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Construction Site Fire Safety Using BIM and Virtual Reality

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Abstract. Due to the dynamic nature of a construction job site, it is challenging to ensure safe operations and avoid accidents. It is imperative to provide/facilitate effective safety workshop/training programs, especially for new employees to familiarize them with the existing hazardous situations on site and ways to address them. Although various visualization techniques were investigated in the past in other industries, their implementation in the construction industry with an emphasis in site safety is still in its infancy. This paper provides the use of Building Information Modeling (BIM) and Virtual Reality (VR) in improving the current scenario of safety in the construction industry, with a particular emphasis on fire safety. This work deals with a combined approach of BIM and VR technologies. These technologies are linked together to develop an immersive environment that provides access to critical locations in case of an emergency such as, the location of fire extinguishers, and exit route for emergency evacuation. This paper investigates the potential of site safety and emergency response management in the construction industry.

Keywords: Construction Safety, Building Information Modeling, Virtual Reality, Fire Safety.

1 Introduction

The Construction industry is inherently prone to safety hazards due to its dynamic and random nature. The census data from the U.S. Bureau of Labor Statistics shows that the construction industry is one of the most hazardous industries in the United States based on the number of fatalities. In the year 2015, 937 or 21.4% out of 4,739 worker fatalities in the private sector were in construction, which is equal to one out of five worker deaths [1]. Various reasons for this may include lack of awareness and inadequate implementation of safety measures. One of the primary reasons for high fatalities in the construction industry is the lack of proper education and training available to construction project personnel [2]. Safety performance at a construction site might be improved through a safety training or workshop program. This may help predict accident scenarios. Safety training is generally provided on site, in the form of toolbox meetings, and also by using workshops or seminars. It helps in familiarizing new employees with the hazards on-site, with the help of mentoring programs and pairing

individuals [3]. However, a large percentage of these workshops have demonstrated unproductive results in effectively communicating the vulnerabilities associated with a construction site [4].

The complexity and uncertainty in the nature of construction industry requires the safety planners to adopt new and innovative technologies to improve the construction safety scenario [5]. One such technology is Building Information Modeling.

Building Information modeling or BIM is one of the most promising developments in the construction industry [6]. This innovative technology has changed the way construction projects are executed from their inception to handover. Associated General Contractors of America (AGC) defines BIM as *"the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analyzed to generate information that can be used to make decisions and improve the process of delivering the facility"* [7].

Another new technology that is gaining ground in the industry is Virtual Reality. Rheingold defined virtual reality as "*an experience in which a person is surrounded by a three-dimensional, computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it.*" [8]. Virtual reality (VR) technology uses computers, software and peripheral hardware to generate a simulated environment for its user. The simulated environment may consist of real or imaginary surroundings. It is a computer-generated environment that gives a person a sense of being within it by engaging their senses and reducing or removing their perception of the real environment. While there is a wide range of technical implementations, VR typically has the following features: it will surround its user, obscuring cues from the physical environment, provide a three-dimensional visual representation of the virtual environment; track the user's location and orientation and update the virtual scene to match the user's movements; and give the user some degree of control over the objects in it [9]. A central notion is that of 'presence' in the virtual environment. This means that the subjects' responses in the virtual environment are similar to those in a real environment [10]. The use of visualization not only presents a more comprehensive construction process than 2D drawings and information [11], but also helps in communication between different project stakeholders [12].

The virtual reality technology has provided benefits to many industries. The military have used it for training recruits. In the field of medicine VR technology has been used to provide medical students with an opportunity to experience dangerous surgical procedures in a virtual environment. Although the technology is relatively new in the construction industry, there is tremendous potential of utilizing it for construction safety.

2 Research Significance

Although prior literature has shown the significance of using Virtual Reality in different industries, the use of BIM along with VR in the construction industry is very limited. This research helps in demonstrating the use of BIM and VR in construction safety training especially focusing on fire safety. There is a potential of changing traditional methods of safety training, and implementing a more proactive approach with the help of new cutting edge technologies.

3 Discussion

The Research process starts off with a thorough literature review. The literature required for this project was collected through extensive search of journal articles, conference papers, reports and books. Mostly recent and relevant papers were collected. The main focus of the literature review was to identify limitations in the construction industry regarding safety and training techniques.

After a thorough literature review, appropriate VR headset and BIM software were identified. There were a number of different VR products available in the market. HTC Vive, was specifically acquired for the study due to its low cost and user friendly interface.

The following BIM technologies were selected on the basis of their low-cost, and the presence of extensive tutorials on the internet:

- Autodesk Revit for creating 3D model
- Google SketchUp for editing and exporting all the equipment, characters and related families needed onsite
- Autodesk Navisworks for 4D phasing simulations
- MS Project for creating construction schedule
- Iris VR- For visual training

For this study, a BIM model of a shed was generated using Revit as shown in Figure 1. Different site equipment i.e. cranes, vehicles, scaffold, and dumpster were downloaded and edited from Google Sketchup's *Ware House* and Revit *Family* to incorporate into the model. The easy availability of these equipment made an otherwise time-consuming process of creating each equipment individually, faster and more convenient.

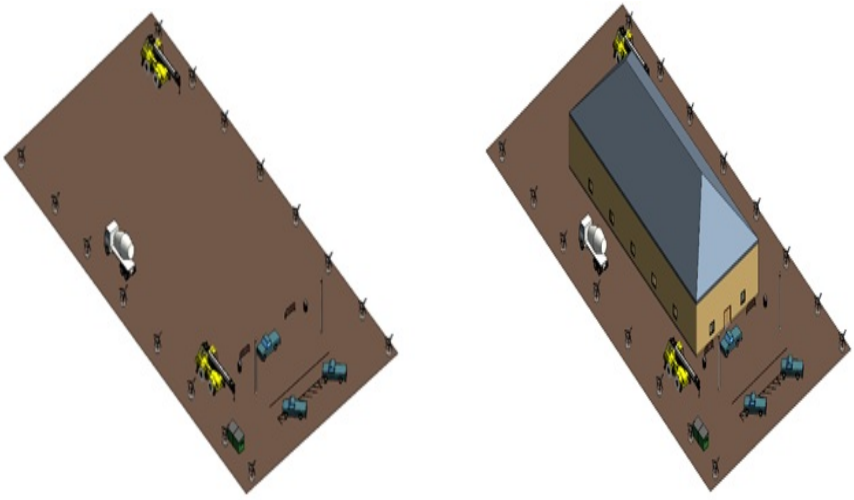
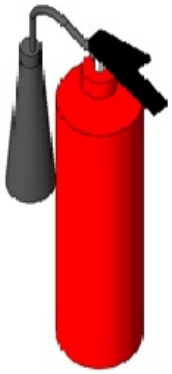


Fig. 1. Revit model of site Area (left) and shed (Right)

The Fire Extinguishers downloaded from Revit's Family (refer to Figure 2) were then added to the model according to the OSHA specifications. The shed's components like doors and windows were finally added to complete the 3D model. As a part of project planning, a simple project schedule was developed using *MS Project* (MSP) which listed all the activities to be executed in the project along with their Planned Start and End dates. This MSP schedule and the 3D model in Revit were exported to Navisworks, in order to link all the individual components to their respective line item on schedule to create 4D simulation of the project. This 4D simulation shows animated visualization of the project and pinpoints the exact scenario of the site on any particular day.



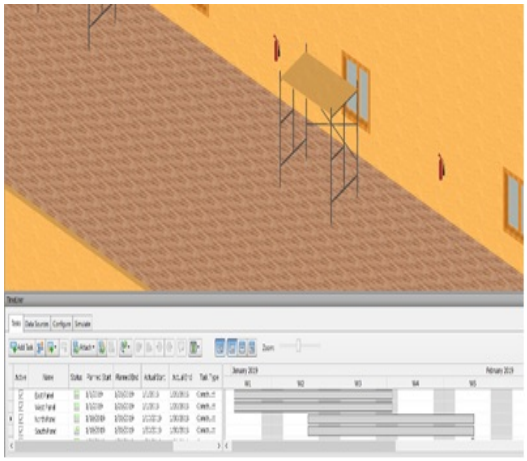


Fig. 2. Fire Extinguisher model and Navisworks 4D model

The model was transformed in to virtual reality walkthrough using *IrisVR Prospect* (as shown in Figures 3 and 4). *IrisVR Prospect* is a Windows based platform that converts 3D models from Revit, Sketup and other similar software into VR experiences using head mounted displays (HMDs), that a person wears to get immersed in a Virtual Environment (VE). By moving one's head and eye this VE can be explored from any perspective. Creating this VR walk through helps in identifying locations of Exit doors and Fire Extinguishers in case of a fire outbreak, and assists new employees to visually explore a virtual environment prior to construction.

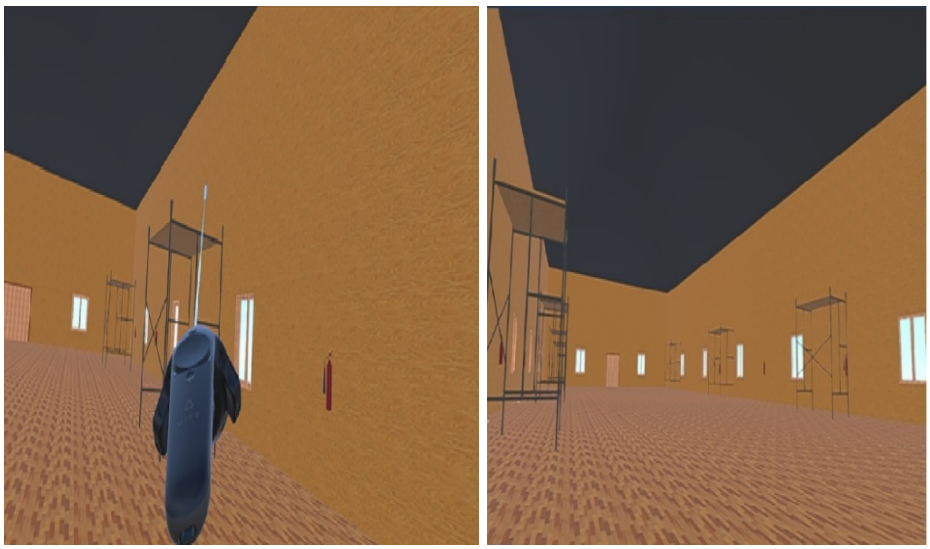


Fig. 3. Viewing Virtual Environment through HTC Vive

Fig. 4. Outside view of shed

4 Results and Conclusion

The paper provides a method of BIM based virtual environment with an intent to improve the safety training programs currently in practice in the construction industry. Through BIM models and VR tools a more proactive approach has been proposed to tackle safety issues. Exposing personnel to hazardous situation in a risk free virtual environment is a viable solution. This technique prepares them for unforeseen harmful situations on site before entering the actual worksite. The paper focuses on the fire safety scenario through a 3D model of a shed which was created using Autodesk Revit and included the fire extinguishers according to OSHA specifications. The safety model was simulated using Navisworks and then linked with IrisVR to give an immersive experience to the user by using Head mounted display (HMD). The authors believe that this method of safety training will create a positive impact in the safety scenario of construction industry, the likes of which may be investigated through surveys and field trials for future work.

There are some potential barriers in utilizing these techniques in the industry, like cost associated with VR equipment, BIM compatible computers, traditional thinking of safety officers, and lack of expertise of administrative personnel. Therefore, future research endeavors can focus on exploring these barriers and ways to resolve them.

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