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Investigating the Feasibility, Procedures, Benefits, and Challenges of Using Mixed Reality in Construction Projects: An Electrical Layout Case Study

Samjhana Shakya
South Dakota State University

INVESTIGATING THE FEASIBILITY, PROCEDURES, BENEFITS, AND

CHALLENGES OF USING MIXED REALITY IN CONSTRUCTION PROJECTS: AN

ELECTRICAL LAYOUT CASE STUDY

BY

SAMJHANA SHAKYA

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THESIS ACCEPTANCE PAGE

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This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Yilei Huang
 Advisor   Date

Teresa J.K. Hall
Department Head   Date

Nicole Lounsbery, PhD
Director, Graduate School   Date

This thesis is dedicated to my mom, Krishna Devi Shakya.

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ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AACC	Avera Addiction Care Center
AR	Augmented Reality
BIM	Building Information Model
HMD	Head-Mounted Display
in.	Inch
MR	Mixed Reality
PPE	Personal Protective Equipment
VR	Virtual Reality

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ABSTRACT

Innovation and development of technology in the field of visualization have affected the way of designing, presenting, and interacting of the design in the architecture and construction industry. With the invention of the Mixed Reality (MR) device, HoloLens, 2016, many researchers and construction practitioners have marched their research of implementing the MR application in the construction industry. However, there is scarce research on the MR application review, the workflow of using BIM models with the HoloLens, its implementation in the site, and the benefits and challenges of the MR application in the construction site. The gap in the research needs yet to be filled, and this research paper will help to bridge the gap.

For this research, the MR application that was available in the market at the time of research were identified through internet research and literature review. The MR applications were installed in two HoloLens and were tested on-site and lab for the construction of the electrical layout. The capabilities of the MR application were studied in the lab and site. The features including scaling, alignment, move, drag, rotate, team collaboration, navigation, and measurement utilities were studied. From the study, the MR application provides several benefits in on-site layout and as-built verification of electrical layout including 3D visualization, less manual work, instruction and demonstration of the construction process, error detection, remote support, quick decision-making, and easy documentation, and efficient progress tracking. Along with the benefits, the MR application has a few challenges while applying it on the site including stud locations, typical rooms, and model drifting. In addition, the limitations of using the MR application

were studied. Future research will focus on solving one of the challenges, model drifting,

through automatic alignment with survey point references.

CHAPTER 1 INTRODUCTION

1.1 Introduction

Development in technology has a huge impact on the process of designing, communicating, constructing, learning, and managing the data. The perception of design and communication has been changed due to human interaction with virtual artifacts. Digital communication and visualization systems like Virtual Reality Augmented Reality, and Mixed Reality has made communication and visualization easier.

Mixed Reality (MR) is the creation of a new environment where the computer-generated virtual world gets co-exists with the real world. Mixed Reality is also known as hybrid reality as it covers both the features of Virtual Reality and Augmented Reality. Virtual Reality (VR) is the technology that creates an artificial environment by replacing the real environment with a virtual object. Augmented Reality (AR) is the technology which is better than the virtual world. It does not replace the real world, but it adds the film of digital information and visuals in the real world. The drawback of the Augmented Reality is that it could not adhere to the real world due to which the interaction with the real world cannot be possible. Mixed Reality makes the user interact with the digital environment which is composed of the physical real world and virtual world in real-time. It links the virtual and real world. From the invention of the Microsoft HoloLens in mid-2016, Mixed Reality has stepped the foot in the field of architecture and construction industry. With its unique ability to overlay digital information in the real world, the users found its importance in construction, architectural, visualization, and verification work. During the time of its early adoption in the industry, many design firms and contractors

have studied its use in the construction industry, maintenance purposes and performed pilot tests with the few available MR applications.

Table 1. Difference between Virtual Reality and Mixed Reality

Features	Mixed Reality	Virtual Reality
Field of view	The field of view is 30 degree, the holograms, apps in HoloLens is tiny.	The field of view is 90 degree; the image is bigger.
Immersive	Less immersive	More immersive.
Interaction with real world	The user can interact real world and virtual at the same time.	Real world interaction is not possible.
Navigate	User can physically move around in immersive view.	User cannot physically move around in immersive view
How it works	Hand gesture can be used to run the HoloLens	The controller is necessary to use VR.
Apps	More apps are supported in HoloLens.	The apps that work in HoloLens does not work in VR
How to run	The HoloLens do not need to tether to any computer to run.	VR need to tether to the computer to run

Inefficient communication and interaction of the design is the main reason for failure in design which makes the construction work delay, create confusion in an employee, and ultimately result in the poor quality in construction. Due to which lots of correction and rework need to be done. MR provides the opportunity to develop a new idea, architectural design, and communicate the design effectively to apply the design in the field and verify the design before building the project. It will not only save time, money, and manpower but also help to produce the quality product by identifying the mistake in design and correct the design in time. Mixed Reality can be a solution to increase the efficiency of the workers in the construction field. This paper will focus more on the study of a comparative review of the capabilities of Mixed Reality applications for the construction of the electrical layout. It explains the workflow of obtaining the Building Information

Model (BIM) models in the HoloLens and find out the benefits and challenges of using the MR application for the electrical receptacles' layout in the construction site.

1.2 Problem Statement

Due to its capability to interact and project the holograms in the real space, the Mixed Reality has been studied to use in construction work. We are going to study the feasibility of the HoloLens in construction work, procedure to convert the BIM model into a readable file format so that the user can access the BIM model in HoloLens, and figure out the benefits and challenges of MR application in the construction of electrical layout, which is currently considered as a gap in the previous research work.

1.3 Research Objectives

This thesis seeks to study the feasibility of the Mixed Reality in construction work and explore the process to implement the BIM model in HoloLens and study the capability, benefits, and challenges of the MR application in the construction work. Due to the capability of interaction and overlaying the holograms in the real space by HoloLens, we can study its use in the construction industry which can make future construction work more accurate and efficient.

1.4 Organization of Thesis

This research paper is composed of eight chapters. Chapter 1 gives the Introduction of the project and the objective of this research paper. Chapter 2 describes the Mixed Reality, Mixed Reality devices, the current practice of Mixed Reality in construction, and research on Mixed Reality in construction. Chapter 3 presents the methodology of the research. Chapter 4 illustrate the capabilities of current Mixed Reality applications for construction. Chapter 5 explore the workflow to use the BIM model in Mixed Reality: An

electrical construction case study. Chapter 6 shows the benefits and challenges of using Mixed Reality in electrical layout tasks. Chapter 7 presents the discussion, conclusions, and future work.

CHAPTER 2 LITERATURE REVIEW

2.1 Background

Due to the capability of overlaying the hologram in the real world, the MR has been experimentally used in architectural and construction work. It is used to visualize the design, check the validity of the design so that the design can be modified and corrected the fault before in hand, and use to inspect the work on the site. Although a few contractors have initiated to test its use in construction, no thorough reviews on its uses have been reported in the existing literature.

Earlier researchers have studied MR and MR device HoloLens in the field of Architecture and Construction work. Similarly, Chalhouband and Ayer (2017) explored field worker's view of using HoloLens to assemble electrical conduit Chalhouband and Ayer (2018) further researched the relationship between productivity and quality with the use of MR to install the electrical installation. Naticchia et al. (2018) did research on the effect of the Mixed Reality on the productivity of the maintenance and operation work of building through managing the data and minimizing the error.

Similarly, Chalhoub et al. (2018) presented the workflow of projecting the MR features on the site. Zhou et al. (2017) studied the feasibility of Augmented Reality in segment displacement inspection in tunnel construction by using the marker by overlaying the BIM model in the real world. Likewise, Fenais et al. (2018) researched the different challenges of using the AR in the construction of underground utilities. Similarly, Imad et al. (2019) examined human performance by using the AR technology without any knowledge of maintenance. Chalhoub (2019) studied the effect of the specific task attribute and model features and factors on the performance of the workers.

Many researchers have invested their valuable time in their research, however, there are scarce preliminary reviews and demonstrations that have been found. However, the comprehensive reviews in the existing literature which could report such uses in architecture and construction practice were not found, and this gap in the body of knowledge has yet to be filled.

2.2 MR Technology

Mixed Reality overlays the digital environment in the real world. It is also called hybrid reality. The user can interact with the real and the virtual world at the same time via the same Head-Mounted Display (HMD). The Augmented and Mixed Reality are breaking the ground with the introduction of HoloLens in the market. Now the Augmented and Mixed Reality are becoming a part of the business-like marketing, design co-ordination, quality assurance, and quality control and service operation. The HoloLens works with the collaboration of Augmented Reality with the real world. The visualization of the model with respect to the real world is possible due to the HoloLens. HoloLens offers the user to experience the project before it is built and assure the design, quality, and correct if necessary. It can be used in the actual site as no cable needs to tether with a computer to overlay holograms. The HoloLens can create a feeling of the presence of the model on the site. The user of HoloLens could walk around the proposed building and can immerse it into the building.

2.3 MR Devices

Due to the capability of the Mixed Reality to solve the complex activity and improve the understanding and visualization, nowadays there are many devices that are

incorporating the MR features. Some of the devices which practice MR in the market are as follow:

2.3.1   HoloLens

The HoloLens was first introduced in the world on March 30, 2016. It is a portable computer that is capable of overlaying holograms in the real world without attaching to any other external devices. Microsoft HoloLens, an MR headset, project the virtual 3D objects right in front of a user's eyes to allow the user to observe the virtual object get co-existed with the real world in real-time. HoloLens is a self-contained computer running the MR platform under the Windows 10 operating system. It can communicate with other devices through Wi-Fi and Bluetooth. The HoloLens allows the user to visualize the digital content with the real world, which makes it substantially different than Virtual Reality. The built-in sensors of the HoloLens help to do spatial mapping, track the physical environment as well as to detect the user's hand gestures as the primary input method, as opposed to the controllers required in VR headsets. It consists of the camera, display, sensor, battery power attached to it, processor, memory, visor, and headband which help to tie it around the head.

Figure 1. Picture of HoloLens 1

Though the HoloLens is certified for eye protection, it still needs some personal protection equipment (PPE) to be used by the employee on site. To implement the hardhat on the site, PPE is needed. So, the hard hat is the only solution for the HoloLens to use on the site. However, the HoloLens along with the hardhat is impossible to use. Due to which few companies and person modify and redesign the hardhat so that the HoloLens can be used with hardhat. Many companies like Trimble, vGIS, and BIM are also producing the hard hat for the HoloLens. Some of the hard hats are as follow:

Table 2. Hardhats for HoloLens

Company	Description	Hardhat Picture
Trimble	This hardhat has got electrical resistance and impact guard certification (ANSI/ISEA Z89.1-2014 Type 1, class E). The HoloLens is attached to the hardhat with the help of suspension shims, yellow clips, and safety lanyard.	
Erieforage	Erieforage created a technique to connect the HoloLens to hardhat by using the hardhat clips. These clips secure the HoloLens to the hardhat without making any modification to HoloLens.	
Visual Live	The HoloLens connect to the hardhat with the help of Visual Live adapter. The HoloLens can quickly attach and detach to the HoloLens with the help of adapter.	
vGIS	The hardhat secures the HoloLens in it with the help of the adapter. With the help of the screw HoloLens can be attached and detached easily without making any modification in it to attached HoloLens in hardhat.	

2.3.2   Magic Leap One

Magic Leap is the device that projects the layer of synthetic light in the environment. It is composed of the magic band with the miniature computer which adheres to the band through the wire and the controller which can supplement the hand gesture to give the command to the magic leap. It projects the 3D magic object in the real world in which the user can interact with it as it can read the hand gesture of the user and track the space in real-time. Though it is considered a good invention in Mixed Reality, it has many drawbacks. The object projected by the magic leap is nonrealistic, poor resolution, and the ununiformed overlay of the Holographic object and graphic.

Figure 2. Picture of Magic Leap One

2.3.3   HoloLens 2

HoloLens 2 is the improved version of HoloLens. It was introduced in February 2019. It can recognize the user, track the eye, project the Holograms more naturally and more comfortable to use. The user can interact with the Holograms by touching, grasping, and moving in a more natural way. HoloLens 2 has a wider field of vision than the previous HoloLens. It has dynamic 365 remote assists, natural language speech processing. It can

work the voice command even in a noisy area. The user can wear the headset longer and more comfortably than HoloLens 1. The display of the HoloLens 2 can flip upside down, which makes the user use the display at the time of needs.

Figure 3. Picture of HoloLens 2

2.3.4   Lenovo ThinkReality A6

Lenovo ThinkReality A6 is a device that can work with both Augmented Reality and Virtual Reality as it is capable to connect both. The virtual object can be viewed, organized, and managed in it. Lenovo ThinkReality A6 provides a good visual quality with 1080p resolution and 40 degrees of field of vision display, good processing speed with Qualcomm processor and good battery attached to it with the wire.

Figure 4. Picture of Lenovo ThinkReality A6

2.4 Previous Research on MR in Construction

Mixed Reality and HoloLens have been instigated to explore by the earlier researcher to implement in architectural design and construction work. Naticchia et al. (2018) researched to figure out whether the productivity of the maintenance and operation work can be increase by Mixed Reality for the management of building by reducing the error. The assumptions for the research are that the automation in data management and knowledge communication can help to increase the productivity in work. The researcher used a qualitative methodology approach. The data were collected via survey and consisted of the creation of a BIM model of the building and using the cloud storage for the management of the data by using the Mixed Reality in the field and taking the survey from the maintenance expert personnel of building for more information and procedures. The authors suggested the combination of three big technology BIM models for data management, cloud storage for the management of information and transfer of the data,

and Mixed Reality as the means of communication to make the maintenance and operation work better. The author further suggested covering the data set of management related to on-site safety, building functional data in the future that was not covered in that project.

Chalhouband and Ayer (2017) investigated the perception of field workers by comparing theirs though of using HoloLens and traditional paper as the means of communication to assemble electrical conduits. The research question for the study is whether the Mixed Reality can replace the paper-based designed work in the site or not. The researcher assumes that Mixed Reality can be the new technology that could replace the traditional method of construction. The researcher used a qualitative methodology for the research. The author collected the data of perception of the participants by organizing the workshop for the electrical construction personnel. The researcher asked the pre-activity questionnaire and post-activity questionnaire to get the participant's perception of using traditional paper by using HoloLens as the means of communication. The study found that although the BIM model in MR was easier to use than paper plans, it can be used as a supplement to the 2D drawing and cannot replace 2D drawings. For further research, the author suggested studying the relationship between the perception, background, and performance of the participant.

Chalhouband and Ayer (2018) further inspected its influence on construction performance in terms of productivity and quality based on the same electrical conduit assembly. The research question for this article is whether the Mixed Reality can influence the productivity and quality of the electrical installation work by minimizing the installation error. Besides this, the researcher also studied the effect of the background or the electrical installation worker's perception of the Mixed Reality. The assumption for the

research is that the Mixed Reality can be the solution for minimizing error and maximizing productivity. The author investigated and explored by organizing the workshop for the eighteen workers and study their efficiency and productivity by using HoloLens and traditional paper as the means of communication of design. The researcher used a quasi-experiment methodology for the research. The researcher used pre-questionnaire and post questionaries' as the instrumentation to collect the data. The author discovered that the productivity of the electrical installation is increased, by lowering the installation error and minimizing the installation time, however most participants still preferred to use the traditional paper as the means of communication. The researcher suggested identifying the attributes that will maximize the benefits provided by Mixed Reality in the electrical installation work for further study.

This earlier research in Mixed Reality which addressed quite a similar problem by using HoloLens in the field of construction in electrical installation and building maintenance. The methodology used in these research projects can be followed as the guideline in our research. We will explore the Mixed Reality application by comparing the features of the application and finding the best one which could address the problem of the construction site and increase the productivity of the installation work. Besides this, we will find a way to implement the BIM models to use in HoloLens. We will study the acceptance of the Mixed Reality in the electrical installation by the worker working on-site to install the electrical conduit. And we will study the benefits and challenges of using the MR application in electrical construction work.

2.5 Current Practice of Mixed Reality in Construction

Continuous growth in technology has been changing the ways of working. Due to the Mixed Reality, it becomes easier in construction management. The traditional paper design process is changing to 3D Virtual Reality. Due to which the stakeholder can visualize the design in the site without constructing the building in the actual site. They can also figure out the mistake and correct it promptly. The Mixed Reality has replaced the traditional process of doing work with the advanced technology-based process. Some of the practice of Mixed Reality in construction are:

2.5.1   Remote Collaboration Work

Remote collaboration features of the Mixed Reality device have made the collaboration work easier. Team members living in a different corner of the world can participate virtually with the help of a Mixed Reality device. Some researchers had dedicated their time to researching the Mixed Reality application in the field of collaboration. Panuwatwanich (2019) had studied the development of a remote collaboration system using VR to help the participant better understand the project presentation by creating the virtual collaborative of the team member.

2.5.2   Construction Safety

After the invention of Mixed Reality devices, many researchers and contractors are studying the Mixed Reality device in the field of construction safety like giving safety training, construction planning, etc. Moore and Gheisari (2019) studied the use of Virtual and Mixed Reality on construction safety. The HoloLens was used as a training device in the construction site.

2.5.3   *Site Inspection*

The digital technology that can be obtained by using the Mixed Reality application is making the site inspection work easier and safer which leads to quality, effective data collection, economic and fast inspection, increase efficiency and productivity in the construction process. Kouch et al. (2018) have research on the HoloLens to inspect the expressway.

2.6 Summary

This chapter covers the background, MR technology, MR devices, previous research on MR in construction, and current practice of Mixed Reality in construction. In the background section, the brief background information of MR was provided. In MR technology the current MR technology was studied. And the current MR devices and their features were studied in the MR devices. The earlier researcher who researched in the field of MR for the construction purpose were researched in detail in previous research on MR in the construction section. And some of the work that the researcher and construction team working currently to implement the MR in the different purpose of construction were discussed in the current practice of MR in construction.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Research Design

This research is descriptive qualitative research. The use of MR applications in construction work like electrical installation will be studied in this paper. We will use a qualitative research design to explore the depth of the subject. In qualitative research, the researcher studies the MR application through an internet search, observes the capability of the MR application in the construction by implementing all the features of the Mixed Reality applications in lab and on-site.

Figure 5. Picture of the Two HoloLens Used in this Study

The conclusion of the Mixed Reality application is done based on their performance and effectiveness of the features to be used on-site and lab. The observation can be studied in the lab as well as in the field. This qualitative study researcher focuses on meaning, and meaning is constructed through careful investigation and interaction with the real world. The workflow of converting the BIM models in Mixed Reality will be figured out by exploring the BIM software and Mixed Reality application.

3.2 Research Methods

3.2.1 *Identification of Existing Mixed Reality Applications*

Nine Mixed Reality applications that can be used in the construction industry were identified through a literature review and internet search. The list of the nine applications along with their name, developer, and purpose of the application is shown in the table below. These nine MR applications were categorized into three groups based on their use. 3D Viewer Beta application can be used to visualize the model in MR. SketchUp Viewer and Trimble Connect are both developed by Trimble specifically for BIM uses. Similar MR applications also include BIM Holoview, MR Builder Lite by Holo Group, HoloLive 3D by VisualLive, and Fuzor AR by Kalloch. The third type of application, although developed for MR presentation, can still be applied for architecture and construction uses, which includes Vyzn (pronounced as vision) by Zengalt and Prism by Object Theory.

Table 3. An Overview of Evaluated MR Applications

Developer	Microsoft	Trimble	Trimble	BIM Holoview	Holo Group	VisualLive	Kalloc	Zengalt	Object Theory
App name	3D Viewer Beta	SketchUp Viewer	Trimble Connect	BIM Holoview	MR Builder Lite	HoloLive 3D	Fuzor AR	Vyzn	Prism
App purpose	3D	BIM	BIM	BIM	BIM	BIM	BIM	Presen-tation	Presen-tation
Tested	Y	Y	Y	Y	Sample			Demo	Demo

Nine out of seven MR applications were installed and tested with two HoloLens in this study. Since the research team was not able to access HoloLive 3D and Fuzor AR, the findings of these two applications were made solely based on online documentation and video tutorials. In addition, while the same BIM model was expected to be used for the evaluation across all applications, MR Builder Lite was not able to open any user models,

and thus all tests had to be performed with the provided sample models. Vyzn and Prism, being MR presentation applications, also provide sample models for presentation demonstrations.

3.2.2 Development of the BIM Workflow for Mixed Reality

BIM models need to transform and be manipulated so that it could transfer to the MR application into a readable file format of MR application. The research team used the Revit models of Avera Addiction Care Center in Sioux Falls and Performing Arts Center at SDSU obtained from an electrical contractor Thompson Electric Company. The walls of the Revit BIM model were removed by using a section cut and exported separately. Similarly, the door, windows, and electrical layout were also exported separately.

The dwg file of the wall and the exported doors, and electrical layout were imported to SketchUp Pro. The imported full model of a building was divided into a different unit based on the area or room. The final Sketchup models were imported in the SketchUp Viewer separately in the HoloLens with the help of Wi-Fi.

3.2.3 Investigation of the Benefits and Challenges of Mixed Reality

The benefit and challenges of the Mixed Reality were tested by installing the Mixed Reality application in the HoloLens and importing the BIM model in the MR application. Different features of the MR application were tested and compared. The benefit of those features of MR application that is beneficial for the architectural purpose was identified and the limitation of some MR applications was discussed.

CHAPTER 4 CAPABILITIES OF MIXED REALITY APPLICATIONS FOR CONSTRUCTION

4.1 Existing Mixed Reality Applications for Construction

The nine MR applications along with the name of the developer that are identified through internet research are presented in the table below.

Table 4. Identified MR Applications

Developer	Microsoft	Trimble	Trimble	BIM Holoview	Holo Group	VisualLive	Kalloc	Zengalt	Object Theory
App name	3D Viewer Beta	SketchUp Viewer	Trimble Connect	BIM Holoview	MR Builder Lite	HoloLive 3D	Fuzor AR	Vyzn	Prism

4.2 Capabilities of Identified Mixed Reality Applications

The features of the MR application can be discussed as follow.

4.2.1 Tabletop View

The 3D model can be visualized on the small scale in a tabletop view. The user can navigate the model by moving, rotating, scaling. Movement can be done either dragging or preset increment. In dragging the model can be moved to different locations, and directions without any control over the movement. Whereas in preset, the model can be moved with the custom directional movement like selecting or defining the distance like 10 ft, 5 ft, or 15ft. Moving and rotating the model is a typical movement in the MR application.

Table 5. Miniature View Capabilities of Evaluated MR Applications

Tabletop View	3D Viewer	SketchUp Viewer	Trimble Connect	BIM Holoview	MR Builder	HoloLive 3D	Fuzor AR	Vyzn	Prism
Move									
Drag	Y	Y	Y		Y		Y	Y	Y
Direction				Y			Y	Y	
Rotate									
Drag	Y	Y	Y		Y		Y	Y	
Direction				Y			Y		
Scale									
Drag	Y	Y	Y		Y		Y		
Preset		Y	Y	Y	Y	Y	Y		
Custom	Y	Y							
Reset		Y	Y		Y		Y		

Among the MR application, BIM Holoview is the only application which provides directional and rotation movement. It moves or rotates the model in either direction or by a preset increment. HoloLive 3D is the only application that does not allow the directional as well as rotational movement of the model, likewise, Prism does not allow rotational movement of the model.
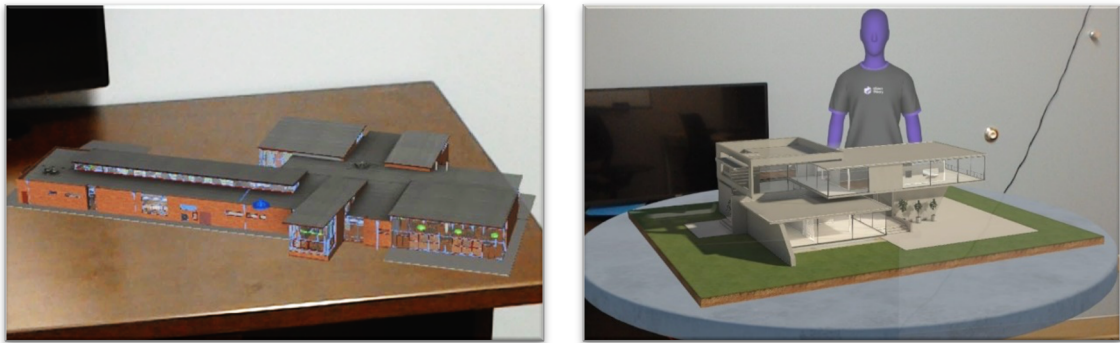
Figure 6. Table-top View of Model in MR Builder Lite and Prism
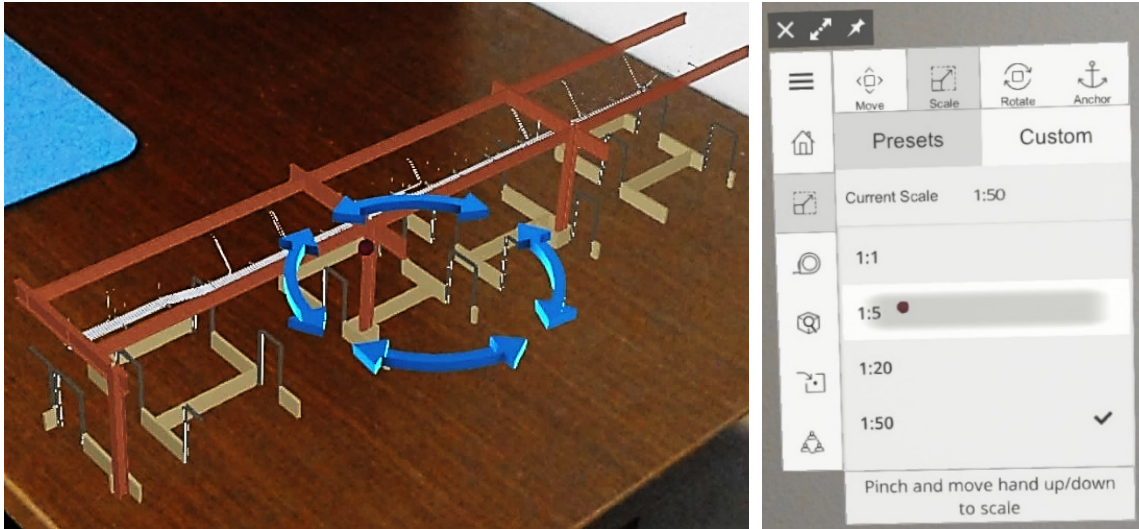
Figure 7. Move, Rotate, and scale in SketchUp Viewer

The miniature model can be scaled either by dragging or with a preset scale or custom scale. The real-time change in the model can be observed by dragging the model however without much control over the size of the model, however, in preset or custom scale the model size can be changed by selecting and defining a certain scale-like 1:10, 1:15, or 1:20. SketchUp Viewer and Trimble Connect support all three scaling methods while Vyzn and Prism do not support any model scaling. Finally, SketchUp Viewer, Trimble Connect, MR Builder, and Fuzor AR allow the model to be quickly reset to the default miniature size and direction by picking an anchor point in the physical space.

Figure 8. Scaling in BIM Holoview
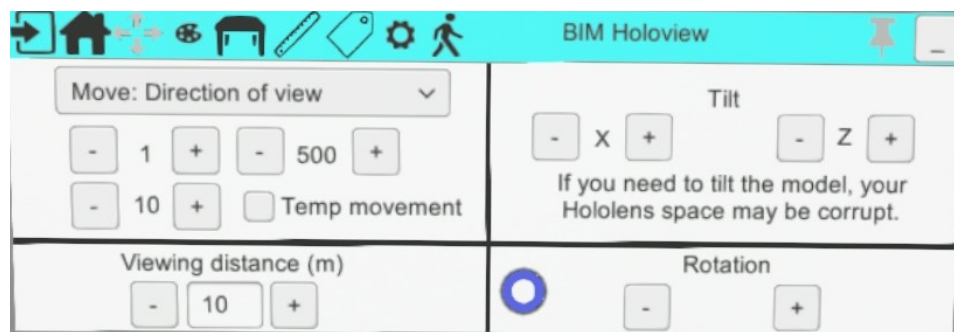
Figure 9. Move and Rotate in BIM Holoview

4.2.2 *Immersive View*

HoloLens allows the user to immerse into the holographic space or model so that the user can take a view and feel the virtual model in front of their in the actual size. Immersive view features are considered the most important toolset for all the MR applications. Table 6 presents the main features of the immersive view of all selected MR applications.

Table 6. Immersive View Capabilities of Evaluated MR Applications

Immersive View	3D Viewer	SketchUp Viewer	Trimble Connect	BIM Holoview	MR Builder	HoloLive 3D	Fuzor AR	Vyzn	Prism
Native		Y	Y	Y	Y	Y	Y	Y	Y
Full scale adjustment		Y	Y						
Alignment									
2 points			2 walls plus floor	Inserted in model	Any	1 on floor w/ north	1 on floor w/ direction		
1 point							On wall		
QR code					On wall	On floor w/ north	On wall		
Pivot			Move/ rotate		Move/ rotate				
Movement									
Walk		Y	Y		Y			Y	
Teleport		Y	Y		Y			Preset	Y
Elevate		Y					Y		
User height		Y	Y						

Among the MR application, 3D Viewer is the only application that does not provide an immersive view as a native feature, although the immersive view can be achieved by

scaling the model to full scale and visualize the model in real-time. The full-scale adjustment of the model can only be done in Trimble Connect and SketchUp Viewer that allows the user to slightly match the full-scale model with a slight adjustment of the scale of the model. The full-size 3D model displayed by HoloLens is about 1-2% smaller than the actual real model at real size. This discrepancy of the size is negligible for the small object however for the BIM model this discrepancy can go up to a few inches. And the full-scale adjustment features of the SketchUp Viewer and Trimble Connect can be used to solve the discrepancy of the full model with the real size model by adjusting the size while laying the Hologram in the field at full scale.

Figure 10. Full Scale Model in SketchUp Viewer

Besides the immersive view, automatic alignment is another important feature of MR application that can serve for effective improvement in the construction industry. It helps the BIM model to be placed at the correct location on-site at full scale. The computer-generated full-sized model can be aligned by attaching the wall, floor of the model to the corresponding wall, and floor of the actual building of the site. Once the size, position, and direction of the walls or floors of the BIM model aligned with those of the physical building of the physical site, the user can move freely to check and verify the position of the object

installed on the site along with the object of the BIM model projected by the HoloLens on site. This not only helps for the verification purpose but also helps to pre-plan the construction and find the fault on the site before actual construction on site.

Trimble Connect, BIM Holoview, MR Builder, HoloLive 3D, and Fuzor AR support automatic alignment through different methods, including two points, one point, QR code, and pivot. Trimble Connect allows the user to identify two walls and a floor in the model and their counterparts in the physical space to align the model. After that, a pivot can be selected for fine adjustment of movement and rotation if needed. BIM Holoview requires the user to insert a provided model with two predefined points in the BIM model, and then identify these two points in the physical space.
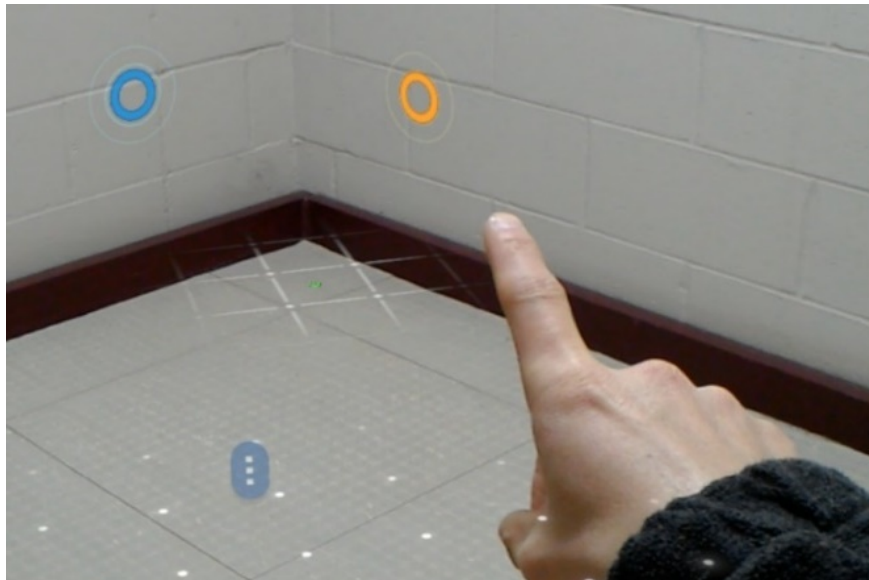
Figure 11. Alignment with Two Walls and Floor in Trimble Connect

MR Builder allows the user to identify any two points in the model and their counterparts in the physical space, or to use a pivot for fine movement and rotation adjustment like Trimble Connect. Besides, a QR code can be inserted in the model in advance to be aligned with the printed QR code affixed to a wall for a quick alignment.

HoloLive 3D aligns BIM models either with one point identified on the floor and another point pointing the north direction or with a printed QR code affixed on the floor pointing north. Fuzor AR aligns BIM models like HoloLive 3D, including identifying one point on the floor and another point pointing a given direction, one point on a wall, and a printed QR code affixed to a wall.
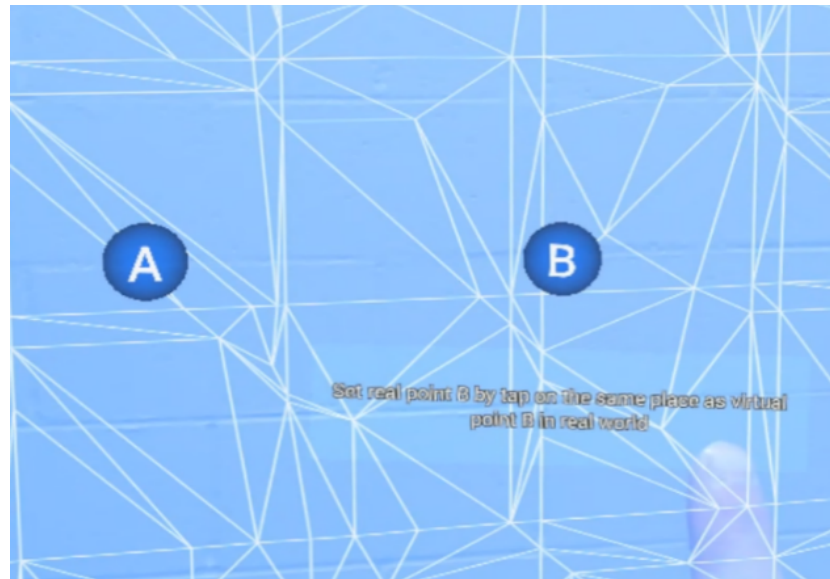
Figure 12. Alignment with Two Points in MR Builder

Lastly, most MR applications allow the user to virtually walk or teleport within the model when alignment is not needed, which appears very similar to the immersive view of VR environments. In such cases, the user stays stationary while the model moves toward the user to bring the selected destination point right in front of the user. BIM Holoview, HoloLive 3D, and Fuzor AR, however, do not support walk or teleportation in the immersive view, while Vyzn can only teleport the user to certain preset locations. SketchUp Viewer and Fuzor AR also allow the user to directly elevate to different levels, while SketchUp Viewer and Trimble Connect allow the user to adjust their eye height at which the immersive view is observed.

4.2.3 Utility Tools

Just like other important tools, MR applications also offer the utility tool that can be used to measure the model, annotate, control the layer and unit to display in the model. All the utility tools that were offered by MR application for the architectural and construction industry along with the application name is displayed in the given table.

Table 7. Utility Tools of Evaluated MR Applications

Utility Tools	3D Viewer	SketchUp Viewer	Trimble Connect	BIM Holoview	MR Builder	HoloLive 3D	Fuzor AR	Vyzn	Prism
Layer									
Isolate		Y		Ext./ int.	Y		Y		
Highlight					Y				
Transparent				Ext./ int	Y				
Color				Preset					
Measurement									
In model		Y	Y						
Real world			Y		Y	Y			
Mixed			Y						
Unit									
Metric	Y	Y	Y	Y	Y		Y	Y	
Imperial	Y	Y				Y	Y	Y	
Annotation									
Markup					Y	Y	Y		Y
Snapshot					Y				
Object info	Y	Y	Y			Y	Y	Preset	Preset

Each desired layer of the model can be turned on and an unwanted layer can be hide by turning off the layer individually in SketchUp Viewer and Fuzor AR to visualize the model in HoloLens. Whereas BIM Holoview can isolate layer of the interior and exterior separately and apply the custom transparency or color to the layer. Similarly, MR Builder allows the user to highlight the desired layer by adding a glowing effect to the individual layer of the BIM model.

MR applications also offer the measurement of the Holographic 3D model projected by the HoloLens. Among the other MR application, Trimble Connect provides

the measurement of the hologram using three different methods. It can measure using two-point within a model, between two-point within the physical object of the real-world and between one point of the model and one point of the real world. Whereas SketchUp Viewer offers the measurement of the point within the model. While MR Builder and HoloLive 3D can be used to measure the point of the physical space. The point can be measure using the metric system of measurement. Most of the MR applications uses the metric system to measure the distance while some applications also support different unit of measurement. It is noted that although not all applications measure distances, they are still displayed to the user for directional incremental movement or scaling. Some applications also allow the user to markup and take snapshots within the model as well as display object information created by the modeling program for the specific object of the model.
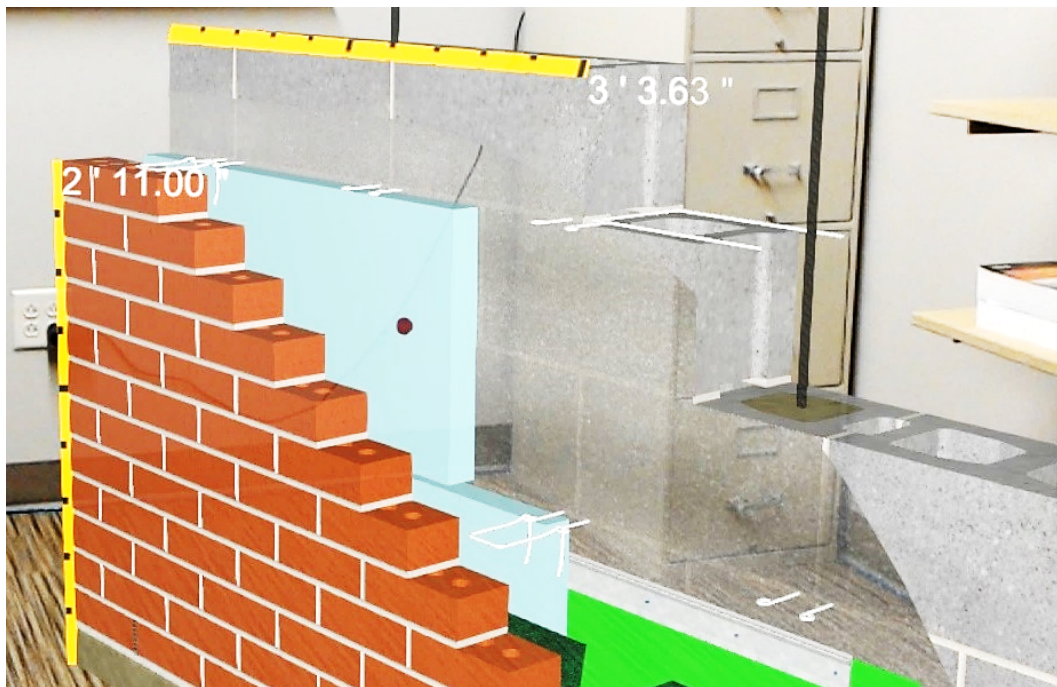
Figure 13. Measurement in SketchUp Viewer

4.2.4   Collaboration

The collaboration features provided by the MR application allows multiple HoloLens user to work under the same project, they can view the same BIM model at the same time, and they can interact with each other to share the ideas. SketchUp Viewer, Trimble Connect, Fuzor AR, Vyzn, and Prism allows model sharing between multiple HoloLens users, as listed in Table 8.

Table 8. Collaboration Capabilities of Evaluated MR Applications

Collaboration	3D Viewer	SketchUp Viewer	Trimble Connect	BIM Holoview	MR Builder	HoloLive 3D	Fuzor AR	Vyzn	Prism
Model sharing		Y	Y				Y	Y	Y
Co-location		Y					Y	Y	

One HoloLens user needs to host the session for the collaboration purpose, whereas other participants need to join the session by using their HoloLens. The BIM model will be downloaded from the BIM model in each HoloLens through the Wi-Fi. Some MR applications are good in co-locating the user and shares the same location and direction between the HoloLens participant. Among the MR HoloLens SketchUp Viewer, Fuzor AR, and Vyzn additionally support the co-location of the user and shares the same location and direction of the BIM model in each HoloLens in the session. Every BIM user needs to identify a common point, location, direction in the physical space to place the BIM model so that every participant feels comfortable during the session. In the collaborative session, each individual participant will be represented by their avatar and their eyesight will be represented by the laser beam.

Figure 14. Collaboration in SketchUp Viewer

Figure 15. Collaboration in Trimble Connect

4.3 Summary

This chapter presents the results of all the features study of the MR applications in the architecture and construction industry. The nine MR applications were identified through internet research. Nine out of seven were installed in two HoloLens and tested the result while the other two results were taken solely based on the internet research as the research team is not able to access the MR application for the HoloLens. The HoloLens was secured in the hardhat to be used on the site for constructional safety. The capabilities of MR application to be used on-site for architecture and construction purposes were evaluated and compared, including different view modes, utility tools, as well as collaboration features. From the experiment, it was found that Trimble Connect seems to be the most capable in various tasks among the evaluated nine applications, there was no single application that offered all desired features. Besides comparing the different features of the MR application, the limitation and requirement of the MR application for the architectural design and construction on the site were also discussed. The features like full-scale adjustment, automatic alignment, and co-located collaboration are the key features for the MR application to be used for the design consultancy and construction industry.

CHAPTER 5 WORKFLOW OF USING BIM MODELS IN MIXED REALITY

For the architectural and construction use of HoloLens in the site, the team worked with the Thompson Electric Company. Thompson Electric Company provided the access to the Revit file of the Model.

5.1 Preparation of Revit Files

The BIM models contain all the drawings of architectural, structural, electrical, sewage, and sanitary detail which make the file difficult to access, view, and use in the HoloLens. Besides that, the storage capacity of HoloLens is just 64GB. And it became difficult to handle and transfer the file. Due to which the Revit model is modified and only included the information needed for the site.

5.2 Manipulation and Export of Revit Models

Since the information of the wall, door, and electrical layout was required for the site, only this information was manipulated and exported. The separate Revit model of wall, door, and electrical layout was created by turning off all the unrequired layer of the model and put only the required layer in the model. The wall of the model was cut to 1 to 2 inches in height by vertically cutting the model with section plane in Revit. Then, the wall, doors, and electrical layout were only exported to dwg file format from Revit.
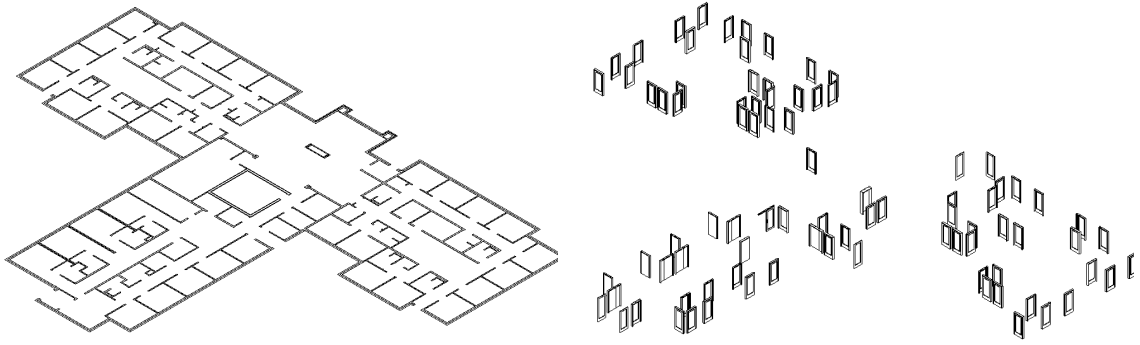
Figure 16. Wall and Door Layout in Revit
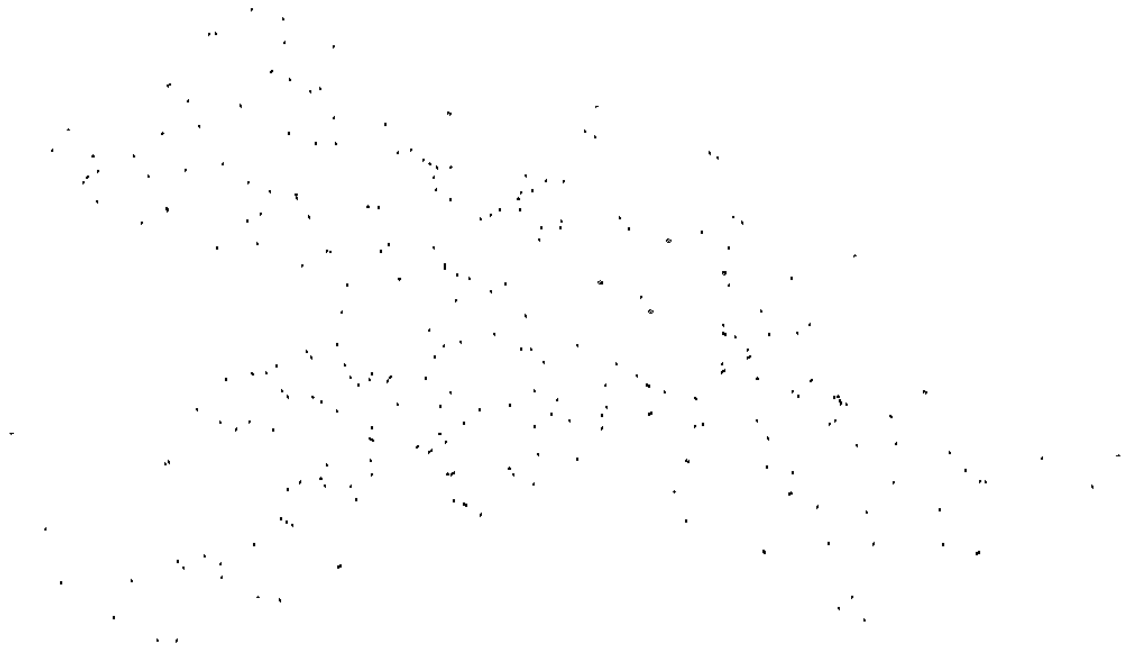
Figure 17. Electrical Layout in Revit

5.3 Import and Handling with SketchUp Pro

The exported dwg files were imported in SketchUp at once. The imported files of walls, door, and electrical layout were assembled into one and the assembled model was divided into a unit based on the area of the room. The site work becomes easier and the file becomes easy to access and handle if the model was divided into a different unit based on the area and space.
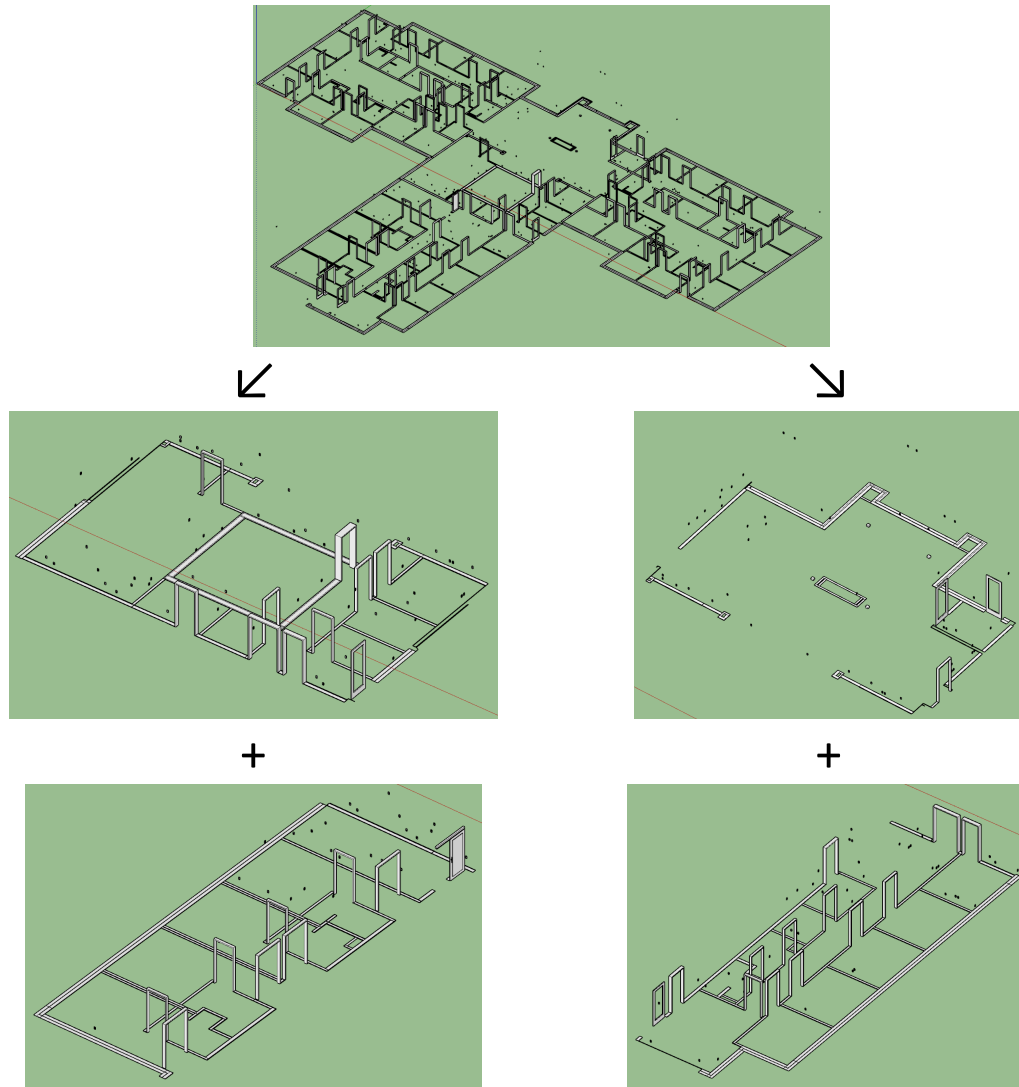
Figure 18. Cutting the Sketchup Model into Small Area and Room

5.4 Uploading to HoloLens

The HoloLens can access different BIM formats like SketchUp, Revit, fbx, Fuzor, and Prism based on the MR application. SketchUp Viewer and Trimble Connect support SketchUp file. The Trimble Connect is the most useful MR application, through the SketchUp Viewer was implemented in the site due to the accessibility and license problem of Trimble Connect.

The user can import the file in the HoloLens from the HoloLens local storage, one drive, through the account, warehouse, and Dropbox depending on the MR application. SketchUp Viewer can upload the file in HoloLens from SketchUp Pro by pushing the file in HoloLens, whereas the Trimble Connect needs the account to access the file in HoloLens which is not feasible due to which the team needs to use the SketchUp Viewer to visualize the BIM model in the site.
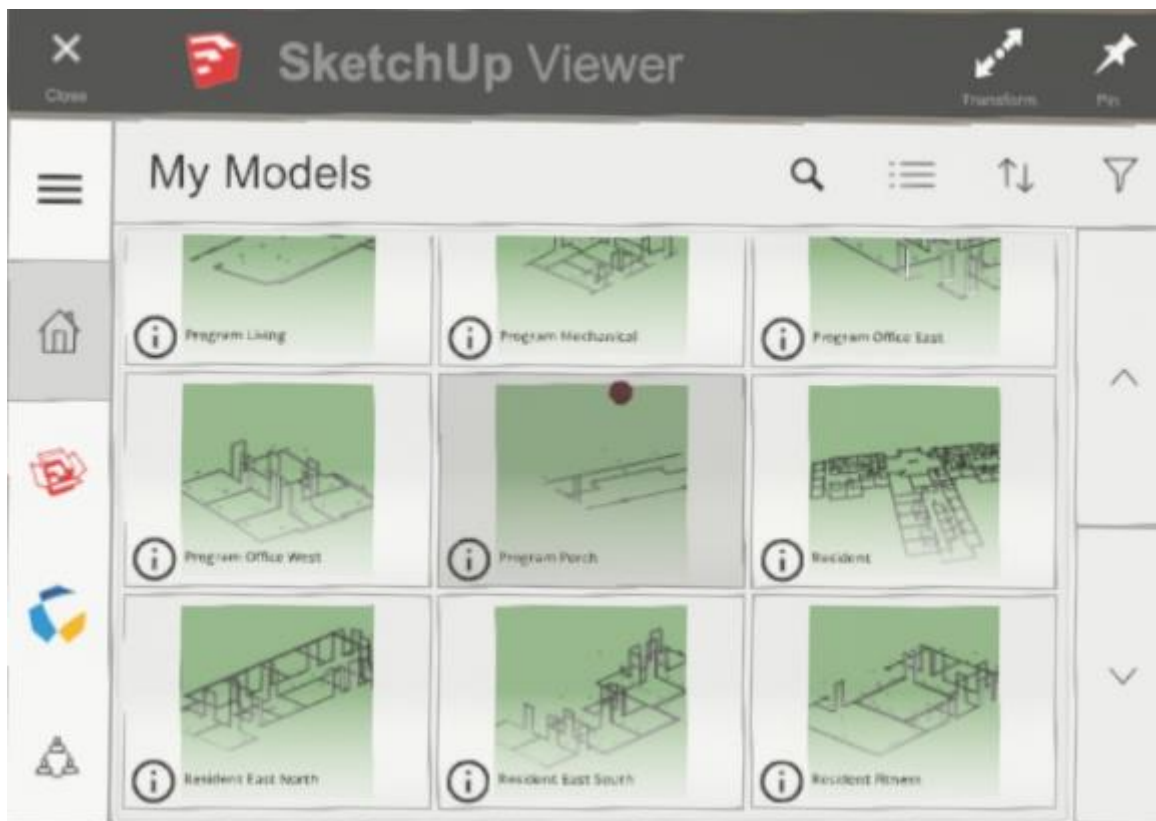
Figure 19. Importing SketchUp Models to HoloLens

5.5 Hologram Alignment and Adjustment

The model can be viewed once all the models were uploaded in the HoloLens using different MR applications. In SketchUp Viewer, the hologram can be aligned and adjusted by scaling the miniature model to a 1:1 scale which is the full-size model. The scaling can

be done either by preset or by custom scale. The full-scaled model can be placed and aligned with the real-world object by moving and rotating with respect to the real world. The full-scaled model appeared to be slightly smaller than the actual size. This discrepancy is negligible for the small object however, this discrepancy can go up to an inch which is not tolerable to the large-scale model especially in the construction work. And this discrepancy in the model can be adjusted with the help of full-scale adjustment.
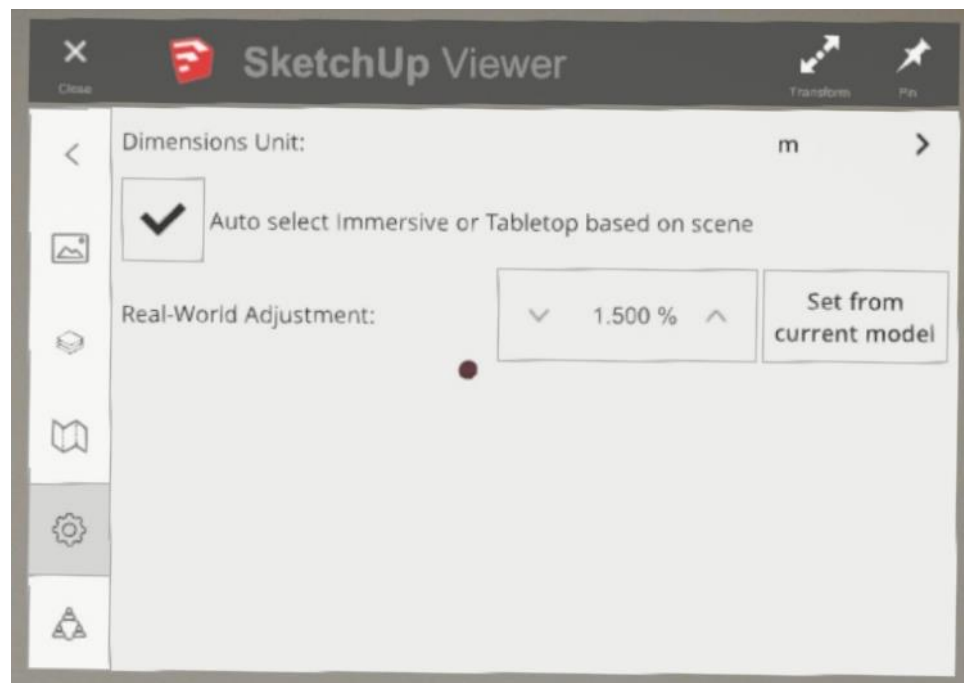
Figure 20. Real-World Adjustment in SketchUp Viewer

For the onsite verification, the holographic model was positioned by moving the digital door of the model and placed it over the door of the site by manually dragging or using directional incremental movement. The holographic model was aligned by horizontally rotating the digital model and aligned to the site object.

Some MR applications like Trimble Connect, BIM Holoview, MR Builder, HoloLive 3D, and Fuzor AR can do auto-alignment. The auto-alignment can be done in a

different way based on the MR application. Four types of auto-alignment were practiced to position and align the holographic model on site. Different types of alignments include:

5.5.1 Two Points

The model can be aligned by using the two-reference point of the digital model and placing the model on the site. Trimble Connect, BIM Holoview, MR Builder, HoloLive 3D, Fuzor AR support two-point alignment. Trimble Connects the model can be aligned by using the 2 points of the wall and floor of the model and aligning them with the wall and floor of the site.

5.5.2 One Point

The alignment of the digital model can be done by using one point in Fuzor AR. The wall of the digital model can be used to match the wall of the site.

5.5.3 QR Code

QR code is the 2D barcode. The model can be aligned in the site by scanning the two-dimensional barcode placed on the site. QR code of the model placed over the QR code of the site then the rest will align itself. Once the alignment is done the onsite inspection can be done.

5.5.4 Pivot

Pivot alignment is the pinpoint alignment. The model can be moved and rotate by pinning the model to a specific point. The model can be aligned by using pivot in Trimble Connect and MR Builder. The model is moved and placed at a specific area. To adjust the direction of the model, the model is rotated. The rotation can be done both horizontally and

vertically. The movement and rotation can be done either by dragging or by using the preset movement.

5.6 As-Built Verification in Electrical Layout

Traditionally, electrical receptacles were laid out on the site with the help of 2D drawing, and the construction team needed to use hand measurement in the site to verify the position of receptacles. It is important to verify whether the conduits were placed in the right position or not so that the mistake can be identified and can be corrected without ruining the project.

As-built verification is a very difficult task by using the traditional method. The placement of the conduit needs to measure one by one, which is very tedious and time-consuming. The ability of the HoloLens to project the Holographic model in the site helped the on-site verification much easier. The as-built work can be compared by placing the Holographic model over the real model in real-time. Once the digital model is aligned and position concerning the real object, the as-built verification can be performed.

The step by step process of implementing the MR application for the as-built verification in Electrical layout is as follow:

5.6.1   Identifying the Reference Point and Plane

The reference point is the point at which the BIM 3D model can be attached in the real world. The reference point needs to be near to all the points of receptacles whose position needs to be identified and verified. The reference point needs to same as in the model and in the physical world.

On the site, the reference point was chosen as the position of the door. To verify the layout of the conduit in each room, the door of each room was taken as the reference position for the accuracy of the alignment of the digital model with the real world.

5.6.2 *Alignment of the Model*

The digital model can place on the construction site once the reference point was identified. The BIM 3D model needs to be manually aligned in SketchUp Viewer. The BIM model can be placed in the real world in an immersive view.

The HoloLens tends to project the full-scaled BIM 3D model slightly smaller than the actual model size. This discrepancy goes up to 1% - 2%, this discrepancy is negligible for the small-scale model but for the big model, this discrepancy is not allowed. However, this discrepancy can be removed by implementing the full-scaled adjustment. SketchUp Viewer and Trimble Connect are the only two MR application which allows the full-scaled adjustment.

Once the model was scaled to the full-scaled and adjusted to the actual size, the model can be positioned and aligned in the construction site. The user needs to manually align the BIM model on the site. This manual alignment is tedious and time-consuming.

The model was moved and aligned with the real-world model by positioning the BIM model in the reference position. In the site, the door was chosen as the reference point to lay the BIM 3D model. The door of the BIM model and the door of the real site was aligned and positioned by using the observation-based method.

5.6.3   Inspection of the As-Built Layout of Electrical Conduit

The invention of HoloLens has made the inspection and layout work much easier than before. The construction team no longer needs to have the 2D drawing or measuring tape carried with them to inspect and layout the design in the construction site.

Once the BIM model was aligned with the real world, the model becomes stationary and the user of the HoloLens can move freely in the construction site and inspect the construction work. The user can measure the distance between two points in the BIM model, or two points in real-world or one point in the BIM model and one point in the real-world with ¼ inch of precision. The user can visualize the BIM model and real-world at the same time and compare the difference. This helps to identify the mistake in the site. The user can also pin the note at an erroneous place so that it can be identified later and make a correction.

On the site, the BIM model was aligned in the door. Once the model becomes stationary by aligning the BIM model the user verified the electrical conduit layout by visualizing the BIM model along with the physical site and marked the point if there is any problem in the site.

5.6.4   Documentation and Sharing

One of the important features of the HoloLens is that the user can document the site condition easily. The user can take a picture of the site for documentation. The inspection work and documentation of the inspection become much easier. The user can write the virtual stick note in the construction site and take the picture of the erroneous construction and these documents can be shared with multiple users.

Besides this, the user can scan the entire site by using the spatial mapping of HoloLens. It can also help the construction team to visualize and document the ongoing progress work and inspection report which is much clearer and easy to understand.

CHAPTER 6 BENEFITS AND CHALLENGES OF USING MIXED REALITY IN ELECTRICAL LAYOUT TASKS

6.1 Benefits for On-Site Installation in Electrical Layout

The Trimble hard hat solution attached to the Microsoft HoloLens allows the construction team to utilize the features of the HoloLens for effective and efficient construction in the site. Some of the features like immersive mode, full-scale adjustment, measurement, and the unit, and interaction of the BIM model and physical space at the same time help the architecture and construction industry. Some of the benefits of Microsoft HoloLens can provide for the on-site installation of Electrical layout are as follow:

6.1.1   3D Visualization

The construction team needs to depend on the 2D drawing to understand the design which is difficult, and time-consuming to visualize and understand the design as all construction team members won't be an expert on the visualization of the 2D drawing. With the invention of the Microsoft HoloLens, it became much easier for the construction team to visualize the design by implementing the immersive view of the MR application in HoloLens. The user can scale the BIM model to the full-scale model and attached the BIM model to the physical environment. The user can visualize and walk through the design once the model becomes stationary after attaching it to the real site.

Figure 21. 3D Visualization of Model On-Site

6.1.2 Less Manual Work

The layout of the 2D design in the site needs both technical and non-technical manpower to manually laying out the design. Measuring the site and marking the point is a very essential and time-consuming job of the layout. However, the layout job can be quick with the use of HoloLens on the site. Both technical and non-technical employees can utilize the HoloLens in site for layout. The user can project the design on the site and visualize the design. Once the user scaled the model to full-scaled and aligned with the physical surrounding the user can do the layout job by marking the position of the electrical receptacles on the site. The user can mark in the site without measuring the site manually with the tape which makes the layout job much easier and quicker.
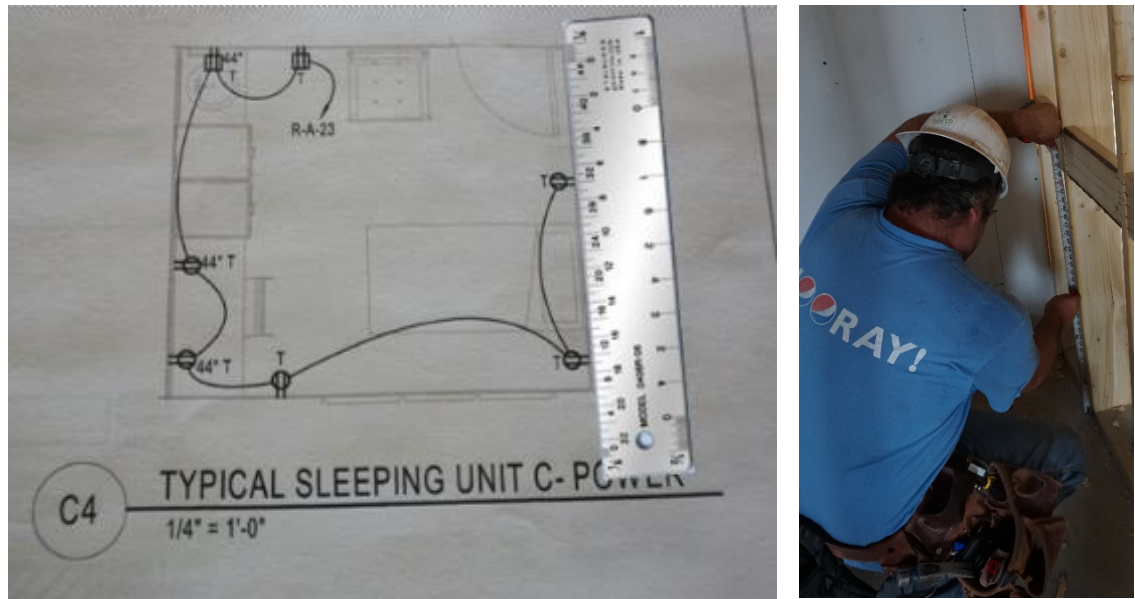
Figure 22. Manual Measurement in the Construction Site

6.1.3 Instruction and Demonstration of the Construction Process

HoloLens can project the digital BIM model by showing the step by step process of construction. Besides that, the user can get information about the properties of the building material in this process. For this, the designer needs to prepare the BIM model by creating a separate layer for the different construction material, write some description of the material and prepare the animation showing process of construction so that the user of the HoloLens can visualize the construction process by playing the animation and turning a different layer on and off to see the construction material and process.

6.1.4 Error Detection

The HoloLens user can detect the error by visualizing the design in an immersive view once the BIM model was aligned with the real world. The error of design, layout, and construction can be detected and corrected quickly.

6.1.5   Remote Support and Quick Decision-Making

In the case of confusion in the design and construction, the user of the HoloLens in a site can easily and quickly collaborate with the technical expert for a quick solution on the site. The technical expert person can guide the person on the site by showing the technical detail through collaboration by sharing the same BIM model. The technical expert can virtually present in the site through an avatar and can help in layout and construction.

6.1.6   Easy Documentation and Efficient Progress Tracking

The documentation of the ongoing construction and progress tracking is very necessary to keep records and report the progress to the client and head office. Documentation and sharing the information on the ongoing construction become much easier with the help of HoloLens. The user can take the picture and can-do a 3D scan of the construction site through HoloLens. The documentation prepared with the use of HoloLens can be accessible and easy to understand both for a technical and non-technical person.

6.2 Challenges of Using Mixed Reality in Electrical Layout

6.2.1   Stud Locations

One of the challenges of using Mixed Reality in electrical layout is the stud locations. Stud is the skeleton of the wall that was laid vertically to support the drywall. The electrical receptacles can be laid after the stud construction. Sometimes the electrical receptacles need to be switched to the nearest stud location to attach the receptacles to the wall. Due to this, the as-built verification will not be always accurate since the electrical receptacles were moved to a different location on the site due to the stud location. The

shifting of the receptacles was not updated in the BIM model which create the accuracy problem in the verification job.
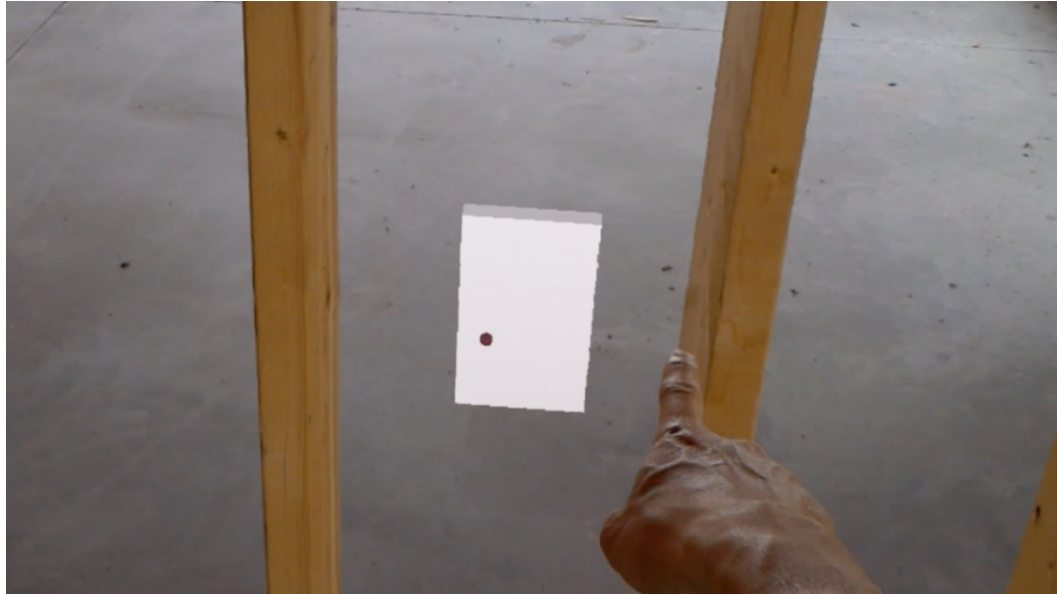
Figure 23. Stud Location and the Position of Electrical Receptacle

6.2.2   *Typical Rooms*

Typical Rooms is another big challenge while conducting the as-built verification of the electrical layout. Typical rooms are the rooms that have the same room size and layout. The designer will not replicate the design while modeling the building in BIM software if the rooms are typical. In the absence of the electrical receptacle layout in the holographic model, it would be impossible to use the MR application to perform the as-built verification of the room that has no layout of the electrical receptacles.
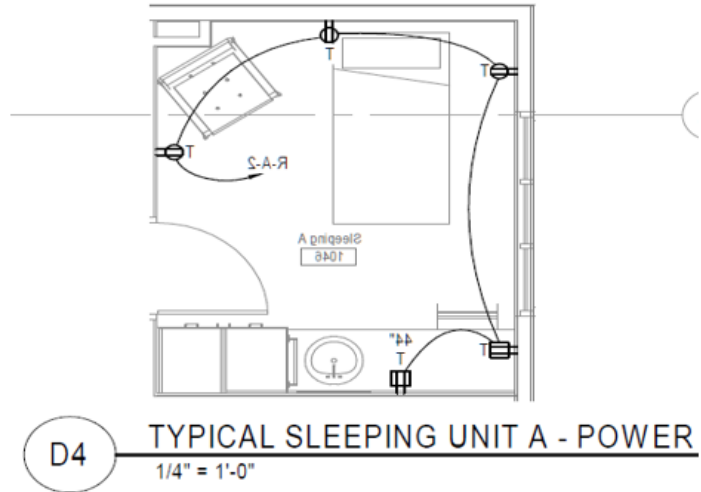
Figure 24. Typical Room Layout
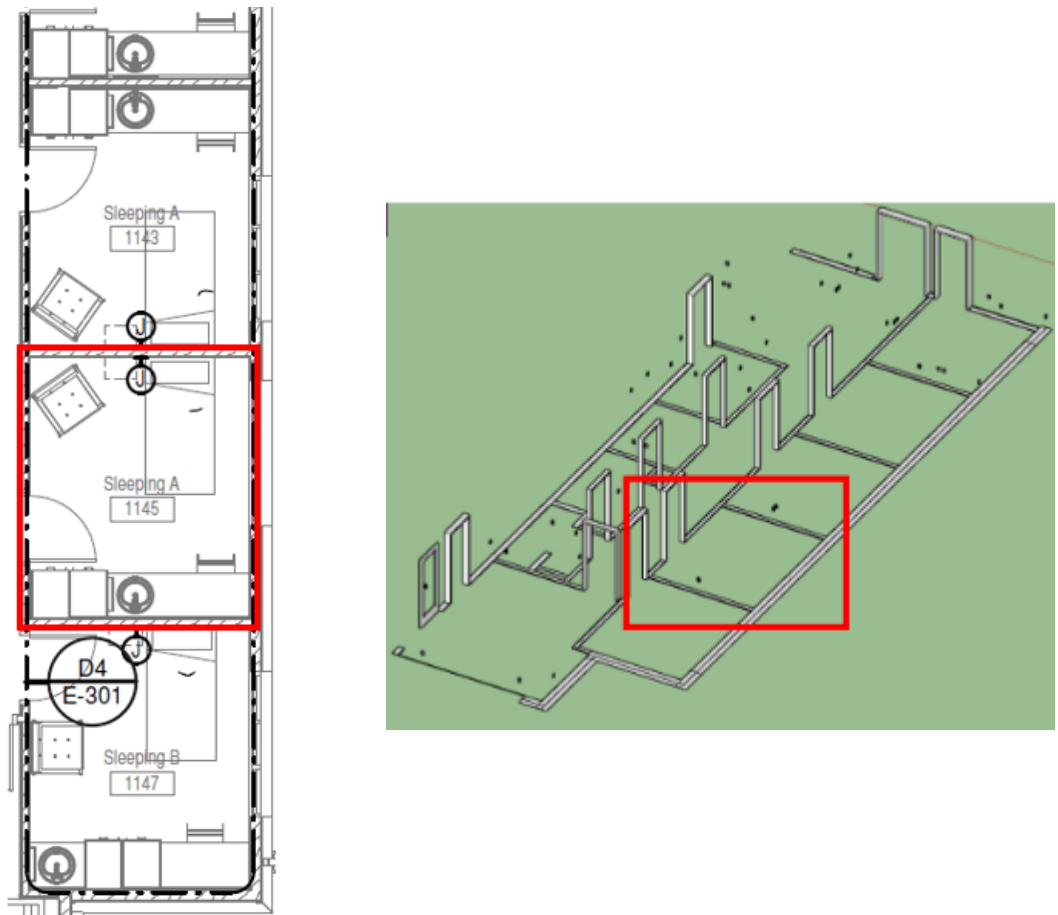
Figure 25. A Typical Room with Different Electrical Layouts in Different Views

6.2.3   *Model Drifting*

Model Drifting is another big challenge while utilizing the MR application on the site. Once the model was scaled, aligned, and positioned in the site which makes the model stationary. However, the model moves a bit in the direction of the user movement. And these movement causes the model drifting problem which makes the as-built verification much difficult to perform. The user needs to align and adjust the BIM model in the site time and again if the user moves from the location from where the alignment was done.

Figure 26. Model Drifting After 4.5 Ft Move to the Left

Figure 27. Model Drifting After 7.5 Ft Move to the Right

6.3 Summary

This chapter discussed the benefits of as-built verification and on-site installation in electrical layout along with the challenges of using mixed reality in electrical layout. The results are based on the sole experience of implementing the MR application on the site with the help of the HoloLens. From the experiment of using the MR application in the site for the onsite installation and as-built verification, it was found that the MR application can be for the 3D visualization to understand the design more clearly, the quick layout of the electrical receptacles, getting the remote support in the site that help for the quick decision making, identify the error in the construction, and effective documentation of the progress in the site. The MR application has many benefits of using for on-site construction and as-built verification. Along with the benefit, there are some challenges of using MR application on the site. Stud location, typical plan, and model drifting affect the accuracy of the MR application in the site. Based on the on-site experience, the MR application is not quite ready for the accurate on-site installation and as-built verification of the Electrical receptacles on the site.

CHAPTER 7 CONCLUSIONS, DISCUSSION, AND FUTURE WORK

7.1 Conclusions

7.1.1   Limitations of Previous Research

Many researchers have stepped their research in the field of Mixed Reality device, HoloLens, to implement in the construction work, including Chalhouband and Ayer (2017), Chalhouband and Ayer (2018), Naticchia et al. (2018), Chalhouband et al. (2018), Zhou et al. (2017), Fenais et al. (2018), Khalek et al. (2019), and Chalhouband (2019). However, there are not many primary reviews of the MR application, the workflow of obtaining the BIM model in the HoloLens and implementation of the MR application in the site have been found and this research will bridge the gap. This research provides comprehensive knowledge of the features and capabilities of MR application and its use in the on-site construction and as-built verification along with the benefit and challenges of using the MR application on the site.

7.1.2   Identified Existing Mixed Reality Applications

Due to the capability of overlaying the holographic 3D model on the site, the HoloLens was used to implement the MR application in the lab and construction site. Two HoloLens were used for this study. From the literature review and internet search, nine MR applications were identified. Seven out of nine were tested in the lab. The comparison of MR application features of 3D Viewer Beta, SketchUp Viewer, BIM Holoview, MR Builder Lite, Vyzn, and Prism was based on the Lab experiment whereas the study of the features of HoloLive 3D and Fuzor AR is based on internet research.

From the comparison of the capabilities of MR applications, 3D Viewer works best to visualize the 3D object in tabletop view and switch to the full scale in immersive view

mode. Vyzn and Prism are good for the MR presentation with the features of collaboration but lacks some navigation features. Similarly, BIM Holoview and HoloLive 3D works best for the immersive mode but lacks some navigation tools in tabletop view mode. For the BIM model the MR application tools like SketchUp Viewer, Trimble Connect, MR Builder, and Fuzor AR work best. However, the SketchUp Viewer lacks automatic alignment features, MR builder does not support collaboration, and Fuzor AR can only work in its computer app. Trimble Connect lacks some layer control, markup, and co-location in collaboration.

7.1.3 *Developed Workflow of Using BIM in Mixed Reality*

The comparison of the capabilities of the MR application was studied and implemented the accessible and available MR application in the construction site for the on-site installation and as-built verification of electrical receptacles. SketchUp Viewer MR application was implemented on the site of the Avera Addiction Care Center (AACC).

To access the required BIM model in the HoloLens, the workflow of developing the BIM model to MR application were studied. The Revit file of the AACC residential building of Sioux Fall was obtained from the construction team of the AACC residential building. The Revit model was manipulated and transformed by including the necessary information for the on-site layout and in-site verification of electrical receptacles. The Revit model was exported separately to dwg file format and imported all the dwg file together in SketchUp. The huge model of the AACC building was divided into smaller blocks for quick and easy accessibility in the HoloLens. Once the separate SketchUp file was created, all the model was imported in the HoloLens. Now the user can access the BIM model in the HoloLens.

7.1.4   Benefits of Using Mixed Reality in Electrical Layout

The digital BIM model of the AACC building was projected on the site through the SketchUp Viewer which is the only MR application available for the site work. The digital model was enlarged to full scale and aligned to the physical object, door, in the construction site manually based on the observation. The electrical receptacles were marked by visualizing the electrical layout of the holographic 3D model. The verification of the job was done once all the electrical receptacles were laid out on the construction site.

Once the HoloLens was implemented for the on-site layout and in-built verification purpose of the AACC building of Sioux Fall, the benefits, and challenges of using the MR application in the construction site were discussed. The benefit of using MR application for the on-site layout was explained along with the process of doing the on-site layout. Based on the experiment of using HoloLens for on-site layout and as-built verification, the SketchUp Viewer MR application could lay the Hologram in the site which helped the construction team understand and visualize the design. The construction team was able to get detailed information on the construction material and procedure if needed. The construction team can also get remote support from the design team by utilizing the collaborative features in the site which helped for quick decision making. The user of the HoloLens can quickly and easily find the error in the construction so that the construction team can correct it easily. The documentation features of HoloLens like scan and taking the snapshot of the construction site along with the Holographic model, make the documentation of the construction work clearer and easier.

7.1.5   Challenges of Using Mixed Reality in Electrical Layout

Along with the benefit, there are some challenges of using MR application for the on-site layout of the Electrical receptacles. Some of the challenges are stud location, typical layout, and model drifting. The electrical layout was performed once after finishing the wall skeleton construction. Some electrical receptacles position was shifted to the nearest stud location. The shifting of the electrical receptacles was done only on the site, but the design remains the same in the BIM model. Due to this change in the site, the accuracy suffered while performing the as-built verification. Similarly, the typical layout is also one of the challenges for on-site installation and as-built verification in the site. Since the design team did not replicate the electrical layout for the typical room. Without the BIM model with the appropriate electrical layout, the HoloLens user cannot visualize the design on the site. And the model drifting is also another big challenge of using MR application on the site. Even after aligning and positioning the BIM model in the physical world, the model moves in the direction of the user. The movement of the model with respect to the user makes the on-site layout and as-built verification difficult. The user needs to stay stationary to visualize the BIM model in the site and or need to adjust time and again after the move. So, the stud location, typical layout, and model drifting are the three main challenges of using MR application in the site for in-site layout and as-built verification.

7.2 Discussion

7.2.1   Needs of Using Various MR Application on the Site

The research team identified nine MR applications. Among the nine MR applications, only seven MR applications were installed and studied the MR feature in the lab. While nine out of one is applied in the construction due to the availability and license

problem. The on-site benefit and challenges of using MR applications were made based on the implementation of an MR application called SketchUp Viewer for in-site layout and on-site verification. To understand the benefit and challenges of the MR device the research team needs to use other MR applications on the site.

7.2.2   *Needs of Implementing Automatic Alignment Tools*

The BIM model needs to align and adjust to the site so that the user can walk through the Holographic model along with the physical environment. The user needs to manually align and adjust the Holographic model in the real world in SketchUp Viewer, which is very tedious, time-consuming, and hard to obtain precision. However, some MR applications like Trimble Connect, BIM Holoview, MR Builder, HoloLive 3D, and Fuzor AR can support the automatic alignment to overlay the holographic model in the real world. The user can use the four types of automatic alignment like two-point, one point, QR code, and pivot. The automatic alignment features can increase the accuracy of overlaying the Hologram in the actual field which helps make the in-site layout and as-built verification job much easier, effective, and efficient.

7.2.3   *Needs of Applying Various BIM Models*

For the on-site layout and in-built verification, the BIM model of AACC building, and performing art center building model for the electrical conduit was applied. Due to the conflict of the time with the construction team, the research team continued to apply the MR application in the AACC building only for the layout and verification purpose of the electrical receptacles in the construction site. The study of the capabilities of MR application can be more effective if the MR application could implement in different BIM model.

7.2.4   Needs of Testing Various MR Device Available in the Market

There are several MR devices in the current market. Some of the MR devices which are currently available in the market are HoloLens, Magic Leap One, HoloLens2, and Lenovo ThinkReality A6. However, the research team used the HoloLens as the HoloLens was the only one available MR device in the market at the time of the lab test and field test. Two HoloLens were implemented for the lab test and one HoloLens were implemented in the construction. But for the better result of the implementation of MR application in the lab and construction site, various MR devices need to use and compared based on the performance of MR application in each MR devices.

7.3 Future Work

7.3.1   Multiple Survey Point

To understand the capabilities and benefit of MR application, further research needs to be carried out in this area by using the multiple survey point for the reference. Survey point references are the locations in the construction site where the holographic model can be positioned to make the model stationary and attached to the physical site. Based on the experience of implementing the MR application in the construction site there are several challenges while performing the on-site layout and as-built verification. One of the challenges which can be correct by using the MR application is the model drifting. The model drifting problem can be solved by using the several survey reference point in the construction site to position the BIM model in the site. For a better understanding of the capabilities of the MR application in the construction site, the researcher could use the multiple reference point for the attachment of the BIM model on site. The multiple survey

point needs to be laid out in the model first and then after that survey point can be identified and locate in the site.

7.3.2   *Use of Weighted weight and index system*

To make the comparison of the MR application better, further research needs to be done in the direction of a quantitative comparison of the features of the MR application. For that, the researcher can proceed using two methods. In one the user will identify the current MR application and study the capabilities of the MR application. And in another way, the researcher will identify the different requirements and important features that are needed for the electrical layout work in the construction industry and construction management. Based on the importance the researcher can give different weight to these features of MR application. In the qualitative method, the user can give an index number to the MR application as well. To do a comparative study of different MR applications the researcher can find the weight of the MR application based on the weight of the functional features that need for the construction work and management of the construction work.

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