

# **VIRTUAL REALITY AS A TRAINING TOOL FOR BUILDING OPERATIONS**

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**Abstract**

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Virtual Reality (VR) applications within the AEC industry have seen a significant rise over the past couple of years. People within the AEC industry have started to realize the benefits and capabilities of VR. The most common use case of VR has been its use as a spatial visualization tool. Immersion and Interactivity have been at the forefront of what VR should offer. This thesis aims at exploring of the one of the many use cases of VR for the AEC industry. This research project aimed at using VR as a training tool for building operations. This meant for outlining what type of building operations training to do, development of an interactive Virtual environment that operators can train on and finally recording their outputs in the form of a written survey. A case study form of research methodology was used to document the findings of this research project. Operators were asked to experience the VR training themselves and provide a feedback in the way of answering a survey form which aimed at documenting their understanding of the system and process knowledge with regards to the training. The findings from this study showed that VR as a training tool has a bright future and that the knowledge transfer through VR training is much more efficient. Looking ahead this research project explored a relatively new use case of VR especially for the conventional construction industry and it can be hoped that such efforts to explore other use cases can make the construction industry's existing work flow more efficient.



## CONTENTS

Acknowledgement .....	2
Abstract .....	3
Introduction .....	4
Research Question .....	5
Literature Review .....	6
What is BIM? .....	7
BIMs Foray into the Facility Management (Life Cycle Management & Building Operations) .....	10
What is Training and how does knowledge transfer work from VE's to real world? .....	11
Virtual Reality Synopsis .....	15
Merits and Demerits of the Virtual Reality System.....	17
Merits of the Virtual Reality System in a learning environment:.....	17
Demerits of a Virtual Reality System in a learning environment .....	18
Virtual Reality used in Building Operations Training .....	19
Conclusion of Literature Review .....	23
Research Methodology .....	25
Goals and Objectives.....	25
Case Study as a Research Methodology .....	26
Why choose Case Study as a Research Methodology? .....	27
Research Phases.....	29
Recruiting Study Population.....	32
Research Setting.....	32
Data Collection .....	32
Construction Project Synopsis.....	33
Pinpointing the Virtual Reality Use case .....	33
Content Development.....	44
Software's Used .....	44



3D model Development .....	45
VR Development .....	46
Hardware Specifications.....	50
Survey Groundwork .....	51
Results and Analysis .....	53
Survey Section 1 (Testing base knowledge after completing training).....	53
Survey Section 2 (Talk out loud and VR questions).....	55
Survey Section 3 (Future Recommendations).....	56
Survey Section 4 (Learning Matrix) .....	56
Quotes from the Operator .....	58
Conclusion .....	59
Limitations of the Research Project .....	60
What was Accomplished? .....	61
Contributions to the Construction Industry.....	61
What does the future look like and what can be accomplished?.....	62
References.....	64
Appendix .....	68
<b>LIST OF FIGURES &amp; TABLES</b>	
Figure 1 VR Training Setup (Goulding et. al., 2011) .....	20
Figure 2 Gamification of learning process (Goulding et. al., 2011).....	20
Figure 3 VR and AR Roadmap for UW Implementations .....	40
Figure 4 Initial VR Training work flow .....	43
Figure 5 Software’s used for developing VR Training .....	45
Figure 6 WCUP Switchgear panel detailed Sketchup 3D model .....	46
Figure 7 Sequence of Operations for the Switchgear assembly .....	48
Figure 8 VR Development work flow.....	49
Figure 9 HTC Vive VR Headset.....	50
Figure 10 Survey Section 1 .....	53
Figure 11 Survey Section 2 .....	55
Table 1: Notable Literature in Virtual Reality in Training	Table 2: Learning Matrix



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## Abstract

Virtual Reality (VR) applications within the AEC industry have seen a significant rise over the past couple of years. People within the AEC industry have started to realize the benefits and capabilities of VR. The most common use case of VR has been its use as a spatial visualization tool. Immersion and Interactivity have been at the forefront of what VR should offer. This thesis aims at exploring of the one of the many use cases of VR for the AEC industry. This research project aimed at using VR as a training tool for building operations. This meant for outlining what type of building operations training to do, development of an interactive Virtual environment that operators can train on and finally recording their outputs in the form of a written survey. A case study form of research methodology was used to document the findings of this research project. Operators were asked to experience the VR training themselves and provide a feedback in the way of answering a survey form which aimed at documenting their understanding of the system and process knowledge with regards to the training. The findings from this study showed that VR as a training tool has a bright future and that the knowledge transfer through VR training is much more efficient. Looking ahead this research project explored a relatively new use case of VR especially for the conventional construction industry and it can be hoped that such efforts to explore other use cases can make the construction industry's existing work flow more efficient.



## Introduction

The past decade has seen a great technological revolution in the construction industry. With the introduction and large-scale commercial application of BIM, the processes within the construction industry have become a lot easier as compared to the earlier times. BIM has helped in organizing the vast data sets of information and integrating it into a 3D model or a 4D model, which in turn has helped in the project visualization, development, and interpretation. The whole design phase has shifted its momentum from being an on-paper approach to a more digitized approach with the help of the BIM process. Virtual Reality as a technology has emerged to act as a great enhancement to these visualization and co-ordination components in day to day construction activities.

VR is a technology that will help bridge the gap between the virtual world and the real world. Virtual reality systems are generally composed of four elements: 3D virtual environment (VE), data, computing, and presentation. These four elements work in coherence with each other to provide an exhilarating experience that is very easy to interpret. The 3D VE makes up for the most important part of VR as it is the base on which other elements provide input to. The data and computing elements go hand in hand providing the necessary understanding that shapes the 3D VE followed by the final element which is presentation which is done with Head Mounted Devices (HMD). VR provides an edge to other technologies out there especially in the context of its spatial representation and how it is very realistic and life-sized.



There have been plentiful studies that show the benefits of VR technologies because of its recent emergence as one of the hottest trends in the information technology world and it has been fast paving its way into the construction industry. The value proposition of VR discussed in this research project was from Operations Training standpoint. Virtual reality systems represent a powerful tool for training humans to perform tasks which are otherwise expensive or dangerous to duplicate in the real world. The idea is not new. Flight simulators have been used for decades to train pilots for both commercial and military aviation. These systems have advanced to a point that they are integral to both the design and the operation of modern aircraft and this research aims at leveraging these VR characteristics of seamless integration to be used in building operations training (Adams et al., 2001).

### Research Question

Research questions are an important component for setting up the framework required to give basis to the thesis. The research questions asked in this thesis pertain to exploring the applicability of VR as a training tool for building operations. The research questions asked for the purposes of this thesis are listed below:

1. To understand whether VR training be a complement to in-person training or can it replace it?
2. How effective can VR training be as a knowledge transfer tool?



## Literature Review

The 'traditional' construction industry has been constantly challenged to improve its inherent problematic practices (Goulding et al., 2011). Furthermore, the construction industry lags other industries in terms of leveraging new technologies and innovative practices which can improve safety, cost effectiveness, quality of life, competitiveness and productivity (DFEE, 2000). The research team for this project took upon itself to bring about a change in this status quo and look at how the implementation of Virtual Reality can help with different tasks in a construction environment. The specific area where the advantage of VR was taken was in the field of training. A VR environment was developed for the Switchgear room of the West Central Utility Plant being built by Mortenson Construction on the University of Washington Campus. Training is a major expense in system operation. The time and resources associated with the development of competence in controllers and maintenance personnel represent a substantial component of overall costs. Maintenance itself requires down-time periods in which productivity is frequently diminished. Consequently, alternative and improved methods of training, which also provide augmented support for operation, promise to provide great return on investment. Traditional computer based programs have provided such alternatives (Flexman and Stark, 1987). The emerging properties of virtual reality provide an opportunity for immersion in three-dimensional, computer-generated worlds and hence a new window on the problem of operator training (Kozak et al., 1993). But, before proceeding on it is very important to know in detail about the different concepts and emerging technologies firstly starting from BIM and going on forward to the fields of training and VR to be understood of.



## What is BIM?

Over the past few years there have been many attempts to define and generalize its concept of BIM but no other definition seems as apt as the definition credited to the (National BIM Standard (NBIMS)) Project Committee of the BuildingSMART Alliance is used as, “A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward. The BIM is a shared digital representation founded on open standards for interoperability (BuildingSMART Alliance, 2010).”

BIMs originate from product models that are widely applied in the different industries that can bear its benefits. BIM gives one the capabilities of presenting structured information systematically and provide with improved and reliable digital building models. BIM is comprehended with object-oriented software and consists of parametric objects which represent building components. BIM Objects are meant to have properties which may categorize itself into two major types of attributes mainly called as a) geometric and b) non-geometric (raw/processed information) which may be useful during the overall design process involved in the different phases of construction. For example, functional attributes can be installation durations or costs, semantic information store e.g. connectivity, aggregation, containment or intersection information and topologic attributes provide e.g. information about objects' locations, adjacency, coplanarity or perpendicularity. The most important of all for this research topic is the one of topological



or if one says in VR terms Spatial information related to a geometric object present in the virtual environment (Volk et. al., 2013).

The above-mentioned BIM functionalities dictate a stable accuracy coupled with systematic information and actuality of the underlying data to fulfill their purposes for which they have been created. A frequently mentioned concept to describe information richness of BIM objects is ‘Level of Detail’ or also referred to as ‘Level of Development’ (LoD). LoD defines geometric and non-geometric attribute information provided by a model component (Volk et. al., 2013). LoD range from 100, 200, 300, 400 to 500 depending upon the project need. But for most parts during actual construction a 500 LoD BIM model is more than sufficient to get work done efficiently.

Taking cues from the above explained functionality and purpose of BIM, building information modeling is a methodology of building the design in which a high level digital model of a building is created instead of the information about a building being scattered over numerous drawings, tables, reports, documents etc. The model is called “Building Information Model” (BIM) and has strongly featured in the development of construction industry. Ideally, BIM as a concept or a system of doing things works as cement to the mortar mixture in gathering all the data from all the design documents and collating it in one place for all make use of it in a structured context potentially saving both time and money.



Theoretical developments in Building Information Modelling suggest that not only is it useful for geometric modelling of a building's performance but also that it can assist in the management of construction projects (Bryde et. al., 2012).

The BIM process if correctly applied to a construction project has the capabilities to be the reagent for Project Managers to reengineer their processes thus giving rise to much better integrations of the different stakeholders at different stages of construction (Bryde et. al., 2012). Functionalities and applications due to numerous design, engineering, construction, maintenance and deconstruction services during building design and operations, potential applications and required functionalities of BIM in buildings and infrastructures are manifold and can provide a technological and administrative edge in a very competitive market that has yet to evolve and get in concurrence with the ever-evolving technology sector.

With time and time again processes and construction project in general have been becoming more and more complex because of the everchanging needs of the owners and in recent times the computer industry has also made many strides forward into the advancement of different new technologies. As a result, of these strides since the last decade the biggest gift to the construction industry has been the proliferation of Building Information Modelling [BIM] in industrial and academic circles as the new Computer Aided Design (CAD) paradigm. BIM is currently the most common denomination for a new way of approaching the design, construction and maintenance of buildings (Bryde et. al., 2012).



## BIMs Foray into the Facility Management (Life Cycle Management & Building Operations)

The overall use of BIM as a tool in everyday workflow of how projects are done has seen an increase; however, its use in postconstruction activities like life-cycle management is still not at par. Because BIM itself is rich in information it can provide immense benefits to the owners who will still be operating the building long after the constructions crews have left and having the power of information that BIM can provide can come in handy to an owner. The biggest deterrent to using BIM is first about its awareness and capabilities for the FM industry and secondly because of the lack of experience by owner organizations in using BIM during operations and maintenance (O&M). But, in recent years many such organizations realizing that these BIM capabilities can help them achieve even higher efficiency have mandated the use BIM on every of their projects. Per (Bryde et. al., 2012, Pg. 972), a document based way of working means that through the project life cycle there is an “unstructured stream of text or graphic entities”. This unstructured stream is a challenge for better integrated practices, with the information exchanged at the document level generally “fuzzy, unformatted or difficult to interpret”.

The architecture, engineering, construction, and operations (AECO) industry is undergoing a major paradigm shift that will require building owners to develop lifecycle-oriented BIM strategies. Consequently, owners will play a vital role in improving the maturity of future BIM-assisted projects through their requirements documentation, assessment of the quality and accuracy of BIM deliverables, and continued application of BIM during facilities management (FM). Many of these owners realizing the potential of BIM have been



implementing IFC integrated databases for FM that can be interoperable with many such components, and with recent research in COBie gives this undergoing effort a new dimension to go towards incorporating it more in an owner's representative's day to day work flow.

According to (Giel et. al., 2015), it is critical that the BIM competency of building owners be addressed if the architecture, construction, engineering, and operations (AECO) industry intends to achieve lifecycle use of building information models. Although there have been several attempts to evaluate the maturity of BIM execution, few studies have addressed the specific needs and information requirements of facility owners as a separate entity. One such requirement has been researched and studied as part of this research project which is the use of VR as a tool to help the owners with building operation and spatial mapping.

But, before we deep dive into learning of about the use of VR as a training tool it is better to first understand training in general.

### What is Training and how does knowledge transfer work from VE's to real world?

According to Hamblin, 2005 training, learning and transfer of knowledge all go hand in hand. Any kind of training forms the basis or the foundations, learning improves that to better understand things and finally transfer happens which aims at passing on the



information or practice learnt. The effectiveness of any training device is determined by the ability of the trainee to transfer the knowledge learned during training to a new task. The ability to apply what is previously learned from one task to another is referred to as transfer. For virtual training, transfer effectiveness is determined by the amount of transfer that occurs from a virtual environment to the real environment. While the bulk of research investigating transfer of training from VEs has involved learning of spatial and motor skills (Stanney, 2002), recent advances in graphical processors and other VR technologies now allow researchers the ability to investigate more complex tasks. The effectiveness and transfer of learning from the VE's to real world depends on many factors as stated below:

1. Spatial Navigation

The psychological process of navigation involves extracting visual information from the physical environment as one moves through space (be it physical or virtual) and creating accurate mental representations that can be used for distance estimation, route planning and wayfinding. Researchers are using VR to address how people extract information from the environment and how it is subsequently used for navigation and wayfinding.

Most of the studies which talk about Spatial Navigational Knowledge transfer have been successful in their pursuit to prove this hypothesis but the one which catches the eye is the one that was performed as a study using a HMD coupled with a 3D joystick to train soldiers to navigate a building. Results showed that spatial skills



learned in a VE could transfer to real-world navigation tasks if the VE provided the appropriate landmarks and cues the participants needed for navigation.

## 2. Muscle Memory

This characteristic relates to the feel of the movement that one can experience while doing a training which gets impregnated into what one calls is muscle memory. This is just like trying to learn something if you do a thing repeatedly you are more likely to get familiar with it over time and thus the steps and the content involved in that process get stored in the memory both in mind and muscle. This characteristic is what makes VR training the most lucrative because it lets you train your mind and muscle simultaneously so that when the actual task is at hand you know exactly when and where to trigger motions so that a successful outcome is achieved.

## 3. Cognitive Tasks

A certain level of aptitude or trade knowledge especially for the construction industry is required if a person wants to undergo successful training in a VR training simulation ecosystem. A thorough demonstration for cognitive skills is likely to bolster this above-mentioned claim. Some study demonstrated that VEs could be used to improve decision-making skills of platoon leaders. After four training sessions in virtual combat simulations both experienced and inexperienced



platoon leaders demonstrated improved decision making skills within urban combat environments.

Despite the positive results of the study described above, successful transfer from VEs has not been observed in all studies. Arnold et. al. (Arnold and Farrell, 2002; Arnold, Farrell, Pettifier and West, 2002) claim that training in VEs is inherently more difficult regardless of the amount of transfer that is achieved especially in the case of complex tasks that require both cognitive and motor skills.

The inference of these findings is that transfer of complex task training is more sensitive to deficiencies in environmental than interface fidelity (Hamblin, 2005).

#### 4. Spatial Aptitude

Spatial aptitude is the all about perception and how a person perceives an object will determine his/her performance within a VR learning environment.

#### 5. Gender

According to Hamblin, gender differences have been shown to play a role in performance on tasks. Especially for construction where the majority of the work force population is male but nonetheless gender does play an important role in



understanding how it can be a factor to study training and transfer of training in general.

## 6. Computer Efficacy

Computer efficacy also can be considered as one of the important factors which directly relate to transfer of learning in a VR ecosystem also very important because human-computer interaction and the application of computer-based education requires efficacy in computer applications.

Per Hamblin, research regarding self-efficacy and HCI has shown that computer self-efficacy is critical to the success of computer-based learning and may mediate gender effects such as those cited above.

## Virtual Reality Synopsis

According to Pratama, 2015, virtual reality has been associated with a computer application or as is called in recent time Human Computer Interaction where people can interact and feel spatial information in real-time. Virtual reality has three defining characteristics: interactive, spatial, and real-time. Though virtual reality is historically associated with high-end computing, a wide range of hardware and software is being used in virtual reality systems.



There are several basic principles that can be incorporated to produce a virtual reality system: position tracking, visual, audio, and haptic feedback (Whyte et. al., 2000).

1. Tracking one's position with context to the real world and hands-on control as the simplest control of hardware is a conventional mouse, trackball, or joystick.
2. Visual is experienced through sight. The representation of virtual environments can be stereoscopic, with a different picture viewed through each eye, or monoscopic, with both eyes seeing the same picture. Immersive virtual displays utilize the head-mounted display, while non-immersive displays utilize desktop monitor and bench.
3. Experienced through hearing, aural inputs and outputs are often neglected in the industrial use of virtual reality. In certain applications, audio quality may become more important than visual quality (Whyte et. al., 2000).
4. Touch and force are the major components that give haptic feedback the characteristics it has. Haptic feedback creates sensation of touching an object in the virtual world. The representation of haptic feedback in VR is typically done through vibration. To produce this sensation, at least a small motor is implanted in the controller. Every touch and force experienced by the user will cause the motor



inside the controller to spin, producing a feedback for the user. (Whyte et. al., 2000).

Although virtual and real environments are two completely different entities it is practically impossible to make a clear boundary between them. They can be better presented with two poles of a continuum, the real and the virtual (Milgram et al., 1995).

### Merits and Demerits of the Virtual Reality System

As is said, that by their true ingenious nature any system, concept or being isn't always perfect in their interpretations and understanding and there is always some room for improvements and modifications, the virtual reality concept is also such which presents itself as the 2 sides of a coin. Like nothing is perfect the VR system has some strengths and weaknesses that are worth exploring.

### Merits of the Virtual Reality System in a learning environment:

1. Interactive and Immersive learning – VR experiences provide one of the most sought after and fun ways of learning stuff that in traditional ways will require more time and be very monotonous.
2. Care free learning – The biggest characteristic where VR excels as a system is the ability of the virtual environments to simulate tasks which in real life may be either dangerous or a mistake doing them could cause much damage. This characteristic



makes VR the best in class at helping people who experience the virtual environment to learn at their own pace.

3. Widespread applications – VR can act as a technology which can be flexible enough to be applied to almost all the fields from aerospace, training, medicine, sales, tourism, real estate to construction and architecture. Not many new emerging technologies can create such a value oriented approach that can touch so many different fields.
4. Portability – In the future VR can allow for making important decisions about crucial projects without even being present on the site. This can save both time and money and make the whole decision making process virtual using and presenting information in a more intuitive way.

#### Demerits of a Virtual Reality System in a learning environment

1. Amalgamation – VR systems are yet to be able to be fully integrate at an organizational level to be able to take full use of their capabilities in day to day activities.
2. Expensive – Due to very few HUD's devices in the market and because it is a new paradigm in the tech industry VR is a very costly investment and unless it commercializes to be affordable and used by the common man it will remain strictly used by large organization that see the benefit in using VR.



3. Ideal VE's – The major drawback of VR is that one can just do so much with it. The VR environment can simulate weather conditions but there is no way it can make you feel the environment or the objects present in the VE. VR cannot promote feedback with the existing real world and that is its biggest drawback.

### Virtual Reality used in Building Operations Training

The Switchgear VR environment developed adopts a '**scenario-based**' learning/interactive experience. From a training perspective, taking advantage of a VR interactive training environment can often provide means to get learners to experience the training objectives (Magerko et al., 2002), help support learning transfer, as well as accelerate learning (Jarvis et al., 2009). Thus an 'ideal' VR interactive training environment is argued to require a realistic appeal to it, with specific set of actions available to the learner, thus simulating the experience as though it is experienced firsthand. Each time the learner enters the environment, different instructions and interactions would lead to different experiences and outcomes, thereby maximizing the learning experience. Also, the inherent cost related to VR is just the hardware and the software and thus it provides with a great ROI than traditional practices in which a physical equipment is required, there is danger involved and the costs are high if something happens to the physical equipment during training.

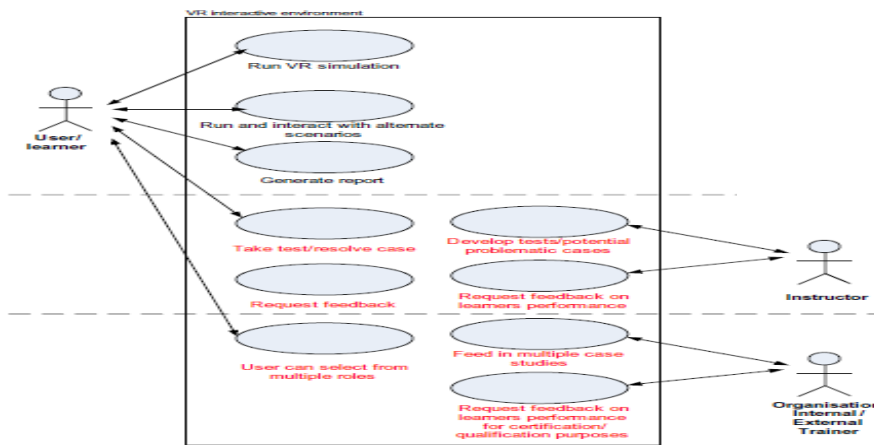


Figure 1 VR Training Setup (Goulding et. al., 2011)

(Piller and Sebrechts, 2003) institute that people develop more accurate and thorough spatial models when the walls of buildings are made transparent. Because this gives perspective to the whole spatial mapping concept and people can perceive it more accurately.

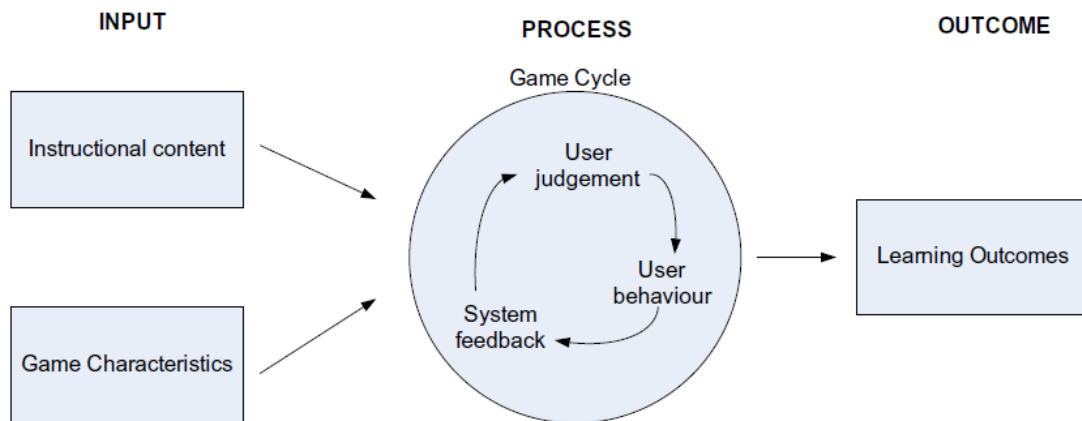


Figure 2 Gamification of learning process (Goulding et. al., 2011)



As can be seen by the dearth of examples, the use of immersive virtual reality for training interventions in construction to date is rare and the knowledge about their use and effectiveness is severely limited (Sacks et. al., 2013). Some of the practical challenges for researchers have been the significant investment required to prepare the immersive VR content, including 3D scenery, animations and the pedagogical aspects, and the need to bring workers to a fixed facility. Pairing instructional content with certain game features can arguably engage users' motivation to achieve desired instructional goals. This rationale was approached and underpinned by applying the input-process-output model of instructional game characteristics matched to specific learning outcomes (Goulding et. al., 2011).

The following table below enlists some literature which elaborate more about Virtual Reality in Training:

Table 1: Notable Literature on Virtual Reality in Training

Sr. No	Title	Author, Year	Content / Learning
1	<b>Construction industry offsite production: A virtual reality interactive training environment prototype</b>	Goulding et al., 2011	The VR environment does not aim to resolve problems, rather aims to allow 'things to go wrong' and consequently allows users not only to 'experience' the resulting implications but also to reflect on those implications as part of the learning process.



2	<b>Transfer of training from virtual reality</b>	Kozak et al., 1993	No significant difference between the virtual reality training group and the group that received no training on the task. The group that received real-world training performed significantly better.
3	<b>Construction safety training using immersive virtual reality</b>	Sacks et al., 2013	Significant advantage was found for VR training for stone cladding work and for cast-in-situ concrete work, but not for general site safety. VR training was more effective in terms of maintaining trainees' attention and concentration. VR Training was more effective over time.
4	<b>Transfer of learning in virtual environments: a new challenge?</b>	Bossard et al., 2008	Research in cognitive psychology and education has shown that acquisitions are linked to the initial context providing a challenge for virtual reality in education or training.
5	<b>Transfer of training from virtual reality environments</b>	Christopher James Hamblin, 2005	-Virtual environments can be effective training simulators for complex assembly tasks although they are less efficient than real-world training.  -Individual differences such as general



			intelligence, spatial aptitude, and computer user self-efficacy influence one's ability to learn in a virtual environment.
6	<b>Virtual Training for a Manual Assembly Task</b>	Adams et al, 2001	Subjects trained with force feedback performed significantly better than those who received no training
7	<b>The Effectiveness of Virtual Reality for Administering Spatial Navigation Training to Firefighters</b>	Bliss et al., 1997	Virtual reality training, if constructed and implemented properly, may provide an effective alternative to current navigation training methods.

### Conclusion of Literature Review

In recent times, there have been many research publications portraying the benefits of Virtual Reality used as a training tool. Many of these studies aim to figure out the factors affecting the transfer of knowledge from Virtual Environments while other studies tend to focus more on the Human computer interaction side of Virtual Reality mainly trending on how people perceive or do tasks when in a VR ecosystem. The primary drive to take up this research project was to first explore the benefits of VR as a training tool for use in building operations.



Building operations are a crucial part of everyday operations of any facility. There are very slim chances for making errors as these mistakes can be costly as well as time consuming. Apart from the part where there is zero tolerance for mistakes, some of these operations to be performed are to be done in hazardous and unsafe environments which pose threat to human life. Thus, the second part of the project included as to how people experiencing the virtual environment created for the project would react to its different aspects such as spatial navigation, attention to detail, process knowledge and so forth. These experiences of the effect of virtual environment on the people undergoing the complex training for the switchgear assembly will provide an invaluable analysis into how important a VE is in the context of a plant operator.

This study presented in the thesis hopes to outline some of the aspects related to Virtual Reality, Virtual Environment and Integration of VR in operations training. Like a two-sided coin this research will also aim at discussing the drawbacks of VR in training from an operator's perspective and also provide with future recommendations for the research as well as what could have been done better for the current project at hand.



## Research Methodology

One of the most important chapters in itself, research methodology provides the fundamental basis and justifications for pursuing the chosen research methodology that dictates the overall research being discussed in the thesis. This section of the thesis gives the overall research a purpose and understanding. Going along, this section also talks about the reason for selecting the below mentioned methodology and why it was best suited considering the direction that the research headed into towards its completion.

## Goals and Objectives

The research discussed within this thesis is aimed at comparing the conventional switchgear training or how training in general is being done currently on a construction site with the VR training. The conventional training included training through in-person sessions and through video recordings of actual people going through a step wise process of the training.

There are lot of inefficiencies in this particular type of training process mainly because of the fact that people responsible for building operation's, work in shifts and it is a 24/7 job that requires continuous monitoring. So, only a certain group or shift's particularly the day shift's get to take the in-person training themselves and the other shift must either depend on the discretion of the shift that has undergone the training or to figure it out



themselves by seeing the video recorded training tutorials. When these groups have some queries after seeing the video then they might probably ask the group that had the training to walk them through their query.

This process or workflow opens a new dimension to envision differently as to how the training process can be made more efficient and how the knowledge transfer can be perfected so that everyone receiving the training is on the same page. This is where the researcher and the project team decided to explore the benefits of Virtual Reality (VR) as a training tool. The researcher felt that the most appropriate research methodology for the undertaken research would be a combination of both a case study setup and a pilot study. This combination of the two methodologies ensured that both aspects relating to both qualitative and quantitative data were investigated and reported.

### Case Study as a Research Methodology

According to Zainal, 2007, a case study approach when applied as a methodology to any research serves as one of the best ways to understand and interpret complex problems. This method serves as one of the best ways to research for problems related to education. And since the whole research project is based on VR in training it very much relates to learning and transfer of learning which in turn relate to education for most segments of it.

Case study serves as a good method for research when just the quantitative data is not enough to provide in-depth explanations to the events occurring during its course and



because of its this unique characteristic it can help express both the outcome and process of a phenomenon which in this case was the VR training for building operations.

### Why choose Case Study as a Research Methodology?

The VR training done as part of this research had a very specific set of instructions for the operators to guide them through the training. And because of this extremely specific nature of the VR training it was important to capture as much of the process and system knowledge gained from the VR training as much as possible. Because the training aimed at just one of the aspects of building operations there was a limited availability of the people to take part in the pilot study. The researcher wanted to explore both the qualitative parts of the research as well as the quantitative parts. For capturing this a survey was taken after the operators had completed their VR training which captured both the qualitative as well as the quantitative aspects which included testing their system and process knowledge, their suggestions to the Virtual Environment and a learning matrix. Because of these data capture requirements, it was decided to go forward with case study as a research methodology to provide enough justification and in-depth analysis of the collected data. Because of case study's flexibility in capturing both types of data and because of the dearth of availability of quantitative data it served best to use it. Case studies, in their true essence, explore and investigate contemporary real-life phenomenon through detailed contextual analysis of a limited number of events or conditions, and their relationships (Zainal, 2007).



According to (Zainal, 2007) Case studies are highly carped and they remain a very controversial approach. So, it is very much important to get the design of the case study right may it be a single case or a multi-case study. The research discussed here is based on a single case here. Also, they lack robustness in their approach as a data collection tool, so combining it with a pilot study makes it a very compelling as a research methodology.

Case Study like any other methodology had it merits and demerits. The merits that a case study provides are as follows:

1. Case study allows to extend or stretch a particular subject related to a specific topic to analyze it within the constraints of the subject.
2. It allows flexibility in a sense that both quantitative and qualitative aspects can be incorporated in one.
3. The quantitative analysis done within a case study provides for more intrinsic understanding of the statistics as opposed to other methods. It helps provide both reasoning as well as justification.

The demerits of case study as a research methodology are as follows:

1. Biases are more common in a case study which can influence the outcome of the results.



2. Case studies can be far from considered as a generalization of scientific explanations because they tend to work better with a small group of people.
3. Lastly, case studies can be too long, going to details that deviate one from their perceived target and distract the reader into interpreting wrong things about the case study.

The main purpose of this thesis is to provide an understanding of using VR as a training tool for building operations as well as assess the hypothesis of knowledge transfer in a VR ecosystem. The thesis does not go into details but rather provide a brief synopsis about the hardware and the software requirements for conducting such a research.

### Research Phases

This research project started as a joint-collaboration between the researcher from the Department of Construction Management and Mortenson Construction. The research project was envisioned to continue for about 6 months since its inception in May of 2016 and it started in June of 2016 and continued until December of 2016. The research for simplicity sake was divided into three phases that will make tracking and monitoring of progress over time easy to deal with.

The first phase of the three phases included investigation into what might be of value in terms of Virtual Reality for construction that might prove to be a gamechanger for how things work in the future. This included researching and reading different literatures as well as talking to people within the owner's team (University of Washington Power Plant



management team) in figuring out what might prove the most worth for them if they had to try to somehow change their existing workflow of conventional practices to a VR oriented workflow for a particular task.

Second of the three phases were the most crucial one as it was the phase which had all the important work related to modelling and getting everything ready to be put into a VR ecosystem. This included detailed modelling of the switchgear room of the West Central Utility Plant which was selected as the portion of the WCUP building in which the VR training would be performed. The next steps included refining and rendering the model in Rhino and Unity and start with coding the elements inside the model within the Unity platform to make it interactive to be used as a training tool.

The third phase was focused on refining the approach of the work flow to be followed inside the switchgear training as well as to continue with coding to make things interactive within the VR environment. The coding was the most time taking on the entire project because of the intrinsic nature of its complexity. Survey design for the pilot study was also designed and refined during this phase. Also, recruiting and figuring out the people who would undergo this training had to be figured out. This phase was the most exciting one as this was when the developed VR training was to be tested.

A pilot study setup for this research project was done which meant for the operators to wear the VR headset and complete the switchgear training. Their interaction as well as



their movement in the virtual environment was monitored as they went through the training. A survey was developed for the pilot study to better record the operator's input that will help make meaningful analysis and to determine the cause and effect relationship.

The VR training was about 10-15 min long on an average less the time to setup the equipment and reset the training after each person had completed the training. After each person, had undergone the VR training a brief survey about 5 min long which measured both quantitative and qualitative aspects was given. The information that the survey amassed was as follows:

1. Their understanding of the research training and what the training wanted to convey
2. General thoughts about what the learnt from and liked about the training and what could have been done better.
3. Would they need more information being portrayed in the virtual environment to help them learn better and make informed decisions?
4. Their comfort level with experiencing something as new as this.
5. A comparison into In-person training vs VR training and how would they like it being implemented in the future.



### Recruiting Study Population

The people who were recruited to undergo the VR training were recommended by the Plant manager. The research team had a general criterion as to who to recruit for the study. The general criterion is as below:

1. Should possess sufficient trade knowledge to undergo training.
2. The recruits must possess an intermediate efficacy with computers.

### Research Setting

The research setting was chosen very carefully to accommodate the needs of the recruits because they are plant operators and there are only three of them on duty at any given time so they may have to rush to get things fixed if there is a problem. The room in which the VR equipment was setup was the O&M manuals room of the Central Utility Plant on the University of Washington Campus. The room had basic needs like access to electrical outlets (at least 4), enough space for the HTC Vive room mapping to work, a desk to hold the computer and decent lighting which would allow the researcher to successfully perform the VR training. There was also a GoPro camera setup in the room to help record their speech as they are undergoing their training.

### Data Collection

This section of the thesis may well be probably the most important of all as it goes into the details from how the discussed research project was decided to how it got developed and finally tested. Furthermore, this will also go into details about the development of the



survey and talk in brief about the information that the survey wanted to capture as part of this pilot study to provide some justification to the research questions asked by the researcher.

### Construction Project Synopsis

The construction project which was chosen to serve as a pilot for the Virtual Reality training simulation for building operations was the West Central Utility Plant (WCUP). This was a new construction project undertaken by the University of Washington on its campus. The main purpose of this project was to provide emergency power to the select few buildings residing in the west zone of the campus. The plant was built under a very new project delivery method which was a progressive design build project delivery method with the contract type as a GMP (Guaranteed Maximum Price). One of the notable features of this new modern day emergency utility plant was that it was a fully automated plant which can run without any necessary human intervention. The plant when completed was estimated to cost somewhere around 35 million dollars.

### Pinpointing the Virtual Reality Use case

One of the most difficult things to do as specially with a fairly new technology and that too coupled with owners who still have an orthodox mentality and liking to their paper based approach to things is to sell them on doing something completely new which changes how they tackle their everyday workflows. The first hurdle to this came at the very first FMO (Facility Management and Operations) meeting when the researcher put forth the initial idea of doing something with the use of VR on the WCUP project. The best part about the



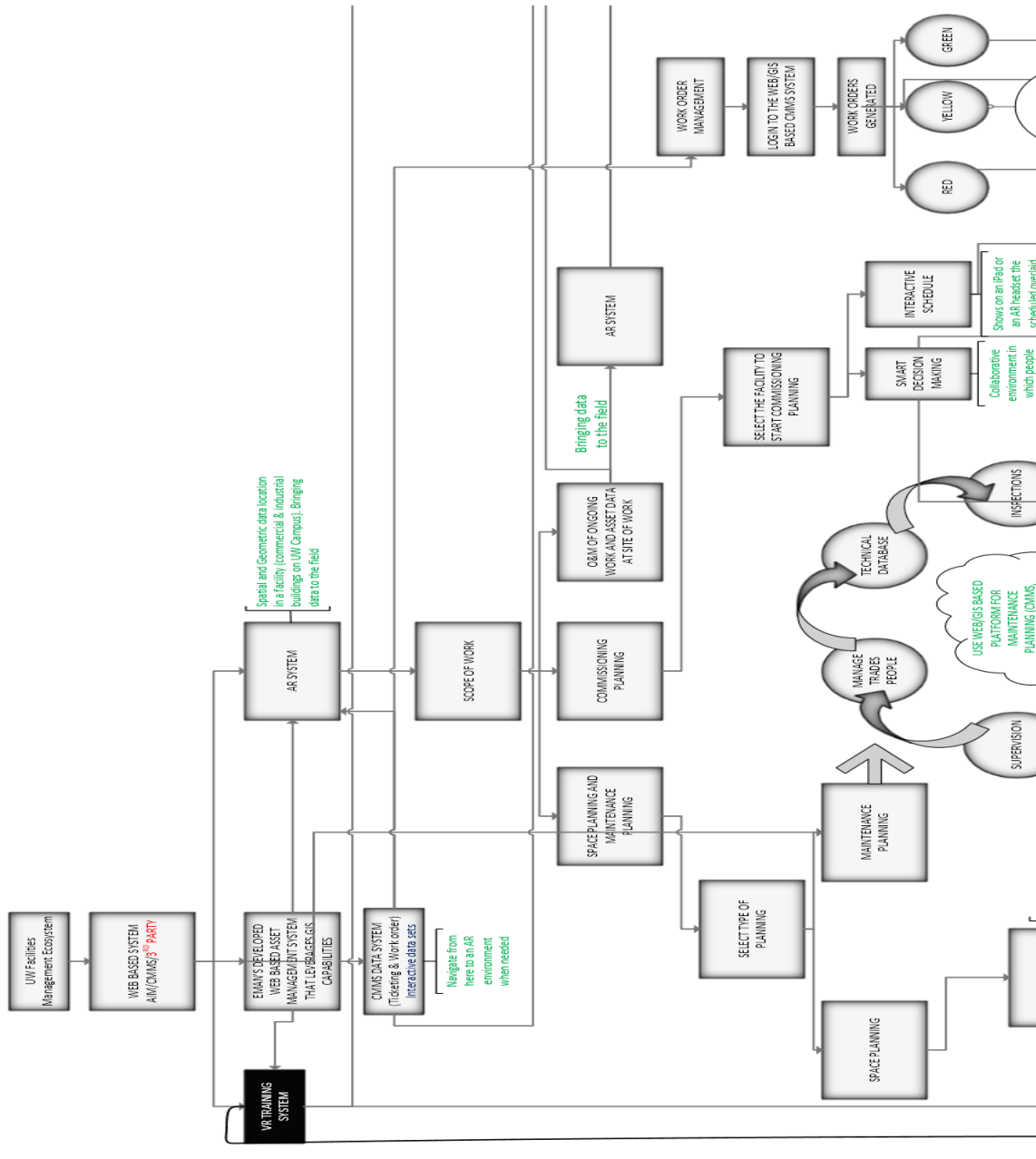
meeting was that even though the owners were very skeptical about why they should try a new thing when their existing systems work well for them, even though they had very little curiosity but they did not wind down the whole idea. This gave the researcher and the project team some hope to work towards a solution for the owner so that they can see as to how advancements in technology especially the use of VR on a construction project can help them make their work flows more efficient.

So, the first and foremost part of the three phases in which this research project was conducted as described in the research methodology was to find out that one particular process or activity that would serve as a value addition to existing work flows to the owner. The researcher had put forth some general guidelines in place to allow for this discovery of a process or activity to take place in a structured manner. Some of the general guidelines followed were as follows:

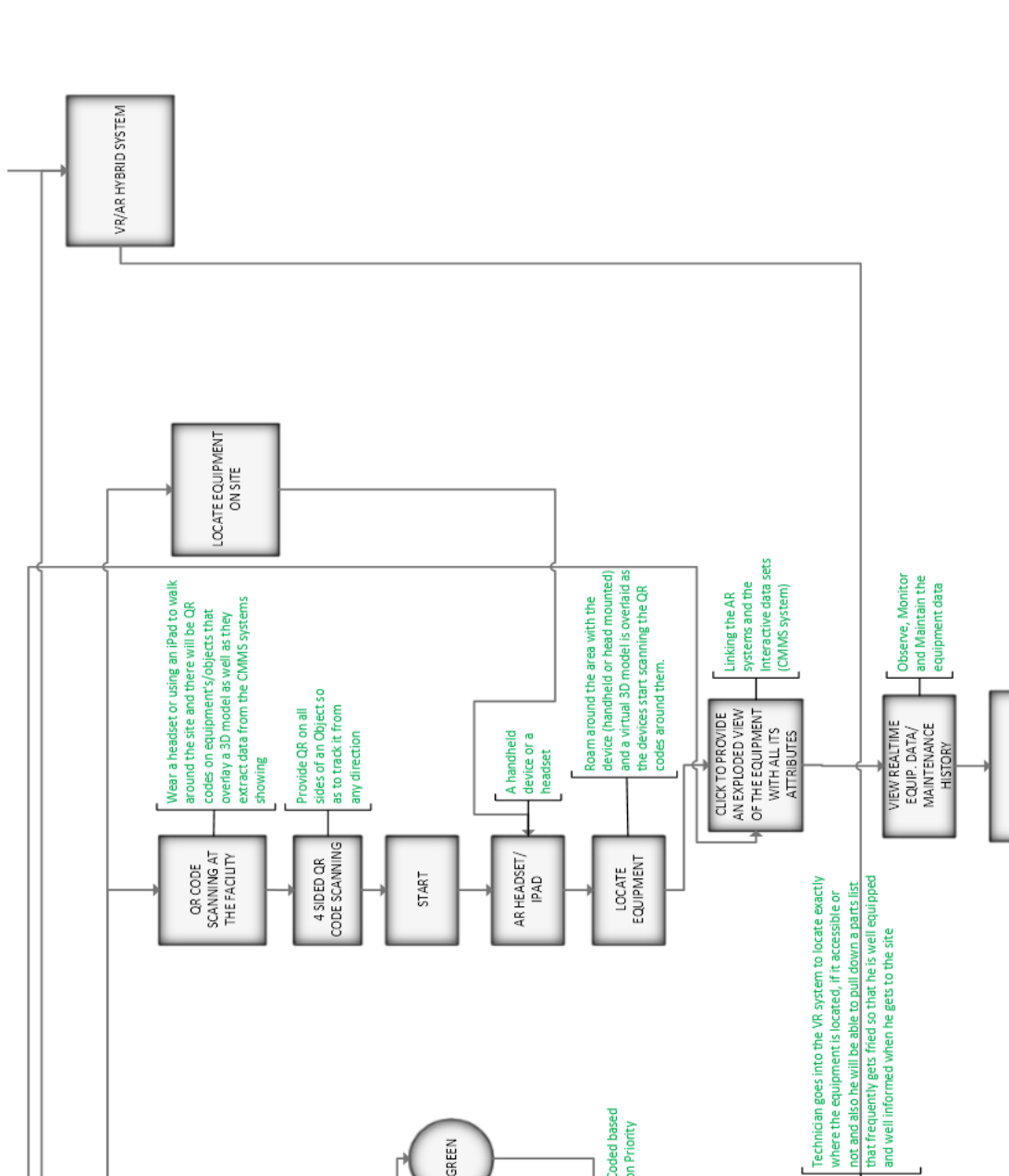
1. The proposed solution to using VR for a Facility Management process as opposed to its conventional process would have to create value for the owner as well as it should be capable in some sense to be a game changer.
2. The VR proposed solution should be simple to grasp and can be easy to get around with.
3. It should be something that can stand as one of the new VR use cases for the construction industry.



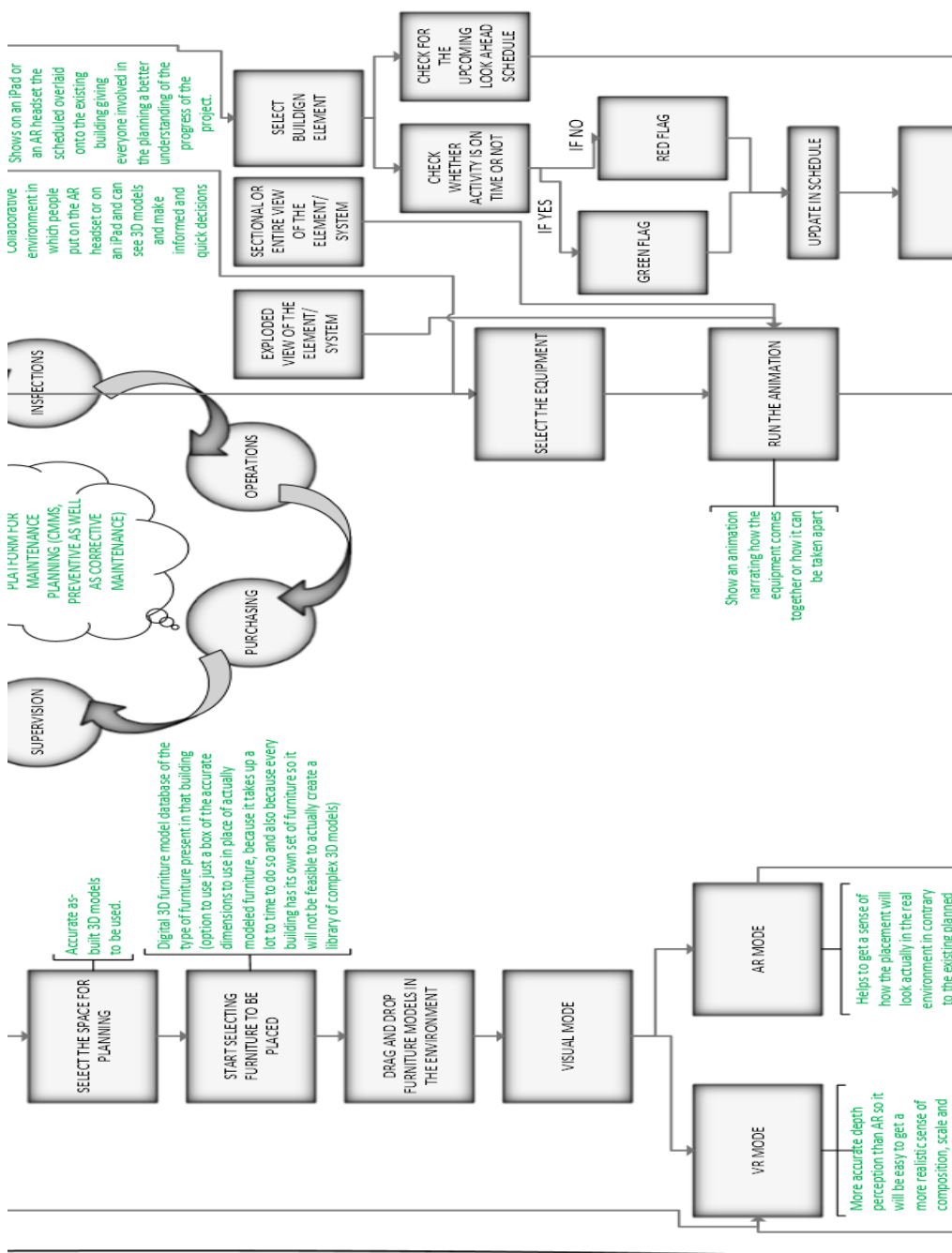
Taking cues from these general guidelines the researcher and the project team moved forward. For proper monitoring of the project so that it meets its completion deadline, meetings were scheduled biweekly with the researcher and the project team. These meetings would serve as follow-up meetings as well as brain storming sessions on selecting a VR use case. The project included the researcher, Thesis advisor, an Integrated construction coordinator and a Senior MEP engineer from Mortenson Construction. For purposes of making the brain storming session more interactive a road map of implementing AR (augmented reality) and VR into campus operations was developed which included all the domains of campus operations on the University of Washington campus that can potentially be beneficial with AR and VR applications in the future. The road map to AR and VR implementations is as below:



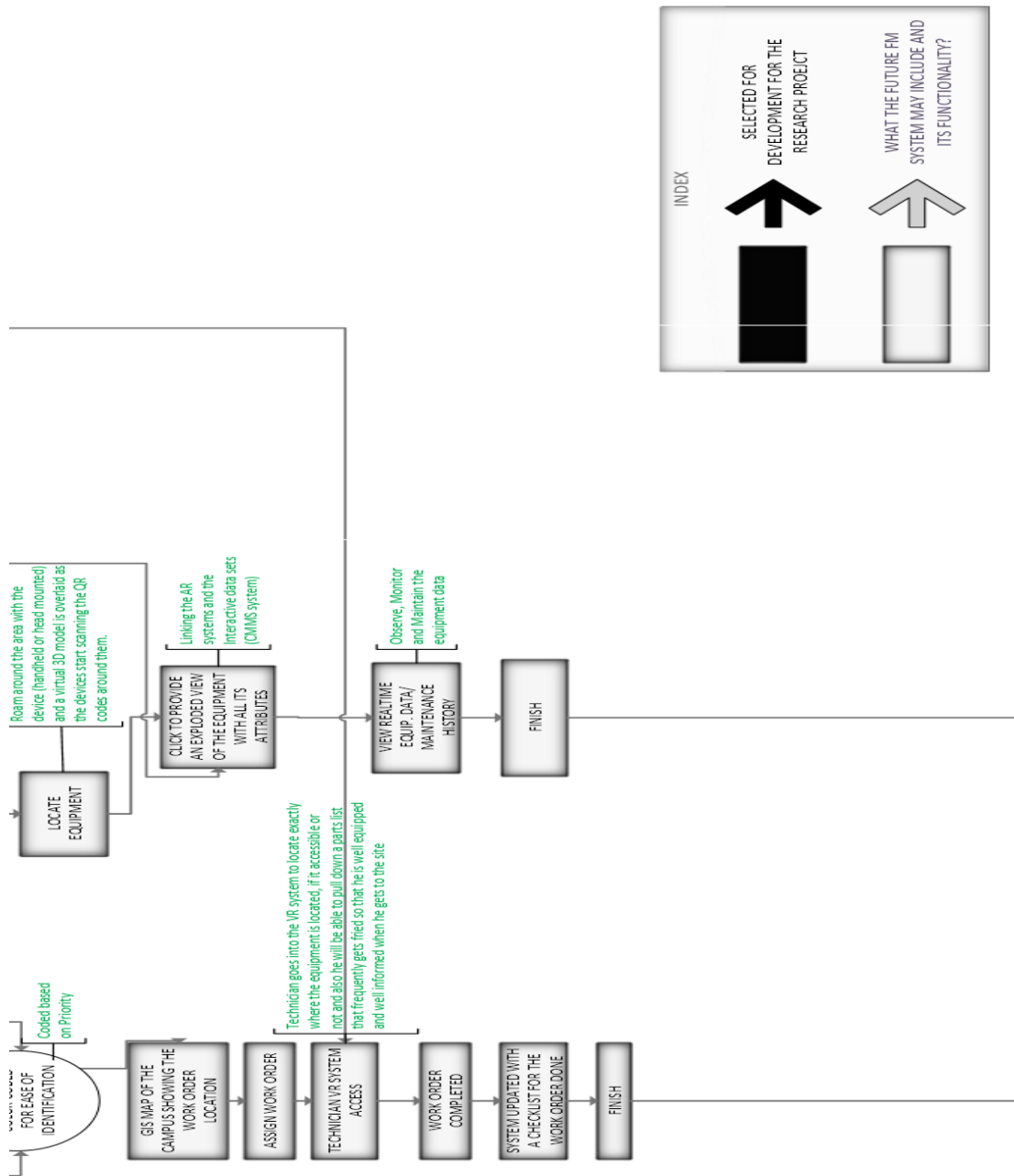
Part 1: Workflow from left to right



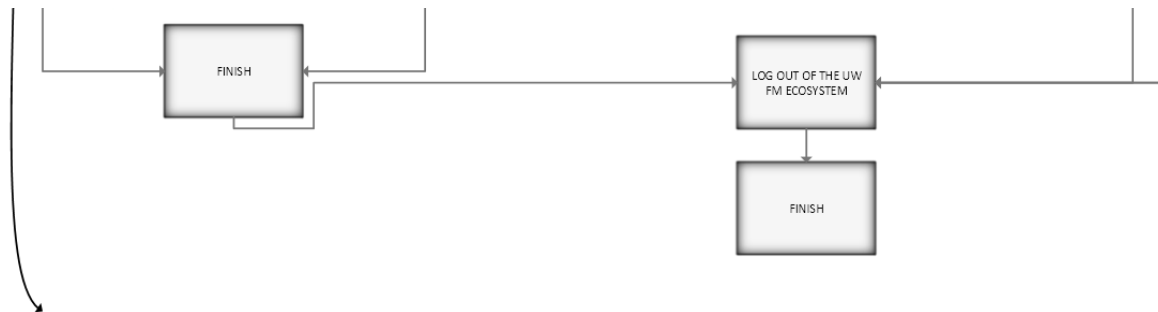
Part 1: Workflow from left to right (continue)



Part 2: Workflow from left to right



Part 2: Workflow from left to right (continue)



### Part 3: Workflow End

*Figure 3 VR and AR Roadmap for UW Implementations*

After about 2 months into brainstorming as well as talking to the workers on site and getting views from the people involved with UW facilities management team and adhering to general guidelines set forth by the researcher, the project team came to consensus about exploring the capabilities of VR as a training tool. Everyone on the project team was convinced that it will best put the value into perspective.

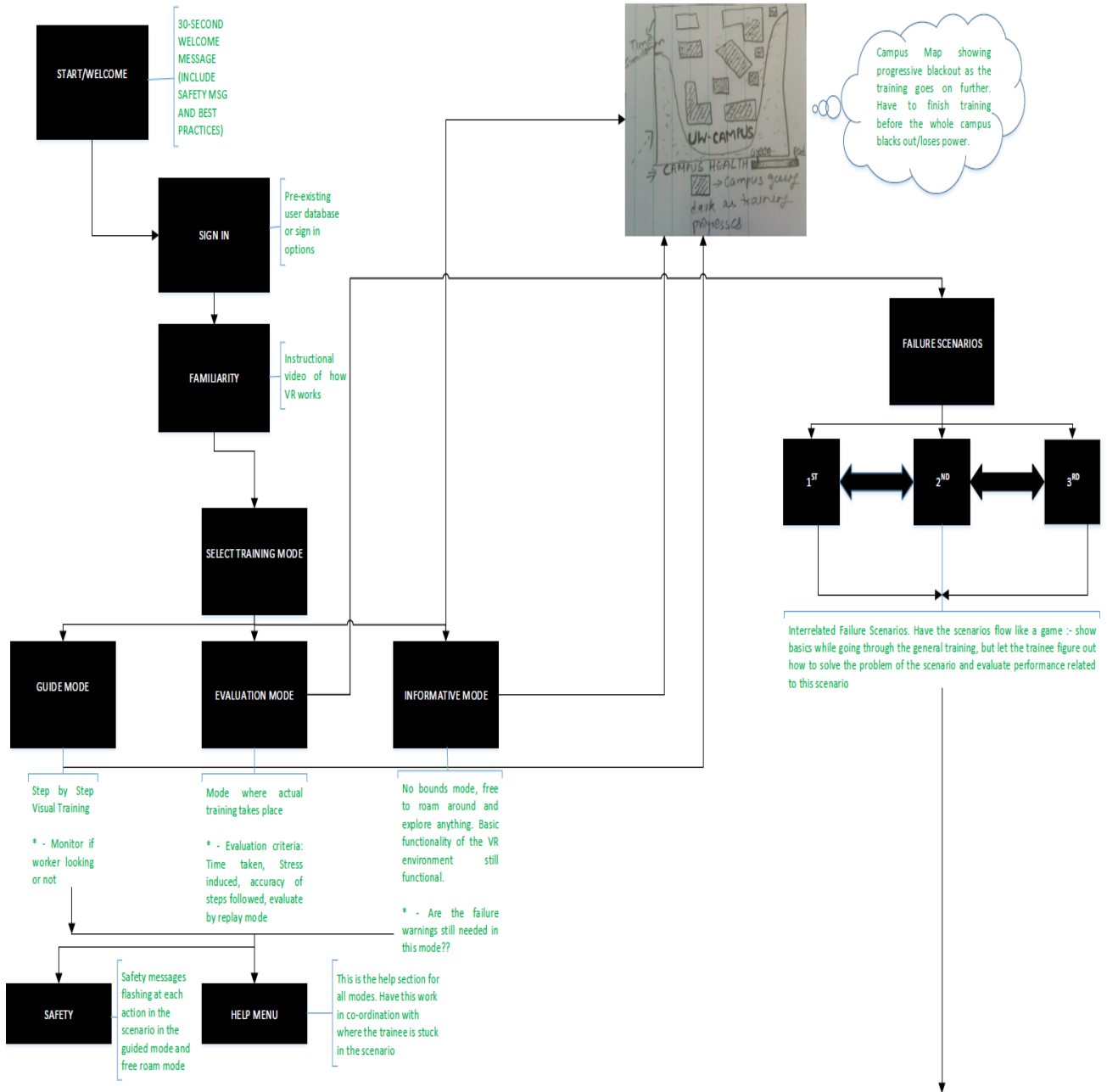
With selection of VR as a training tool the project team had only just scratched the surface seeing training can be applied to a ton of different work processes. So, to pinning down the task to which VR training would be applied to again some guidelines were created to systematically explore different options. The guidelines which dictated the outcome were as follows:



1. The task on which VR training would be applied to should be simple yet very crucial. Because it was an automated facility this criterion was paramount in the selection of the task.
2. The task on which the training was to be applied to should serve as a refresher to the already got training. Meaning it should be used to refresh one's memory of how to perform that training either once every quarter or twice annually.

Keeping these guidelines in mind, many different possibilities and scenarios were considered for implementing VR at different stages of construction. By talking with people who were going to run the plant and taking into consideration their value proposition we embarked upon developing something that was very critical to the overall operations of the plant and was such that was not supposed to be used frequently but to be used to refresh learnings. So, the decision was reached to develop a Virtual Reality training simulation for the LOTO (Lock out and tag out) procedure for a switchgear assembly. This assembly was very critical to the operations of the plant mainly because the whole plant is automated and this activity is manual so doing it wrong can lead to serious mishaps. This was the activity where leveraging the VR capabilities was best suited.

The conceptual use case VR work flow for VR as a training tool for building operations is shown in the figure below:



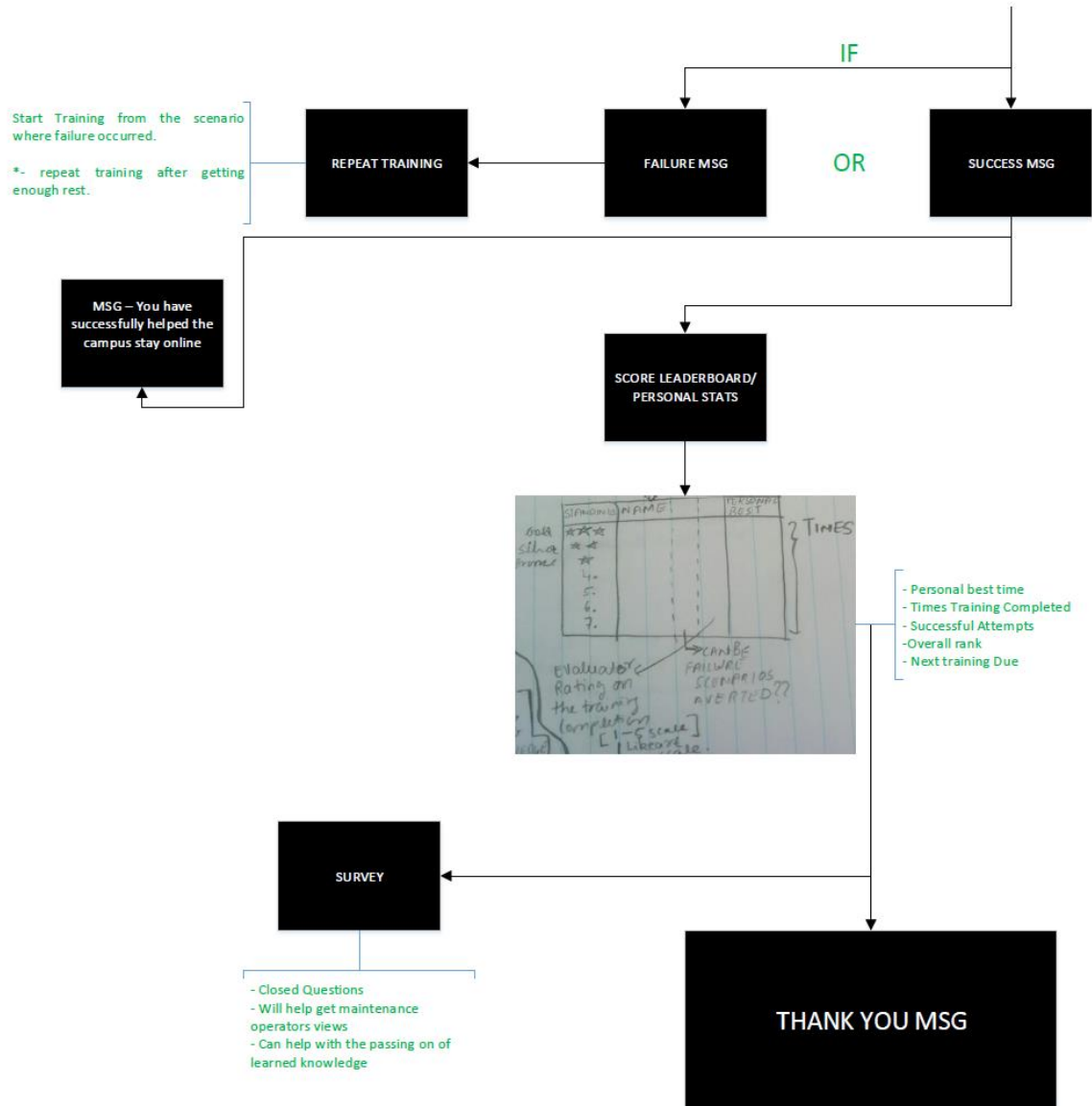


Figure 4 Initial VR Training work flow



## Content Development

Developing real world like content for VR is a very time consuming job. Fortunately, because of widespread awareness and the increasing value of BIM in the construction industry, this problem of content creation has been solved to a great extent. Most of the construction companies these days use BIM for co-ordination on all the projects they construct and for this co-ordination effort they develop 3D models that can be leveraged to be used for creating virtual environments. A typical timeline for developing a real world like virtual environment's is about 2 weeks keeping in mind that the 3D models for the building are already developed.

## Software's Used

Use of different modelling software's and a game development engine was essential to the overall success of the research project. The 3D modelling software's used in the process of creating and refining the created 3D content to be used in the game engine are as follows:

1. AutoCAD Revit
2. Sketchup
3. Rhinoceros (Rhino)

The game engine software used for making the virtual environment life-like and to make it interactive was Unity. Unity is a very powerful tool and was the best available tool to create the virtual environment for this research project.



**Revit** – 3D Model



**Sketchup** – Switchgear

Detailing



**Rhino** – Cleaning/Refining

Model



**Unity** – Game

Engine (VR Dev.)

*Figure 5 Software's used for developing VR Training*

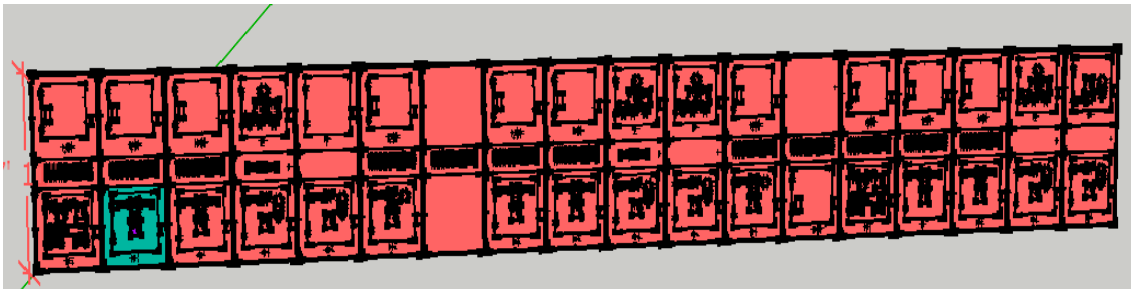
### 3D model Development

Model development for creating a real world like virtual environment is a complex task requiring 3d models that depict the exact dimensions and geometries of the buildings. As mentioned above due to awareness of BIM and most of the general contractors incorporating it in their everyday workflow, it becomes quite convenient if a VR ecosystem is to be developed. Same can be said about Mortenson who use BIM on almost all projects that they end up constructing.

The basic 3d models developed for WCUP projects were somewhere between LoD 400 to LoD 500 and same can be said about the models developed by Mortenson for their projects. Most of these models were used for BIM coordination and so they don't require a high level of detail. But, this is not true if a virtual environment is to be constructed using the already built 3d models. The 3d models for the switchgear rooms of the WCUP built by Mortenson had just plain simple rectangular box geometries showing the switchgear equipment and for developing a real world looking virtual environment the 3d model



needed a lot of face-lift. The figure below shows the model of the detailed switchgear assembly that was developed using Sketchup.



*Figure 6 WCUP Switchgear panel detailed Sketchup 3D model*

The project team had two options in terms of the software one being Sketchup and the other being Rhinoceros (Rhino) to be used for detailing the switchgear but the researcher was more comfortable and had experience using Sketchup so Sketchup was the software of choice for modelling. The model developed had to be very detailed to be able to capture the geometric details of the actual switchgear assembly because the switches and knobs on the assembly would serve as the basis to make it interactive to be used in the training simulation.

### VR Development

The most important step which would mark the start of VR development after all the 3D content was developed was the one of cleaning/refining and making the 3D models so they are ready to be loaded into Unity. For refining of the 3D model Rhino software was used. Models authored using modeling software's are a mix of polygons and other geometric shapes. The models as it is cannot be loaded into Unity mainly because it takes



much longer to process this information and the software runs into errors most of the times. So, what Rhino helps with is that it can convert these different geometries made up of polygons to meshes which makes it easy to process inside the game engine Unity. Rhino was also used in sorting of all the components of the model which include: electrical, mechanical, partition walls, HVAC and the structural systems into layers which makes it easy to code the interactions necessary for the VR training easy to code with in Unity.

Every movable component of the model was made a group using the group command in Rhino so that interactions relating to that particular geometry's movement in the three axis (X, Y & Z) was possible. If it was not grouped every mesh had to be individually coded which in general is not an appropriate method when it comes to creating the virtual environment and it takes a lot of time. After refining the model in Rhino, the model was saved as a .3ds format file which made it readable in Unity.

The rest of the major work related to developing the VE and making it life-like was done in Unity. Unity has material filters which can be used to give rendering to the different components of the switchgear room. These material filters were bought by Mortenson construction from a third party. Unity accepts coding from different language platforms but C Sharp was used as a coding language to give the interactive ability to the model. This is the stage where the VR training finally started to take shape.



Now, before the coding for the interactions and their sequencing could start it was very important to understand the step wise procedure included in the LOTO (Lock Out and Tag Out) procedure. So, for understanding it better a pictorial representation was created so that the logic behind the LOTO procedure could be replicated in Unity. The pictorial representation of the work flow followed for undergoing the LOTO procedure is shown as below:

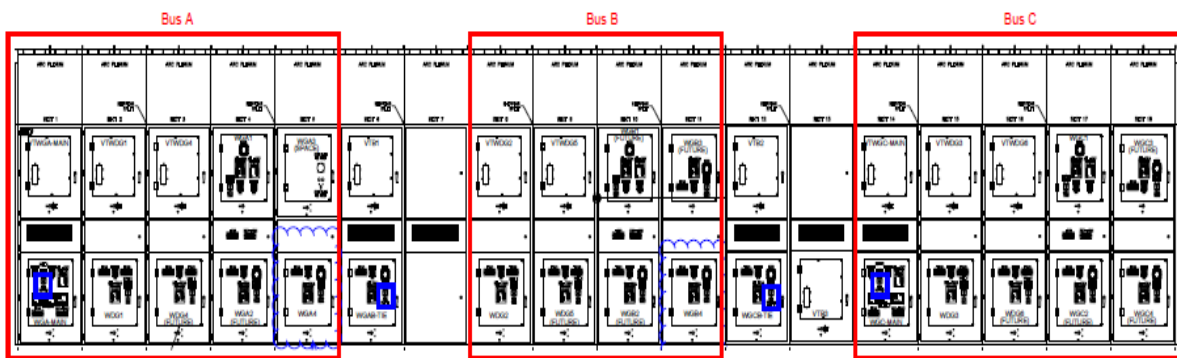


Fig 1. Medium Voltage Switchgear

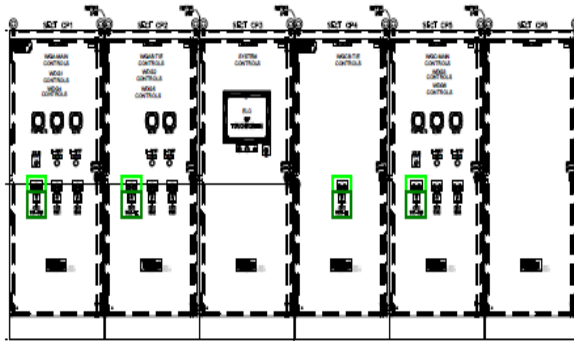


Fig 2. Paralleling Gear

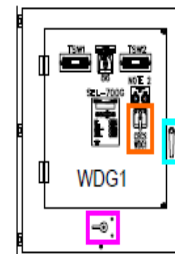


Fig 3. Typical Cubicle

Make Safe

- 1) Cut power to **Bus** - Trip and Pull-Out **CBCS** on Mains and/or Ties
  - A) WGA-MAIN and WGAB-TIE
  - B) WGAB-TIE and WGCB-TIE
  - C) WGCB-TIE and WGC-MAIN
- 2) Verify **Light** on paralleling gear
- 3) Trip **CBCS** on Feeder or Generator cubicle
- 4) **Rack out** breaker
- 5) **Open** Cubicle

Re-Energize

- 1) **Close** Cubicle
- 2) **Rack in** breaker
- 3) Arm **CBCS** on Feeder or Generator
- 4) Arm **CBCS** on Main and/or Tie
- 5) **Energize** Main and/or Tie on paralleling gear

Figure 7 Sequence of Operations for the Switchgear assembly



Apart from this, the workflow of getting a VR training ecosystem developed and to get it running can be seen in the figure below:

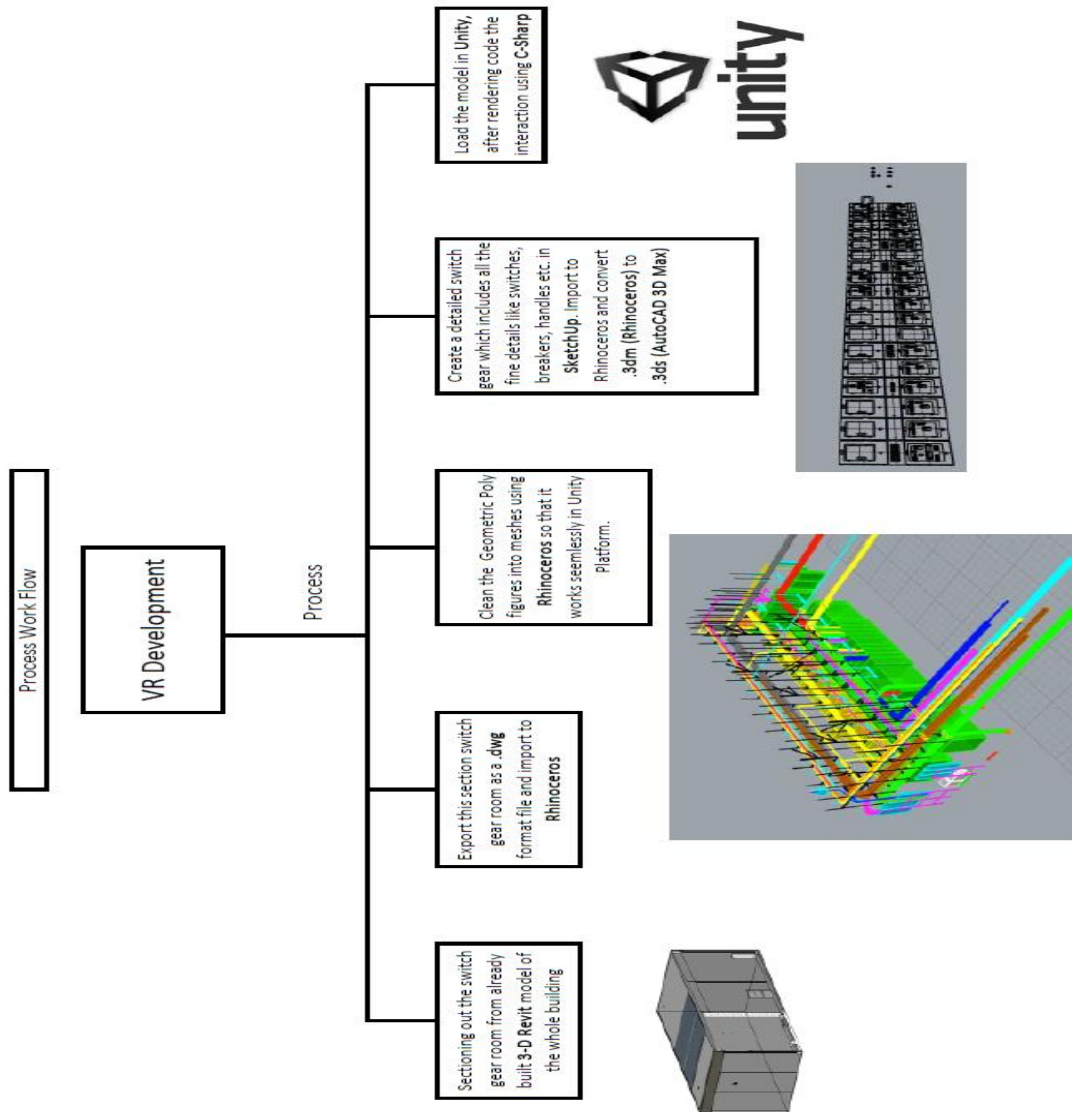


Figure 8 VR Development work flow



## Hardware Specifications

Good software without a nice piece of hardware amounts to nothing. The VR hardware used for this study was the HTC Vive. It is one of the first few VR hardware's to come to the market. The best thing about this hardware is that it can map the area that a person will use to precisely monitor and record the movements in the 3D space so that the VR view remains aligned all the time. One can interact with the virtual environment through two handheld remotes that allow a user to use it for navigating in the VE. The best part about HTC Vive is that because it runs smoothly at 90 FPS (frames per second) one does not feel dizzy while experiencing VR which is the case with other such competing hardware's. For any organization who want to implement the benefits of VR to their everyday work flow it costs just about 2000\$ to get all the necessary equipment needed to get VR capabilities. The most expensive of this setup is the desktop or laptop computer needed to run VR because it requires a very high powered GPU and these laptops/desktops don't come cheap.



*Figure 9 HTC Vive VR Headset*



## Survey Groundwork

The research aimed at comparing the conventional switchgear training with the VR training and measure the effectiveness of VR as a learning transfer tool. Typically, conventional training includes training through in-person sessions and through video. A survey was designed to better capture the results that will help make meaningful analysis and to determine the cause and effect relationship. A group of about 12 operators from three different 8 hour shifts were chosen to give a shot at the VR training and of that 4 operators agreed to undergo the VR training. The research protocol was as follows:

1. Pre-survey to assess baseline knowledge
2. Talk out loud when in VR.
3. Post survey to assess VR training.

The procedure for the pilot study went as follows:

Firstly, the research group intended to assess the baseline knowledge of the Operators attained from the in-person training but due to some limitations that was not the case and their responses after the in-person training couldn't be recorded for the purpose of the research.

As discussed above the research was designed such as to assess the effectiveness of VR training versus the in-person training. VR Training was scheduled to happen after a week



of the in-person training so that the other operators had a chance to learn the training by video or through the guidance of the people who had the in-person training. But unfortunately, only two of the people within the plant operations team had a chance to undergo the training. And of that two people none of them participated in the VR training. So, when the VR training happened none of the people who had undergone the VR training had any exposure to the in-person training. So, the teams goal of proving whether one training was effective than the other couldn't be put to fruition.

Despite this fact, the research team was able to capture their answers in section -1 of the survey but this was only limited to them answering the questions after undergoing the VR training and in conjunction with their prior experience with such operations.

The operators who participated in the training were asked to fill out the sections 1 to 4 of an individual experience survey and the detailed survey with the questionnaire asked can be found in the appendix section of the thesis.



## Results and Analysis

For the data collection, a pilot study was implemented and right after that a survey sheet was given to a group of 4 operators who participated in the survey. The earlier sample size estimated was of 12 operators but only 6 of them were present and of that only 4 people participated to experience the VR training pilot study and fill out the survey afterwards. Because sections 1 to 3 were open ended qualitative questions it was very difficult to record their responses in a tabular format. So, it was appropriate to explain everything with the analysis of the collected data to its interpretation in this section of the thesis.

### Survey Section 1 (Testing base knowledge after completing training)

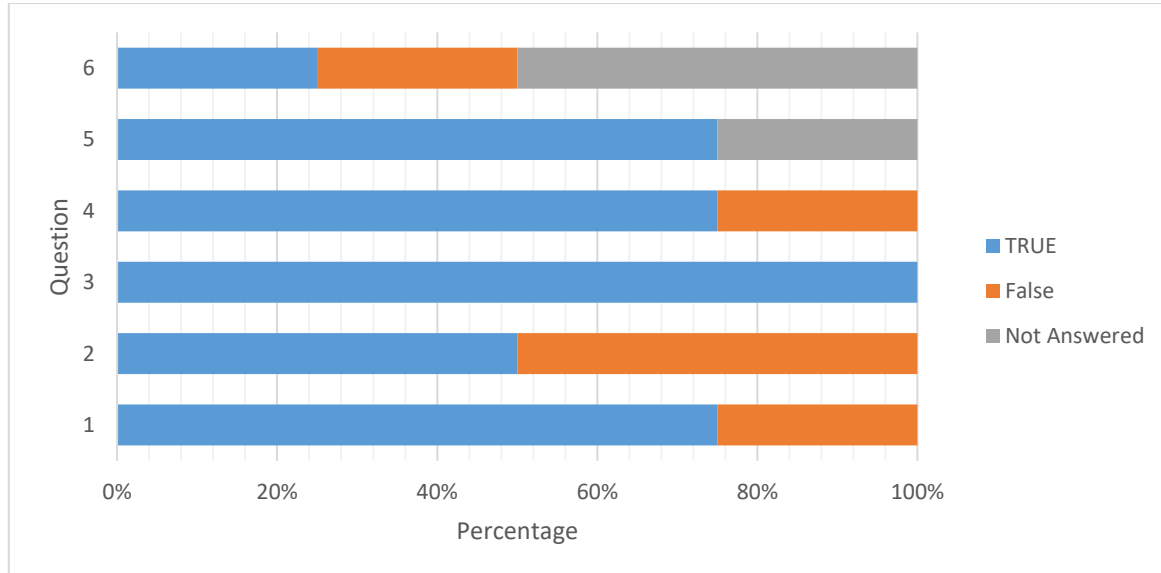


Figure 10 Survey Section 1



- **75%** of the Operators got the 1<sup>st</sup> question correct showing they fully understood it after successfully completing the VR training and could answer correctly to the asked question.
- **50%** of the operators got the 2<sup>nd</sup> question correct and the other half got it incorrect which indicated that the learning through the training for this specific process was average.
- All of them got the 3<sup>rd</sup> question correct indicating they fully understood what was being conveyed.
- **75%** of them answered the 4<sup>th</sup> question correctly showing an above average learning for that process.
- All of those who answered the 5<sup>th</sup> question for it correct stating that VR as a training tool provided significant learning of that process.
- The 6<sup>th</sup> question was the most important of all because it was a step in the training which was different from traditional plant operations of a switchgear and the learning outcome was expected to be high from this because of the training being more centered around this. Only **25%** could get it correct **25%** got it incorrect or their answer was irrelevant and about half of them did not answer the question because they did not fully understand it.



Survey Section 2 (Talk out loud and VR questions)

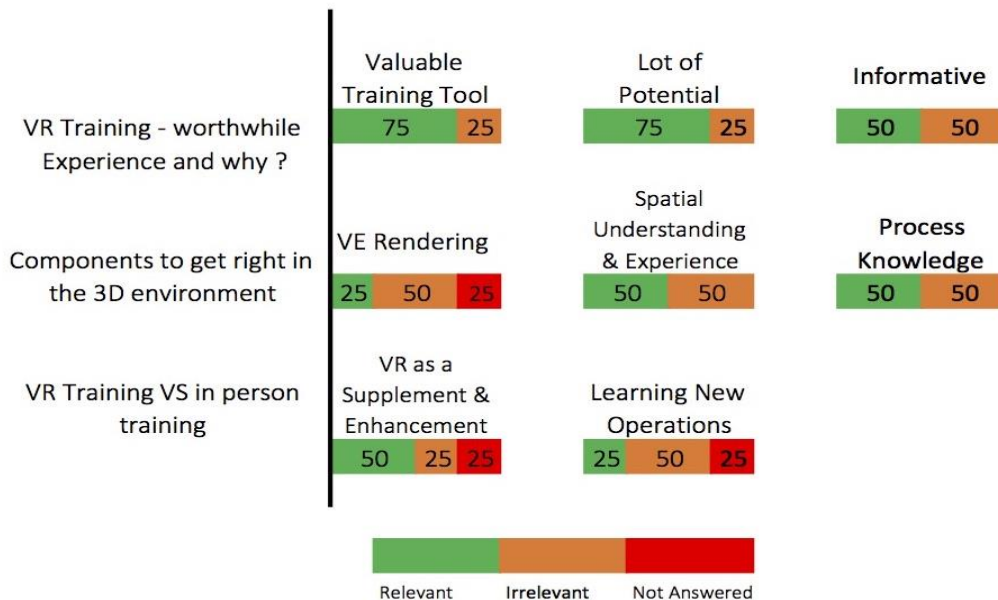


Figure 11 Survey Section 2

- From the above shown graph, it can be inferred that the operators had a very good experience with VR training and they can see its value proposition being used in the future. About **75%** of the operators found the VR training tool as a valuable and having lots of potential. About half of them found it to be informative and the other half to be not that informative and liked their in-person training better.
- Their comments of what to get right in the virtual environment were diverse and it spanned across all aspects of VR which was a good sign. One operator felt that the rendering was very important to make it look life like, about **50%** valued getting the spatial understanding and experience right and about **50%** valued to get the step by step process right as it was the most important part of the training.



- **50%** of the lot valued VR training to be used as a supplement and enhancement to in-person training rather than it taking over the in-person training completely. Also, **50%** of them valued it being used in learning new operations to be able to practice this new operations in a safe environment where their actions won't blow up anything.

### Survey Section 3 (Future Recommendations)

- Rendering of human hands instead of the blocks at the front of the controller in the VE.
- Wireless HMD VR system.
- Better key-pad arrangement and more detailed step wise procedure.
- Haptic feedback to know the feel of a breaker switch being tripped.

### Survey Section 4 (Learning Matrix)

Table 2: Learning Matrix

In-Person		Mean
	Relationship between the main bus and individual breakers	<b>1</b>
	Connect to paralleling gear	<b>0.75</b>
	Difference between CBSC switches	<b>1.5</b>



	Bus systems	<b>0.25</b>
	Safety procedures (safely operating switchgear)	<b>0</b>
	Meanings of the different light signals	<b>0</b>
<b>VR Training</b>	Relationship between the main bus and individual breakers	<b>3.25</b>
	Connect to paralleling gear	<b>3.25</b>
	Difference between CBSC switches	<b>2.25</b>
	Bus systems	<b>2</b>
	Safety procedures (safely operating switchgear)	<b>2.5</b>
	Meanings of the different light signals	<b>2</b>

The learning matrix was developed to better understand the as how in-person training does vs the VR training when the operators experience both. From the results, it can be seen from the mean for the in-person training that they average out very poorly as there is almost no learning to very little learning and these numbers were affected because the operators knew most of the stuff from prior experience. On the other hand, the VR training performs good showing the operators had significant learning from the VR



training then they had when they did the in-person training. This signifies that VR as a training tool has lots of potential and people using it for the first time can also understand the value proposition it can provide.

### Quotes from the Operator

*“WOW!! This is great. I can see the value proposition of this being used as a training tool. For me VR training would be a complement in use for low risk and more frequent operations and replacement for high risk and less frequent operations”.*

-

### Operator

*“Ohh Whoa, this is amazing. VR as a tool will be great help for me to use to tour facilities and being familiar with them because I don’t usually leave the Central Utility Plant”.*

**- Operator & Plant Manager**



## Conclusion

VR is the new trend within the tech industry and has quickly made forays into different fields which included construction. The advantages that VR as a tool can offer are slowly but proactively being understood by the construction industry. Construction as an industry has been inundated for being very slow at adapting newer trends which in the end increase their efficiency. But with this research and the course in which it was completed as well as talking to people who were very much critical of its introduction into everyday workflow, after getting first-hand experience into experiencing it had only good things to talk about it. Apart from their good reviews about how it was a new and interesting way of doing training to their constructive criticism about how they would want more functionality or what was missing as well as listening to new ideas as to where the true value of VR can be taken advantage of were put forth by the operators. This says just one thing about people and technology, that one can never know the true potential of things unless one experiences it.

VR is slowly but progressively making fronts into the construction industry. It will take some time before construction personnel begin understanding its potential. The benefits at various levels of different workflows in the construction industry that VR can provide are immense and taking cues from this, the thesis explores one such domain in which VR can be used apart from as a spatial visualization tool.



The research project aimed at validating the possibility of using VR in the construction industry especially as a training tool for the operators on the site. The results were both on a positive as well as a negative note but it is safe to say that the advantages that VR offers outweigh its limitations and it can prove to be a go-to training tool in the future which has lots of potential. One of the drawbacks of this research project was that the results of the pilot study and surveys cannot be taken as a true sense of what it represents because of the sample size being too small to make very conclusive remarks. But it indeed was very helpful in analyzing the research questions asked by the researcher in this thesis to a great extent.

### Limitations of the Research Project

Having discussed in detail about the research project and analyzing the results it is also important to discuss its shortcomings or limitations. Every research is prone to some limitations and these limitations help pave way for future research to make amends on the lesson learned and move forward for the greater good in that particular field of research. The research project discussed in this project also had some limitations worth mentioning. The research was studied as part of the case study methodology and it was more of a quasi-research because there were some inherent limitations while conducting the research. The most important limitation of all was that the research was not able to establish a baseline knowledge for the operators that did the VR training because none of the operators received the in-person training. The learning matrix presented in section - 4 of the survey aimed at comparing the in-person training vs the VR training captured the in-person training from the operators based on their years of experience rather than them actually doing the in-person training. Another limitation was the study population was



very small because of the nature of the VR training and also of the fact that it was a specific building on campus operated by a handful of qualified people. So, because of this the survey results cannot be taken at their face value as they don't signify conclusive results. These were the two important limitations encountered during the research project.

### What was Accomplished?

An already existing but a new dimension of Virtual Reality for construction practices was explored, not just as a spatial representation tool but to be used as a more interactive tool helping the operators to learn new operations and be trained effectively.

### Contributions to the Construction Industry

#### **1. A different way to undergo building operations training was explored.**

Most of the trainings that happen on-site are either in-person trainings or the operators learn these trainings while watching the video recordings of these trainings. On top of these they might have to undergo training on live equipment which has two facts to it, first it is not very safe and second mistakes working on actual equipment can be costly. The use of VR in training for building operations use case shows how these inherent inefficiencies in in-person trainings can be minimized by implementing VR training. Also, VR allows for the operators to undergo training and learn about stuff and get familiar with the facility even before



the facility is constructed and this gives them a tactical advantage because they are better prepared and know what to expect.

## **2. Efficient way of knowledge/learning transfer was demonstrated**

No one can shy from the fact that the construction and the building operations industry's major workforce has a very high average age. And an aging work force is a problem for the future generation because the learnings and experiences that any senior person has is not recorded anywhere. Thus, it becomes very important to take into consideration of this issue. VR can serve as a bridge to collect and portray this information in a much more interactive way. Because of its unique characteristics, VR can record as well as represent. Also, from the data collected for this research study from the survey it was that VR was a very useful knowledge transfer tool and that the operators actually learned something out of their VR training experience.

### What does the future look like and what can be accomplished?

The future for VR to be used as a training tool look bright. For future studies, it should be kept in mind to have a higher sample base to start with. The activity selected and the type of building really narrowed the number of people who would be performing operations on that equipment for the research team and so an activity which could potentially be



used/operated by a higher number of people should be selected for the VR training development to get more specific and conclusive results of VR as an effective training tool.

Also, VR has capabilities to allow for two or more people to be present in the same environment. Another good study would be to compare how people who are undergoing the VR training react to a computer simulated VR training giving out steps or an actual trainer who is present in the VR environment and guiding the person through the training. It would be exciting to see the results of this studies. It would also be more exciting to understand collaboration on a VR platform for building operations because this concept has immense capabilities if an abstract of its capabilities are thought through. However, as much as the researcher would like to see these studies of the future come to fruition, it can be said for now that the use of VR in the construction industry has a lot of potential and it was a great learning experience for the researcher and the researcher hopes to see more studies exploring a different VR use case to support construction and lead to the furtherment of the industry in general.



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## Appendix

### SURVEY

#### Section – 1 Training Procedures: (Refer to Appendix for pictures of the switchgear)

1. What is the first step to open Bus B for maintenance?
2. If you wanted to take out of service, the B bus terminal what procedure would you follow?
3. When closing Bus B, what does the red light on the switchgear breaker control panel indicate? If it is on, what is your next step?
4. If the green light on the switchgear breaker control panel is on, what does that indicate? If it is on, what is your next step?
5. What is different on the main breaker CBSC switch on the VTWGC - MAIN as compared to the other switches?



6. Why is the main breaker (WGC – Main) different?

### **Section – 2 Talk out loud**

Step 1: First Guided walk through then test scenario: Ask them to conduct a lock out tag out a breaker (question asked within VR). Ask them to Talk Out Loud throughout.

Step 2: In VR questions:

1. Has the VR training presented a worthwhile experience to you and why?
  
2. Thinking about graphical accuracy – what components do you think are important to get right in the 3D world?
  
3. What will drive you to use VR training over the in-person training?



**Section – 3 What are future recommendations?**

1. What would you like to improve in the VR training experience with regards to process (sequence of operations)?
  - a. With regards to System (which breaker, elements, visual signals)?
  - b. With regards to Safety?
  
2. What more technical information related to the training would you like to see in VR? e.g. access to training manual in VR
  
  
  
  
  
  
  
  
  
  
3. Would you recommend the VR training as complement or as a substitute to the in-person training? Why?

**Section – 4 Matrix for VR vs In-person Training (Rate your learning based on a Likert scale, 1 – no learning & 5 – learnt a lot) OR Knew before training (KT)**

1 – don't get it yet, 2 – a little learning, 3 – some learning, 4 – more learning, 5 – completely understand, KT – knew from prior experience with plant operations



Rating	1	2	3	4	5	KT
Relationship between the main bus and individual breakers						
Connect to paralleling gear						
Difference between CBSC switches						
Bus systems						
Safety procedures (safely operating switchgear)						
Meanings of the different light signals						
Rating	1	2	3	4	5	KT
Relationship between the main bus and individual breakers						
Connect to paralleling gear						



Difference between CBSC switches						
Bus systems						
Safety procedures (safely operating switchgear)						
Meanings of the different light signals						

Appendix - Section 1  
- Response

Question No	TRUE	False	Not Answered
1	3	1	0
2	2	2	0
3	4	0	0
4	3	1	0
5	3	0	1
6	1	1	2

Appendix – Section 4 Response

	Person 1	Person 2	Person 3	Person 4
<b>In-Person</b>				
Relationship between the main bus and individual breakers	1	2	0	1
Connect to paralleling gear	1	1	0	1
Difference between CBSC switches	1	1	1	3
Bus systems	0	1	0	0



Safety procedures ((safely operating switchgear)	0	0	0	0
Meanings of the different light signals	0	0	0	0
<b>VR-Training</b>				
Relationship between the main bus and individual breakers	1	3	5	4
Connect to paralleling gear	1	2	5	5
Difference between CBSC switches	1	4	1	3
Bus systems	0	3	1	4
Safety procedures (safely operating switchgear)	0	2	5	3
Meanings of the different light signals	0	3	5	0