to control their own risks environments as direct observers. However, the trainees in this study were not allowed for direct control of view point and moving path, and the training was conducted in the scenario prepared beforehand by the trainer. This was due to the fact that environmental constraints at the actual site needed to be taken into consideration. Few trainees could maximize the effectiveness of training, as it increases the opportunities for environmental control in individual subjects. On the other hand, as the group of trainees grows in size, the intensity of training experience is bound to decrease. Yet the reality is that large numbers of workers are trained in a limited space, time and environment and for that reason, the extent to which safety training and its methods are applicable at the site should be taken into account. In addition, considering poor safety training facilities at small and medium-sized enterprise's sites, limitations on space, utilization of equipment, and costs for applying virtual reality to safety training are high. There has been a strong demand for devising and improving the means for safety training, while maintaining the balance between the capacity for large number worker training and the capacity for providing indirect experience through scenarios [42]. The innovative method of safety training utilized in this study clearly presents improvement of effectiveness over the existing safety training and provides the information as to the degree to which the actual on-site safety training with the virtual environment technology could be applied.

However, there are some limitations in carrying out the training method utilizing the virtual reality used in this study. That is, in the course of construction site modeling, the lack of libraries of nonstructural parts, such as construction equipment and safety devices including platforms, scaffolding, and cranes has some limitations in sophistication and real-life re-enactments. However, improvements in the required levels of safety environments are likely to be made in the future by commercial models. Certain parts of the virtual reality model that were created for experimentation in this study were less sophisticated in terms of their elaborateness and the sense for the real, compared to the materials of the existing methods of training, e.g., pictures of the actual accident scenes and of preventional action. Thus, while the improved methods are mainly effective, it is also necessary to maximize the effectiveness of training by adopting the abovementioned materials from the existing training methods.

The findings of this study concerning effectiveness of the educational method in safety training will not only contribute to increasing construction site workers' understanding of safety but also serve ultimately as an essential stepping-stone for accident prevention. The fundamental objective of safety training is to reduce the occurrence of safety accidents. This research was intended to compare the difference between trainees' understanding level by different types of training methods. Future study should attempt to examine the ultimate correlation between training method and the actual data of accident prevention.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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