Virtual Reality Application in Construction Jobsite Organization

Ahmad Abbas Muhammad

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
July 2017
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Mustafa Tümer
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Assoc. Prof. Dr. Serhan Şensoy
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion, it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Assoc. Prof. Dr. İbrahim Yitmen
Supervisor

Examining Committee

1. Assoc. Prof. Dr. İbrahim Yitmen
2. Asst. Prof. Dr. Tolga Çelik
3. Asst. Prof. Dr. Umut Yildirim

ABSTRACT

Virtual reality (VR) can be defined as a combination of headsets, computer generated models, and smartphones/touch tablets and other advance technology join together to provide a user with an experience that feels like close reality, though it is unnatural environment. Various areas of VR technology in construction industries has been identified in this research study. This study focused on the application of VR in construction jobsite organization which includes; site layout planning, collision detection and evaluation of construction site layout scenarios.

The main aim of this research study is to explore the benefits, advantages and how this technology can enhance the effectiveness of jobsite layout planning. A comparison was made between the traditional methods i.e. 2D site plan and 3D site plan model used in jobsite organization and 3D VR site model. Two scenarios of construction jobsite 3D model were created during the structural phase of the building using Autodesk Revit software, SketchUp and Lumion. VR box headset was selected for testing the 3D jobsite model.

A descriptive case study was represented to describe the organizational plan of the two jobsite scenarios created. Questionnaire survey was adopted for the data collection and feedback from the participants. Presented in this research are the findings and results of this study that helped in exploring this new technology of VR that could aid in construction jobsite organization. The results from this research study helped in determining the application and the benefits of VR in jobsite planning. Lastly, it was found that VR headsets are very beneficial when determining jobsite plan compared to the traditional methods.

Keywords: Virtual Reality, Site Layout Plan, Construction, Jobsite Organization, 2D, 3D-CAD model, Jobsite Planning

ÖZ

Sanal gerçeklik (SG), gözlük seti, bilgisayar tarafından üretilen modeller, akıllı telefonlar/dokunmatik tabletlerin birleşimi olarak tanımlanan ve kullanıcıyı doğal olmayan bir ortamda olsa da, gerçeklik hissi veren bir deneyim sunmak için bir araya getirilen ileri teknolojiler olarak tanımlanabilir. Bu araştırmada inşaat sektöründe SG teknolojisinin çeşitli alanları tespit edilmiştir. Bu çalışma, inşaat şantiye organizasyonunda saha yerleşim planlaması, çarpışma tespiti ve şantiye yerleşim senaryolarının değerlendirilmesini içerene SG'nin uygulanmasına odaklanmıştır.

Bu araştırmanın ana amacı, SG teknolojisinin şantiye yerleşim planlamasının etkinliğini nasıl artırabileceğinin faydalarını ve avantajlarını keşfetmektir. Geleneksel yöntemlerle, örneğin, 2B vaziyet planı ile şantiye organizasyonu ve 3B SG saha modelinde kullanılan 3B vaziyet planı modeli arasında bir karşılaştırma yapılmıştır. Binanın yapısal inşaası aşamasında Autodesk Revit yazılımı, SketchUp ve Lumion kullanılarak 3B şantiye modelinin iki senaryosu oluşturuldu. 3B şantiye modelini test etmek için VR gözlük seti seçilmiştir.

Oluşturulan iki şantiye senaryosunun organizayonel planını tasvir etmek için tanımlayıcı bir vaka çalışması sunuldu. Veri toplamak ve katılımcılardan gelen geri bildirimler için anket çalışması yapılmıştır. Bu araştırmada, inşaat şantiye organizasyonuna yardımcı olabilecek SG'nin yeni teknolojisini keşfetmeye yardımcı olan çalışmanın bulguları ve sonuçları sunulmuştur. Bu araştırmanın sonuçları, SG'nin şantiye planlamasındaki uygulama ve faydalarını belirlemede yardımcı

olmuştur. Son olarak, geleneksel yöntemlere kıyasla şantiye planını belirlerken SG gözlük setlerinin çok faydalı olduğu bulunmuştur.

Anahtar Kelimeler: Sanal Gerçeklik, Şantiye Vaziyet Planı, Yapım, Şantiye Organizasyonu, 2B, 3B BDÇ modeli, Şantiye Planlaması

ACKNOWLEDGEMENT

First of all, I would like to Thank God who gave me the strength and power to accomplish this great work. I would like to express my deepest gratitude to my supervisor Assoc. Prof. Dr İbrahim Yitmen for being supportive and giving me the opportunity to widen my knowledge on construction jobsite organization using new emerging technology of VR. There is no doubt that your infinite support and advice helped me heading in the right direction. Your patience and expertise is truly appreciated.

Secondly, I would like to thank my parent who made me what I am today for their endless prayers, motivation and financial support. For the support you have given me, I have no words to express the degree of my appreciation. You are truly the most important part of my life.

In addition, I would also like to express my appreciation to the staff working with the University City Island Project and the construction firm for providing me with more information and data about the construction site.

Finally, throughout this research work, I have been surrounded by supportive and helpful people whom I am very grateful for their infinite advices and support. Thanks to all that participates in testing the jobsite models, without your help the research work would have been far less rich in information.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BIM	Building information modeling
AEC	Architectural Engineering Construction
VR	Virtual Reality
VE	Virtual Environment
VSE	Virtual Simulated Environment
CAD	Computer-Aided Design
2D	Two-Dimension
3D	Three-Dimension
HMD	Head-Mounted Display
V-SAFE	Virtual Safety Analysis for Engineering Applications
PC	Personal Computer
TF	Temporary Facility
CSUP	Construction Site Utilization Planning
AR	Average Rating
SUP	Site Utilization Plan

Chapter 1

INTRODUCTION

1.1Background

VR technology has recently become known across the world; however its origin can be traced back decades ago. VR is a rising advance technology nowadays, which is also known as unnatural virtual simulated environment (Qin, 2013). The technology is more precisely an arrangement of set of older technologies such as CAD combined together with the VR hardware's such as headset to experience the virtual environment. As time develops, this emerging technology of VR is turning out to be more available and less expensive (Froehlich and Azhar, 2016). In general, the meaning of virtual reality originates actually from the definition of both words, i.e. the first word "virtual" and the second word "reality". Virtual can be defined as near and reality is the things we encounter as people. However the term virtual reality essentially signifies "close reality".

These innovations are basically computer-generated environment models also known as CAD. VR technology gives an immersive feeling with the help of a particular hardware (headset) and software (CAD software's) used in creating the model and enables the user engage in visual environment to roam freely in the VE and view the design in order to find defects and problems in the project (Si and Yang, 2012). The models are created through the use of 3D CAD software's such as Autodesk Revit and sketch up. The Autodesk Revit is utilized to create the design of reinforced or steel framing structure of the building under construction, and also provides the BIM of the built frame structure. The 3D frame structure modeled on Autodesk Revit of the ongoing building is imported to Sketch up in other to model the construction jobsite. The sketch up is utilized to edit and import the materials, equipment's and some temporary facilities needed on the construction site. The final 3D model of the construction jobsite is therefore used to experience the VR through the use of headset.

Virtual reality consists of head-mounted display known as HMD. The head mounted display is a pair of goggles headset (VR headset), which enables the user to view and explore the 3D model graphics representation of VE or video. The user wearing the VR headset will be able to have a sensory experience such as vision. About Seventy percent of information is gained by people through vision, systems such head-mounted display produces the immersive virtual environment (Kizil and Joy, 2001).

VR application can be greatly advantageous in the construction jobsite management. The technology of VR could essentially help in organizing construction jobsite, comprising of generous tasks in the jobsite logistics/ layout planning. Several method of coordinating construction design and site organizational layout planning have been taken in the past, one method for discovering clashes is through the use of VR models walk through in the VE (Cheng and Teizer, 2013). Jobsite layout plans are also known as SUP. An optimum jobsite layout plans can leads to decrease materials movement on site; as a result workers and laborers can focus on performing construction work tasks. A project manager is in charge of producing a jobsite organizational site layout plan/site utilization plan based on knowledge, imagination, intuition and past experience (Osman et al, 2003). Without a well-organized jobsite plans, numerous issues can happen in the construction site bringing about cost overruns and time delay.

Previous researchers have identified the area of virtual reality (VR), application in jobsite organization, which includes; firstly, site layout planning (Kan and Azhar, 2016). Secondly, evaluating different construction scenarios (Bouchlaghem et al. 1996). In addition, using immersive VR in construction workers safety training (Sack et al. 2013). This research will focus on studying construction jobsite layout and planning through VR headset.

Construction site layout and planning have depended on traditional two dimensional (2D) sketches and drawings in other to illustrate the site layout plan, which includes; the location of material storage, jobsite fencing, construction site access, temporary facilities needed on site and location of crane. The two dimensional site layout plans is limited to 2D drawings, therefore it cannot provide adequate details of the construction jobsite plan. Also the three-dimensional (3D) models that are shown on computer screens or projectors screen will give the user less information compared to VR. 3D models shown in virtual environment through the VR headset is more effective than the normal 2D drawings/sketches and 3D models on screen, as it makes visualization of the built construction jobsite environment easier and more efficient.

Due to various numbers of factors and complexity involved in organizing construction jobsite, organizers have adopted advance technology to enhance the effectiveness of their work (Kan and Azhar, 2016). Jobsite layout/ logistic planning can be effectively studied, and make some changes if needed on the site through the use of this emerging technology of VR.

1.2 Scope and Objectives

The purpose of this research is to model a 3D construction jobsite layout plan and explore the construction jobsite in 3D using VR HMD technology otherwise known as VR headset. The main objectives of this research are mention as to;

1. Examine the application of virtual reality headset in construction jobsite logistics/layout planning.
2. Demonstrate and compare traditional 2D site plan, 3D model site plan on screen and 3D site plan model in virtual environment.
3. Explore the benefits and advantages of using VR headset in construction jobsite organization.

1.3 Research Methodology

The research will be divided into three phases; planning, modeling and data collection & validation. The main aim of the planning phase was to review the applications of VR in construction industry and evolve the process involved in modeling the 3D construction site layout jobsite plans.

In the modeling phase; 2D site layout plan and 3D site layout plan model will be created. A 3D model of building frame structure and jobsite plan of the ongoing construction of university of city island ltd, located in Famagusta Cyprus will be created and use as a case study in this research. The 3D model will be created using CAD software's; sketch up and Autodesk Revit. Autodesk Revit software will be used to model the building frame structure and export the model to sketch up for editing and importing site fencing, equipment's, materials, and other facilities on site.

The final model will be rendered on Lumion (rendering software) and kubity exporter to export the model to a smart phone through scanning the bar code of the model. The smart phone will be later inserted into the VR box for visualization.

In the last phase, which is data collection and validation; the three site layout plans i.e. the 2D site plan, 3D model and 3D model using VR box will be demonstrated. For data collection and testing the model, the participant will be graduate students that have experience in construction industry. Each participant involved in testing process will test all the models and at the end of the testing a short questionnaire will be given. The responses of the participants will therefore be analyzed quantitatively and the overall ratings of the 3 site plans will be represented in statistical data analysis format.

1.4 Research Limitation

In this research, a number of virtual reality headsets were identified such as: Google cardboard VR, Samsung gear VR, oculus rift VR and VR box. Among the entire VR headset products identified, the available VR headset here in Cyprus is VR box. The VR box sensory experience is limited to sight, but doesn’t include features such as hearing, touch and smelling. Due to its availability, VR box is going to be used in this research. Lastly, this study will only focus on the application of VR in construction industry especially construction jobsite organization.

1.5 Thesis Guideline

This thesis consists of five different chapters, starting from chapter 1 to chapter 5. Chapter 1 presents the background information of VR technology and its application in construction jobsite organization. This chapter provides concise information about VR technology, what the term VR technology means, brief overview of the application of VR in construction jobsite, some important features of VR and the way VR is been used.

Chapter 2 discusses the theoretical background of VR. The theoretical backgrounds include; definition of VR, history of VR, and the approaches to VR model creation, VR and construction jobsite organization and the application of VR in construction industry. All the mentioned sub topics of this research are discussed in this chapter.

Chapter 3 presents the methodology used in this thesis, consisting of descriptive case study and quantitative method. In the quantitative method, a questionnaire survey will be used for data collection from the participants.

Chapter 4 discusses the findings obtained from testing the site models, which include direct observations of the models, responses of the analysis of the short questionnaire survey and managerial application of VR in jobsite management.

Chapter 5 presents the overall conclusion, recommendations and recommendations for further research work on this research topic.

Chapter 2

THEORETICAL BACKGROUND

2.1 Definition of Virtual Reality

The term “virtual reality” is used much often in the construction industry, though it passes on various meanings to various individuals in the industry (Greenwood et al. 2008). Many people working in the construction industry (e.g. site engineers, site planners, construction manager etc.), might heard of the term “Virtual reality”.

A wide range of VR definitions can be found in various literatures by different researchers. Virtual reality can be defined as a system that provides a 3D VE and visualization through the use of computer generated models, in which a user can be able to engage in visualizing the models created (Bouchlaghem, 2000).

Computer technology such as CAD is utilized to make a simulated VE for VR experience. The user can therefore experience, immersed in VR 3D world, rather than viewing or looking at the 3D world on a screen or projector. VR is made out of an intuitive PC simulation, which gives the user or observer immersed in the virtual world sensory feedback information of the simulated VR environment (Matjaz et al. 1999).

2.2 Virtual Reality Technology

Virtual reality technology has become one of the widely used technologies in construction management (Cheng and Teizer, 2013). Construction industry is one of the recent areas in which virtual reality technology is been applied, the areas include; collision detection in building design and construction jobsite organization such as site layout planning, this advance technology is bringing about changes and improvement in the industry. Collision can be detected in the construction phase through the use of VR technology construction simulation (Kang and Laia, 2009). Intuitive computer gadgets with visualization techniques combined together forms VR 3D world.

Some construction companies have already began applying the virtual reality technology and the companies are already gaining several advantages from the technology. For example, a company in the United States of America represented as US3 utilizes this VR technology in almost 40% of the company's projects and another company in United Kingdom represented as UK5 uses the VR technology in almost 20 to 30% of the company's projects (Greenwood et al. 2008).

VR technology utilizes computer software's and hardware's to experience the simulation of virtual environment created (Si and Yang, 2012). This current technology of VR coordinated recent accomplishment of 3D display technology, simulation technology and computer graphics representation technology. This technology can offer advantages in construction industry as it will help in detecting problems that may arise for example clash detections in buildings, construction jobsite planning can be studied using this advance technology of VR, thereby leading to changes, improvements or solutions in the construction site layout and planning problems.

Through the use VR, workers associated to the construction jobsite can have a clue on how the construction site will look like without setting their foot on the actual construction site. It is likely that this technology can contribute if there is a need to identify and solve issues or problems in the construction jobsite plan before the actual construction site. Virtual reality technology is categorized into two, the immersive VR and non-immersive VR.

Immersive VR: Immersive VR system enables user to be immersed in 3D environment and experience the computer generated environment through the use of VR headsets. Therefore the user will be a participant in the close reality VR environment rather than observing the environment from outside or PC screen.

Non- immersive VR: Non-immersive VR system is sometimes called desktop VR. It is the VR system that is represented on a projector board or computer screen. The user experiencing non-immersive through a computer screen views the 3D environment model representation as an observer (Greenwood et al. 2008).

2.2.1 Characteristics of Virtual Reality Technology

VR technology is characterized into three features, i.e. imagination, immersion and interaction, which are also known as the three I's of VR technology (Jian-Hua, 2008). The three I's demonstrates the characteristics of VR system, in addition provide interaction between the VR user and the VR system.

The first feature of VR which is interaction enables the user engage in the VR system to add inputs and be able to remodel or immediately modify a virtual world. Secondly, immersion which is another principal feature of VR facilitates user to feel immersed in the virtual world and explore the realistic simulated environment.

In addition, imagination feature of VR technology allows the user to build up a way that will be beneficial in solving a particular problem. However, VR applications in areas of research and construction industries aids in improving, identifying and solving problems such as design problems and improving the efficiency of construction jobsite organization. Figure 1 illustrates the three I's of VR.

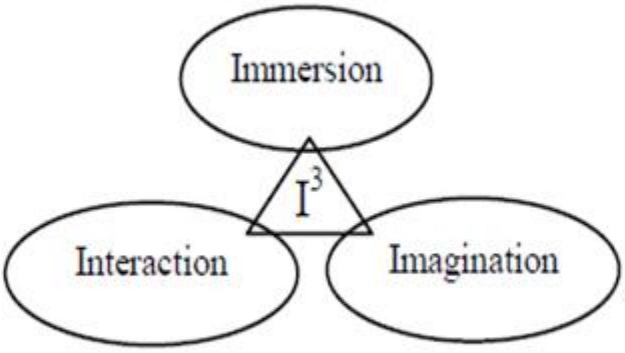

Figure 1: The Three I's of Virtual Reality (Yang and Si, 2012)

2.2.2 Virtual Reality Headsets

VR technology consist of various HMD headsets, the headsets provides the VR world for the user experiencing the VE. The VR headsets comprises of different HMD devices, some of the headsets works with computers devices to provide the VR experience while others works with smart phones for VR experience. Table 1 shows a list of VR headsets and limitations.

Table 1: List of virtual reality headsets

Name	**Image**	**Limitations**
Oculus rift VR		VR experience with computer devices.
Samsung gear VR		Works with smart phones.
HTC vive		Works with PC devices.
Sony morpheus		VR for gaming.
VR box		VR experience with mobile devices.
Google cardboard		VR experience with mobile devices.

2.2.3 VR Model Creation Approaches

There are different approaches of creating VR model by translation of the computer-aided design (CAD) to VR models. The translation process involve a downstream process, in which the computer-aided design (CAD) model created in CAD software is translated into VR through rendering package (default rendered and well rendered) (Whyte et al. 2000). The final 3D-CAD model can be observed through the VR head-mounted display otherwise known as VR headset. Figure 2 illustrates the downstream of VR creation.

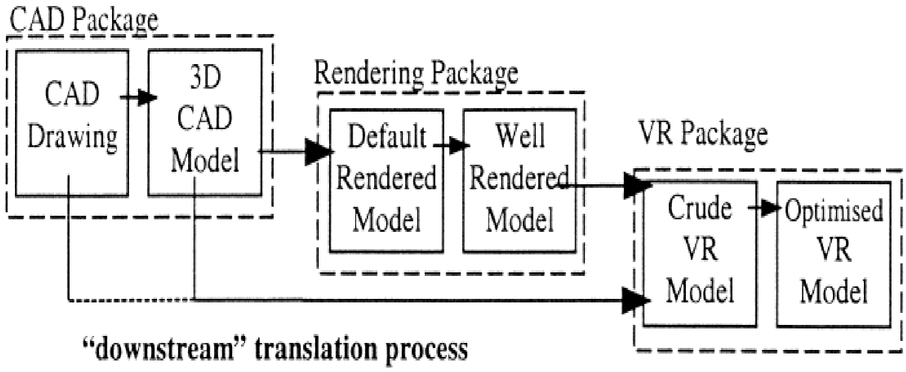

Figure 2: Downstream Process of CAD to VR Translation (Whyte et al. 2000)

The current VR model creation approaches are:

- Direct translation approach
- Library-based approach
- Database approach

1- Direct Translation Approach: The whole CAD model can be translated through direct interpretation to produce the VR experience. Direct translation of CAD models produces a high rendered 3D model using rendering software used for presentation of the models to users, clients and other individuals that participate in the model testing process (Whyte et al. 2000). The model produced for VR testing is obtained through gaining prior knowledge of the translating process or sometimes base on past experience.

2- Library-Based Approach: In this VR model creation approach, a library of components is obtained for the VE. The library based approaches dismisses the need for optimization and insistent data transfer. More effort and significant time is needed in other to create the library and the components which can be produced from optimized CAD data (Whyte et al. 2000).

3- Database Approach: In database approach both the VR and CAD is utilized as graphical interfaces of the database. This approach to VR model creation controls components of the CAD and VR through the use of central data base. The 3D model created through this approach in central database can be observed in different applications. Updating of model through this approach is allowed by full system implementation (Whyte, 2000). The VR creation process is shown in Figure 3.

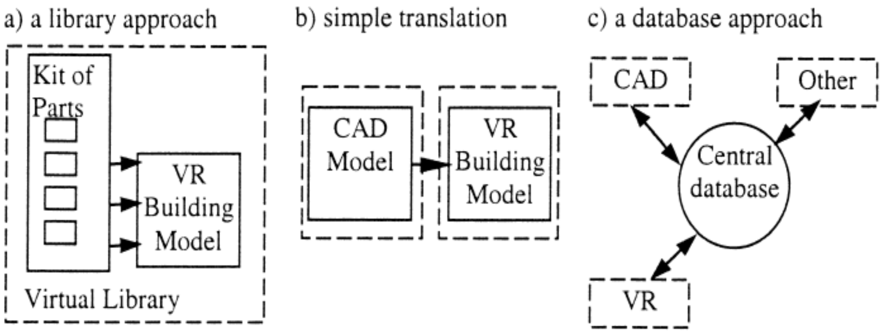

Figure 3: VR Model Creation Current Approaches (Whyte, 2000)

2.3 What is Visualization?

Visualization can be defined as a process of discovering and representing a data as images, animations or videos, which help the user to visualize and gain information of the data represented. The visualizer can utilize different techniques in other to display the data so as to enable the user to understand the vital information (Jonathan, 2000). Both the visualizer and the user can be one person. In other words, visualization can be describe as any form of CAD technique that images or videos are produced in other to communicate a message to the user.

Products visualization such as building requires a software technology to view and manipulate the models created in 3D. Data interpretation, concepts understanding and communication ideas can also be assisted through visualization (Ganah et al. 2001). For example, visualization of a building to the project team facilitates the team to have a clear understanding and also enables them to communicate different ideas on how to achieve the project goals. Some of the data's represented through visualization are sometimes samples from real world for example a 3D model of a real environment.

Visualization consists of two main processes. The first process of visualization is that the data concepts are changed into a representation, so that the visualizer or user can view it. The second process is the perception, in which the user or visualizer tries to identify and understand the underlying information. Visualization process is shown in Figure 4.

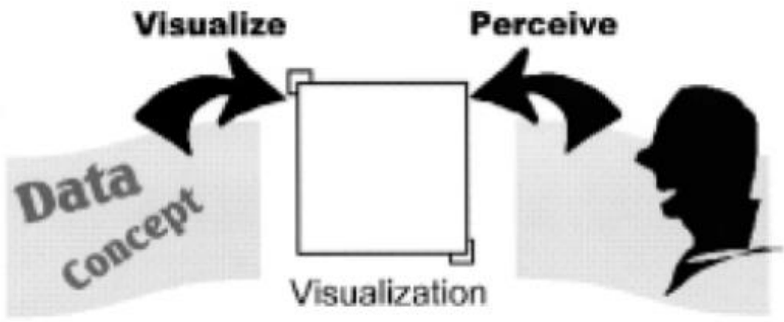

Figure 4: The Two Processes of Visualization (Jonathan, 2000)

2.3.1 Benefits of 3D Visualization.

Most information in this world today is outwardly conveyed in prevailing 2D. Many construction documents, for example; building plans, reinforcement details drawings, and construction site layout plans are demonstrated on tradition 2D and 3D on computer screen. 3D visualizations of construction jobsite related VR applications and building design such as structural frame, formworks, jobsite layout planning should be insistent as it can make some changes as a result of insight gained by visualization of the process. However, the insistent nature of this process is supported by suitable software. In collaborative building design understanding and sharing of information between all the parties involved is very beneficial, therefore the 3D techniques enables the parties to understand, explore and visualize the design.

3D visualization offers a way for visualizing building design and can be utilized to simulate stage of construction process and explore design options. By allowing engineer and site planners to immerse themselves and visualize the 3D model of the building design and site layout plan, it will enable them to make changes and improvements before the actual construction begins.

VR which serve as a visualization tool help building designers in communicating design ideas to their client and generates walkthrough of the models, so that the client can have a look at the design in direct manner and gain an idea of how the building will look like after completion.

2.3.2 Virtual Environment

Virtual environment is a computer- generated environment that shows the description of 3D objects placed within the simulated environment (Matjaz et al. 1999). VE can be observed through a virtual reality system such as HMD’s (VR headsets); this system displays the 3D objects and also creates virtual presence to the observer.

Virtual environment consists of objects and characters, these two contents of virtual environment are displayed through the VR system and the user will be able to perceive the information of the model through vision. The objects which occupy space in VE are in 3D forms (Matjaz et al. 1999). These 3D objects in Virtual environment have similar properties with the objects in real world, examples of these properties are: color, shape and texture. Figure 5 shows a 3D-CAD model of virtual environment of an ongoing building construction, from the image a 3D construction equipment graphics and other 3D objects in the virtual environment.

Figure 5: Partial View of VE of a Building under Construction (Sack et al. 2013)

2.4 Differences between Computer-Aided Design and Virtual Reality

Whilst VR has evolved from advance computer graphics technology, CAD has developed from 2D packages (Whyte, 2000). There are different latest versions of CAD packages/software’s that can be used to create a 3D model from 2D drawings. For example, architectural drawings such as building plans are designed in 2D, the two-dimensional plans can therefore be utilized to generate a 3D model through extracting the geometry of the drawings (i.e. sections and plans).

CAD software’s are used to create 3D models but cannot immersed user into the 3D environment, while VR is an advance technology that immersed the user into the VE. In addition various CAD software’s such as AutoCAD has been greatly utilized in construction industry to create building plans, drawings and modification of reinforcement drawing details in two-dimensional, while virtual reality system works only with three-dimensional models.

The 3D models developed for the VR experience are created from CAD software. Both computer aided design and virtual reality are all part of computer graphics technology. Functionality and organization of models also differentiates CAD from VR (Whyte, 2000).

The differences in functionality between these two is that, computer-aided design can achieve a very high functionality without any programming language support, while VR in other to gain greater functionality it requires programming language (Whyte et al. 2000).

2.5 Virtual Reality in Construction Industry.

VR is an interesting technology that construction industry is gradually implementing (Ajang, 2016) .Construction industries utilize VR technology in other to create and experience 3D models of construction project through the use of a computer software and VR system hardware. The 3D models can be visualized and explored before the construction process takes place in jobsite. Through VR technology, jobsite organization, building design and client interaction can be enhanced.

Utilizing VR in the construction industry holds an incredible potential in improving the effectiveness and additionally enhancing planning and construction process (Greenwood, 2008). One way, of using VR in construction is through the use of BIM. Building information modeling and 3D are already being adopted within the construction industry. 3D models that are needed for virtual reality experience can be produced through the use of BIM technology (Greenwood, 2008). Design and construction errors can be reduced through VR system by testing the design viability of the model, thereby highlighting the errors such as collision detection between two structural members.

2.5.1 Virtual Reality Application in Construction Industries

The design and construction process is the main focused area of VR applications in construction industry. Bouchlaghem et al. (1996) discovers different applications of VR in construction industry at various stages of development which includes:

- **In Design**
- Interior design
- Space modeling
- Lighting design
- Air conditioning and heating ventilation design
- Landscaping
- Space selling
- Fire risk assessment
- **In Construction**
- Site layout planning
- Evaluation of different construction scenarios
- Planning and monitoring of construction process.

Through coordination of meeting, logistics of the construction jobsite can be viewed and new safety issues can also be presented (Froehlich and Azhar, 2016). Issues such as clash detection can also be observed through VR, therefore meeting can be coordinated among the project team in other to share ideas and come up with a solution to the problem. Froehlich and Azhar (2016) summarized the application of VR in both early design stage and construction in Table 2.

Table 2: Application of VR in construction industry

Design	**Construction**
Space modeling	Site layout and planning
Detailed design	Monitoring and Planning of construction process
Landscaping	Inspection and maintenance
Safety/fire assessment	Safety training
Heating ventilation design and lighting	Rehearsing erection sequence
Functional requirements	Different construction site scenarios evaluation

Lyne, (2013) identified other applications of VR in construction industry which includes: Clash detection, coordination of meeting, site management and safety training. Figure 6 illustrates the virtual reality application in construction.

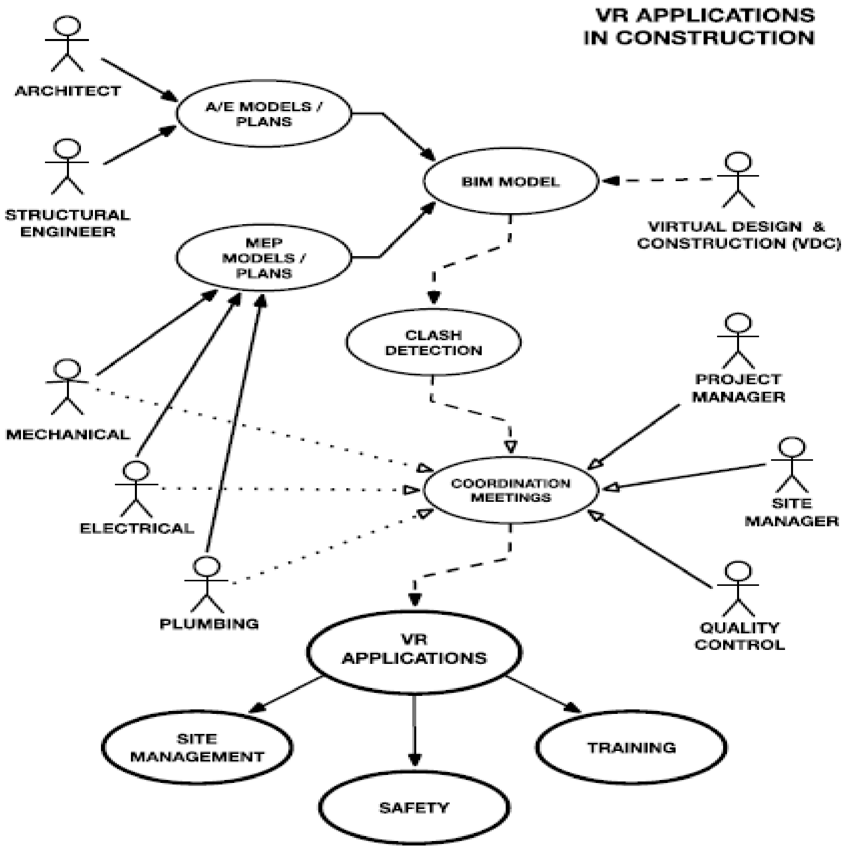

Figure 6: Application of VR in Construction (Lyne, 2013)

Building design such as architectural design is a major driving force for developments in 3D model and VR (Bouchlaghem et al. 2005). The architectural design can be communicated to the construction team by visualizing the design through VR. Since this technology of VR offers a medium for visualizing building design in 3D, it will enable the construction team to have a better and clear understanding of the design.

Building design is one of the potential areas of VR application in construction (Whyte, 2003). In addition, Virtual reality technology enables architects to visualize building design and immerse themselves in the 3D virtual environment, which will help the designers to a have better understanding of the nature space (Bouchlaghem et al. 2005). Building design is shown in Figure 7 and Figure 8 shows users view through VR headset.

Figure 7: 3D-CAD Building Model

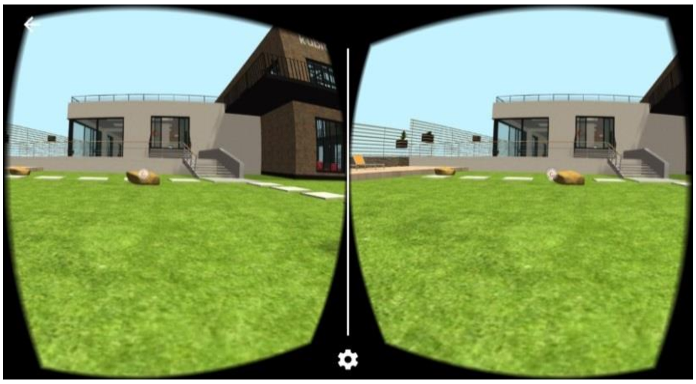

Figure 8: Viewing Virtual Reality Environment of 3D Building Model

According to Bouchlaghem et al. (2005), Building scales and proportions of an interactive 3D model can be evaluated by the designers through VR. BIM assists building designer to produce 3D building information geometry, the 3D geometry information of the building can be visualized through VR to check for clash detections and make some improvements in the design. VR serves as a tool to improve building design process because of its capability of detecting many design problems (Woksepp and Olofsson, 2006). Figure 9 shows a design problem detected through VR model (pipe blocking the transport way).

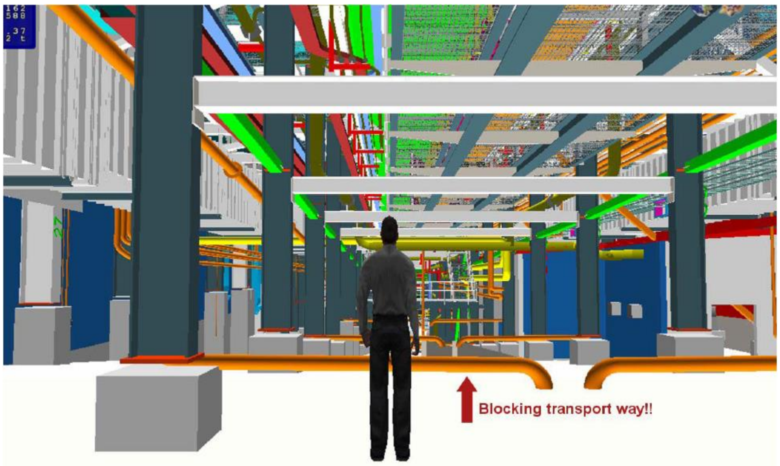

Figure 9: Virtual Reality Model Showing a Design Problem; Pipe Blocking Access (Worksepp and Oloffon, 2006)

Collision detection is another area of VR application in building design. Through visualization of building design in 3D model, collisions in building design can be detected. For example, collision can occur between building structural system and ventilation system. Figure 10 shows collision between two members detected in VR model.

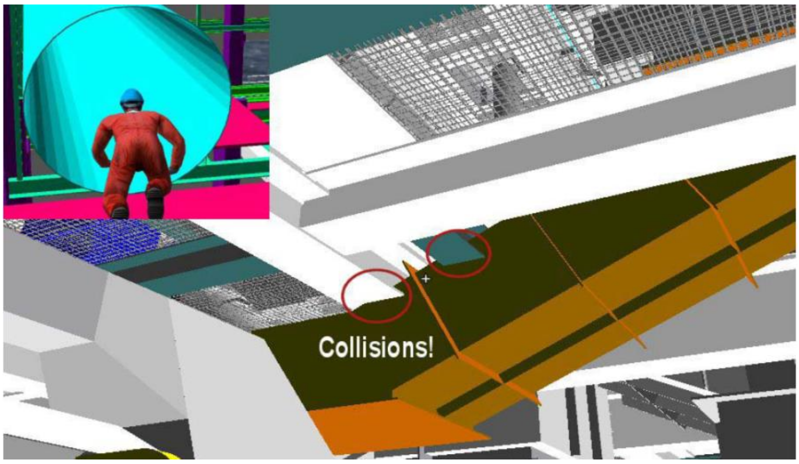

Figure 10: Collision Detected Between Structural System and Ventilation System through VR Model (Woksepp and Olofsson, 2006)

2.6 Construction Jobsite Organization and Virtual Reality

Construction jobsite can be described as the area within the boundaries of a construction project. VR technology can be highly beneficial in organizing construction jobsite as one of its applications in construction jobsite is to study the site layout planning (Froehlich and Azhar, 2016). The ability of VR technology to visually convey issues or problems in the jobsite layout planning has made it very important to utilize this technology in other to solve issues or problem that may arise due to poor construction jobsite organization. Construction jobsite view through VR headset is shown in Figure 11.

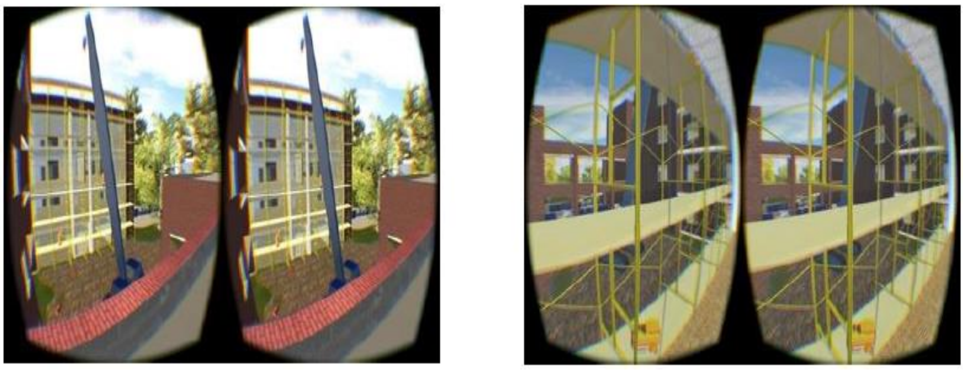

Figure 11: Construction Jobsite View through VR (Froehlich and Azhar, 2016)

In general, construction jobsite organization consists of different important number of tasks in construction project (Kan and Azhar, 2016). Among the numerous jobsite organization tasks, making a good site layout planning is very important as it vital to ensure effectiveness, operation efficiency and the safety jobsite working environment. A site layout that is well planned leads to improvement in construction jobsite by increasing moral of workers and reducing travel time through providing a better site layout plan and safe construction working environment.

A well-organized construction jobsite is crucial for construction projects; the reason is that it provides huge benefits in the projects efficiency and also productivity, which in turn will lead to reduction in the project total cost of the construction project (AEC Business, 2015). During organizing of jobsite in construction phase of a project, there is a need to identify; site access, TF location, storage areas, parking areas, construction equipment location (crane placement location) and batch plant within the jobsite boundary (El-Rayes and Khalafallah, 2005).

Due to various number of factors and complexity involve in jobsite planning, construction jobsite planners can improve their jobsite planning task through accepting technologies such as VR technology, as this technology enables them to study site layout plan also provide a very good means of verifying site logistics (Kan and Azhar, 2016). There are some objectives that a site planner should adopt in other to develop a well-organized construction jobsite. Firstly, in other to promote the construction worker’s productivity and also reduce the cost and project time, the jobsite should be designed in such a way to maximize the efficiency of operations. Secondly, in other to retain best personnel and also add to productivity and the quality of the work, a very good site plan with good working environment should be provided.

2.6.1 Virtual Reality Application in Construction Jobsite Organization

VR technology has different areas of application in organizing construction jobsite. Site layout and planning is one of areas of virtual reality application in construction jobsite (Kan and Azhar, 2016). Secondly, Collision detection is another area of VR application in jobsite (Ebner et al. 2012). Evaluating different construction site scenarios is another area of VR technology application in jobsite (Bouchlaghem et al. 1996). VR technology is used in safety training of construction workers (Sack et al. 2013). Figure 12 shows a construction jobsite organization model testing used by Kan and Azhar, (2016) in testing the 3D model with VR headset.

Figure 12: Construction Jobsite Testing Model (Kan and Azhar, 2016)

Site layout planning in the construction industry is the most ignored aspect by site engineers (Sanad et al. 2008). The reason why site engineers overlooked the aspect of site planning is that they believe that as the project progresses site layout plan can be done. Availability of CAD software's assists construction managers to create and visualize construction site layout, in addition through visualization, layout intentions can be communicated to all concerned (Li et al. 2001).

It is very important to develop an efficient site layout plan before project progresses, because an efficient site layout plan plays an important key role in cost of a project, quality of construction and operational efficiency (Sanad et al. 2008). Better communication of site layout plan will enable the construction team to have a clearer understanding of the site layout. Construction managers can utilize computer software's to create 3D-CAD as it will enable them to plan the layout and visualize the jobsite layout through VR technology. Problems in construction jobsite such as potential interference can be identified through site visualization of the jobsite computer graphics model (Li et al. 2001).

Site layout plans are usually represented in 2D site layout and 3D site layout model. Kan and Azhar, (2016) conducted a research using immersive VR technology to investigate VR application in jobsite layout plan and make a comparison between the traditional methods of representing site layout and the new VR 3D technology. Figure 13 & Figure 14 shows a 3D jobsite model for VR testing.

Figure 13: 3D Jobsite Layout Plan for VR Testing (Kan and Azhar, 2016)

Figure 14: Side View of a Different Construction Scenario (Kan and Azhar, 2016)

Traditional method of site layout plans are usually conveyed in 2D drawings, these drawings cannot be visualized because they represented as line sketches. 2D site layout plans sketch represented on a sheet of paper will not provide detailed information of the jobsite as compared to 3D model in VR mode. Figure 15 below illustrates two scenarios of 2D site plans.

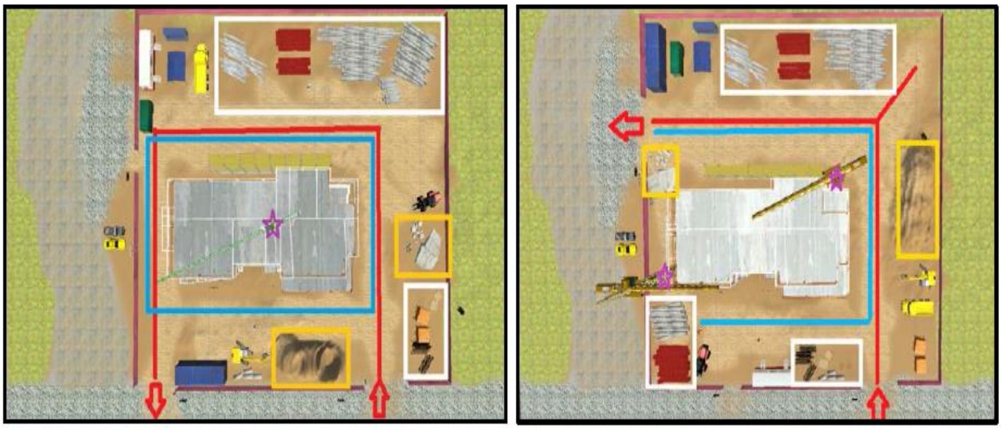

Figure 15: Two Different Scenarios of 2D Site Plans (Kan and Azhar, 2016)

The decisions of making a construction site layout plan can affect some certain activities such as materials handling in the jobsite, because material handling on site occupies much working time. Space planning is also another important factor that should be considered in creating a construction site layout. Visualization of a 3D model of construction jobsite can enable the user to have a clear understanding of site space planning.

Failure in construction site layout planning results in excessive walk on site; double handling of materials and also low productivity caused by wasteful practices. Location of materials storage, construction equipment’s and other items needed in construction jobsite can affects productivity.

In addition overcrowded areas in jobsite can be formed, when construction jobsite is poorly planned or organized and as a result will lead to; firstly, high density of construction workers gathered in one area of work. Secondly, it leads to poor productivity due to congested area. Different site layout planning elements are:

Site Access: Among many considerations in jobsite layout, site access (entrance and exit) to the jobsite for vehicles is one of them (Small and Bager, 2016). Due to inaccessibility of construction jobsite, productivity may decreases. For example heavy construction equipment or materials kept in the path of construction workers may affect workers operations and chances of accidents and getting injured may increase. Jobsite access is one of the factors that should be considered when designing a site utilization plan (Desphande and Whitman, 2014). Easy jobsite accessibility will facilitate vehicles (e.g. trucks) drivers to deliver materials on time. For example, concrete mix has a specific setting time, therefore it is very important to deliver the mix on time for casting before it set. Through the use of this visualization technology, user can visualize and have clear information of the site access and also check if there is any equipment or material blocking the site access. Figure 16 shows view of construction site access through VR headset.

Figure 16: Jobsite Access View through VR Headset (Kan and Azhar, 2016)

Temporary Facilities: Temporary facilities in construction jobsite can be classified as those facilities that are not part of the building but serves the whole the project. After the construction project is completed, temporary facilities (TF) are no longer required. According to Sanad et al. (2008) states that items such as: facilities that serve the project i.e. temporary facility (TF), site boundaries, movement routes and the building structure are all involved in construction site. In other to support construction operations, there is a need to identify facilities that are needed on site, determine shape and size and the location in which they are going to be positioned within the jobsite boundary. Examples of some temporary facilities (TF's) in construction jobsite are listed in Table 3 below:

Table 3: List of some temporary facilities on construction jobsite

No	**Facility Name**
1	Jobsite office
2	Toilet on site
3	Material storage
4	Subcontractor office
5	Parking lots
6	Aggregate storage
7	Water tank
8	Rebar fabrication yard
9	Pipe storage yard
10	Scaffold storage yard
11	Cement warehouse

VR can serve as 3D aid, which can facilitate visualization and identifying of site layout problems. According to Guo et al. (2013) Collision between tower crane and mobile can also be detected through VR. Figure 17 shows collision detected between two cranes using desktop VR technology which is also known as non-immersive.

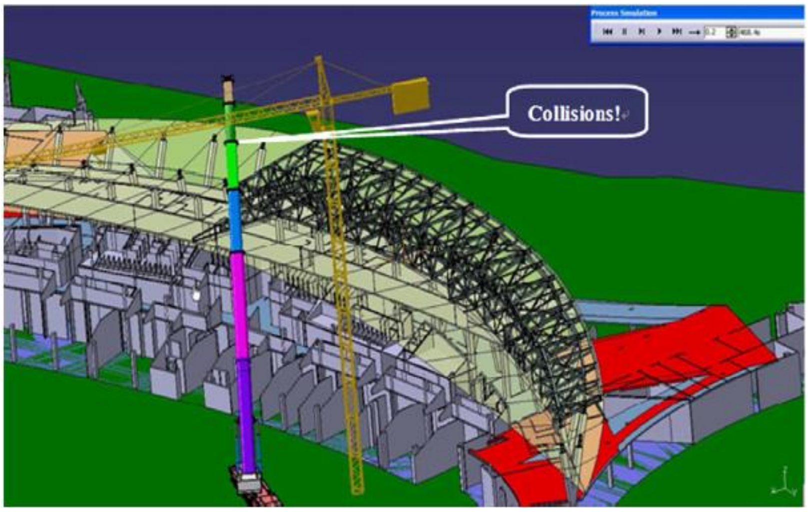

Figure 17: Collision between Two Cranes in Construction Site (Guo et al. 2013)

As stated by Li et al. (2001), problems on how the construction jobsite is organized can be identified through visualizing the jobsite model. Collision can be detected in a simulated jobsite environment as the VR will enable the user to understand potential interferences and object in any area of the jobsite (Kamat et al. 2006).Visualization serves as a tool that allows the observer to identify collision between cranes or collision with buildings (Ebner et al. 2012). Figure 18 shows collision detected through VR multi touch tablet.

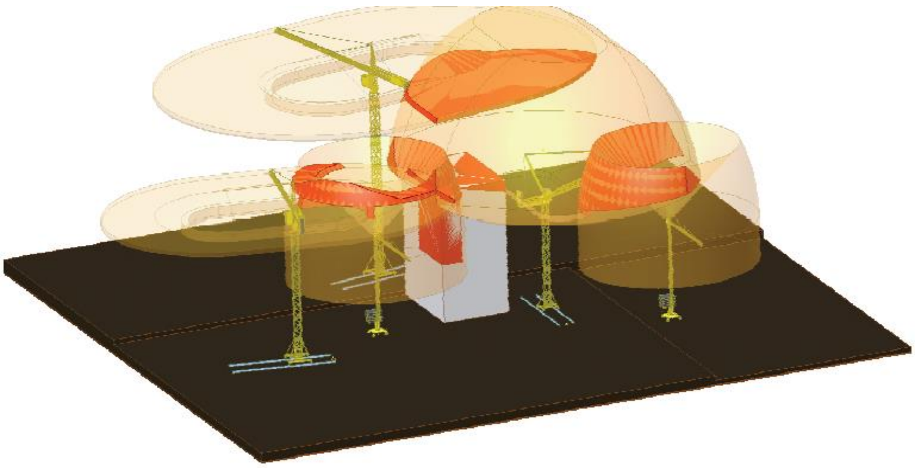

Figure 18: Collision between Cranes and Building (Ebner et al. 2012)

Virtual reality technology such as V-SAFE has been developed so that construction workers can be trained in VSE (Kiral et al. 2015). Construction workers safety training can enable them to identify hazards and assess risks (Sacks et al. 2013). Due to the hazardous nature of construction work, it is very important to train the construction workers before they set their foot on the construction site so that they can be able to identify hazards and also experience the consequences' of their mistake in a safe virtual environment. This can be done through VR safety training as this technology will enable the workers to identify potential hazards that may occur during the construction phase.

Chapter 3

METHODOLOGY

3.1 Introduction

The purpose of this research, as mentioned earlier in chapter 1, is to create a 3D construction jobsite plan and explore the jobsite plan in 3D environment utilizing VR technology (VR headset). Through conducting an extensive literature reviews on VR application in construction jobsite organization, it provides a clear knowledge and also in depth understanding of the topic under research. Continuous literature studies were also performed in other to achieve the following.

- Provide knowledge (VR applications in construction, VR technology, 3D model creation software's, VR headsets etc.).
- Provide a review of the previous and ongoing research on the topic under study.
- Choose methodologies

The research method used in this study comprises of descriptive case study and quantitative method. The descriptive case study aims to demonstrate the construction jobsite of the University of City Island under construction in the city of Famagusta, Cyprus. The project details of the case study are as follows: (1) Contractor Firm: Lahza Construction LTD. (2) Number of stories: 4 Storey. (3) Project location: Kurtulus Sk, Famagusta, Cyprus. (4) Starting date: 20/10/2016 (5) Date of completion: 20/05/2017. The construction jobsite 3D model created will contribute to the understanding of construction jobsite plan. Secondly, the quantitative method, which includes a short questionnaire, is utilized in this study. The results of the questionnaires will be represented in numerical percentage rating format. The top view locations of the construction site used as descriptive case study is shown in Figure 19 and construction jobsite view from the site access are shown in Figure 20.

Figure 19: Location of the Construction Site

Figure 20: Construction Jobsite View

After the 2D site plan demonstration and 3D site plan on screen demonstration and the 3D site model for testing using VR headset, a short questionnaire will be provided in other to collect data from the users. This study is divided into three main phases, i.e. the conceptual planning, modeling and data collection & validation as shown in Figure 21.

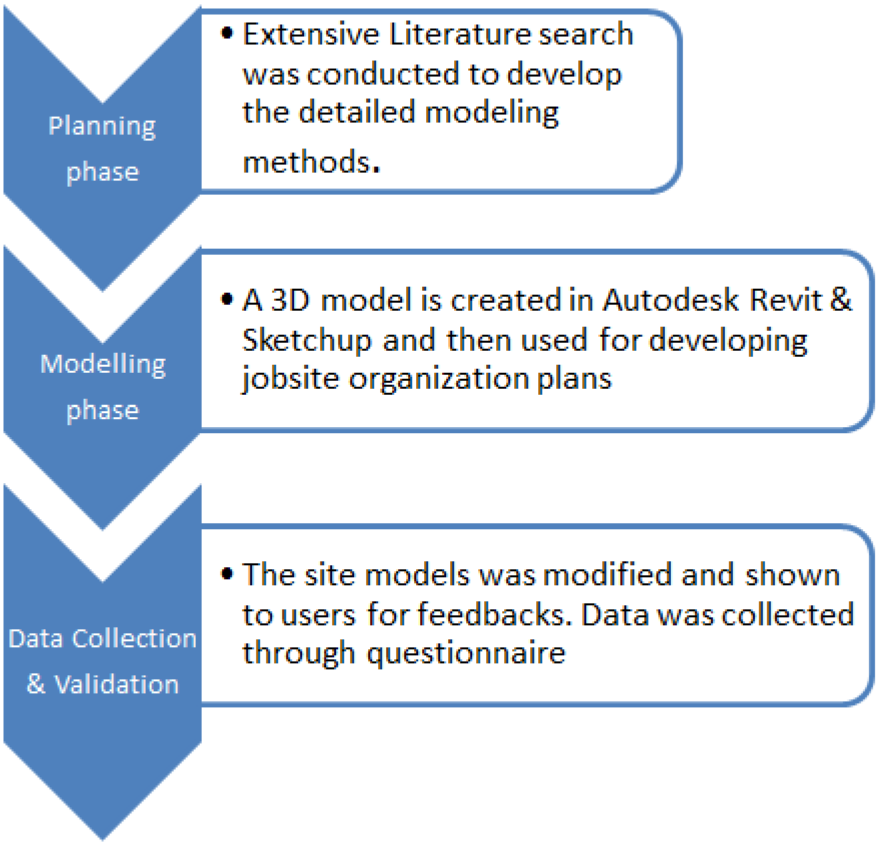

Figure 21: Three Phases of the Research Method

3.2 Phase 1: Conceptual Planning

The main purpose of the planning phase in this study was to identify the application of virtual reality technology in construction industry and also how to create 3D model of jobsite organization environment. Through an extensive review of the theoretical background of this topic under study, site layout planning which is one of the most important task of jobsite organization was found to be one of the areas of virtual reality application in jobsite organization. Lastly, through the conceptual planning various types of VR headset were identified and 3D modeling software's were also identified in this phase. Figure 22 illustrate the workflow of the 3D model.

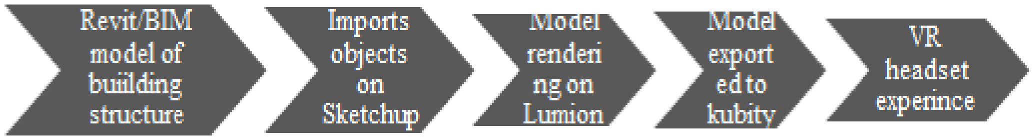

Figure 22: Workflow of the Model for VR Experience

3.2.1 Software's Selected

- Autodesk Revit: Autodesk Revit is a building information model used in designing 3D building model. This research focuses on jobsite organization; therefore the building structural framing of the jobsite was modeled on this software. The final 3D structural framing will be transferred to different software known as sketch up for final model modifications.
- Sketch Up: Sketch up software is used to develop the 3D site layout plans after the building frame structure is been imported from Revit/BIM software. This software is utilized in this study to import construction site fencing, cranes, construction materials, temporary facilities on site and other construction equipment. The final construction jobsite organization model is developed through this software.
- Lumion: Lumion is a 3D model rendering software use for rendering 3D environment. The final jobsite model will be rendered on lumion, so as to provide better images and realistic 3D objects.
- Kubity Exporter: This software is used to export and visualize 3D models on a web, computer and also works with smartphone for both Android and IOS. To export the 3D model, a bar code of the model scanned converts the model into VR mode, which will enable the observer to explore the 3D model.

3.2.2 VR Headset Selected

There are various VR headsets identified in this study such as; Sony Morpheus, HTC vive, Oculus rift, Google Cardboard, Samsung gear and VR box. The VR headset selected for this research is VR box, the reason is stated in section 1.4. Figure 23 shows the image of the type of VR headset used in this study.

Figure 23: The Type of VR Headset used in this Study

3.3 Modeling of the Construction Jobsite Organizational Plan

The first step of modeling of the construction jobsite organizational plan was the modeling of the building structural frame, which will serve as the main permanent building structure in the construction site. This was done on Autodesk Revit software. The structural elements such as foundation, columns, beams and slabs are assigned to the model through structural element toolkit on the software.

The structural element toolkits supports BIM process, in which the user can select a certain structural element such as column and check the elements information that includes, shape type, size, dimension and height. The toolkit allows the user to select and positioned structural element on the model. For example, selection of column type i.e. rectangle or cylindrical shape and dimensions and positioning at the grid axis of the model plan.

The model plan can viewed in two ways, either from the 2D plan or 3D model depending on the view the user selected. The Autodesk Revit software allows the user to create a building structural frame and check the model of structural elements within the Autodesk Revit environment. Foundations are created utilizing foundation slabs from the structural element toolkit; in this model mat foundation was modeled. Columns are added vertically as load bearing elements to the model mat foundation of the building through the use of structural columns on the toolkits of the software. The process of column positioning is shown in Figure 24.

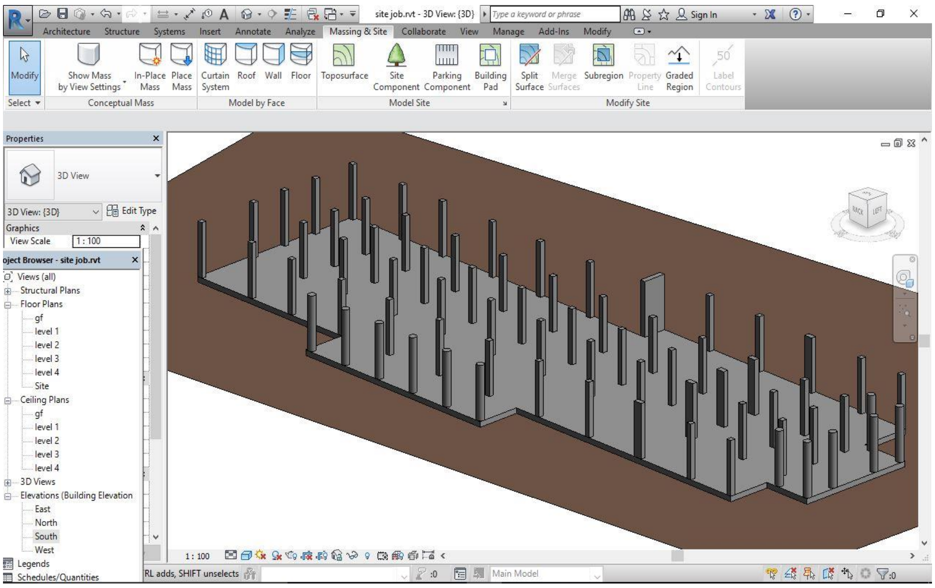

Figure 24: 3D View of Columns Positioned On the Building Foundation

After positioning the columns, beams are also added to the structural model through selecting the beam type, size and dimensions on the beam tools displayed on the toolkit, which provides a series of beams that are placed parallel on the model. A series of beams placed parallel to each other on the structural columns of the 3D structural frame model are shown in Figure 25.

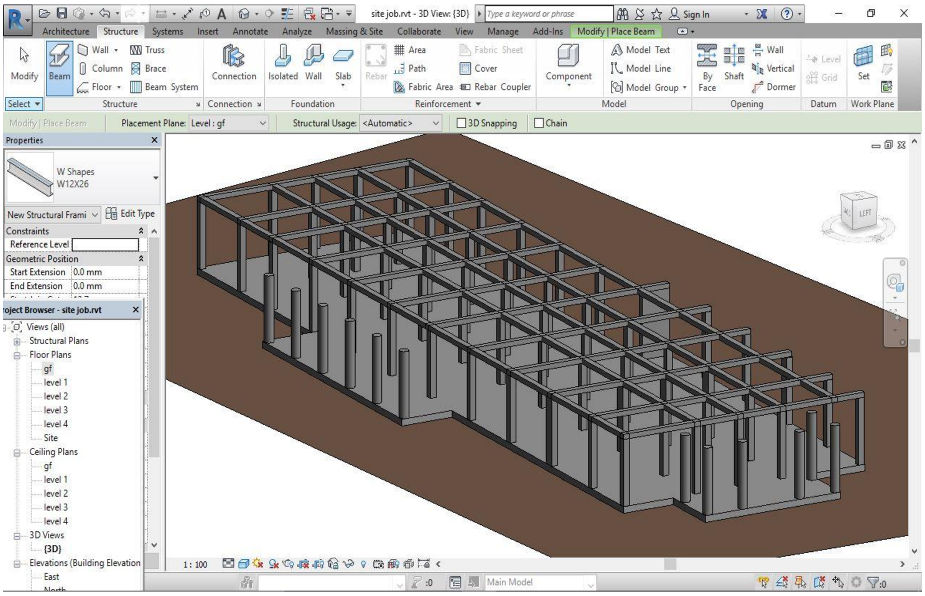

Figure 25: Beams Positioning On the 3D Model

The structural floors tools on the toolkits of the Revit software was used in selecting the slab and provides information modeling of the slab which includes thickness of the slab. The same procedure was done for the 1st floor, 2nd floor and 3rd floor of the structure. The final building structural frame modeled on Autodesk Revit software is shown in Figure 26.

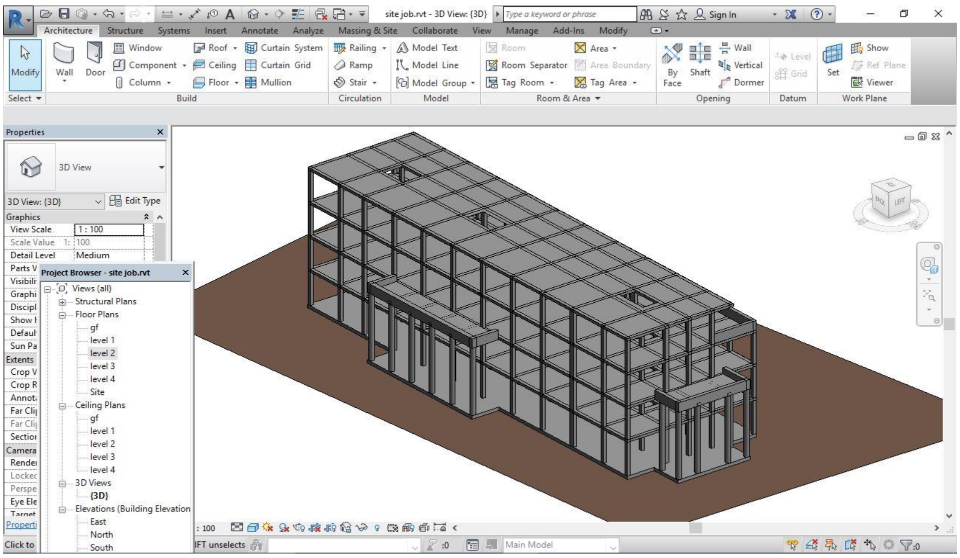

Figure 26: Final Building Structural Frame

The final model was saved in AutoCAD file format, as this file saved is exported to sketch up software for importing construction equipment's and objects and preparing the final 3D construction jobsite models. The sketch up software used to import equipment's, characters and construction materials, as they will make the simulated construction jobsite looks real. The equipment's (e.g. tower crane), characters (construction workers) and materials downloaded from sketch up warehouse are based on real life dimensions. The 3D model was uploaded to Lumion software for the final rendering of the model. Figure 27 shows the 3D construction jobsite organizational plan model screenshot from Lumion rendering software.


Figure 27: 3D Construction Jobsite Organization Model

The final rendered model of jobsite will be used to create different jobsite organizational plan scenarios. Two scenarios will be created; the first scenario will be based on how the jobsite is being organized from the real construction jobsite used as case study. The second scenario of the jobsite organizational plan is modeled different from the actual one.

Difference of site access, crane placement location, trash waste location, locations of materials, stockpile of excavation, site office, equipment's location and site orientation between the two scenario's will be observed through the VR system (VR headset). 2D site plan and the 3D site plan is modeled base on two different scenarios. The 3D site model of the two scenarios will be used for the VR experience.

3.4 Data Collection and Validation

Two 2D site plans for scenario 1 and scenario 2 is created and represented in two-dimensional format. Scenario 1 differs from scenario 2 based on the site access (entrance and exit), location of site office, parking areas, equipment location, crane placement, material locations, trash waste access and stockpile of excavated soil. The 2D plan was created from AutoCAD. The 2D site plans for scenario 1 is shown in Figure 28 and scenario 2 is shown in Figure 29.

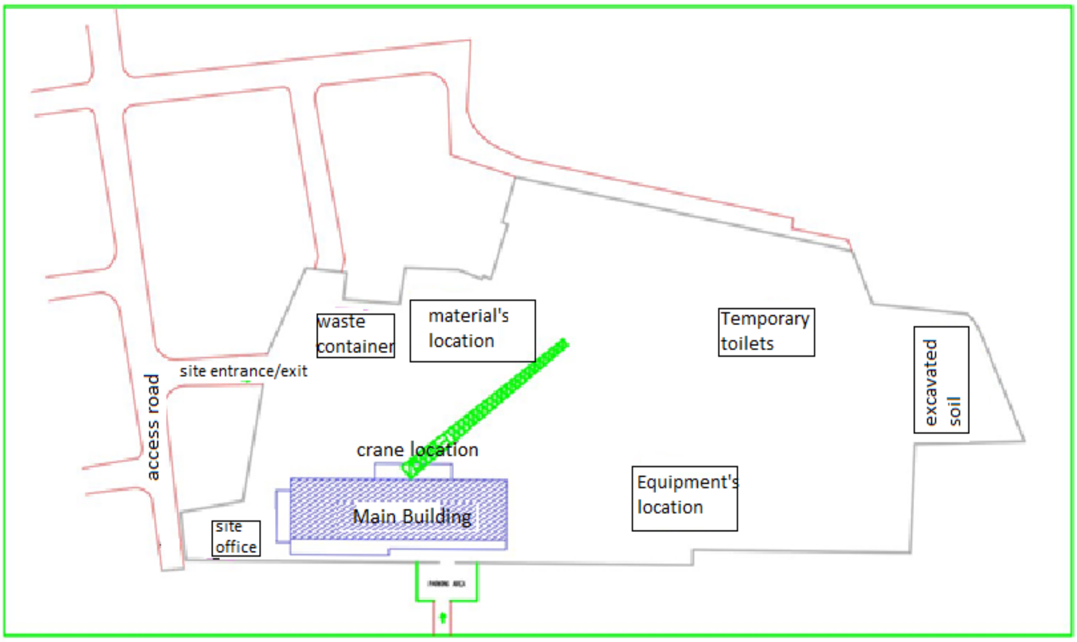

Figure 28: 2D Site Plan for Construction Jobsite Scenario One

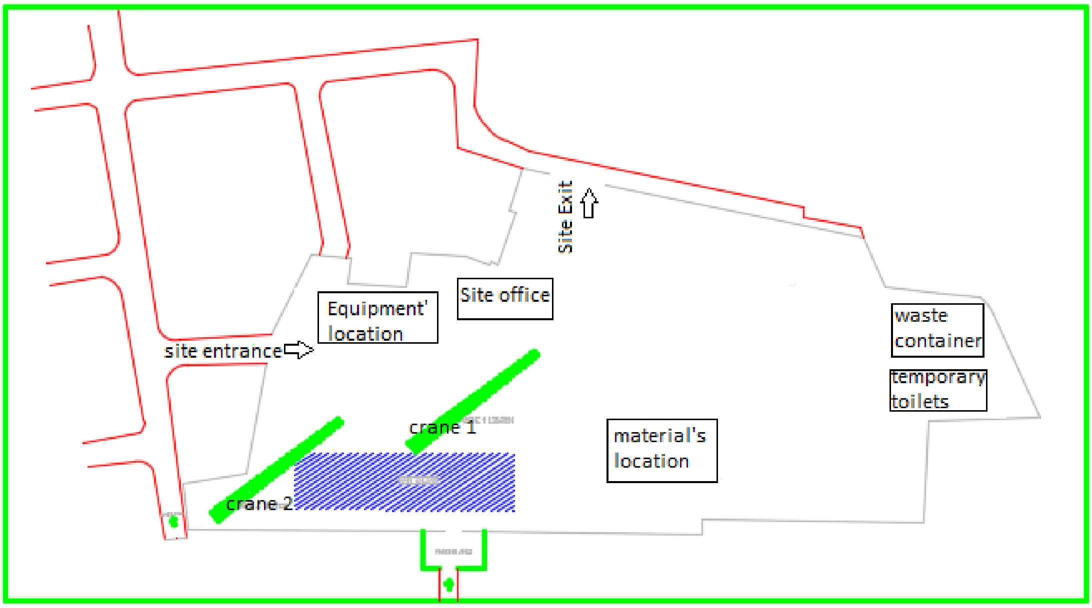

Figure 29: 2D Site Plan for Scenario 2

Three-Dimensional (3D) plan model was also created for the construction jobsite plan demonstration. 3D site plan has a more features of visualizing tools which will enable the observer or viewer to explore the 3D model and also gives a life-like experience. In the 3D site plan model, equipment's, materials and other components that are present at the construction jobsite are shown in detailed clearly from the rendered model. Figure 30 below shows the 3D jobsite model for scenario 1 and Figure 31 shows the jobsite scenario 2.


Figure 30 :3D Site Model for Scenario 1

Figure 31 :3D Site Model Scenario 2

The two 3D site plans scenarios were used for the immersive environments that provide the VR experience for the user. A 360-degree view of the virtual world is experienced through the VR box through which the user can engage in observing the simulated construction jobsite model. Figures 32 shows the users view for jobsite scenario 1 and Figure 33 shows the users view for jobsite scenario 2.

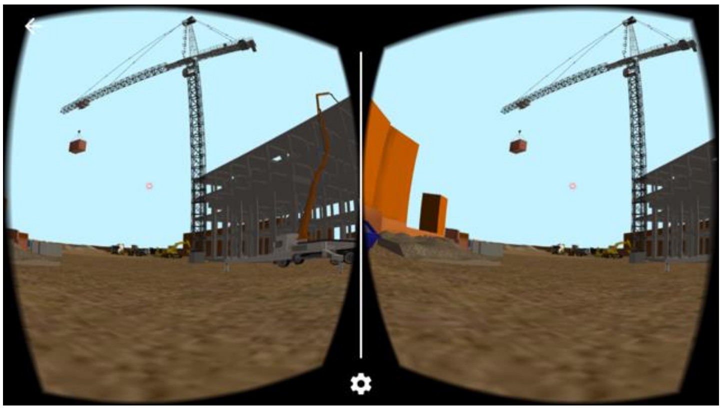

Figure 32: Users View through the VR Headset for Jobsite Scenario 1

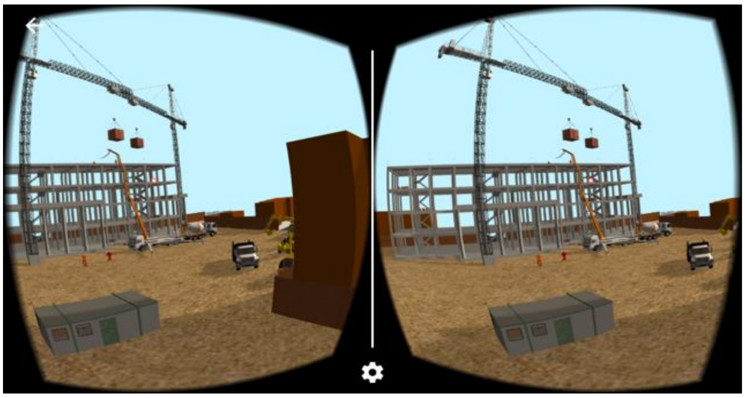

Figure 33: Users View through VR Headset for Jobsite Scenario 2

The 2D site plan and the 3D model on screen will also be demonstrated to the participants. Using the VR box headset the 3D model of the jobsite will be tested by the participant for the two jobsite scenarios. The target participants are graduates from civil engineering and architecture that already have experience in the construction industry. Among the respondents, 7 of them specialized in construction management, 3 of the respondents specialized in structural engineering and the other 2 respondents field of specialization in architecture. The demography of the respondents is shown in Table 4.

Table 4: Demography of the respondents

Position	**Field of Specialization**	**Years of Experience**
Assistant Site Supervisor	Construction Management	4
Revit-BIM specialist	Architecture	5
Assistant Site Engineer	Construction Management	3
Site Engineer	Construction Management	5
Site Supervisor	Construction Management	4
Structural Design Engineer	Structural Engineering	5
Site Engineer II	Construction Management	3
Structural Engineer	Structural engineering	4
Structural Site Engineer	Structural engineering	4
Assistant Site Supervisor	Construction Management	2
Site Engineer	Construction Management	5
CAD specialist	Architecture	4

After all the demonstration a questionnaire will be given to the participant in other to collect feedbacks. The sample questionnaire used in this research study can be found in appendix A. The ratings (1 to 5) from the questionnaires will be as follows:

1 Represents –Bad

2 Represents – Fair

3 Represents – Good

4 Represents- Very Good

5 Represents – Excellent

The responses of the participants i.e. the frequency of the rating will be used in analyzing each questions. The results of the analysis are going to be represented in scientific manner, which include tabulated results and bar charts graphical representation. Final result will be calculated based on distribution of Reponses from the participants. Based on the outcomes of the questionnaire, overall rating of the 3 site plans will be represented in statistical data analysis format.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

This section describes result of the three site plans (2D, 3D and 3D VR) model's direct observation using VR headset and the responses of participants engaged in testing the models.

Firstly, the 2D jobsite plan demonstration results obtained from the short questionnaire will be represented. Secondly, the 3D jobsite plan model demonstration results will be discussed. In addition, the 3D jobsite model experience using VR headset will be discussed in this section. Based on the outcomes of the direct observation and questionnaire responses, the benefits and applications of VR in construction jobsite organization will be discussed.

Next, comparison between the three jobsite plans (2D, 3D and 3D in VR headset) will be discussed in this chapter. However, the results from the three site plans demonstrations will be represented in tabular format showing the participants ratings (out of 5), average rating and the overall rating percentage (%). Lastly, the overall rating of the 3 site plans will be represented in descriptive statistical format.

4.2 Direct Observation of the 3D Jobsite Model Using VR Headset

The 3D jobsite model was utilized for the VR experience using VR box headset. During the 3D model testing some direct observations were examined and will be discussed in this section. These direct observations include; criticism of the construction jobsite organizational plan for jobsite model scenario 1 and scenario 2 observed through exploring the 3D jobsite models in VR headset. Through visualizing the jobsite models for scenario 1 and scenario 2, the following issues concerning the jobsite organization were observed through the VR system (VR box headset).

4.2.1 Site Access

In scenario 1, through the VR headset it was observed that the construction jobsite has only one site access i.e. for both exit and entrance. Kan and Azhar (2016) utilized immersive VR technology to check the construction jobsite access for vehicle's entrance and exit, in the findings two different jobsite access was observed. Comparing the findings of Kan and Azhar (2016), with the findings of this study shows some differences. This is due to differences on how the jobsite is been organized. Having one site access can hinder the movement of jobsite trailers in and out of construction site, as it will lead to obstruction in smooth flow of jobsite traffic across the site boundary.

As stated by Small and Bager (2016), site access for entrance and exit locations for vehicles is one of the various factors that should be considered when designing a productive jobsite. In this way, through visualizing the construction jobsite, issues concerning the inaccessibility of the jobsite can be identified and solved before the actual construction jobsite. Thus, this finding indicates that the ability of the VR to identify such issue is one of the benefits of using this technology in jobsite organization. Through the VR headset it was clearly observed that the site entrance/exit is too narrow for two vehicles (e.g. trucks and trailers etc.) to pass at a time. This can lead to delay in delivering and off-loading of materials on site because sometimes the truck drivers has to wait for other vehicles to pass before they can gain access to the construction site. As a result this will affect the project schedule. Another benefit of using VR technology in jobsite organization is the ability of the system to identify such issue concerning the construction organizational jobsite plan.

In this project, the access roads to the construction jobsite are leading to the nearest highway. The location of the site access is provided by an adjacent road, which joins the project site with the nearby highways. In this way, vehicle drivers can be able to deliver premix concrete, materials and equipment’s on time without any delay. Easy accessibility will keep the morale of the vehicle drivers high, minimize the chance of accidents, and save time in maneuvering to arrive at and leave the construction site. Figure 34 shows of the VR view of the jobsite entrance/exit.

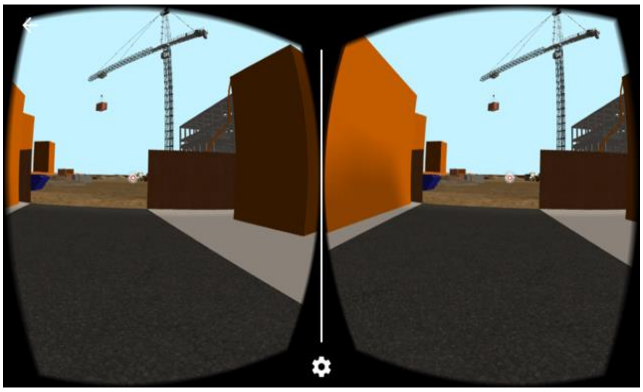

Figure 34: Jobsite Access Entrance/Exit View through the VR Experience

4.2.2 Materials Location

In scenario 2, through the VR headset it was observed that the materials where located at the backyard of the construction site, which is too far from the working areas and also far away from the second tower crane placement location. This issue will lead to multiple handling of material to a different location closer to the working areas and within the accessible range of the second tower crane.

As stated by Mincks and Johnson (2010), poor site planning can prompt double handling of materials, misplacement of construction materials and work delays. In this way, this issue can affect the project schedule. For example a construction task is assign to a specific date in the project schedule, instead of construction workers to focus on performing the construction tasks; they will focus on moving the materials to a location closer to the crane and working area.

This finding shows that VR technology offers great advantage in the identification of such issues and solution can be made at the early stage of jobsite organization in other to create effective and efficient construction jobsite. Excess movement of materials on site can be reduced through creating effective and efficient jobsite layout plan (Small and Bager, 2016). Figure 35 shows the VR view of materials location in the backside of the construction site.

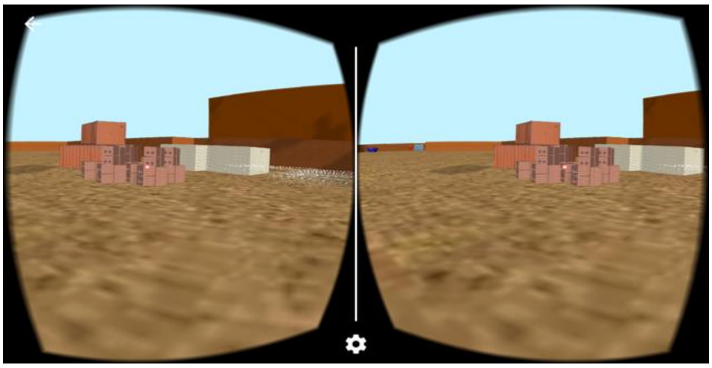
Figure 35: Materials Located at the Backyard of the Construction Jobsite

4.2.3 Collision Detection

Interferences between two cranes in scenario 2 were observed through the VR system. Many researchers (Kang and Laia, 2009, Kamat et al. 2006, Guo et al. 2013) found that this technology of VR can aid in detecting collisions on construction site. Accidents such as collision between two tower cranes is one of the risk factors concerning construction site hazards, therefore this finding shows that VR technology provides the user/observer with an immersive experience to detect or identify such hazards before the actual installation of cranes on site.

The result obtained from this research study is more consistent to findings of Ebner et al. (2012), in which collision between different cranes was detected using non immersive (VR multi touch tablet) VR technology. Rework can be reduced and also save money and time due to errors that can be fixed before the actual field installation (Deshpande and Whitman, 2014). Figure 36 illustrates the collision between two cranes observed through the VR headset.

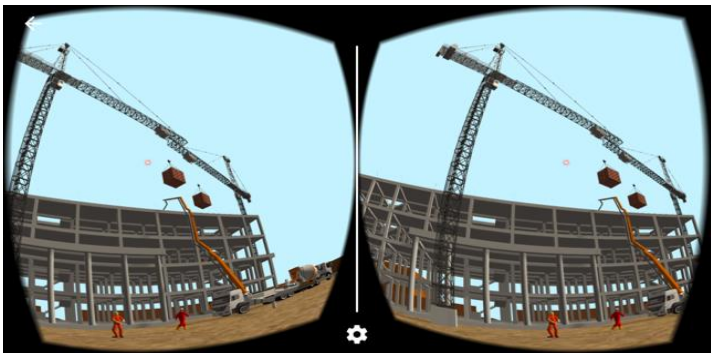

Figure 36: Interferences between two Tower Cranes

4.2.4 Temporary Facilities Location

Through the VR technology (headset) experience, scenario 2 shows the location of the temporary toilet and waste/trash container were located at the back of the jobsite which will lead to increase in travel time. Location of temporary facilities such as toilets and waste/trash container in construction jobsite can affects productivity, in this way construction workers have to walk along distance in other to dispose construction waste and also to make use of the TF's toilets. Figure 37 shows the location of the trash/waste and TF's toilet on site.

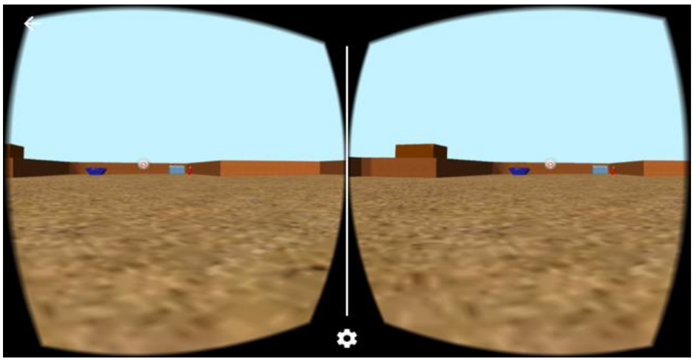

Figure 37: Temporary Toilets and Trash Container Location

In a situation, where changes are made based on how the construction jobsite is been organized as the project progresses, updates should be performed on the jobsite 3D model arrangement. Through updating the jobsite model, new issues concerning the jobsite arrangement can be observed through visualization the model in VR. By doing so, problems can be identified and solutions can be made.

4.3 Questionnaire Survey Responses

In this section, the result from the three models (2D, 3D and 3D in VR) demonstration will be discussed. The average rating of the questionnaire survey was calculated through combining categories and numerical representations. The ratings for each question will be represented using this approach:

- High - Greater than or equal to ≥ *80%*
- Medium – *79% - 60%*
- Low – less than or equal to ≤ *59%*

For example, in question 1 from the 2D questionnaire, the scores were given to the categories as shown in Table 5.

Table 5: Questionnaire ranking category

Excellent	**Very Good**	**Good**	**Fair**	**Bad**
5	4	3	2	1

For the participants' responses, the number of participants that select a certain category will be assigned to each category and represented in tabular format. Sample method used in calculating the average rating and the overall rating percentage for question 1 is shown in the equation and Table 6.

$$\text{Average Participants Ratings} = \frac{(4 \times 5) + (6 \times 4) + (1 \times 3) + (1 \times 2)}{4 + 6 + 1 + 1} = 4.08$$

Table 6: Number of participants that selected a certain category

Category	**E**	**V**	**G**	**F**	**B**	**AVG**	**Overall**
Frequency	5	4	3	2	1	**Rating**	**Rating %**
Number of participants	4	6	1	1	0	4.08	82%

4.3.1 2D Site Plan Demonstration Results

In this section, the results obtained from the 2D site layout plan demonstration questionnaire will be discussed. Table 7 shows the 2D site plan demonstration result.

Table 7: 2D Site demonstration results

Questions (2D site plan demonstration)		**Participant's Rating (Frequency)**					**AR**	**R %**
		5	**4**	**3**	**2**	**1**		
1	How easy is the 2D site plan to understand?	4	6	1	1	0	**4.1**	**82 %**
2	How effectively does the 2D site plan facilitate evaluation of two different site plan scenarios?	1	3	5	3	0	**3.2**	**64 %**
3	How effectively does the 2D site plan shows differences of jobsite organization in scenario 1 and scenario 2?	3	5	4	0	0	**3.9**	**78 %**
4	How well the 2D site plan shows how the jobsite is going to look in reality?	0	0	3	8	1	**2.2**	**44 %**
5	How effectively does the 2D site plan aids in identifying collision between two cranes on the construction site in scenario 2?	0	0	2	7	3	**1.9**	**38 %**
6	How well the 2D site plan does shows the distance between the tower cranes and the materials location?	0	4	5	2	1	**3.0**	**60 %**
7	To what level of extent can the 2D site plan help in improving site layout accuracy?	0	2	4	6	0	**2.7**	**54 %**
8	How well the 2D site plans show the volume and amount of spaces on site?	0	3	6	3	0	**3.0**	**60 %**

9	To what extent is the level of details of the 2D site plans?	0	2	5	4	1	**2.9**	**58 %**
10	What is the overall rating of the 2D site plan for both scenarios?	1	3	4	4	0	**3.1**	**62 %**

In question 1, the result of the overall rating of how easy the 2D site plan to understand, showed a high rating of 82%. Some of the participants were satisfied that the 2D site plan is easy to understand due to less amount of time spent in understanding and demonstrations of the 2D jobsite layout planning. The rating in question 2, shows a medium rating of 64% on the effectiveness of the 2D site layout in evaluation of the two jobsite layout scenarios created. In question number 3, the overall rating of the site layout plan on its capability to identify differences from the two site scenarios, in the way the jobsite is been organized showed a medium rating of 78%.

The result of the rating in question 4 showed a low rating of 44%, indicating that most participants believed that the 2D site plans doesn't have the potential to show how the representation of the jobsite is going to look like in reality. In question 5, overall rating of the participants on how effective the 2D site plan helps in identifying issues such as interfaces between two cranes on the construction site showed a low rating of 38%, this is due lack of visualization and simulation ability, which can aid in identification of interfaces between two or more components or objects on site.

The participants rating in question 6 was recorded as a medium rating of 60% on how the 2D plan showed the distance in relation with the materials location and the two tower cranes location. It can be clearly seen from the 2D site plan of layout drawings (scenario 2) that the materials are not located within the accessible range of the second tower crane located in front of the main building under construction, this indicate that about half of the participants were able to identify this issue.

The level of extent the 2D can aid in improving site layout accuracy asked in question 7 has a low rating of 54%. Next, the rating in question 9, on how well the 2D plan showed the amount and volume of available space on the construction site has a medium rating of 60%. A low overall rating of 58% was recorded on the extent of details the 2D jobsite layout plan. In the last question, which was the overall rating of the 2D site layout plan, a medium rating of 62% was obtained.

4.3.2 3D Jobsite Model Demonstration Results

This section describes the results obtained from the participants evaluation of the 3D jobsite model demonstrated on computer screen. The result is shown in Table 8.

Table 8: 3D jobsite model demonstration results

Questions (3D site plan model demonstration)		**Participant's Rating (Frequency)**					**AR**	**R%**
		5	**4**	**3**	**2**	**1**		
1	How easy is the 3D site model on computer screen to understand?	2	4	5	1	0	**3.6**	**72 %**
2	How well the 3D site plan models enable the viewer to identify collision between cranes on site in scenario 2?	3	6	3	0	0	**4.0**	**80 %**
3	How well the 3D model aids in identifying the location of cranes within the jobsite boundary in both scenarios?	3	5	4	0	0	**3.9**	**78 %**
4	To what degree of level does the 3D site model plans aids in checking the location of site office	2	4	5	1	0	**3.8**	**76 %**

	in both scenarios?							
5	How well does the 3D jobsite plan model shows how the jobsite is going to look in reality?	2	6	4	0	0	**3.7**	**74 %**
6	To what extent of level does the 3D model enables the viewer to evaluate different site plan scenarios?	4	5	3	0	0	**4.1**	**82 %**
7	How well the 3D plan does shows the distance between the tower cranes and the materials location?	2	5	5	0	0	**3.8**	**76 %**
8	How effectively does the 3D jobsite organizational model site model on screen show the volume and amount of spaces on site?	1	6	5	0	0	**3.7**	**74 %**
9	Rate the level of details of the jobsite organizational plan in 3D site model on computer screen?	4	6	1	1	0	**4.1**	**82 %**
10	What is the overall rating of the 3D jobsite model?	5	4	3	0	0	**4.2**	**84 %**

In question 1, the overall rating from the participants on how easy the 3D model to understand the two scenarios of the jobsite layout plan has a medium rating of 72%. In question number 2, the rating on how well the 3D model can facilitate the identification of interference between two towers cranes showed a high rating of 80%. The overall participants rating on how well the 3D model help in knowing the cranes location in the construction site showed a medium rating of 78%. Question number 4 showed a medium rating of 76% on how the 3D model help in checking the location of site office from both scenarios. A high rating of 74% in question 5 was obtained on how the 3D model is going to be like in real world. The ratings of the extent of level the 3D model on screen enable the observers to identify and evaluate the differences in the two construction jobsite scenarios demonstrated has a high rating of 82%.

In question 7, a medium rating of 76% was obtained on how the 3D model shows the distance between the place where the materials are located and the crane location. A medium rating of 74% was observed on the capability of the 3D jobsite model to show the amount of available spaces on the construction jobsite area. Based on the level of details of the 3D jobsite model, a high rating of 82 % was recorded from the evaluation of the participants it is clearly noted that most of the participants are satisfied with the level of details the 3D offers over the two-dimensional site plan details. Lastly, a high rating of 84% on the overall rating of the 3D model on computer screen was recorded in last question.

4.3.2 3D model in VR headset demonstration

This section describes the results obtained from the 3D jobsite model testing participant's evaluation. The result is shown in Table 9.

Table 9: Results of the 3D jobsite model testing using VR headset

Questions (3D site plan model using VR headset demonstration)		**Participant's Rating (Frequency)**					**AR**	**R%**
		5	**4**	**3**	**2**	**1**		
1	How easy is the VR system (VR headset) to use?	0	3	5	4	0	**2.9**	**58 %**
2	How effectively does the VR headset help in checking and verifying problems in jobsite organization (e.g. collision between two cranes)	6	5	1	0	0	**4.4**	**88 %**
3	How well does the VR headset help in identifying the materials stacked location are far away from the second crane in scenario 2?	3	5	4	0	0	**3.9**	**78 %**
4	To what level of extent does a VR headset provide a better understanding of what to expect on site?	2	8	2	0	0	**4.0**	**80 %**
5	How effectively the VR technology facilitate evaluation of two different	4	6	2	0	0	**4.2**	**84 %**

	site plan scenarios?							
6	How well the VR system help in identifying the site access (entrance/exit) is too narrow for two trucks to pass at a time?	5	6	1	0	0	**4.3**	**86 %**
7	How well does the VR system help in checking the crane placement location in both scenarios?	3	7	2	0	0	**4.1**	**82 %**
8	To what level of extent can the VR technology help in improving site layout accuracy?	2	5	5	0	0	**3.8**	**76 %**
9	To what level of degree does a VR headset enables the user to feel a life-like experience?	4	7	1	0	0	**4.3**	**86 %**
10	How effective does the VR headset help in showing that temporary toilets are located far away for the working areas?	2	7	3	0	0	**3.9**	**78 %**
11	To what level of possible advantages does the VR headset offers in jobsite orientation?	3	6	3	0	0	**4.0**	**80 %**
12	To what extent is the level of jobsite organizational plan details through VR headset?	2	9	1	0	0	**4.1**	**82 %**
13	To what extent of level do you think VR headset is beneficial when determining construction jobsite organization?	3	8	1	0	0	**4.2**	**84 %**
14	How well the 3D VR jobsite model does shows the volume and amount of spaces on site?	2	6	4	0	0	**4.0**	**80%**
15	What is the overall rating of the VR technology (VR headset)?	6	5	1	0	0	**4.4**	**88 %**

In the first question, a low rating of 58% was obtained based on the easiness of the VR system (VR headset) to use. The low rating of how easy the system is to use showed the evaluators that engaged in testing the 3D model in VR headset found it difficult to manipulate the VR headset. This is due the complexity of adjusting the VR headset lenses sideways in other to provide a clear view for the user and avoid double images effect and also avoid blurry view through the headset. One of the participant commented that the assessment of the system is a little bit slower but you will be able to get a close reality experience of the jobsite layout.

A high rating of 88% in the second question was recorded, which showed that the VR technology have greater potential in checking problems in the construction jobsite that may arise due to poor jobsite organization. Collision between two cranes from scenario two was observed by the VR headset. A screenshot from the VR view of the jobsite was shown to the participants, the reason is that not all participants can be able to explore all parts of the construction site due to the large amount of area in the construction jobsite.

In question 3, which is based on how well the VR headset can help in visualizing the distance between the crane position and the materials stacked location in the second scenario showed a medium rating of 78%. This indicates that most participants were able to visualize the materials in relation with the crane placement location on site. A high rating of 80% was obtained on how the VR provides a better knowledge of what to expect on the construction site. This showed that most of the testing participants are satisfied with the VR technology ability in visualizing the construction site and provides in depth knowledge of what to expect on the construction site.

The effectiveness of the VR in evaluating the two different jobsite scenarios showed a high rating of 84%. As stated by Bouchlaghem et al. (1996), VR technology can be used in evaluation of different construction scenarios. This finding proved that, the VR technology can be utilized in different construction site scenarios evaluation. The rating of the VR system ability to show that the jobsite access for entrance and exit is too narrow for more than truck to pass at a time showed a high rating of 86%. A screenshot of the site access for the VR system was shown to the testing participants. This indicates that the 3D model testing participants are satisfied with the effectiveness of the system in showing the narrowness of the jobsite access.

A medium rating of 76 % was recorded in question 8, which is based on the level of extent VR can aid in enhancing the accuracy of the site layout. In addition, a high rating of 86% was obtained on how the system facilitates the observer to feel a life-like experience. This is because the VR system enables the users to be immersed in the virtual construction jobsite environment and be able to view the environment in 360˚, which enables the observer to feel a close reality experience. In this way, it's concluded that most of the participants agreed that VR provides a user life like experience in which the observer feels like they are in a near/close reality environment. Question 10, has a medium rating of 78%, on how the VR shows location of TF's (toilets and trash container) located far from the construction working area. This indicates that most of the evaluators observed the distance between the TF's and the working area through the VR headset.

A high rating of 80% was obtained on the advantages of VR headset, which includes orientation of the construction jobsite. One of the participant commented that the VR technology was a good tool that can be used in orientation of the jobsite. The ranking for the level of details of the 3D models in VR headset showed high rating of 82%. This result obtained indicates that the testing evaluators are satisfied with the level of details of the 3D jobsite model in VR mode. High rating of 84% was observed in question number 13, on the level of degree the participant believed that VR technology is important when determining the construction jobsite.

The overall rating of the VR system showed a high rating of 88%. This overall rating result of the VR system indicates that most of the evaluators are satisfied with the level of details of the 3D CAD jobsite model in VR, and also the applicability of VR technology in construction jobsite organization which includes; studying site layout plan, evaluation of different scenarios and collision detection.

4.4 Comparison of the 3 Construction Jobsite Models

In this section, comparison of the 3 jobsite plan model will be represented in bar charts showing the percentages of the ratings of each site model. The first comparison will be based on how easy the models are to understand. Figure 38 shows the rating of each of the models from the evaluators' responses on how easy the 3 jobsite models are to understand.

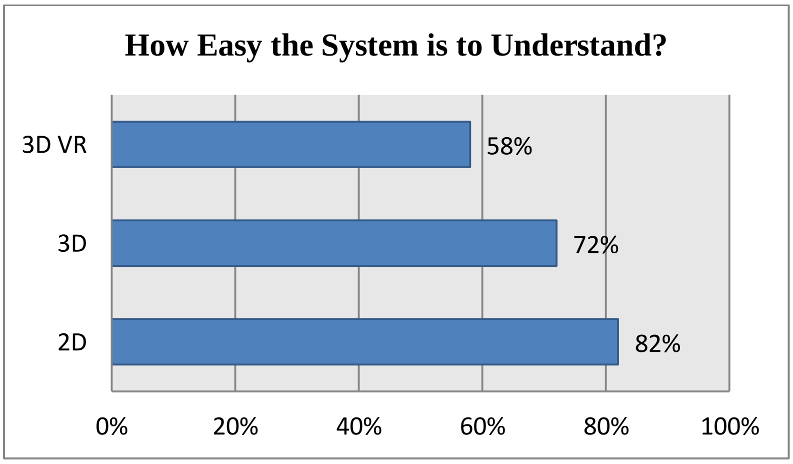

Figure 38: Comparison of How Easy the System is to Understand

The 2D site layout plan had the highest rating of 83%, followed by the 3D site model which had a second medium rating of 72% and lastly, the 3D model in VR mode had the lowest rating of 58%. These results obtained indicates that the 2D site plan is easier and takes less time to understand when compared with the 3D model in VR mode and 3D model on screen.

The application of VR technology was explored through gaining knowledge from theoretical background and literature review. One of the areas of the VR application is the evaluation of different construction scenario. Bouchlaghem et al., (1996), states that VR technology in utilized in evaluation of construction scenarios. In this way, a comparison was made based on 3D in VR mode, 2D site layout and 3D model ability to evaluate different construction site scenarios. Figure 39 shows the result of the comparison which is represented in rating percentages for each of the site model.

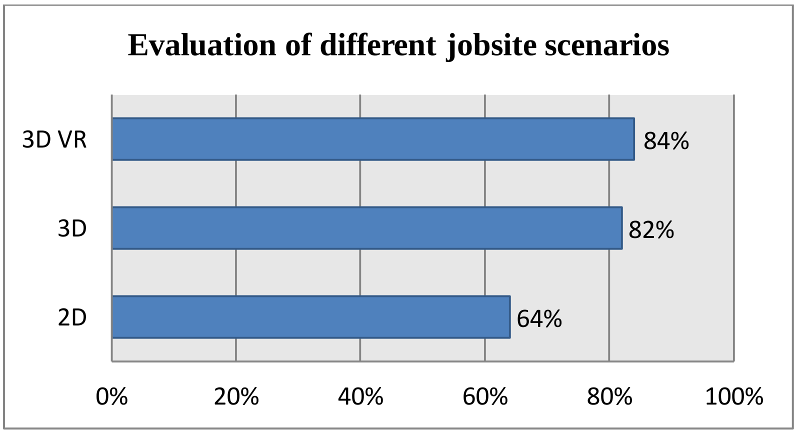

Figure 39: Result of Evaluation of Two Different Site Scenarios from the 3 Models

The above figure shows that the 3D jobsite model in VR mode had the highest rating of 84%. The second highest rating was the 3D model on screen which has a rating of 82%. The 2D site layout has a lowest rating of 64%. There is a slight rating difference in the 3D in VR and 3D model on screen, which indicates that the 3D model can also be utilized when evaluation two site scenarios.

The results of the comparison of 2D site layout plan and two 3D site models, one 3D model demonstrated on a PC screen and the other one was the testing of 3D model in VR mode using headset, showed that the 3D in VR headset has the highest rating of 88 %. This result indicates that the 3D model virtual environment provides a high level of details of 3D space in which 3D collisions can be detected compared to the 3D model and 2D site layout plan. The 3D model shown on PC screen showed the second highest rating of 80%, which indicates that the 3D model on computer screen is also beneficial when determining issues or problems on the construction jobsite such as collisions. A low rating of 38% was observed in the 2D site layout plan. Furthermore, through the use of the 2D site layout plan it is very difficult to visualize collisions on site (Ebner et al., 2012). This is because of low level of realism and lack of graphics simulations which aids in the identification and detection of collision on site. The comparison of the collision detection in the 3 site plans are shown in Figure 40.

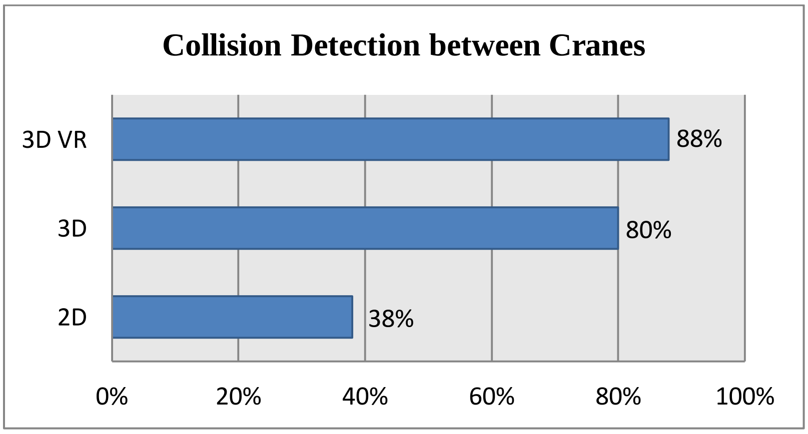

Figure 40: Result of the 3 Models on Collision Detection between two Cranes

The results from the comparison of the three jobsite models based on each CAD model's ability to facilitate the observer to identify the issue of materials stacked are located far from the accessible reach of the tower crane in scenario 2 is illustrated in Figure 41. From the bar charts result representation, it is clearly shown that the 2D site layout has a low rating of 60%. Secondly, the 3D model showed a rating of 75%, which is higher than that of 2D site layout. Lastly, the 3D model in VR headset showed a rating of 78%. When compared with the 3D model it showed a small difference of 3%, in this way, we can say the evaluators believed that the 3D model can also aid in identifying such issue. A difference of 18% was obtained when the 2D site layout is compared with the 3D CAD model on VR headset

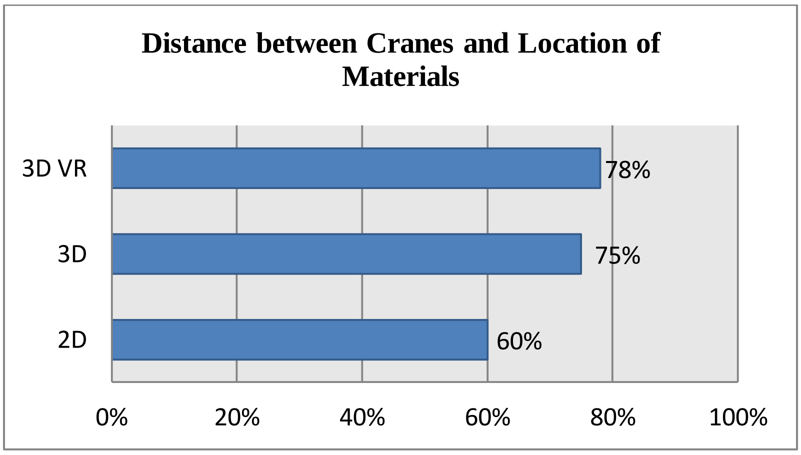

Figure 41: Distance between the Range Of Cranes and Location of Materials

4.4.1 Overall Rating of the 3 Site Plans

In this section, the overall rating of the 3 site plans i.e. the 3D model in VR, 3D model on screen and the 2D site plan will be discussed. The overall rating of the 3 site plans is represented in descriptive statistics showing the mean, mode, median and standard deviation value for each of the site plans. The results were calculated through the use of Microsoft Excel. The total average ratings for each of the 3 site plans were assigned as inputs to the model data analysis. Table 10 shows the result of the 3 site plan's overall rating.

Table 10: Overall rating of the 3 site plans

Measure	**Mean**	**Median**	**Mode**	**S.D**
2D site plan	3.00	3.00	3.00	0.66
3D site plan model	3.89	3.85	3.80	0.20
3D site plan in VR headset	4.03	4.10	4.00	0.36

From the descriptive statistics data analysis result obtained, the 3D site plan in VR mode has the highest mean value of 4.03 with the medium standard deviation of 0.36. This result indicates that the 3D site model in VR has the highest overall rating and also indicates that it is highly effective in jobsite organization. The 3D site plan model on screen has the second mean value of 3.89 with the lowest standard value of 0.20. The result indicates that the 3D site model on PC screen has the medium overall rating. The 2D site plan has a mean value of 3.00 which indicates that it has the lowest overall rating.

Considering the high mean value of the 3D site model in VR, this showed that the 3D CAD tested using VR headset is more effective than the 3D site plan model shown on screen with the medium mean value and also the 3D site model is more effective than the 2D site plan with the lowest mean value. Some of the 3D site VR model testing participants indicated that the model testing takes much amount of time compared to the 2D site plan and 3D site plan. This result is consistent to findings of Kan and Azhar (2016), in which the 3D in VR headset showed the highest overall effective rating than the other two site plans (2D and 3D on screen). The raw data of the statistical data analysis is attached in appendix B.

4.4.2 Benefits of VR Technology Compared to Traditional System

Among the benefits of using VR technology in construction jobsite organization compared to the traditional method is the ability of the system to convey issues and problems regarding how the jobsite is being organized. Many construction site arrangements are planned in 2D. With the 2D drawing document it is nearly impossible or difficult to detect 3D collisions. Through the VR technology collisions between cranes can be observed, therefore rework can be reduced and also save money and time due to errors that can be fixed before the actual field installation of cranes on site.

Another benefit of using VR technology compared to the traditional system is the ability of the system to identify site access and look for issues that might hinder the movements of vehicles in and out of the construction site, therefore problems regarding the inaccessibility of the construction site can be observed and solutions can be made before the construction site. Traditional method doesn’t have the features and simulation ability to let the user observe issues concerning site access as it are represented in 2D drawing.

In addition, comparing VR technology with traditional system, VR has the potential to let the observer identify the location of materials in relation with the crane location and working areas. In this way, double handing of materials by laborers to a different location within the jobsite boundary to a closer location accessible to the range of crane and working areas can be avoided by visualizing the jobsite arrangement in VR. Lastly, comparing the benefits of using VR to traditional system shows that with the use of VR system, volume and amount of spaces on site can be observed, thus providing the users with a more illustrative site plan and letting them visually see the space utilization and create site utilization plan.

4.5 The Major Impediments of Adopting VR in Construction Industry.

Cost and time for creation of the 3D models for VR appears to be the major impediments in embracing VR in construction industry. However, a relatively large amount of money is required for investing on the use of VR. This include the investment on advanced computer software and VR hardware and software for the 3D modeling instruments, also it requires consulting fee and labor cost on management of the system.

Construction industry should consider the process of innovation and product development that occurs after a new technology is adopted and eventually as a step to next generation product. For example, in the early 80's, hand sketches were used to communicate drawings and design ideas. However in the late 80's, CAD software such as AutoCAD had emerged and wiped out poor quality drawings. Nowadays, AutoCAD is still the traditional construction drawings tools, although it has certain limitations.

Visualization can be built upon the early success of 2D CAD with revised and refined features that can bring industry to another climax. From this analogy and consecutive successful examples, we can extrapolate that although the cost of implementation was the major impediments to the industry, adopting virtual reality in construction sector is an inevitable trend.

Collective feedback from participants indicated that there is a strong interest in learning more about VR headsets in the construction industry and high amount of effort and time is needed in developing 3D site plans. Therefore, we can conclude that the time for modeling is definitely an existing barrier for the adoption of VR. Despite these facts, the advancement of computer hardware and software can greatly overcome the significant modeling time currently.

4.6 Managerial Application of VR Technology in Construction Jobsite Management

VR technology has the potential to serve as a tool for managerial to improve construction jobsite management tasks such as site layout planning. Modeling techniques and manipulation of the VR system requires computer skill knowledge for the 3DCAD model creation using either database approach or direct translation. All the necessary skills, tools and software's to develop visualization are available. Therefore, site engineers and planners should be trained by BIM specialist and CAD experts as it will enable them to have knowledge on how to create 3D-CAD model and understands the appropriate application of the VR technology in jobsite organization. By doing so, the engineer can be able to convert 2D to 3D in VR through modeling the jobsite based on how the construction site is been organized on the 2D drawing.

Construction managers have the responsibility of managing individuals with various roles appropriate in the construction project. The construction manager can hire or organize individual such as site engineer, site planner etc, and assign duties to the individuals. Creating site layout plan is among the duties of jobsite planner and site engineer. Construction managers should provide the site engineer and jobsite planner information on how the jobsite should be organized. The final 3D CAD site layout plan model developed by the site engineer and site planner should be visualized by a focused group leading by the construction manager using immersive or desktop VR technology. Through visualizing the model, underlying information of the jobsite organizational plan can be perceived. The visualization of the jobsite layout plan aids in verifying site logistics, problems identification, collision detection, and evaluation of site scenarios in a situation where more than one site scenarios are created.

Meetings should be coordinated among construction manager, jobsite planner, site engineer and the construction team so as to communicate the jobsite layout intentions and issues concerning the jobsite. By doing so, problems can be eliminated before the actual construction site and therefore effective jobsite can be developed. Figure 42 shows the managerial application of VR in construction jobsite management.

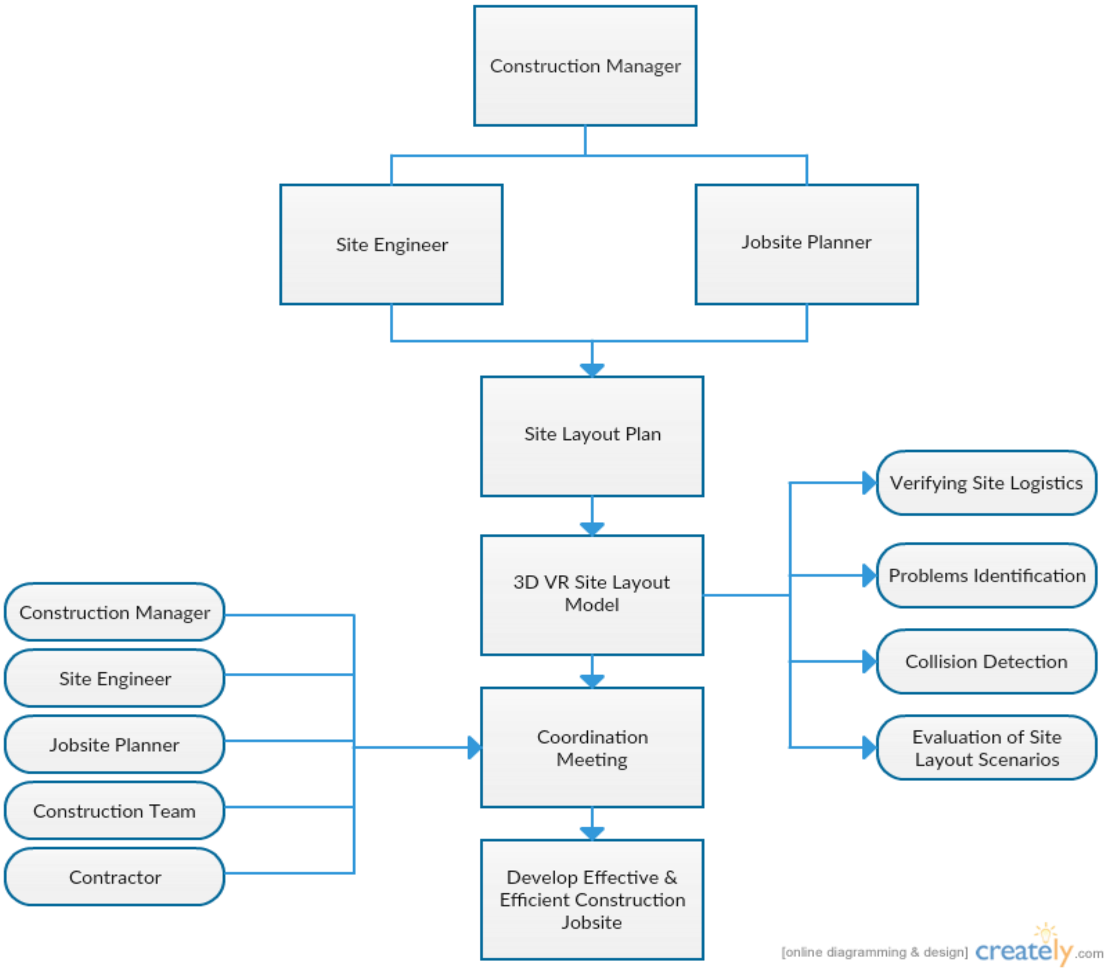

Figure 41: Managerial Application of VR Technology in Construction Jobsite Organization

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research aimed to explore the applicability of VR technology in construction management which focused on construction jobsite organization. Secondly, comparison between the traditional methods used in construction jobsite organization and the 3D site plan in VR headset was conducted in this study research. Furthermore, the benefits of using this technology in jobsite organization were explored.

In this research insight knowledge of the application of VR in construction industry in general was gained through review on theoretical background, which focused on previous and ongoing research on VR application in construction. Among the areas of VR application in both building design and construction, this research project focused on 3 areas of VR applications which includes; firstly, site layout planning which is an important tasks of construction jobsite management. Secondly, different construction site scenarios evaluation. In addition, detect problems such as detecting collisions that might happen in the construction site.

The results and findings in this research study are based on both direct observation of the 3D VR site plan model, which are supported by illustrative figures screenshot from the VR headset and testing participant’s response. Through conducting a direct observation of the 3D VR jobsite model, some issues concerning how the construction jobsite is been organized was observed.

One of the issues identified in this study was that scenario 1 has one site access that is too narrow. As a result this will obstruct the smooth flow of vehicles such as trailers in and out of the construction site. Secondly, it was observed in scenario 2 that the construction materials are not located close to the tower crane and this will result in multiple handling of construction materials on site.

Enhanced visualization of the VR system aids in detecting problems on site such as collision between two cranes in the second scenario, which indicate that the VR technology have great ability in detecting problems on site. By conducting the 3D VR test of the jobsite plan, it was observed that TF's are located very far away from the working area; as a result will increase workers travel time to dispose waste.

In a situation where there is lack of construction site layout evaluation techniques, advance technologies such as 3D-CAD models in conjunction with virtual reality (VR) technology can assist in evaluation of the construction site layout scenarios and provide a good solution to the problem.

The results of the comparison between the traditional methods used in site layout planning with the 3D site plan model in VR obtained through analyzing the evaluators response showed that 2D site plan takes less time to understand and is easier to understand when compared with the 3D site plan in VR. In comparison of other factors such as ability of the site plans in helping the user to understand and evaluate different jobsite scenarios and collision detection ability, showed that 3D site plan in VR is more effective in evaluating the two scenarios compared to the 2D and 3D site model.

The overall rating of the 3D site plans represented in the descriptive statistical format showed that 3D VR site plan has the highest rating compared to the other traditional methods; this indicates that it is more effective when determining jobsite organization. The results from this study showed that with the help of VR technology, construction site plans can be studied. Thus, contributing towards the identification of problems and solving the issues before the actual construction jobsite.

5.2 Recommendations

With the results gained in this research and the benefits of VR technology explored in this study. Recommendations will be stated as follow:

- Construction managers should experiment this 3D CAD visualization technology as it is beneficial when determining how construction jobsite is been organized. Jobsite planners should make use of this visualization technology in other to improve the efficiency of construction jobsite organization tasks. This visualization technology can help construction managers and jobsite planners to visualize the arrangement of jobsite, thus providing them with more detailed illustration of the site plan and also allow them to visualize the amount of space on site. By visually observing the space utilization, one can be able to develop a better CSUP. Lastly, it is therefore recommended to use this technology because it offers a positive advantage in identifying possible problems. Through contributing towards the identification of problems, measures can be taken at the early stage of the project.

- All the findings obtained in this research study showed that 3D CAD virtual reality technology is among the most promising technology that construction organizations can benefits from. In this way, the use of 3D visualization technology to visualize both the building design and construction is recommended to construction organizations. As this technology can aid in detecting issues at the early stage of a construction project. However, it will be very hard for construction organizations to replace traditional methods such as 2D site plans. Thus, this technology can be used in conjunction with the traditional method, through modeling the 3D site plan based on the 2D site plan drawing and convert the model to VR reality to test the model in VR mode using the VR headset.
- Designers, architects and real estate developers can communicate design ideas to their clients by using VR technology to explore and show the 3D models such as buildings, homes and office, as this virtual tower enables the client to have a VR experience of the design and how it is going to look like after construction.

5.3 Recommendation for Future Research

Based on the identified various aspects and applications of VR technology in construction, recommendations for further research are suggested below:

- During the extensive knowledge gained through reviews on theoretical background of the topic under study, safety training was identified as one of areas of VR application in construction. Therefore further research on this topic under study should try and focus on examining how this technology can best serve as a tool for training construction workers and identification of hazards through training workers in the immersive VR environment.

- In this research study, limited ability of the VR system to let the user interacts with the 3D objects in the virtual world was revealed. Therefore, further research on this technology should try and address this issue by expanding the current research.

REFERENCES

AEC Business (2015). Why Logistics Are Key to Any Construction Site. (available online http://aec-business.com/logistics-key-construction-site/ [accessed on 13/03/2017]).

Ajang, B. (2016). Using Augmented and Virtual Reality Technology in the Construction Industry. *American journal of engineering research* (AJER), 12, pp.350-353.

Bouchlaghem, N. M., & Liyanage, I. G. (1996). Virtual reality applications in the UK's construction industry. *Cib Report*, 89–94. Retrieved from http://itc.scix.net/data/works/att/w78-1996-89.content.pdf

Bouchlaghem, N.M., Khosrowshahi, F., & Whyte, J. (2000). Virtual reality as a Visualization tool: benefits and constraints, *International Journal of Computer Integrated Design and Construction*, 2, No.4, pp216-224.

Bouchlaghem, N.M., Shang, H., Whyte, J., & Ganah, A. (2005). Visualization in architecture, engineering and construction (AEC), *Automation in Construction*, 14 , pp.287-295.

Cheng, T., & Teizer, J. (2013). Real-time resource location data collection and visualization technology for construction safety and activity monitoring applications. *Automation in Construction, 34*, 3–15. http://doi.org/10.1016/j.autcon.2012.10.017

Deshpande, A., Ph, D., & Whitman, J. B. (2014). Evaluation of the Use of BIM Tools for Construction Site Utilization Planning. Proceedings of the 50th ASC Annual International Conference, Provo, Utah, May 4,2014.

Ebner, A., Kammergruber, F., & Horenburg, T. (2012). Logistics and Layout Planning Of Equipment on a VR-Multi-Touch-Tablet Construction. Proceedings of the 12th International Conference on Construction Application of Virtual Reality, Taipei, Taiwan, November 1-2, 2012.

El-Rayes, K. & Khalafallah, A. (2005). Trade-off between Safety and Cost in Planning Construction Site Layouts. Construction Engineering Management 10.1061/(ASCE)0733-9364(2005)131:11(1186), 1186-1195.

Froehlich, M., & Azhar, S. (2016). Investigating Virtual Reality Headset Applications For Construction Education and Practice. Proceedings of the 52nd ASC Annual International Conference, Provo, Utah, April 13-16, 2016.

Greenwood, D., Horne, M., Thompson, E. M., Allwood, C. M., Wernemyr, C., & Westerdahl, B. (2008). Strategic perspectives on the use of virtual reality within the building industries of four countries. *Architectural Engineering and Design Management*, *4*, pp.85–98. http://doi.org/10.3763/aedm.2008.0076

Guo, H. L., Li, H., & Li, V. (2013). VP-based safety management in large-scale construction projects: A conceptual framework. *Automation in Construction*, *34*, 16–24. http://doi.org/10.1016/j.autcon.2012.10.013

Ganah, A., Anumba, C. & Bouchlaghem, N., (2001). Computer Visualization as a Communication Tool in the Construction Industry, IEEE 2001, pp.679-683.

Jonathan, C. R., (2000). Display models: ways to classify visual representations, *International Journal Of Computer Integrated Design And Construction*, 2, No.4, pp. 242-250.

Jian- hua, S. (2008). The Application of Virtual Reality Technology Status and Future Prospects. Journal of computer knowledge and technology, 2008 (18): 1706-1708.

Kuan-Chen, L., & Shih-Chung, K. (2009). Collision Detection Strategies For Virtual Construction Simulation, *Automation In Construction* 18 (6) 724-736.

Kan, C., & Azhar, S. (2016). Virtual Reality Headsets for Immersive 3D Environment : Investigating Applications in Construction Jobsite Organization. Proceedings of the 20th CIB World Building Congress - Intelligent Built Environment,Tampere, Finland, 30 May 2016- 03 June 2016.

Kiral, I.A., Comu, S., & Kavaklioglu, C. (2015). Enhancing the Construction Safety Training by Using Virtual Environment: V-SAFE, in: 5th International/11th Construction Specialty Conference. Presented at the Construction Specialty Conference, Publications Office of the European Union, Vancouver, British Columbia, pp. 1–10.

Kizil, M., & Joy, J. (2001). What can visual reality do for safety? Berkeley, CA, Peachpit press.

Kamat, V. R., & Martinez, J. C. (2006). Interactive Collision Detection in Three-Dimensional Visualizations of Simulated Construction Operations, Engineering with Computers, Springer, London, UK.

Lyne, D.S. (2013). Development of virtual reality applications for the construction industry using the Oculus RiftTM head mounted display. Proceedings of the 13th International Conference on Construction Applications of Virtual Reality, 30-31 October 2013, London, UK. 556–563.

Li, Z., Anson, M., & Li, G. (2001). A procedure for quantitatively evaluating site layout alternatives. *Construction Management and Economics*, *19*(5), 459–467. http://doi.org/10.1080/01446193.2001.9709622

Mincks, W. R., & Johnston, H. (2010). Construction Jobsite Management, 3 rd Edition, Delmar Cengage Learning.

Matjazˇ Mihelj, Novak, D., & Beguš, S. (1999). Virtual reality technology and its industrial applications. Control Engineering Practice (Vol. 7). http://doi.org/10.1016/S0967-0661(99)00114-8

Osman, H. M., Geory, M. E., & Ibrahim, M. E. (2003). A hybrid CAD-based on construction site layout planning system using genetic algorithms. *Automation in construction*. 12(3), 749-764.

Qin, Y. P. (2013). Application of Virtual Reality Technology in Construction Control and Management. *Applied Mechanics and Materials*, *427–429*, 2851–2854. http://doi.org/10.4028/www.scientific.net/AMM.427-429.2851

Si, H. F., & Yang, Z. (2012). Research of the Application of Virtual Reality in Green Construction. *Advanced Materials Research*, *462*, 592–597. http://doi.org/10.4028/www.scientific.net/AMR.462.592

Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management & Economics*, *31*(9), 1005–1017. http://doi.org/10.1080/01446193.2013.828844

Small, E. P., & Baqer, M. (2016). Examination of job-site layout approaches and their impact on construction job-site productivity. *Procedia Engineering*, *164*(June), 383–388. https://doi.org/10.1016/j.proeng.2016.11.634

Sanad, H. M., Ammar, M. a, & Ibrahim, M. E. (2008). Optimal construction site layout considering safety and environment. Journal of construction engineering and management. *134*(July), 536–544.

Woksepp, S., & Olofsson T. (2006). Using virtual reality in a large-scale industry project, ITcon Vol. 11, pp. 627-640. http://www.itcon.org/2006/43

Whyte, J. (2000). From CAD to virtual reality: modelling approaches, data exchange and interactive 3D building design tools. *Automation in Construction*, *10*(1), 43–55. http://doi.org/10.1016/S0926-5805(99)00012-6

Whyte, J. (2003). Innovation and users: virtual reality in the construction sector. *Construction Management and Economics*, *21*(6), 565–572. http://doi.org/10.1080/0144619032000113690

.

APPENDICES

Appendix A: Sample Questionnaire Survey

QUESTIONNAIRE

You are invited to participate in this survey of VR application in construction jobsite organization which focused on testing 3 site layout plans, i.e. 3D model, 2D site plan and 3D model in VR headset. Your responses will be very beneficial in picturing the application, benefits and advantages of VR technology in construction jobsite organization. In addition, your responses will contribute to the comparison of this new emerging technology and the traditional methods used in jobsite organization.

PART 1

1) Position held in the construction industry:___________________
2) Years of experience:____________
3) Field of specialization:_______________________

PART 2

Please tick the appropriate rating category as 5 represents excellent, 4 represents very good, 3 represents good, 2 represents fair and 1 represents bad.

Questions (2D site plan demonstration)		**Participant's Rating (Frequency)**				
		1	2	3	4	5
1	How easy is the 2D site plan to understand?					
2	How effectively does the 2D site plan facilitate evaluation of two different site plan scenarios?					
3	How well does the 2D site plan shows differences of jobsite organization in scenario 1 and scenario 2?					
4	How well does the 2D site plan shows how the jobsite is going to look in reality?					

5	How effectively does the 2D site plan aids in identifying collision between two cranes on the construction site in scenario 2?					
6	How well the 2D plan does shows the distance between the tower cranes and the materials location?					
7	To what level of extent can the 2D site plan help in improving site layout accuracy?					
8	How well does the 2D site plan show the volume and amount of spaces on site?					
9	To what extent is the level of details of the 2D site plan?					
10	What is the overall rating of the 2D site plan for both scenarios?					

PART 3

Please tick the appropriate rating category as 5 represents excellent, 4 represents very good, 3 represents good, 2 represents fair and 1 represents bad.

Questions (3D site plan model demonstration)		**Participant's Rating (Frequency)**				
		1	2	3	4	5
1	How easy is the 3D site model on computer screen to understand?					
2	How well does the 3D site plan model enable the viewer to identify collision between cranes on site?					
3	How well does the 3D model aids in identifying the location of cranes within the jobsite boundary?					
4	To what degree of level does the 3D site model plans aids in checking the best location of site office.					
5	How well does the 3D jobsite plan model shows how the jobsite is going to look in reality?					
6	To what extent of level does the 3D model enables the viewer to evaluate different site plan scenarios?					

7	How well the 3D plan does shows the distance between the tower cranes and the materials location?					
8	How well does the 3D jobsite organizational model site model on screen show the volume and amount of spaces on site?					
9	Rate the level of details of the jobsite organizational plan in 3D site model on computer screen?					
10	What is the overall rating of the 3D jobsite model?					

PART 4

Please tick the appropriate rating category as 5 represents excellent, 4 represents very good, 3 represents good, 2 represents fair and 1 represents bad

Questions (3D site plan model using VR headset demonstration)		**Participant's Rating (Frequency)**				
		1	2	3	4	5
1	How easy is the VR system (VR headset) to use?					
2	How effective does the VR headset help in checking and verifying problems in jobsite organization (e.g. collision between two cranes)					
3	How well does the VR headset help in identifying the materials stacks location are far away from the two cranes in scenario 2?					
4	To what level of extent does a VR headset provide a better understanding of what to expect on site?					
5	How effectively does the VR technology facilitate evaluation of two different site plan scenarios?					
6	How well does the VR system help in identifying the site access (entrance/exit) is too narrow for two trucks to pass at a time?					
7	How well does the VR system help in checking the crane placement location in both scenarios?					

8	To what level of extent can the VR technology help in improving site layout accuracy?					
9	To what level of degree does a VR headset enables the user to feel a life-like experience?					
10	How effective does the VR headset help in showing that temporary toilets are located far away for the working areas?					
11	To what level of possible advantages does the VR headset offers in jobsite orientation?					
12	To what extent is the level of jobsite organizational plan details through VR headset?					
13	To what extent of level do you think VR headset is beneficial when determining construction jobsite organization?					
14	How well the 3D VR jobsite model shows volume and amount of space on site?					
15	What is the overall rating of the VR technology (VR headset)?					

Appendix B: Statistical Data Analysis

Table 11 shows the statistical data analysis of the overall 2D site plan rating obtained from MS excels 2010.

Table 11: Statistical data analysis for 2D site plan overall rating

Column1	
Mean	3
Standard Error	0.2113449
Median	3
Mode	3
Standard Deviation	0.668331255
Sample Variance	0.446666667
Kurtosis	0.040646978
Skewness	0.092120732
Range	2.2
Minimum	1.9
Maximum	4.1
Sum	30
Count	10
Largest(1)	4.1
Smallest(1)	1.9
Confidence Level (95.0%)	0.478095379

The table below shows the statistical data analysis of the overall 3D site plan rating obtained from MS excels 2010

Table 12: Statistical data analysis for 3D site model plan overall rating

Column1	
Mean	3.89
Standard Error	0.064031242
Median	3.85
Mode	3.8

Standard Deviation	0.202484567
Sample Variance	0.041
Kurtosis	-1.342454888
Skewness	0.16863676
Range	0.6
Minimum	3.6
Maximum	4.2
Sum	38.9
Count	10
Largest(1)	4.2
Smallest(1)	3.6
Confidence Level(95.0%)	0.144848734

Table 13 shows the statistical data analysis of the overall 3D VR site plan model rating obtained from MS excels 2010.

Table 13: Statistical data analysis of 3D VR site plan model overall rating

Column1	
Mean	4.033333333
Standard Error	0.093943583
Median	4.1
Mode	4
Standard Deviation	0.363841933
Sample Variance	0.132380952
Kurtosis	6.898555975
Skewness	-2.270472137
Range	1.5
Minimum	2.9
Maximum	4.4
Sum	60.5
Count	15
Largest(1)	4.4
Smallest(1)	2.9
Confidence Level(95.0%)	0.201488947