Investigating Virtual Reality Headset Applications in Construction

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Virtual Reality (VR) or immersive environment can provide enriching experiences to users by simulating real world environments. The popularity of VR headsets has recently been on the rise primarily in the gaming market, however VR applications are being adapted for use in other industries as well. This paper presents findings of a research study which investigated the applications of 3D VR headsets in construction - specifically for safety training and jobsite management. The renovation of Dudley Hall at the campus of Auburn University was selected for a case study. Various safety and jobsite management scenarios were modeled in VR environment using a variety of software. Utilizing the Oculus® DK2 VR headset, the users visited the virtual jobsite and identified safety hazards as well as site logistics issues. Demonstrating a real world environment allowed users to visit and explore the renovation project without being on the jobsite. This research helps us to explore an emerging technology that could be a game changer in the design and construction industry. The results of this research will be a great aid in determining the value and best applications of VR headsets in construction.

Keywords: Virtual Reality (VR), Virtual Reality Environment (VRE), Head Mounted Displays (HMD), Construction Simulation, Oculus Rift®, Safety Training

Introduction and Background

Virtual reality may have popped into the headlines only in the past few years, but its roots reach back decades ago. As time evolves, this technology is becoming better, cheaper, and more accessible. It is weaving its way into our daily lives (University of Illinois, 1995). VR refers to an immersive multimedia or computer-simulated life, replicates an environment that simulates physical presence in places in the real world or imagined worlds. Virtual reality can recreate sensory experiences, which include virtual taste, sight, smell, sound, and touch (Luo, 2015). People gain 70 percent of information by vision, resulting in systems like HMDs that provide the visual component of immersion have been widely used to develop virtual environments. VR provides one of the best tools for accident reconstruction, training and hazard identification by immersing the trainee in an environment that is as real as possible. The use of high quality three-dimensional graphics, sound and dynamic simulation combine to form a uniquely engaging experience (Kizil and Joy, 2001).

Although the numbers of injuries in the construction industry have decreased significantly since the passage of the Occupational Safety and Health Act in 1970, several hundred workers still face fatalities every year. Addressing safety challenges remains a priority in every construction project as a result of this legislation. Safety managers now constantly attempt to enhance the effectiveness of training materials provided to workers (Bhoir and Esmaeili, 2015).

Out of 4,251 worker fatalities in private industry in calendar year 2014, 874 or 20.5% were in construction—that is, one in five worker deaths last year were in construction. The leading causes of worker deaths on construction sites were falls, followed by electrocution, struck by object, and caught-in/between. As shown in Table 1, these "Fatal Four" were responsible for more than half (58.1%) the construction worker deaths in 2014, BLS reports. Eliminating the Fatal Four would save 508 workers' lives in America every year (OSHA, 2015).

Table 1

Leading causes of worker deaths on construction sites.
(OSHA, 2015)

Falls	349	39.9%
Electrocutions	74	8.5%
Struck by Object	73	8.4%
Caught-in/between	12	1.4%

With the advances in VR headsets and their wide popularity, there is still limited research available to the construction industry. VR has the potential to change jobsite communications with its ability to visually convey conflicts or issues. VR applications in construction can have considerable value in coordination meetings, as shown in Figure 1. Coordination meeting are unique to every project, allowing for presenting new safety issues as well as viewing the logistics of the jobsite. Other applications include but not limited to: (1) site layout and planning; (2) rehearsing erection sequences; (3) progress and monitoring of construction processes; (4) evaluation of construction scenarios; (5) inspection and maintenance; and (6) fire safety and access assessment.
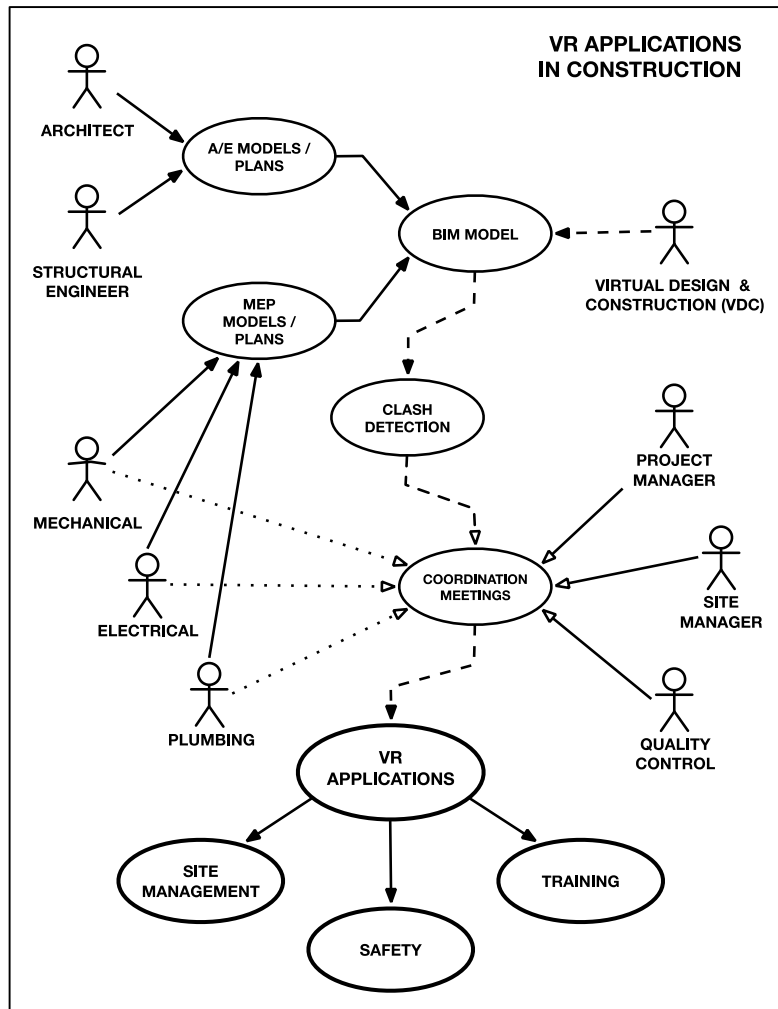

Figure 1: VR applications in construction. (Lyne, 2013)

Research Aim, Key Questions, and Scope

Existing research on the use of VR headsets in the construction industry is limited, however the research conducted in other industries appraised the value of VR headsets for training and education (Desai *et al.*, 2014). The aim of this research is to demonstrate how VR headsets can be utilized for construction safety training and jobsite management. This research seeks answers to the following key questions: (1) Are VR headsets feasible for construction planning, and training; (2) Does the VR headsets provides the same experience as the real-life construction environment; and (3) What are the limitations of VR headsets specifically in construction practice?

The VR headset used in this study is the Oculus Rift®. It is a light weight headset that allows a user to step into the VR environment and being able to "walk through" and "look" in any direction. The Oculus Rift® is currently available in the Developer Kit (DK) version. Two DK versions have been released namely the DK1 and the DK2 models. The consumer version is planned to be released in early 2016 (Desai et al., 2014).

Figure 2: Components of Oculus Rift DK2. (Source: https://www.oculus.com)

Literature Review

Research of VR applications in construction has been gaining momentum with the release of the Oculus Rift HMD. Lyne (2013) experimented with the Oculus Rift in the early stages, exploring a number of interesting use cases via initial prototyping. Proposing that the enhanced simulation of depth perception could benefit health and safety applications, virtual maintenance training and BIM data visualization. In addition, it is likely that the HMD can reduce costs by replacing expensive traditional multi projector display technologies with its inherently large field of view and head tracking technology. Kiral et al. (2015) have developed V-SAFE, a virtual reality based safety training tool as well as evaluate the potential benefits of using it in order to achieve a better safety performance level. The trainees are exposed to real construction risks in a virtual simulation environment. Accordingly, users learn about the hazards they may face in their workplace and experience the potential consequences of their own mistakes or their colleagues' mistakes, in a safe virtual environment.

(Rüppel and Schatz, 2011) suggest development of efficient implementation method for bringing BIM and serious gaming together in the area of building safety applications. BIM software tools could provide the bridging technology between the real world and the virtual game world. The basics of a framework that could be used to achieve this goal could be designed and constructed into a working prototype that allows a user to interact with a design created in a Building Information Modelling (BIM) program, namely Autodesk® Revit® Architecture. This interaction could be achieved utilizing a game engine that aims to provide intuitive controls and an immersive environment to allow non-technically trained persons to engage with the building and add to the design (Edwards et al., 2015).

(Hilfert and König, 2016) describe having a low-cost VR environment at disposal, which works on a normal desktop level, may be favorable for the Architecture, Engineering and Construction (AEC) industry, as well as for education outside of this field. Although, head mounted devices have greater potential for the Architecture, Engineering and Construction industry, a user can experience realistic first-person situations without having to care about injuries. Automated processes for the simplification of content creation, leveraging existing models, and the usage of visual programming languages enable even nonprogrammers to create scenarios to their needs.

Theses studies provide evidence of widespread use of VR and its use within the construction industry. Although, much of the research has been preliminary with limited testing of user experiences using VR headsets in construction practice.

Research Design

A qualitative research design was adopted. The research was divided into three phases as shown in Figure 3.

Phase I

Conceptual Planning:

Scope: Extensive literature review; identifying hardware and software to develop a virtual environment from a BIM model.

Phase II

Modeling:

A BIM model of Dudley Hall (Auburn University Campus) during renovation was developed in Autodesk Revit then taken into Unity 3D. The model was used to identify safety hazards and jobsite management.

Phase III

Implementation and Validation:

The virtual (environment) scenarios were shown to industry professionals and students using Oculus Rift® headset. During this testing, continuous modifications were made to the model. Feedback was collected via discussion and surveys.
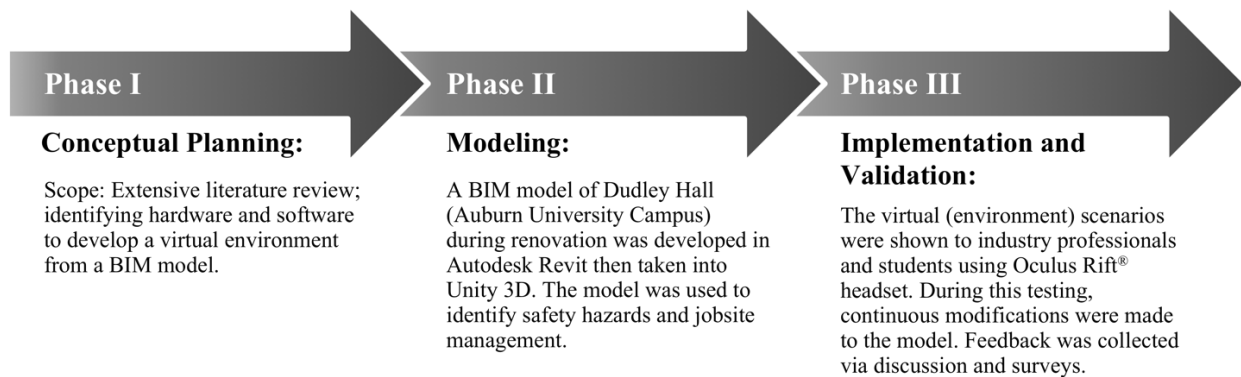
Figure 3: The Research framework.

To demonstrate the immersive VR environments, the renovation project of Dudley Hall on the campus of Auburn University was selected as a case study. The project scope consisted of: Major exterior renovations; removal of existing brick; installation of rigid insulation and waterproofing to the CMU block backup wall; reinstallation of the previously removed brick. Also several walls were replaced by floor to ceiling storefront glazing. The building had to remain open and functional for students and faculty during the renovation process. The renovations were to be completed over a two-year period. Limited street access was able to be maintained due to the building's location within the campus. Photos taken during renovation are shown in Figure 4.

Figures 4: Dudley Hall during renovation.
Methodology and Main Findings

Phase 1: Conceptual Planning

The intent of the first phase was to explore existing uses of VR Headsets in construction. During an extensive literature review, the following areas were identified (see Table 1):

Table 2

Potential Applications of VR headsets in design and construction.

Design	Construction
• Preliminary/detailed design	• Site layout and planning
• Space modeling	• Rehearsing erection sequences
• Lighting and heating ventilation design	• Progress and monitoring of construction processes
• Ergonomics and functional requirements	• Evaluation of construction scenarios
• Fire/safety/ access assessment	• Inspection and maintenance
• Landscaping	• Healthy and safety training

The next step was to review all available hardware (i.e. VR headsets). A number of VR headsets were identified and reviewed as shown in Table 2. Among all of the head mounted VR products which are available in the market, Oculus Rift® is found as the best choice. Oculus Rift® delivers a stereoscopic 3D view with smooth frame rates at high resolutions for immersive virtual environment. A gyroscopic sensor is embedded in the headgear, which can track any tiny rotation your head makes so the view can change accordingly, while simultaneously a 3D environment image will be generated on the connected computer (Desai *et al.*, 2014).

Table 3

Applications and limitations of current VR headsets.

	Name	Applications & Limitations
	Oculus Rift DK2	VR gaming Architecture Construction
	Sony Project Morpheus	VR gaming PS4-only
	Samsung Gear VR	VR experiences with mobile devices
	Google Cardboard VR	VR experiences with mobile devices

Phase II: VR Modeling

For this study, a BIM model of the Dudley hall was developed in Autodesk Revit®. Utilizing Revit® allowing the investigation of current VR implementations in real-world construction workflows. The model depicted construction

and renovation of the building at different phases. Construction equipment - a crane, scaffolding, tools, vehicles, debris removal, jobsite trailer, and construction fencing – were added in the model to simulate the active jobsite environment. This modeled environment served the basis for investigation of construction safety and jobsite management training. The workflow of converting a BIM model into VR environment is shown in Figure 5. Unity 3D® software was used for creating VR environment and eventually viewing it via Oculus Rift®.

Figure 5: Modeling workflow for developing a VR environment for safety training.

It is important to note that the software capable of producing VR experiences are geared toward game development. The structure and file types differ than those traditionally used in the AEC industry. The following software were selected for this study: (a) Autodesk Revit® for creating a BIM model; (b) SketchUp® for editing and exporting all the equipment, characters and related families needed onsite; (c) Autodesk 3Ds Max® for cleaning up the model; (d) Unity 3D® for rendering the model; and (e) Camtasia Recorder® and iMovie® for producing the videos. Oculus Rift headset is used to view the model in VR environment.

As shown in Figure 5, the BIM model of Dudley Hall was developed in Autodesk Revit®. Construction equipment, cranes, tools, vehicles and characters were imported from SketchUp®'s 3D Warehouse into Revit®. Use of these publically accessible models enhanced the environment, as well as added efficiency to the process. The parametric nature of Revit required the developed model to be scrubbed of unnecessary information thus reducing the complexity and overall file size. The faces were combined by material type into layers, (this proved to be a key step for success once imported into Unity3D®). The file was then exported as an .FBX file type. Next the .FBX file was imported into Unity3D® where textures, materials, lighting, and trees were added. The following end products were produced in this phase: (a) 2D site plan captured from Unity3D®; (b) 3D site plan; (c) 3D site plan with immersive environment for Oculus Rift®; and a (d) video of the immersive environment.

Phase III: Implementation and Validation

To test the VR experiences and collect necessary feedback, following steps were performed:

(1) A focus group session was conducted among eight BIM professionals. The VR models were explained and shown. After that, discussion was held to gather their opinions;
(2) Based on the outcome of step 1, the VR models were modified and then shown to 15 construction students in multiple sessions. Students were briefed as how Oculus Rift® works and given a chance to test it. Afterwards, a short questionnaire survey was used to get their opinions.
(3) All responses were analyzed. The pros and cons of using Oculus Rift® in the construction industry were identified.

Figures 6-8 depict representative screenshots from the VR models.

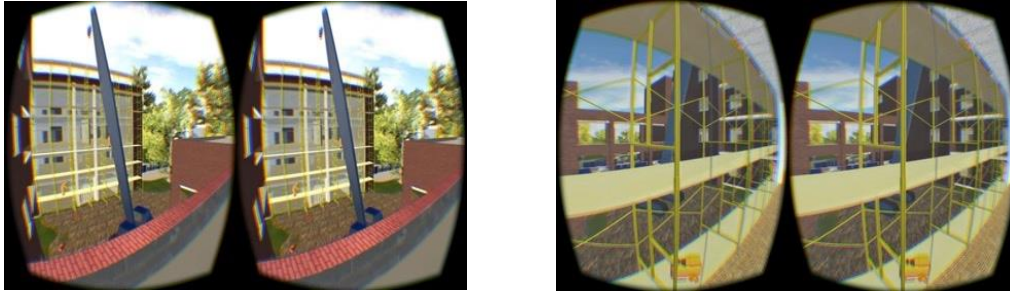*Figure 6*: BIM (left) and VR (right) model of the Dudley Hall.

Figure 7: Viewing VR environment through Oculus Rift – shows crane operation and scaffolding.

Figure 8: Viewing VR environment through Oculus Rift – shows workers movement and site access

Participants considered 'Safety Training' as best candidate for VR applications. Some specific comments were as follow: (1) "Very promising way to assess potential danger without being put in the actual situation." (2) "It reminds me of a game. It's very interactive and effective. I think it's an interactive idea for safety training and the immersive environment is definitely useful."

The following comments were collected for the application of VR in jobsite management: (1) "Crane placement has a great deal to gain from a VR interface. This would allow workers to see where a jobsite is in relation to the crane. The improved awareness would be beneficial for jobsite safety and planning."; (2) "Was a good tool for identification and orientation of the jobsite, which provided a better understanding of what to expect on the site."; (3) "Slower assessment but you get a real life hands on idea of the site layout."; and (4) "Very beneficial when determining jobsite area and organization as well as safety."

Some users complained about the motion sickness which affected participants for various lengths of time. The motion sickness could be directly related to the amount of time spent in the VR environment. Participants stated that "using the Xbox game controller instead of the built-in head tracking eased the blurring associated with the movement". Collective feedback from participants indicated there is a strong interest in learning more about VR headsets in the construction industry. The participants interacting with the built scenarios and being able to identify key aspects as well as conflicts confirms VR as a viable option for construction safety and jobsite management. Many participants wanted to explore beyond the built scenarios such as visiting the surrounding site and testing various site logistics options to obtain the best combinations (e.g. best location for tower crane placement).

Concluding Remarks and the Way Forward

The applications of VR headsets in the construction industry have endless potential. Overall, we found that VR headsets are indeed very beneficial - allowing the users to immerse into a near-actual environment. The users were able to interact, identify, and gain an in-depth experience pertaining to construction safety and jobsite management. The application of textures, materials and site development were found to create a life-like feeling. Each participant became physically involved in his/her exploration, exhibiting natural movements outside of the VR environment. This observation confirms the immersive viability of the VR environment, creating a lifelike reality. There are unrealized

benefits of Virtual Reality scenarios, tailored to specific tasks or trades for training purposes. Not only for safety, but the life-like experience of performing tasks in a risk-free environment.

The workflow outlined in this paper allows for gaming like scenarios to be developed. A significant time commitment, as well as technical expertise are required for production. Additionally, over the course of this study, software and technology updates were continuously being rolled out. Each update provided improvements to workflow efficiency, resulting in improved user experiences. There are many other software options for creating a VR experience, these options do not provide a gamming like scenario and are primarily for visualization. Some simple click and go options are, *insiteVR*®, *irisVR*®, and *Revizto*®. Autodesk® is currently developing a software titled "Stingray®" (their own gaming/visualization engine) and is in beta testing with support for the Oculus Rift®. Additionally, Autodesk® is developing Project Expo® which will bridge the gap between Revit® and the Stingray® software. With the consumer release of the Oculus Rift will further expand this research and its use in construction.

This study revealed limited ability to interact with all the objects in the game. Future research intends to address this issue, expanding on the current research. Areas may include ability of the user to select the location of jobsite objects, i.e. the crane, materials, and tools. Additionally, giving the user the ability to operate operable objects such as the crane.

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