Development of a Virtual Reality Safety-Training System for Construction Workers

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Abstract

Safety training is an important and time-consuming task for many construction companies. Virtual Reality (VR) simulation can be used in safety training to help users understand and learn safety rules, standards, and regulations. VR can also be used to evaluate the degree to which construction workers acquired skills after taking safety classes. This project focuses on creating a Virtual Reality Safety-Training System and assessing the perceptual and behavior impacts of the VR environments on a trainee. Perceptual and ecological psychology are studied in creating VR worlds in order to make the system effective. The authors' analysis determined that a streamlined, scenario-developing pipeline is needed to support flexible, computer-generated variations of the VR world. This reconfigurable and reusable system creates 3-dimensional virtual images and produces memorable experiences for trainees. Modules of various virtual objects and virtual environmental factors such as temperature, air composition, and visibility are also studied and simulated in the proposed system. The authors also plan to assess the areas of safety training that can benefit most from VR use.

Keywords

Virtual Reality, Construction Information Technology, Safety Training

1. INTRODUCTION

Due to the inherent hazardous nature of construction, safety management is a must for the construction industry. The many methods and types of operations needed by construction companies to meet and complete tasks result in confusion about safe methods to accomplish work activities (Mincks and Johnston 2004). For example, many construction corporations use safety regulations, safety manuals, and Material Safety Data Sheets (MSDS) to comply with federally required safety training. MSDS on all materials that will be used on the site during the construction process should be developed and maintained on the project. However, MSDS usually come from different companies, and the complicated writing style, organization, tiny print, and few illustrations often leave workers bored, unmotivated, and confused.

There are multiple ways to perform safety training. For example,

- Reading the words, charts, or figures on paper;
- Listening to safety training lectures;
- Watching videotapes, such as "Tool Box Safety Talks" produced by AGC (The Associated General Contractors of America); or
- Taking online classes, such as the online OSHA (Occupational Safety and Health Administration) 10-hour class, which is interactive in a basic way and used by many today.

Some researchers have already started discussing other methods to arouse trainees' interest and to improve the learning quality of safety training. Using Virtual Reality (VR) to facilitate teaching is one of the new methods. Delmia Safework Pro (CSA 2005) is an example of using VR in teaching. VR simulation can be used as a comprehensive knowledge management system that integrates all of the elements necessary for active learning. This VR feature makes simulation feasible in safety training and for evaluation of construction workers' learning results.

The proposed project will focus on creating a VR Safety-Training System and assessing the perceptual and behaviour impacts of the VR environments on a trainee. By walking through the VR environments and experiencing the different scenarios, a trainee can understand and memorize safety rules, standards, and regulations in a totally different way. The purpose of this paper is to discuss the development of the VR Safety Training system for construction workers. Meanwhile, the authors will streamline a scenario-developing pipeline that allows computer-generated variations of the VR world. Streamlining helps to create scenarios for various working conditions. In addition, randomness is used in the proposed system because it can create a large number of variations for each scenario. Each scenario shows the effects of the various choices the worker makes; the trainee can quickly go through a number of choices and see the final result of those choices (or at least the more likely outcome). This supports workers in making better decisions when it comes to safety and in memorizing rules. For example, information in MSDS can be incorporated into various virtual objects and be simply imported into a workplace scenario. When workers experience this scenario, they can understand the information and process it. In this research, the authors will study perceptual and ecological psychology when creating VR worlds in order to make the system effective. Other modules of various virtual objects and virtual environmental factors such as temperature, air composition, and visibility will also be explored in this research. This reconfigurable and reusable system creates 3-dimensional, virtual images and produces memorable experiences for trainees. The authors will also assess the areas of safety training that can benefit the most from VR.

1.1 Problem Statement

More and more people realized that it is important to cultivate workers' safety habits instead of only memorizing a certain amount of book content. It is one of the fundamental principles of learning that people "learn by doing." To a trainer, this means that learners must be given ample opportunities to apply what they are learning (Goetsch 1993). For example, if the topic of a training session is how to administer a fire extinguisher, application should involve having the learners actually practice in-plant training. A select group of personnel should be acquainted with all extinguisher types and sizes available in a plant or work area. Training should include a tour of the facility, indicating special fire hazard operations (ETE 2000). While the learners practice, the trainer observes, coaches, and corrects. Regardless of the nature of the material, learners should be given plenty of opportunities to apply what they are learning. Such practices are essential in learning and familiarizing workers with possible, dangerous real occurrences.

However, in construction safety-training sessions, due to uncontrollable or unpredictable reasons, on-site or in-plant trainings are not always practical. For instance, there may not be an appropriate job site where learners can observe; tools or equipment may be unavailable or too expensive for safety training; or learners may not be able to hear or see all the demonstrations in a limited period of time. In addition, if similar safety lab training is repeatedly used, a student may reproduce other people's solutions and practical work without understanding all possible situations that arise in real jobs.

1.2 Research Problems

High-fidelity VR simulations for occupational health and safety applications have the potential to resolve the above-mentioned problems. In virtual reality, construction workers experience the inherent danger of their working environment without being in real jeopardy. At the same time, they use their knowledge to find out potential problems; use adequate methods to correct, adjust, or remedy the mistakes; and learn how to react to different situations randomly generated by the VR system.

In order to build a VR system that is suitable for construction safety training purposes, the following issues need to be addressed:

- The main reasons why VR is taking part in this research project need evaluated and justified.
- What scenarios are best suited to the VR Safety-Training System approach need to be determined. The goal of this project is to develop a re-configurable and reusable system to create 3-dimensional virtual images.
- The scenarios will be developed into a set of encapsulated system rules that satisfy the prescribed requirements.
- The system will have random effects that provide a mechanism for altering the VR scenarios. These random effects need to appear realistic for a specific scenario, and, therefore, a range of random values needs to be specified with the scenario.
- The virtual components of a VR site should include general settings such as architectural drawings of the site, virtual objects that react to and can be manipulated by the trainees and environmental factors like air composition, temperature, lighting, and dust conditions. These components also have a dynamic aspect that determines changes in position, shape, or environment over time or in response to users' interactions.

1.3 Significance of the Project

Virtual reality allows trainees to experience and play in a safe and controlled environment. Employees are able to explore the outcomes of their decisions without risk to themselves or equipment. They are able to visualize what cannot be visualized: degrees of risk, temperature, air quality, chemical exposure levels, and the effects of these. The virtual world can show the possible results of actions and let workers explore different outcomes as a result of their decisions, all of which helps trainees develop better thought processes for decision-making. Because virtual reality safety tutorials are designed modularly, modifications are easily made as workplace situations change. Given the importance of safety in construction, this research will benefit construction companies and the state and federal governments.

2. LITERATURE REVIEW

The Occupational Safety and Health Act, or OSHA, of 1970 mandates that employers provide health and safety training. OSHA and the U.S. Secretary of Labor are responsible for both providing training directly and for ensuring that industrial firms provide training at the local level. In order to meet their legal and ethical obligations regarding health and safety training, companies must rely on their health and safety professionals who, in turn, must rely on first-line supervisors. Health and safety professionals and first-line supervisors should work closely in the preparation, presentation, application, and evaluation of safety training. Supervisors are more likely to provide job- and task-specific training, while health and safety professionals are more likely to provide the more generic training (Goetsch 1993). In presenting training sessions, educators hold that the following percentages apply regarding what learners retain from the instruction they receive (Table 1):

Table 1: Retaining percentage of learning styles (Goetsch 1993).

Learning Style	Retaining Percentage
Reading	10 %
Listening to lectures	20%
Observing	30%
Observing and Listening	50%
Observing and speaking, using own words by oneself	70%
Listening to lectures and doing what is talked about	90%

Instruction can be presented in several different ways. The most widely used are the lecture/discussion, group instruction, demonstration, conference, and multimedia methods. Instructors should get the learner actively engaged seeing, saying, listening, and, most importantly, doing. Goetsch (1993) discussed and compared different learning methods such as:

1. Lecture/discussion method
2. Demonstration method
3. Conference method
4. Simulation
5. Videotapes,
6. Programmed instruction
7. Interactive video

In his definition of simulation, Goetsch says it involves structuring a training activity that simulates a line situation and role-playing by trainees. The last four learning methods (simulation, videotapes, programmed instruction, and interactive video) can become computerized. They are appropriate to be further developed into 3-dimensional computer simulations or VR systems.

Research on new technologies, methodologies, and strategies for preventing injuries in the workplace was highlighted at the National Occupational Injury Research Symposium 2000 (NOIRS 2000). NOIRS 2000 was sponsored by the National Institute for Occupational Safety and Health (NIOSH) along with the American Society of Safety Engineers and the Liberty Mutual Research Center for Safety and Health. Attendees in that conference agreed that through research using today's cutting-edge science, the factors that put workers at risk could be better identified, and more effective preventive measures could be designed (NOIRS 2000). Becker and Morawetz (2004) administered detailed survey questionnaires to 55 workers prior to and 14-18 months following training. Surveys queried trainees' interests and involvement in safety and health, use of information resources, training activities at their worksite, and their attempts and successes at making worksite improvements. Post-training, the study population showed an increase in training of other workers, use of resources, attempts at improvements, and success rates for those attempting change, and overall success at making improvements. They also found computer technologies help by increasing a worker’s interest and involvement in health and safety (Becker and Morawetz 2004).

Computer technologies have been extensively used in architectural and construction implementations. Three-dimensional (3D) visualization and VR are successfully applied in construction projects, communication, sales and marketing, and training. Researchers in Carnegie Mellon University used game engines to visualize building construction projects (Navia and Loo 2004). Maldovan and Messner (2005) from the Pennsylvania State University discussed the application of a game engine environment in the construction education aspects. Many 3D representations are built off CAD software, Autodesk VIZ, Form Z, and Rhino. The game engine was developed and used for educational purposes, and it was set up by adopting the Unreal game engine level editor. The game engine was similar to VIZ, where material properties are assigned to particular 3D building components (Maldovan and Messner 2005). The video game engine can be a viable option or additive when discussing virtual reality and education. In construction education and visualization research, virtual reality and advanced visualization tools can help improve construction education. Using VR technologies can help students understand the construction process and planning (Messner 2003). The VR Safety Training system proposed here is different from above systems (Maldovan and Messner 2005, Messner 2003, Navia and Loo 2004). The VR Safety Training system has randomness, which creates variations for each scenario, which are not needed for construction engineering. Our system is also intended to provide trainees with the skills to identify visual clues of danger and to follow safety procedures in the real-world. Another difference is that our system shows the effects of the various choices the worker makes.

Home et al. (2005) proposed visualization using building information modelling. They found out that one of the reasons that VR technologies were not yet widely used in the field of building design is due to the cost and time required to develop the models. VR models can add the components of interactivity and immersion to building models, which is an undividable part of construction education. When VR is required, special visualization companies are often used. This involvement by third-party specialists adds to the production time and cost of VR models. However, emerging evidence suggests that adoption of building information modelling software is resulting in productivity gains of 40-100% during the first year (Khemlani 2004; Home et al. 2005).

Stappers et al. (2001) proposed narrative enhancements aimed at improving experiential quality of walkthroughs in a Collaborative Automated Virtual Environment (CAVE). They realized the importance of incorporating narrative elements in the development process of architectural presentations and put forward a “number of solutions, none of which involve much technical effort, but try to improve the fit between the simulation and the users’ needs on the basis of existing technology.” These advanced visualization methods are complemented by their virtual walkthrough capabilities. In these narrative enhanced walkthroughs, teams can explore a project site by either stepping through to predefined viewpoints or navigating in real-time with orbit, examine, or walk functions (Calderon et al. 2005).

Khatab et al. talked about an integrated VR decision support system (IVR-DSS) for outline design reinforced-concrete building structures (R.C.B.S). IVR-DSS is an integrated decision support system that can assist designers and decision makers at the outline design stage of the design process by developing a rapid outline design solution. Their system integrated VR technology with design rules and database. The paper develops the design rationale for such a system and designs a prototype that was developed in the case of their research (Khatab et al. 2005).

A few research centers or organizations are conducting research on construction safety training using VR and multimedia. The Construction Safety Alliance in the Division of Construction Engineering and Management at Purdue University has a research project: Delmia Safework Pro for human modelling. They propose using a VR environment in Safework to evaluate a design through virtual mock-ups. Their main application is the development of an articulated virtual mannequin controlled by a set of motion-capture devices placed on a human subject. This project is partially funded through a grant from the National Institute for Occupational Safety and Health (CSA 2005). In this proposed project, besides using VR to train people with all the construction safety concepts and procedures, major effort will be allocated in testing and observing the performance of the trainees. For example, the time trainees use to resolve some exam questions will be observed. This proposed research, although it will eventually make use of the virtual mannequin and data collected by the Purdue project, will focus more on 1) developing dynamic environments in which workers experience real-like scenarios and learn safety procedures and decision-making, and 2) establishing a production pipeline for scenario creation. Artificial workers can later be introduced into the developed environments, and the Purdue data can be used to better customize the concepts to be emphasized in the proposed VR safety training system scenario. Another group at the University of Florence in Italy is developing multimedia applications for safety training, but its emphasis is more on the streaming, interactive, movie-like scenarios rather than VR, where the trainee has more freedom and can "walk" and "fly" around in the environment (Assfalg et al. 2002). This research group, however, developed guidelines for determining the tasks required for the trainees and the relative merits of 3D graphics for each type of task, and the authors will adapt those results into the work.

Virtual reality has also been employed to help people cope with dangerous situations in other domains, such as flight training (for an example of a commercial system, see http://www.frasca.com) or military training (Korris 2004). These domains are radically different than construction safety because the main skill required of a pilot or soldier is to be able to survive dangerous situations, while a construction worker’s training is intended to keep workers from ever finding themselves in physical danger. There are also big differences in the amount of time, effort, and capital that is needed in training a pilot or a soldier compared to safety training.

Table 2 in the Appendix compares the features and differences of these visualization systems, including video game engines, visualized building information systems, VR decision support systems, and the VR teaching systems. It also shows the features of the proposed VR safety training system. Table 2 further shows that the proposed VR safety training system has a set of rules, which is an expert system. It also has random effects to simulate the various situations that might happen on real job sites. The system architecture will also be capsulated so that it can re-configure to different users and, at the same time, be extensible.

3. CASE STUDY

A preliminary assessment of the realism of the immersive VR was performed for a virtual worksite. The main goal was to determine whether there is a strong sense of presence in immersive VR and to test the usage of VR through a simple, non-interactive scenario. A virtual, two-level scaffolding was created and fitted with a dangerous wire hanging on the side of the building. Figure 5 (see Appendix) shows the first level and Figure 1 shows the top level of the building. The virtual worksite was modelled in about 120 minutes by an undergraduate student assistant. Another world we considered was a suspended crane featured in one of our demonstrations (Figure 2). The display system has three 10’x 8’ screens-- one under the user, one in front, and the third to the right.

Figure 1: A virtual scaffolding observed by a real user on the top level of the building. There is a virtual wire hanging on the wall.

The virtual worksite had a “natural” feel, and it seemed appropriate for safety-training. It can be observed in Figures 1 and 5 that, even for an outside observer, the world and the user seem quite natural, and it is easy to observe the interaction between the environment and the user. This technique has the potential to be used not only in a first-person VR, where the trainee interacts directly with the virtual world, but also in a third-person system, where the trainee observes another user in the VR. An instructor can use the third-person, live approach to test the safety skills of workers in a manner appropriate to each trainee.

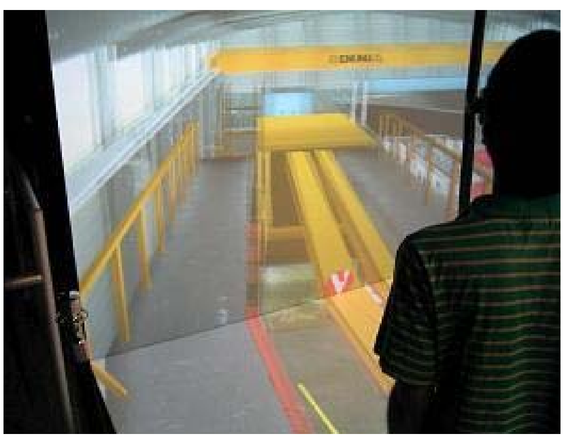

Figure 2: A real user in a virtual suspended crane.

Another finding of this informal experiment was that there needs to be more work to determine precisely how to represent features of interest, such as hanging wires, in order to avoid making them too difficult or too easy to identify. This problem stems from the current display technology that has limitations on color palette, resolution, and focal distance, which makes a virtual world different in some aspects than a natural one. These differences make people susceptible to easily detecting environmental features that would be difficult to identify in the real world or to failing to detect easy targets in a simulated world. The informal training scenario had to exaggerate some objects and to dampen others. For instance, the wire hanging through the wall in the scaffolding worksite had to be drawn larger than in real life in order for the viewer to detect it.

4. PROJECT PLAN AND METHODOLOGY

In the context of this approach, a proposed system tool is being developed that implements the prescribed requirements and produces an interactive VR environment for safety training. The system tool will include the following parts: risk assessment, hazard identification, safe working procedures, facilitating communication, skills training, assessment and correction of risk takers, all of which can be loaded into a VR system and used to teach and test the important safety concepts and procedures. It incorporates knowledge rules expressed in regulations, safety manuals, and MSDS. The details of system contents are shown in Figure 3.

This is a new approach that would contribute towards improving the expert knowledge of construction safety. It endeavours to combine the exciting VR technologies with safety knowledge. It will benefit the construction industry if it is developed and utilized

The work consists of the following four activities: safety scenario sketching, evaluation, implementation, and adding random effects. Figure 4 shows the relationship between these activities.

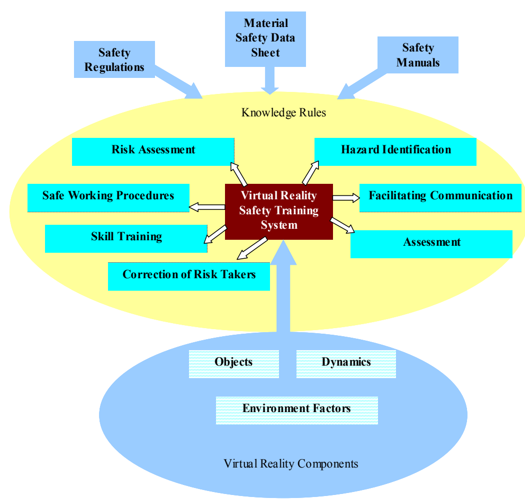

Figure 3: Details of Virtual Reality Safety Training system

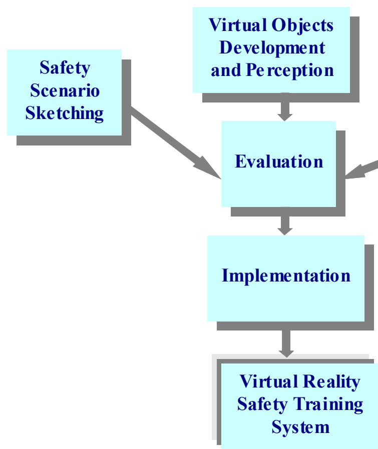

Figure 4: Relationship between System Design Activities.

4.1 Safety Scenario Sketching

Safety scenario sketching is preceded by an evaluation of the safety areas: Risk Assessment, Hazard Identification, Safe Working Procedures, Effective Communication, Skills Training, Assessment, and Correction of Risk Takers. The PIs will work on sketching a few simple scenarios and will analyze the merits of implementing each of them. One scenario will be chosen for implementation, and a few basic items such as wiring, wood boards, air composition, and temperature will be set to be analyzed.

The users are able see the potential consequences of poor planning or failing to follow proper procedures. The VR environments can be set according to the topics covered in training materials. For example, trainees are taken through the jobsite hazards where they see a steel structure of a high-rise building or a narrow trench and hear the 3D construction sounds. Additionally, trainees can experience such sensations as falling, injury, and even death. The shock value in such a safety program will make the lesson a memorable one. With minor changes, the VR jobsite training environments can be used as examination tools to test the trainee’s degree of understanding of the safety training materials. With observation of the time consumed and the trainees’ performances during the exams, evaluation of these trainees on how well they learn the construction safety materials can be obtained. Moreover, variations of a scenario can be rendered in a computerized environment in order to convey diverse experiences that allow trainees to sharpen their observation skills and decision-making processes. These scenarios will benefit the trainees, especially the ones going through them multiple times, if the participants encounter different situations in different executions of the same scenario.

4.2 Evaluation of Perceptual and Ecological Aspects of Immersive VR

People perceive VR in a slightly different fashion than the real world due to the limitations of display and computer graphics technology. We intend to empirically evaluate two psychological characteristics of immersive VR used in safety training--perceptual and ecological.

The perceptual part will examine graphical features such as color, size, or distance for the viewer of various objects in the environment and how they relate to difficulty of perception of these objects. For instance, this part will examine whether a wire hanging from above the trainee needs to be bigger or smaller than in the real world in order to be detected by the trainee or whether the relative height of a wood scaffolding to the viewer matters in how the trainee might detect danger.

The ecological aspect, a branch that is regarded as distinct from perception by psychologists, deals with the interactions of all the objects in the world. Ecological psychology postulates that people are tuned to interpreting the interrelationship in the natural world such as the relationship between a pendulum speed and its length.

The authors will only focus on the relative movement of objects (and their edges) in the world. This movement might occur due to the user's movement, which the user can stop or hasten, or due to the object’s natural motion (e.g., falling). The authors may have to emphasize some of the edges of the virtual objects to allow easier detection and interpretation of their relative positions and speeds. The whole problem driving this activity is that the virtual world, even in an immerse system that surrounds the user, is not as precise as the real world. Some things may need to be exaggerated, while others may need to be removed because they may be distracting. The evaluation will involve making a subjective evaluation of the graphical features of the basic world components (perceptual) and of their interactions (ecological).

4.3 Implementation

The evaluation of a few promising training scenarios will provide us an opportunity to determine which one is the most likely to help trainees. Authors will implement the chosen scenario using the virtual components designed according to perceptual and ecological principles valid in VR. The main problem is to determine the right pipeline for scenario development. The authors will be using 3D modelling tools such as Maya or 3D Studio Max to build worlds and parts of the worlds. These 3D models will be imported in a simple program that allows user interaction. The problem is finding the right balance between work in a modelling program and software development. The software is responsible for interactive navigation, on-the-fly model modification, and conveyance of the effect of various decisions to the trainees.

4.4 Adding Random Effects

The PIs will add random effects in the generated scenario. Randomness is especially important for testing, especially if knowledge about the exam propagates from the students who have taken an exam to the ones who have yet to take it. Random effects can also be beneficial to people who have to study repeatedly because the scenario will be made slightly different in each execution. The authors will briefly review two ways of producing randomness in the virtual world: combining pre-defined choices, which requires more models for each scenario, and creating software-generated, on-the-fly, random patterns, which requires a one time substantial effort in coding. It is likely that only one technique will be extensively developed.

5. CONCLUSION

This project is in the initial stages. The authors are sketching the safety scenarios, which could represent the real working conditions. This requires expert knowledge in safety training. The final result of this project is expected to be a virtual reality system that could be used to train workers and improve their performances.

6. REFERENCES

Assfalg, J., Bimbo, A.D., and Vicario, E. (2002). Using 3D and Ancillary Media to Train Construction Workers. *IEEE MultiMedia*, *9* (April-June 2002). pp. 88-92.

Becker, P., and Morawetz, J. (2004). Impacts of health and safety education: Comparison of worker activities before and after training. *American Journal of Industrial Medicine,* 46, (June 10, 2004). pp. 63-70.

Christianson, D. B., Anderson, S. E., He, L., Cohen, M.F., Salesin, D.H., and Weld, D.S. (1996). Declarative camera control for automatic cinematography. In proceedings of *AAAI '96*. pp. 148-155.

Calderon, C., Worley, N., and Nyman. K. (2005). A cenematic camera control engine for architectural visualisations in virtual worlds. In proceedings of Conference on Construction Applications of Virtual Reality 2005. http://cumincad.scix.net/cgi-bin/works/Show?3032,

CSA (2005). Delmia Safework Pro – Human Modelling, Feburary 2006. https://engineering.purdue.edu/CSA/about_us/csa

ETE (2000). Electrical Safety, April 2006. http://www.elec-toolbox.com/Safety/safety.htm#fire

Goetsch, D.L. (1993). *Industrial safety and health in the age of high technology for technologists, engineers, and managers*. Macmillan Publishing Company: New York.

Home, M., Roupe, M. and Johansson, M. (2005). Visualisation using building information modelling. In proceedings of Conference on Construction Applications of Virtual Reality 2005. http://www.adetti.pt/events/CONVR2005/

Karp, P. and S.K. Feiner. (1990). Issues in the automated generation of animated presentations. In proceedings of Graphics Interface '90. Halifax, California, May 14–18, 1990. pp. 39–48.

Khatab, A., Dawood, N., and Hobbs, B. (2005). Development of an integrated virtual reality decision support system (IVR-DSS) for outline design for reinforced concrete building structures (R.C.B.S.) In proceedings of Conference on Construction Applications of Virtual Reality 2005, Durham, UK Sep. 12--13 2005. http://www.adetti.pt/events/CONVR2005/IndustrialDay.htm

Korris, J. (2004) Full Spectrum Warrior: How the Institute for Creative Technologies Built a Cognitive Training Tool for the XBox. 24th Army Science Conference Orlando, Fl; December 2004.

Messner, J. I., and Horman, M. J. (2003).Using advanced visualization tools to improve construction education. In proceedings of *CONVR 2003.* Virginia Tech, Sep. 24 – 26 , 2003. pp. 145-155

Mincks, W.R., and Johnston, H. (2004). *Construction jobsite management*. Thomson Delmar Learning: Clifton Park, NY.

Navia, J., and Loo, B. (2004). Virtual Carnegie Mellon University, January 2006. http://www.andrew.cmu.edu/user/jnavia/vCMUWeb

NOIRS (2000). Research on new technologies, methodologies and strategies for preventing injuries in the workplace. National Occupational Injury Research Symposium, April 2006. http://www.cdc.gov/niosh/noirs2000.htm

Stappers, P.J., Saakes, D., and Addriaanse, J. (2001). On the narrative structure of virtual reality walkthroughs. In proceedings of *CAAD Futures 2001*. http://www.caadfutures.arch.tue.nl/cf2001/default.htm

7. APPENDIX

Figure 5 shows a virtual scaffolding observed by a real user.

Table 2 compares the features and differences of some visualization systems.

Figure 5: A virtual scaffolding observed by a real user. There is a virtual wire hanging on the wall to the left of the black, real cable used to control the immersive display. The display consists of three screens below visible to the user's left and right.

Table 2: Comparison of construction visualization systems

System Name	Design Purpose	Visualization Feature	User Interface	Game Engine
Virtual Carnegie Mellon University (VCMU)	To have real time virtual tour	Rewritten A.I.; Lighting engine based around per-vertex lighting; "Observer mode", complete with vector positioning "laser" for the user to interact with the environment. Not intended for teaching skills in danger avoidance.	Interact with Artificial Life forms ("Actors") through computer screen.	Unreal Engine 1.0
Virtual Facility Prototype (VFP)	To visualize building construction projects	Determine the capabilities of the Unreal platform; Converting CAD models into usable models for Unreal; Triggers added to objects or areas, but messages displayed were limited in content. Not intended for teaching skills in danger avoidance but rather for engineering.	A participant can enter a level of the video game and different scenarios of "player's" choice.	Unreal Tournament 2004
Visualization using building information modelling	To introduce building information modelling to students for the purposes of visualization.	Students using 3D CAD to develop their 3D models	3D CAD computer software	N/A
Narrative enhancement of walkthrough in a CAVE	Incorporating narrative elements in the development process of architectural presentations	Teams can explore a project site by either stepping through to predefined viewpoints or navigating in real-time with orbit, examine, or walk functions	VR walkthrough	N/A
Integrated VR decision support system for outline design reinforced-concrete building structures	An integrated decision support system that can assist designers and decision makers at the outline design stage by developing a rapid outline design solution	This system integrated VR Technology with design rules and database.	VR	N/A

Delmia Safework Pro for human modelling	To use a VR environment in Safework to evaluate a design through virtual mock-ups	Themain application is the development of an articulated virtual mannequin controlled by a set of motion-capture devices placed on a human subject.	VR	N/A
Multimedia applications for safety training	Streaming, interactive movie-like scenarios	Developed guidelines for determining the tasks required for the trainees and the relative merits of 3D graphics for each type of tasks	Movie	N/A
Proposed VR Safety Training System	Creating a VR Safety-Training System and assessing the perceptual and behavior impacts of the VR environments on a trainee	Teaches trainees how to recognize dangerous situations and to apply safety procedures. Perceptually and ecologically balanced world to present the same difficulty in VR as in real world. Can be used for live testing of trainees. Allows computer-generated variations of the VR world.	VR walkthrough	Custo m code