An Investigation of Visualization Technologies for Remote Work in The Architectural, Engineering and Construction Industry

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DEDICATION

To my father, Solomon Sowunmi, thank you for standing by and fulfilling your promise.

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ABSTRACT

The recent COVID-19 pandemic has impacted the way everyday professional work is being performed. Organizations have devised innovative ways to work remotely, staying home, or in secluded offices. One of the technologies that many industries are relying on is visualization for remote work. Professionals in the Architecture, Engineering, and Construction (AEC) industry are applying technology solutions to facilitate remote work, making the work site less crowded. Visualization technologies (VT)—extended Reality and Unmanned Aerial vehicles' ability to monitor construction activities—can help the AEC industry remotely work. It is unknown that, after the beginning of the pandemic, the use of visualization technologies has increased or not in the AEC sector and what tools and technologies are proving helpful. To understand this, the author designed and implemented an industry-wide survey and interviewed industry professionals to analyze the state of VT use, barriers to their implementation, and factors influencing these barriers. The study found out that although remote work had increased significantly since the onset of the COVID-19 pandemic, the rate at which people utilized VT for remote work had not increased at the same pace. The study also proposed a few strategies for implementing the use of visualization technology within the AEC.

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LIST OF ABBREVIATIONS

AEC	Architecture, Engineering and Construction
AR	Augmented Reality
BIM	Building Information Modeling
COVID-19	Corona Virus Disease of 2019
HMD	Head Mounted Devices
MR	Mixed Reality
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality
VT	Visualization technologies

CHAPTER 1

Problem statement

The recent Corona Virus Disease of 2019 (COVID-19) pandemic has altered how routine tasks are carried out in order to slow the coronavirus's spread. Various job sectors have devised innovative ways to work remotely using technological innovations and advancements. One of such new technologies industries are turning to is by utilizing visualization technologies such as Augmented and Virtual Reality for remote work. The Architecture, Engineering and Construction sector is among sectors that have been hit hard by the pandemic as most of the work performed is on-site or at pre-determined spaces.

The Architecture, Engineering and Construction (AEC) industry has been implementing technological solutions to improve the effectiveness of remote work. Visualization technologies are one such innovation. Numerous studies have been conducted using visualization technologies such as Extended Reality and Unmanned Aerial Vehicles to successfully and satisfactorily perform activities within the AEC. Zaychenko et al. (2018), in a study about the use of drones in construction, identified several advantages such as reduced resource cost and faster data collection. Augmented Reality and Virtual Reality have also been employed in progress tracking and effective communication between project participants (S. Ahmed, 2019).

Studies have indicated the overall slow pace of the AEC sector in adopting these visualization technologies. Davila Delgado et al. (2020) noted that the adoption of digital technologies in the AEC sectors was still considerably low compared to other sectors. It is currently unclear if the pandemic's onset has reversed such trends, leading to a rise in the adoption of visualization technologies (VT) within the AEC sector due to the need for a less crowded work site.

This study investigates the levels of VT implementation in the AEC sector for remote work in the context of the current public health crisis of COVID-19. Understanding the state of utilization will help those construction firms slow in adoption technology to see the most commonly used technologies to carry out construction activities uninterrupted and meet important project objectives.

Aim and objectives of this study

The research investigates the current use of Visualization technologies for remote work in the Architecture, Engineering and Construction industry. The objectives of this research thesis are the following:

1. Identify the various types of visualization technologies currently in use in the AEC industry,
2. Identify and evaluate the current use of visualization technologies in the AEC industry both in the field and in the workplace, prior to and after the outbreak of the COVID-19 pandemic,
3. Identify and assess the barriers to the utilization of visualization of technology in the AEC industry,
4. Propose a framework for the implementation of visualization technologies in the AEC industry, and

5. Demonstrate the potential use of at least one visualization technologies (Augmented Reality) for remote work.

Hypothesis

This study contains two hypotheses outlined below.

H_1: There is no significant difference in the mean responses between the respondent group categories to the use-case of visualization technologies.

H_2: There is no significant difference in the mean responses between the respondent group categories to the barriers and constraints to visualization technologies.

Scope of the study

The study focuses on visualization technologies' use in carrying out work duties remotely in the AEC industry. It contains an overview of visualization technologies types, the use-cases in the AEC industries, the barriers encountered in implementing them for remote work, and strategies discussed to mitigate the identified barriers. For this study, this study's sample demographic mainly consists of AEC professionals (contractors and consultants). The sample population's responses will be evaluated on the usage of VT to provide more insight into this topic.

Significance of the study

The results of this study could greatly benefit both the AEC industry and academia in the following ways:

AEC industry- The results of this study will provide knowledge on understanding the most prevalent barriers that affect VT's effective utilization for remote working, especially during the COVID-19 pandemic where remote work has become a necessity and project objectives in terms of cost and schedule baselines still need to be met.

Academia- This study's results will help guide academia on developing new content to ensure that students are better prepared to fill industry gaps identified in the study. This would help prepare students to be more suited to the increasingly dynamic demands of the AEC workspace.

Thesis organization

Chapter 2 of this study is a review of relevant literature related to visualization technologies. It defines the various terms and technology associated with VT. It provides an overview of the different use-cases of visualization technologies in the AEC sector for both design and construction activities. Furthermore, a brief look at the barriers to implementing VT for remote work is also discussed alongside future visualization technologies used for remote work.

Chapter 3 provides information on the methodology utilized in carrying out this research thesis. It provides information on the approach used, methods of gathering data, and the methods used to analyze the data gathered to make a meaningful analysis.

Chapter 4 provides the results of the analysis carried out from data gathered from the sample population. The results are discussed, and relevant correlations are observed and discussed. This chapter would also contain selected responders' interview responses on mitigating strategies for identified barriers to VT usage.

Chapter 5 contains the conclusions and recommendations deducted from the analysis and discussions carried out in chapter 4. Recommendations for future research would be outlined in this chapter.

CHAPTER 2

LITERATURE REVIEW

Overview

Remote work

Telework, also known as remote work or virtual work, refers to work done away from the normal workplace (Bailey & Kurland, 2002).

Traditionally, work among work teams had to be done in co-located spaces. This required project team members to convene at central locations where work will be performed. In the past two decades, we have witnessed a shift in how work has been carried out among teams (Boell et al., 2013). As technology has improved and birthed innovations such as the internet, mobile phones, people have been able to leverage the new innovations in making it possible to work from other spaces other than the traditional workspace and diminish the limitations linked to it. The concept of telework has become increasingly popular and important as technology has evolved (Herschel & Andrews, 1997).

In a study reviewing telework research, telework was defined as work being accomplished externally from the normal workplace and utilizing telecommunications and computer-based technology to communicate with the workplaces (Bailey & Kurland, 2002). Boell et al. (2013) are of the opinion that asides from the spatial freedom or temporary flexibility that teleworking provides, it introduces a clear shift from the way work is performed and how people engage with the work process. It was also noted that this shift from the usual process could be attributed to the potential advantages and challenges that teleworking proposes for both employees and their organizations. Advantages such as an increase in workers' productivity due to being in an environment in which minimal interruptions and disruptions occur are key drivers for the adoption of telework (Boell et al., 2013).

The next section gives a brief introduction into visualization technologies and its use within the AEC sector.

Visualization technologies

As advances in technology have improved over the years, various industries are leveraging the benefits of these technologies to carry out daily operations in a safe, effective, and efficient manner. Visualization technologies, in particular, has been used to great effect among different sectors in society ranging from education, aviation, manufacturing, gaming, and construction (Manuel et al., 2020)

The AEC is currently one of the fastest-growing industries in the world but still lags behind in comparison to others in the shift from traditional methods of working to automation. Various visualization methods have been employed with varying degrees of success by design teams in presenting and sharing their ideas and the construction team on projects. While physical mockups have been used for a long time, recent design teams are turning to visualization technologies such as Virtual and Augmented Reality (AR&VR) and Building Information Modeling (BIM) to take advantage of the benefits that these technologies can afford (Alsafouri & Ayer, 2019).

Visualization technologies have gradually evolved from the cumbersome use of two dimensional (2D) paper-based documentation to time-tasking physical models and then to recent innovations such as Augmented Reality and Virtual Reality applications, which allow the user to interact with the environment and obtain feedback in real-time (Alsafouri & Ayer, 2019). Technological advancements in drones and high-resolution cameras have also seen an increase in the use of these technologies in the AEC sector.

The next section provides a brief overview of visualization technologies currently in use in the AEC sector.

Extended Reality

Extended Reality refers to the range of experiences that blurs the line between the virtual and real environments (Alizadehsalehi et al., 2020a). It is the general term for immersive realities, consisting of Virtual, Augmented, and Mixed realities. Extended Reality (XR) can be used to enhance Building Information Modeling by allowing the user to be immersed into the BIM model on a real scale, thereby permitting the user to experience it from multiple angles and viewpoints (Davila Delgado, Oyedele, Demian, et al., 2020).

As VR and AR technologies have increasingly improved over the years, these technologies have been used in other sectors such as marketing, tourism, manufacturing, aerospace, and education for a variety of tasks ranging from training to better product improvements. Built environment professionals have used VR and AR (to a lesser degree) to support the visualization of design, construction, and city operations since around the 1990s (Davila Delgado, Oyedele, Demian, et al., 2020). Since the turn of the 1990s, XR (in particular VR) has gradually been used in supporting the visualization of the design and construction industry by the built environment professionals. (Davila Delgado, Oyedele, Demian, et al., 2020)

In a study about Extended Reality in the AEC industry, Alizadehsalehi et al. (2020) identified the ability of VR to permit real-time virtual collaboration for stakeholders from different locations as a strength of this technology. While the use of XR in the AEC sector has been commonly accepted to possess a huge potential in reimagining how work is performed,

its current use in the industry is still in its infancy, as with a lot of digital innovations.

Extended Reality consists of realities distributed across the virtual continuum. The virtual continuum shows the degree of immersion a person experiences ranging from the completely real environment to the completely virtual environment (Milgram et al., 1995). Both Augmented and Virtual Reality are briefly overviewed in the next subsection.

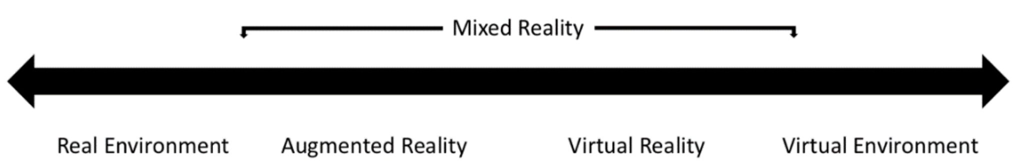


Figure 1.1: Reality-Virtuality (VR) Continuum (Milgram et al., 1995)

Virtual Reality

Virtual Reality is "a technology which enables the visualization of large amounts of complex information" (Woksepp, 2007). It is an environment where users are able to interact and navigate a three-dimensional environment freely in real-time. Navigation refers to the ability to move around the virtual environment, while interaction means controlling the features of the environment. VR can also be used not just as a spatial but a communicative medium to aid collaborative efforts between the project team from the process of design to construction.

Whyte (2003a) broadly defined Virtual Reality as applications "that provide an interactive, spatial real-time medium for visualization."

VR from the construction point of view was largely not looked into till the mid-1990s. However, the rapid growth and availability of technology have led to an upshot in this area to the extent that large digital models can be visualized in a virtual environment using personal computers. Woksepp (2007) noted a mentality shift regarding the use of VR over the past few decades. While The focus was on the level of immersion and interaction in the 80s and 90s, the main attention of VR from the 2000s has gradually evolved to be focused on functionality, compatibility, and user-friendliness.

VR user environment

In a virtual environment, the user experiences a world completely made up virtually (S. Ahmed, 2019). There are two viewpoints in which a user might experience the virtual world. VR user environments are either exocentric or egocentric (Kaushal, 2013). An exocentric environment is when the user experiences the VR environment from an external viewpoint (window-like). In this view, the viewer experiences the virtual world like an overview. However, in an egocentric climate, the opposite is the case as the viewer is immersed in the virtual environment—the virtual objects are in relation to the viewer's avatar (Kaushal, 2013).

Categorization of VR

Wang et al. (2018) categorized VR-based on the level of immersion provided to the user. They identified four spectrums under which VR can be classified. The four spectrums identified were Desktop-based VR, immersive VR, 3D game-based VR, BIM-enabled VR.

According to their study, Desktop and BIM-based VR are the most commonly adopted forms of VR, with 3D-based VR and Immersive VR being the least commonly adopted VR in the AEC sector currently.

Desktop-based VR

This is considered relatively inexpensive compared to other types of VR due to the availability of the technology needed to run it (monitors, keyboards, and mice) hence why it is the most commonly adapted VR technology (Wang et al., 2018). It works by displaying "a 3D virtual world on a desktop screen without any tracking equipment to support. This VR system solely relies on the user's perception and spatial abilities to understand the system. It is the least immersive form of VR in the AEC sector.

Immersive VR

In contrast to Desktop-based VR, which relies on the user's perception and spatial abilities, this form of VR utilizes special hardware like sensor gloves and head-mounted devices to experience the VR environment, which is fully immersive (Wang et al., 2018). The author also explained further that the virtual world is experienced as a real-world where special sensors can also be embedded to give users real-time feedback, giving this VR type a major advantage over Desktop-based VR.

Game-based VR

Game-based VR goes a step further than immersive VR by making users interact with game objects rather than just providing the immersive effect by providing similar to real-life scenarios and tasks for game-based training, collaboration and interaction can be greatly improved (Wang et al., 2018). Integrating visual, interactive multi-user, and network technology make this process possible.

BIM-based VR

BIM VR relies on a 3D construction model with geometrical attributes and data associated with the model to simulate construction activities. Virtual environments can serve as extensions of CAD designs, offering an outlet for the user to communicate more and interact with the computer model (Murray et al., 2003).

Classification of VR Application in Construction Engineering and Education Training

VR has increasingly been used in the AEC industry as the maturity of the technology improves. Wang et al. (2018) identified four applications of Virtual Reality in a study of its utilization in construction engineering education and training. Architecture and visualization were found to be the highest use-case, followed by both construction safety and equipment training, which highlights a shift from workers learning directly on the jobsite and the hazards associated with it to being trained remotely, thereby eliminating those associated hazards. The final identified application was for structural analysis education in schools (Wang et al., 2018).

VR hardware

In experiencing Virtual Reality, specific and specialized hardware is mostly required to successfully run software programs. Desktop-based VR, which offers a low level of immersion, can utilize personal computers; however, more immersive forms of VR require more specialized hardware. Immersive Virtual Reality is experienced usually using head-mounted displays (HMDs) and hand-held devices for navigation within the virtual environment. There are a variety of head-mounted display devices available, ranging from high ended options such as the Oculus Rift (*Oculus | VR Headsets, Games & Equipment*) to the Google cardboard (*google cardboard – Google VR*), which utilizes a smartphone (Kaushal, 2013).

Augmented Reality

Augmented Reality uses sensory technology to provide a live direct or indirect view of a physical environment with augmented virtual information (Höllerer & Feiner, 2004). The sensory technology can provide sound, video, or graphics. It should be noted that AR and VR are different visualization technologies (Wang et al., 2018). AR affords users the capability to project and modify objects into the real-life environment, while VR creates a virtual environment with virtual objects that can be interacted with within the created environment.

Kalawsky et al. (2000) defined Augmented Reality as the process of using computer-generated imagery and data to supplement the real world, usually by overlaying the former over the latter.

Augmented Reality affords users the opportunity to experience virtual objects projected in the real-word by superimposing the former over the latter. Kaushal (2013) noted that AR had been indicated to improve the understandability of, what's more, the convenience of undertaking documentation in the perception of starter contemplates and in monitoring construction progress.

AR can be used on a range of hardware ranging from the use of head-mounted devices such as the Google glass, HTC Vive, and google cardboard to mobile tablets and phones.

Drones (Unmanned Aerial Vehicles) and High-Resolution Cameras

Unmanned aerial vehicles (UAV) or drones refer to aerial vehicles or aircraft flown without a pilot on board to navigate or control the aircraft (Ciampa et al., 2019). Drone usage in construction has increasingly become more popular, and the market is projected to reach billions of dollars in the coming years, which highlights their growing importance in the AEC industry and in general (Zaychenko et al., 2018). Furthermore, the authors are of the opinion that the case for drones has been strengthened due to their ease of access to large and/or complex facilities such as high-rise buildings to provide visual data that aids in activities such as inspections and progress monitoring which would otherwise have been difficult, expensive, or dangerous tasks to achieve normally.

Drones can be deployed at various points of the construction project cycle for a range of activities, including site survey and mapping, pre-planning activities, and monitoring of construction activities. This is achieved by using photogrammetry techniques to construct 3D models of drone images from various locations and point clouds (F. Ahmed et al., 2018).

High-resolution cameras have increasingly been utilized in collecting and processing data on the construction site as the technology has rapidly improved. "Cameras are used in taking static images at set time intervals and record moving videos of a site and its operations" they are mostly used for still photos rather than videos due to storage considerations and concerns (Bohn & Teizer, 2009).

Certain factors influence the position of High-resolution factors before they can be deployed for construction activities. Silva et al. (2009) identified three key factors that influence the positions where cameras are located on the site for visual supervision. The three factors identified were view, ease of accessibility, and access to a power source.

Bohn & Teizer (2009) outlined a process where high-resolution cameras are utilized for progress monitoring by setting up cameras at predetermined positions, especially from a distance to have a broad view of the site. Recorded footage is uploaded to the cloud or a website accessible only to the project team, where users can view the work being done remotely either in real-time or playback mode and make decisions regarding the progress of the project accordingly.

Building Information Modeling

Building Information Modeling (BIM) is currently one of the more mature and widely used visualization technologies in the AEC currently (Aslani et al., 2009). BIM is a three-dimensional computer-based model linked with related databases. These databases range from geometric attributes and additional attributes such as cost and schedule data, which can greatly increase the utilization and effectiveness of the model (Aslani et al., 2009).

BIM is also a center point containing accessible data consisting of designs, policies, rules, etc., from a design and/or construction team where daily updates and decisions can be made and reviewed. This enables the best option in terms of cost and schedule considerations to be selected for the production of a facility or building (Alizadehsalehi et al., 2020b)

Alizadehsalehi et al. (2020b) noted how VR technology could be optimized by incorporating BIM technology into the experience. Most BIM-based VR technology has been used in performing a series of AEC activities in the design and decision-making progress as well as for construction safety training and planning. This affords team members the ability to experience the properties of a proposed building or facility within the 3D-VR environment, which can also be done remotely. BIM can also be used with AR, especially for inspections and progress monitoring where the BIM model is superimposed over the real world and discrepancies identified between the two.

Use-cases

Visualization technologies have been used in the AEC sector for a variety of construction tasks ranging from onsite activities to off-site activities. As technology has improved and access to the internet has become more mainstream, visualization technologies have been adapted to perform work remotely. The following use-cases of VT for remote work were derived from the literature review.

Inspections

The traditional practice of carrying out inspections is based on human visual inspections. This method usually involves the use of scaffolds, ropes, or special machinery to access difficult or complex areas (Ciampa et al., 2019).The use of these methods leads to high costs in terms of machinery or platform acquisition, setup, and the training of highly skilled individuals to perform inspection tasks (Ciampa et al., 2019). Inspections carried out at heights using these methods also have the risk of injuries to workers due to falls which happens to be the number one cause of fatalities in the construction industry and represents about 51% of total falls among industries nationwide (CDC, 2019).

Drones can be used to inspect infrastructure and building structures which are complex in terms of logistics and worker safety due to their ability to maneuver and get to places that would otherwise be difficult to achieve. This use of drones commonly for inspection tasks aid in detecting deterioration, planning future maintenance, and verification of as-built structures to the plan (Ciampa et al., 2019). The main benefits of drones for inspection of civil and building structures are safety, speed, and cost economy compared to traditional inspection methods (Zaychenko et al., 2018). It also does not require the same amount of people and effort needed in traditional inspections as teams can log on to a shared portal to view and study information collected from the drones being operated by a single operator (F. Ahmed et al., 2018). Ciampa et al. (2019) utilized drones to perform an inspection of a bridge from sections (areas) that would otherwise have been difficult to achieve. Screenshots from the videos were used to develop a 3D model which experts reviewed to determine corrective actions to be taken.

Progress monitoring

Progress monitoring is a key and continuous process in the lifecycle of a construction project. There is a need to keep track of what has been built against what has been planned to ensure the success of the project in terms of both cost and schedule. Project managers utilize progress monitoring only to keep up with the pace of progress and to serve as a system that alerts them to inaccuracies, discrepancies and discretions in the performance of the work been done (Golparvar-Fard et al., 2009).

Golparvar-Fard et al. (2009) tracked the construction progress of several projects in a 4D-Augmented Reality environment by super-imposing as-planned models over high-resolution photographs of as-built structures. The as-planned 4D models consisted of a 3D model with the additional element of schedule. This allowed the project managers have a quick visual idea of the progress of the project at any given time with respect to the project schedule, the discrepancies present, and the corrective actions required to get the work back on track.

F. Ahmed et al. (2018) developed and tested a framework utilizing UAV mounted sensors based on organized real-time data gathered with the aid of advanced tools. The data gathered was then analyzed by an advanced software “3DF Zephyr,” which affords team members the ability to better monitor, plan and adjust on operations where necessary. Throughout the construction life cycle, routine visual progress of the project was provided to project stakeholders on an agreed frequency (usually fortnightly or monthly) or on an ad-hoc basis to monitor, record, and update important project milestones. These updates were provided with the drone/UAV capturing data along a pre-agreed flight path concerning the project site. Information captured from the drones was then used for workspace planning and optimization, periodic inspections for safety measures, and schedule comparisons between photogrammetry and BIM models.

Safety training, planning and management

With an injury rate 71% higher than the average injury rate across all industries, the construction industry is notorious for having one of the worst safety records compared to other industries (Zitman, 2021). VR has greatly improved the construction worker training process by eliminating the risk factor associated with on-site training. Workers can train on various scenarios associated with specific job tasks at unlimited frequencies (Wang et al., 2018). S. Ahmed. (2019) noted the use of game-based VR as a safety training system where users participated in operating virtual tasks online ranging from material delivery to equipment operation. This afforded the users the ability to repeat these tasks to the point of efficiency and eliminated the risk of training at the job site.

Le et al. (2015), identified the high-risk nature of construction tasks, limited safety knowledge, lack of safety awareness, and education of construction workers as key reasons why the construction industry has almost double the rate of accidents compared to the industrial average. The author then developed a serious game-based social Virtual Reality system that allowed participants to learn about construction workplace safety by focusing on role paying, dialogic learning, and social interaction within the system. The study concluded that participants obtained higher safety knowledge and practical skills when using the game-based VR prototype system.

VR has also been employed for construction equipment training away from the job sites by simulating work activities due to the high cost and hazards associated with new operators learning on the job site (Wang et al., 2018).

Space planning

The ability to design and represent spaces in interactive, spatial and real timed media lead to the beginning of new markets for the architectural professionals (Whyte, 2003a). This enabled the architects to have better representations of how the spaces were designed to fit into requirements in real-time and adjust where necessary.

VR was used on more than one project by AEC professionals to have a feel of designed spaces and experience their practicability (Kaushal, 2013). Team members for this project used the Revitzo cloud-based software (*2D & 3D BIM collaboration platform. BIM collaboration software from Revizto*) in performing this task. This works by transferring 3D models into the software. BIM projects can then be exported to Oculus VR at the click of the button, which puts the user in a virtual environment of the BIM model. Remote members can easily access the BIM model from mobile devices which aids fast and easy communication.

Clash detection and design coordination

BIM software such as Autodesk Navisworks (*Navisworks Features | 2022, 2021 Features | Autodesk*) have functionality that has made the design coordination process a lot easier and afforded teams the ability to work remotely. Different design teams work on a model secured on a shared cloud platform, constantly check that no interference from other design teams is occurring and update affected parties where necessary (Aslani et al., 2009). Woksepp (2007) concluded from a case study that VR had an overall positive effect in terms of total installed costs when compared to a similar project that utilized 2D project drawings. Also, the number of dedicated staffs involved in the design coordination process compared to a similar 2D project was reduced by approximately 50% (15 to 7 persons) leading to further reduction in cost savings. This would also allow for more project team members to channel more time to supervising and have the effect of increased productivity among teams.

Virtual supervision

Silva et al. (2009) developed a model framework for virtual supervision which utilizes high-resolution cameras from a Construction Monitoring and Visualization Center based on three major segments

- Site supervision
- Engineering supervision
- Administrative supervision

The authors opined that the combination of these three segments presented a solid model to effectively manage and supervise the major aspects of a project remotely, either by a designated individual or a team and lead to benefits.

Value engineering and design reviews

Design reviews involve sharing and analyzing data and information (structural, mechanical, electrical, architecture, etc.) about the project between the various stakeholders to allow for identification, discussions, and mutual agreement of varying concerns as it concerns the project objectives and strategies (Alsafouri & Ayer, 2019). Virtual Reality is an important technology in the value engineering process in aiding better-informed decisions on obtaining value for money by reducing costs without a trade-off in design quality (Whyte, 2003a).

BIM-based VR allows a building design to be viewed in a virtual environment with cost and material attribute data attached to it. Real-time changes can be viewed in the model and help project members make quick and informed decisions accordingly (Wang et al., 2018).

Woksepp (2007) utilized VR in his study to conduct design reviews considering multiple perspectives and functions and was able to solve clashes between the various disciplines involved in the design review process seamlessly and with less risk in comparison to the traditional 2D methods. This method saved time.

Surveying and site mapping

Visualization technologies have made it possible to have accurate site planning with less people and logistics than would be required without its use (Zaychenko et al., 2018). Images of the entire project can be taken with high-resolution cameras from multiple pre-determined points to get a clear idea of the site and its corresponding parameters to aid in planning adequately (Zaychenko et al., 2018).

Accurate and cost-effective measurement of large areas can be achieved within the centimeter range with the use of accurate aerial photogrammetry techniques. This has the advantage of being done without causing disruptions to ongoing site activities (F. Ahmed et al., 2018). The authors also highlighted how clients could be provided exocentric views of the construction site from the beginning stages of the construction in pictorial and video formats without visiting the jobsite. These are beneficial for future planning purposes. 3D scanned models can be used in planning for landscaping due to the high quality of visualization it provides.

Virtual conferencing

VR affords the construction team the means to have collaborative meetings in a virtual environment and make decisions based on the same model and information (Kaushal, 2013).

Benefits of Visualization technologies for remote work

There are various benefits attached to utilizing the identified forms of VT for performing remote work in the AEC sector. Murray et al. (2003) are of the opinion that visualization tools can help site managers have better perception of the project and can lead to greater gains than utilizing traditional methods. For example, using a 4D schedule simulation could lead to better decision-making, minimize overall risk, improve project communications among stakeholders and significantly enhance the value engineering process. Some of the benefits of utilizing VT for remote work in the AEC are explored below.

Higher productivity

High-resolution cameras can be used to achieve higher productivity by monitoring real-time tracking of the workforce and inventory management, thereby leading to quicker task completion time and generally fewer inefficiencies (Bohn & Teizer, 2009).

Silva et al. (2009) proposed that their proposed framework for the virtual supervision model could save a substantial amount of ineffective time between workers and the supervisory team while increasing productivity.

Cost and schedule savings

VR-based worker training can lead to massive schedule gains and cost savings on a project. As training is taken away from the traditional job site to remote training locations, the financial risk attached to minor and major accidents occurring as well as the schedule losses attached are greatly reduced (S. Ahmed, 2019).

Ability of Project Manager to manage multiple sites

Most project managers are usually overseeing the work going on at multiple construction sites. Utilizing cameras for project monitoring affords the Project Manager the ability to work remotely and maintain control of multiple projects' progress in real-time (Bohn & Teizer, 2009).

Less logistical costs

Significant travel costs can be saved on projects located in remote areas or locations at a great distance from team experts. Experts and project managers can greatly reduce costs associated with logistics by managing, overseeing work and communicating from a remote location by simply logging into a website containing high-resolution photographs and videos of site activities (Bohn & Teizer, 2009).

Performance of high-risk tasks

Visualization technologies such as the use of drones afford the construction and design team opportunities to reduce the risks associated with some activities that have a high tendency of risk or otherwise difficult to perform (Ciampa et al., 2019). VR allows the construction team to select an optimized process for construction tasks to be done or for processes in which more efficient methods can be selected by simulating these processes in a realistic virtual environment (Kaushal, 2013).

Hi-res cameras access areas of the project or site for supervision which would otherwise have been impossible or extremely difficult to access (Zaychenko et al., 2018).

Retrospective review

Virtual supervision using high-resolution affords the supervisory and management team the option of going back in time to review archived footage and identify areas for improvement (Silva et al., 2009). Photos and videos captured during inspections with AR HMDs can also be reviewed at later periods.

Worker safety

The construction sector is notoriously reputed to be the industry with the worst record on safety records and leads the statistics with falls occurring on the job site, with 33% of construction deaths related to falls (Zitman, 2021). One key benefit of utilizing drones for inspections stemming from reducing the number of people needed on-site is the increased worker safety, especially in a situation involving high elevations (Ciampa et al., 2019).

Easy access to specialized experts

The use of HMD's can permit quick and easy access to specialized competence in assisting on-site work remotely through a shared view, thereby eliminating unproductive work time (Kaushal, 2013).

Expedited decision-making.

Virtual Reality has the added benefit of expediting project decisions in the planning phase of projects without having the whole design or planning team physically present at one location. This is beneficial considering the constraint of time associated with AEC projects (S. Ahmed, 2019).

Design reviews & value engineering

Clients are more likely to understand the impacts of various choices when it can be visualized, leading to informed decisions of them selecting the higher quality proposal over the least cost option (Whyte, 2003b).

Barriers to implementing Visualization technologies

The use of VT in the AEC sector has been considered to be relatively low in comparison to other sectors. This section is an overview of major barriers to VT use in the AEC sector identified during the literature review.

Lack of skilled personnel

One of the common barriers to the use of drones for inspection is the availability of skilled personnel. Drones need to be operated by qualified persons, and generally, it requires the pilot to acquire an operating license. The ability to also skillfully pilot the drone in the event of unforeseen circumstances is required (Ciampa et al., 2019).

Le et al. (2015), noted that game-based VR requires highly skilled personnel due to the complex scenarios that may be required for quality education purposes, for example, programming skills for developing the VR environment. Kaushal (2013) highlighted the lack of training among AEC personnel, especially those in the industry, as a barrier to VR usage for a considerable period of time. The lack of training of this demographic not only acts as a barrier but limits the important transference of knowledge this group has to offer to the younger professionals.

Cost of training

Due to a lack of skilled personnel, companies that desire to use VT need to train their own workforce. In their study about drivers and barriers to VR and AR implementation, Manuel et al. (2020) noted that very few construction firms except the larger ones had dedicated teams to VR and AR. Upskilling the workforce in many construction firms is a need that would be too expensive for a lot of firms to satisfy at this point in time.

Cost of technology

As most of the visualization technologies are emerging and not yet mature in the industry, very few companies can afford to invest in these technologies. Also, accessing the funds to acquire these devices can also prove difficult as the potential benefits of these technologies are not yet clear to some (Davila Delgado, Oyedele, Beach, et al., 2020). The cost to access this equipment might be an important factor, especially to small construction firms in the decision not to adapt these technologies at this time. In their study of barriers to BIM implementation, Wong & Gray (2019) identified the cost of technology as the main barrier to BIM implementation. Over 56% of respondents agree that the cost of BIM software deterred them from using it.

Security of data

Lack of capabilities in ensuring smooth data and information exchange within various parties also poses a limitation to VT's adoption in the AEC sector.

Interoperability between different devices has also been touted as an important factor to consider (Manuel et al., 2020).

Access to software and hardware required

As new and emerging technologies, most software for VT need either specialized equipment such as HMDs for AR and VR or highly dedicated computers to run the needed applications (Alizadehsalehi et al., 2020a; Manuel et al., 2020).

Lack of standardized process and procedures

The absence of a clear strategy for using VTs such as VR and AR can reduce its implementation on a project. Clear strategies addressing when and how these technologies should be used and what use-case and who should be using them should be developed in terms of templates that can then be tailored to specific projects (Kaushal, 2013). A lack of guidelines and procedures was also identified as a major barrier to BIM implementation (Wong & Gray, 2019).

Management aversion to new technology

Generally, the construction industry is well recognized for its resistance to Information Technology related solutions. Silva et al. (2009) highlighted management resistance as one of the main barriers to implementing remote supervision using cameras stemming from a lack of trust in the system.

Seen as a cause of job insecurity

A few studies have noted that workers might not be too keen to embrace new technologies if they feel it could have the potential to eliminate their job roles. In a study about the limitations to AR and VR implementation in the AEC, Manuel et al. (2020) identified construction workers seeing new technologies as a cause of job insecurity to be an important non-technical factor in the limitation of AR and VR implementation.

Lack of interest from owners

Manuel et al. (2020) identified a lack of interest on the part of the owners as one of the main limitations to VT implementation. The authors noted that this holds true for VT and other forms of digital technologies available in the AEC sector. It has been suggested that this attitude from owners is due to the high-risk, low-profit nature of the AEC sector (Davila Delgado, Oyedele, Beach, et al., 2020).

CHAPTER THREE

RESEARCH METHODOLOGY

Research definition

Gounder (2004) defined research as "a structured inquiry that utilizes acceptable scientific methodology to solve problems and create new knowledge that is generally applicable." The research methodology for this study is seen in Figure 3.1 below.

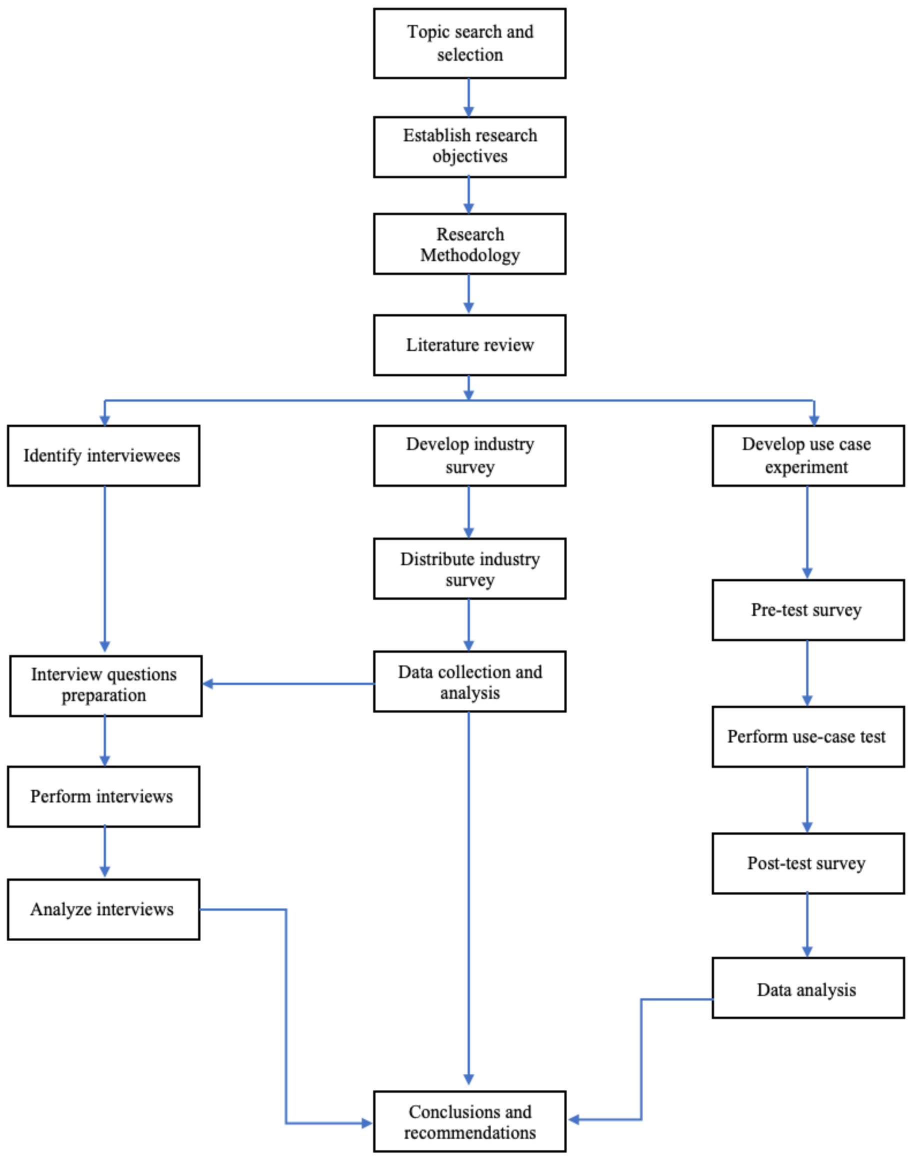


Figure 3. 1: Research Methodology

Study design

This study is a semi-experimental, mixed-method study that combines quantitative and qualitative approaches to achieve the objectives laid out for the study. Kumar (2011) defined a cross-sectional study as a study designed for researching the status of a phenomenon at a particular time across a population. He also described it as a study in which participants are contacted just once throughout the study. A cross-sectional approach was selected as the study seeks to investigate the current state of visualization technologies used for remote work in the context of the COVID-19 pandemic. A literature review was used to identify the various visualization technologies currently in use in the AEC industry. A quantitative questionnaire survey was used to capture data relevant to draw important statistics relevant to the aim of this study. A qualitative survey was employed to provide a deeper understanding and reasoning to data collected from the quantitative questionnaire survey. The experimental aspect of this study involves the demonstration of a use-case of visualization technologies.

Research procedures

Quantitative industry survey

A quantitative questionnaire survey tool was used to collect data from participants in the AEC industry. Quantitative research involves the collection, organization, and analysis of numerical data. This type of research aims to quantify a phenomenon under observation. Quantitative research aims to measure the amount or quantity of a factor relating to a phenomenon (Gounder, 2004). This questionnaire was hosted on Microsoft Forms and distributed electronically via email to the study participants. This was used to assess the current use of Visualization technologies for remote work in the AEC industry.

Data analysis

The data collected from the survey participants in the previous step was analyzed using a statistical package (SPSS) and Microsoft Excel to draw relevant descriptive statistics and correlations between variables relating to this study's aim.

Qualitative Interview survey

The second phase of this study involved qualitative research. Qualitative research is interested in understanding a phenomenon by gathering data in the form of feelings, ideas, opinions, or thoughts of respondents. Unlike quantitative research, this research is less concerned about larger sample sizes but focuses on targeted samples to gain in-depth information about a topic (Gounder, 2004).

Based on the quantitative survey data analysis results, a few selected participants were invited to participate in interviews focused on identifying factors leading to the top three barriers to visualization technologies (VT) and developing strategies to use VT in a remote context better. This survey comprised structured open-ended questions and was done via a video-conferencing application, the University of Houston (UH) licensed Microsoft Teams platform. The duration of these interviews was 30 to 40 minutes.

Data analysis

Data collected from the interview process were analyzed by reviewing the transcribed interviews, identifying themes, opinions, and beliefs, and presenting this in an organized manner.

Pre-test survey

A survey was administered to intending participants of the experiment to measure their use and familiarity with visualization technologies.

Use-case demonstration

This research phase aims to show the demonstration of visualization technologies in performing a construction activity remotely. In this demonstration, the Microsoft HoloLens' Mixed Reality features were used for remote supervision between an expert and a field worker. This demonstration aims to show that remote supervision can be as adequate as on-site supervision, reducing cost and unproductive time. The expert supervised an assembly/installation process via a Microsoft Teams video call displayed on the Microsoft HoloLens of the fieldworker, where he could receive directions and guidance in carrying out the work adequately.

Post-test survey

After the study, a survey was administered to record the participants' experience and satisfaction with the use-case demonstration experiment for remote work.

Setting

Due to the current COVID-19 pandemic and in line with CDC guidelines of limiting physical contact when possible, the questionnaire survey was carried out virtually online via email and Microsoft Forms, UH licensed platforms. Interviews were carried out utilizing the UH licensed Microsoft team's platform. This study's experimental part was conducted in Office 111-B at the Technology Annex building, University of Houston, 4730 Calhoun Rd, Houston-TX 77004. Researchers used only university officially licensed applications.

Sample

The industry survey test used the non-random data sampling design method due to the ease of access to the sample population. The survey sample size was 60 participants.

For the qualitative survey, the research utilized a mix of judgmental and expert sampling designs. Judgmental sampling depends on the researcher's judgment to determine the population who can provide the best information to achieve the study's objectives (Kumar, 2011). The author also describes expert sampling as a method of sampling that prioritizes experts in the field of research as study participants**.** These methods were utilized to ensure experts in visualization technologies provide in-depth data relating to the quantitative approach's research objective**.** There was no defined sample size; instead, the number of participants were determined as sufficient when a point of data saturation had been reached. This sample size was 4 persons.

The experimental part of this study consisted of a sample size of 6 participants.

EXPERIMENTAL PROCEDURE

The experimental part of this research explored the use of Mixed Reality (MR) to perform remote supervision. This part of the study was conducted with the

Microsoft HoloLens' MR feature using the remote assist application Dynamics 365 Remote Assist (*Remote Assist | Microsoft Dynamics 365*). The study participant wore the HMD while the remote expert supervising the study participant was connected to via the Microsoft Teams platform.

The experiment that was carried out involved installing a receptacle on a framed prototype and installing a wall plate on the receptacle. The remote expert guided the participant by walking participants through the various steps by verbally explaining and annotating where necessary.

Procedures.

1. Participants were first assigned a randomly generated identification number which assisted the research team in tracking both their pre-test and post-test survey results for analysis.
2. Participants filled a pre-test survey. The pre-test survey was designed to collect information on the study participants previous use of visualization technologies especially in the context of remote supervision.
3. A brief orientation on how to operate the Microsoft HoloLens Head Mounted Device was given to the participants. Participants were guided on how to perform the basic functions such as how to navigate within the HMD environment and make a call to a remote expert.
4. The participant began the experiment by mounting the HMD and navigating to the Remote Assist application. Participants then called the remote expert who had the same view as the participant and walked them through the installation process by verbally directing and using annotations where necessary.

5. Participants completed a post-test survey to assess the use of MR in performing remote work.

Analysis

The responses of both the pre-test and post-test surveys were analyzed via descriptive statistics to draw insights from the participants experiences of Mixed Reality for remote supervision. The analysis of the post-test survey aimed to assess the suitability of Mixed Reality for remote supervision and to gather any concerns or recommendations the participants might have.The use-case experiment procedure is outlined in Figure 3.2

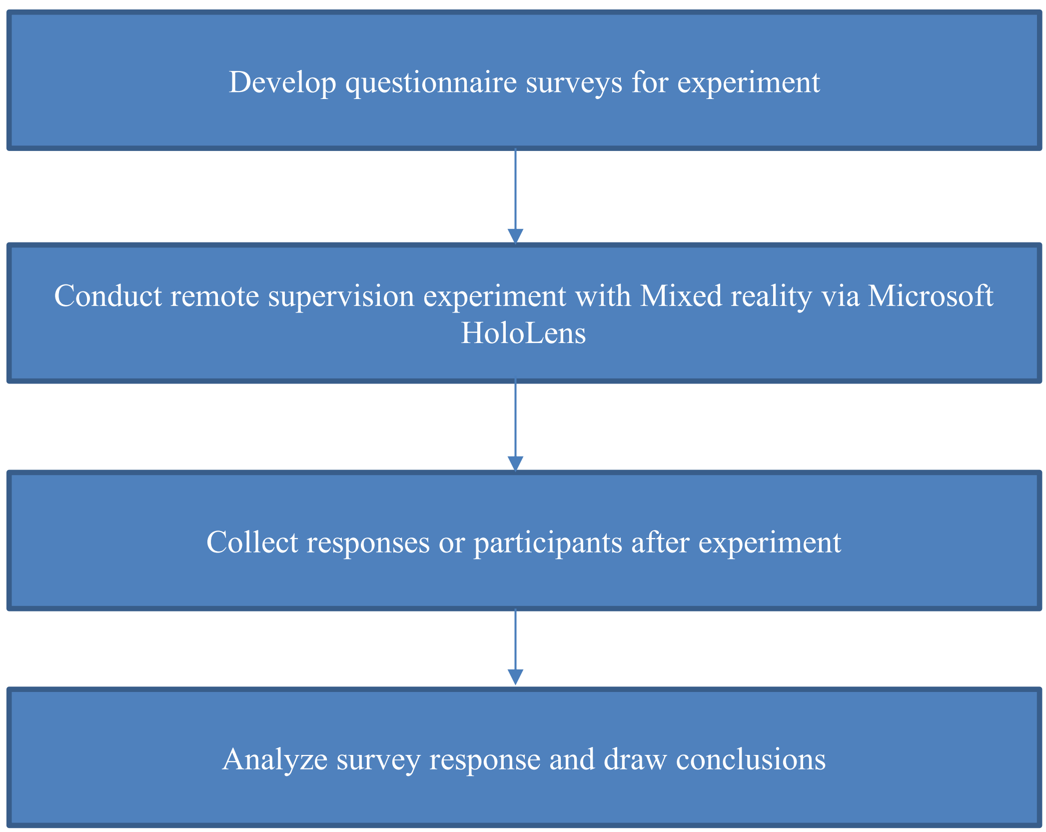


Figure 3.2: Use-case experiment procedure

CHAPTER 4

DATA ANALYSIS

Industry survey

The industry survey section of this study was conducted with the aim of gaining insight into the current use of visualization technologies in the AEC sector for remote work. The sample for this portion of the study consisted of professionals in the Architecture, Engineering & Construction industry. The results of this survey are analyzed through the use of descriptive statistics. Out of 227 respondents contacted to take part in the survey, only 60 responded, leading to a response rate of 26.43 %.

Demographics section

The demographic section of the survey was developed with the aim of grouping participants into different categories to draw comparisons between the different groups and to determine if categories had a particular response to certain questions.

Age of respondents

Respondents to the survey were asked to indicate their ages. As seen in Table 4.1, the majority of the survey respondents, 56.7% (34 respondents) were between the ages of 20-30, 21.7% of respondents were between the ages of 31-40, 10% (6 respondents) were between ages 41-50. Only 3.3% (2 respondents) were between the ages 51-60, while 8.3% (5 respondents) were above the age of 60.

Table 4.1: Age of respondents

Age	Frequency	Percent
20-30	34	56.7
31-40	13	21.7

Age	Frequency	Percent
41-50	6	10.0
51-60	2	3.3
> 60	5	8.3
Total	60	100.0

Experience

The question was designed to see if the number of years in the AEC industry played a factor in the number of people who worked remotely with a form of VT after the onset of the COVID-19 pandemic. In response to the question "Number of years in the Architecture, Engineering & Construction industry" as seen in Table 4.2, of the 60 respondents to the survey, 30% (18 respondents) had been in the industry for 0-5 years, 38.3% (23 respondents) had been in the industry for 6-10 years, 8.3% (5 respondents) had been in the industry for 11-15 years, 8.3% (5 respondents) indicated 16-20 years. Just 5% (3 respondents) had been in the AEC industry for 20-25 years, while 10% (6 respondents) had over 25 years of experience in the AEC industry.

Table 4.1: Years in the Architecture, Engineering & and Construction industry

Number of years	Frequency	Percent
0-5 years	18	30.0
6-10 years	23	38.3
11-15 years	5	8.3
16-20 years	5	8.3
20-25 years	3	5.0
>25 years	6	10.0
Total	60	100.0

Role in the AEC

Respondents were asked about their roles in the AEC to categorize them within three different groups. This was done to compare the responses of VT use-cases for remote work and barriers to VT use between the different groups. The results below in Table 4.3 show that when asked "how would you classify your role in the AEC industry" out of the 60 respondents, 38.3% (23 respondents) fell into Group 1 (Project Manager/Owner/General contractors), 36.7 % (22 respondents) were categorized in Group 2 (Architects/Designer), while 15% (15 respondents) were categorized in Group 3 (Engineers).

Table 4.2: Role in the AEC

Group	Frequency	Percent
Project Manager/Owner/General Contractor	23	38.3
Designer/Architect	22	36.7
Engineer	15	25.0
Total	60	100.0

VT section

Respondents were asked questions in this section that gave insights into the use of visualization technologies prior to and since the onset of the COVID-19 pandemic. This section comprises of the following questions.

Experience with VT on AEC projects

This question, "Do you have experience with visualization technologies on AEC projects?" had the purpose of finding out the number of respondents who had had experience with visualization technologies on AEC projects. As seen in Table 4.4

below, out of 60 respondents to this survey, a high number of respondents, 93.9% (56 respondents), had some form of experience with VT on AEC projects. In comparison, only 6.7% (4 respondents) did not have prior experience with VT on an AEC project.

Table 4.3: Experience with VT on AEC projects

	Frequency	Percent
Yes	56	93.3
No	4	6.7
Total	60	100.0

Visualization technologies implemented

The question "What type of visual technologies have you utilized in your projects" was asked to the respondents. According to the survey, 76% of the respondents indicated that they had utilized BIM at some point on an AEC project, 45% reported having experience with Drones/UAV, 41.6% had experience with high-resolution cameras, while just 13% of the respondents had utilized AR on their projects as seen in Figure 4.1.

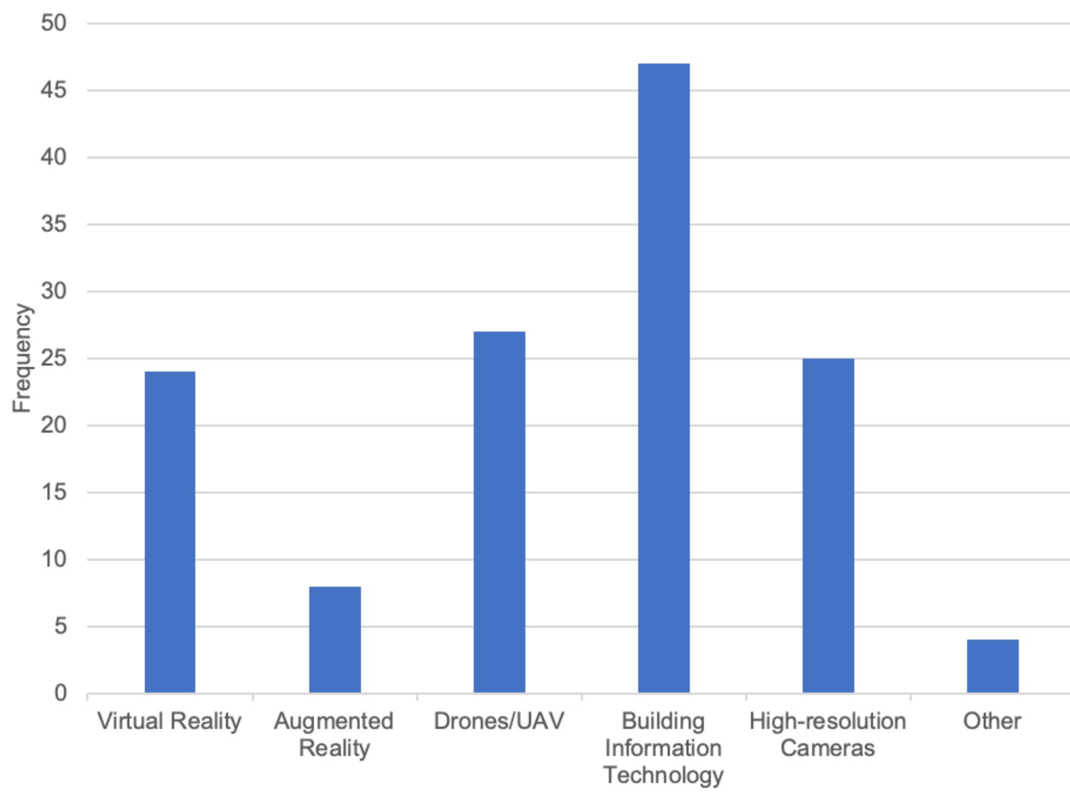


Figure 4.1: Types of Visualization technologies utilized on projects

Visualization technologies utilized the most

The responses to the question "what visualization technologies have you used the most" provided insight into the most frequently used visualization technologies by survey respondents. Figure 4.2 shows that BIM emerged as the VT utilized the most among the respondents with 76% (46 respondents), which indicates its maturity as a visualization technology in the AEC sector. High-resolution cameras, Drones/UAVs and VR had 28.3% (17 respondents), 26.6% (16 respondents) and 20% (12 respondents) identify them as their most utilized VT. AR had the least number of respondents 10% (6 respondents) identify it as the VT most utilized on their projects. This agrees with studies that have noted the slow adoption of AR in the AEC compared to other forms of VT.

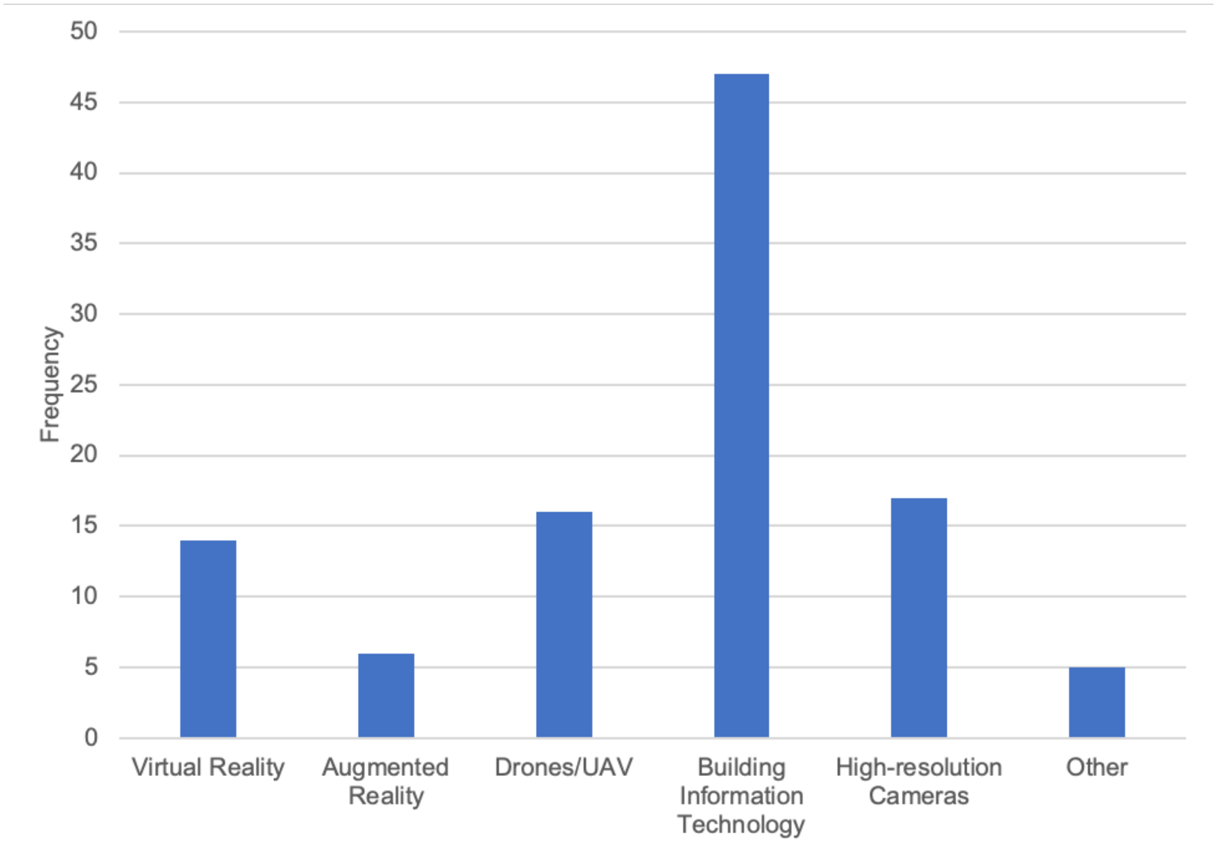


Figure 4.2:Type of visualization technologies utilized the most

Familiarization with visualization technologies

These questions were designed to show the difference in familiarization in VT among the respondents due to the COVID-19 pandemic. Respondents were asked to rank their familiarization on a scale ranging from Not at all familiar to Extremely familiar. As seen in Figures 4.3 & 4.4 below, there was an increase in awareness in the level of familiarity with VT after the onset of the COVID-19 pandemic.

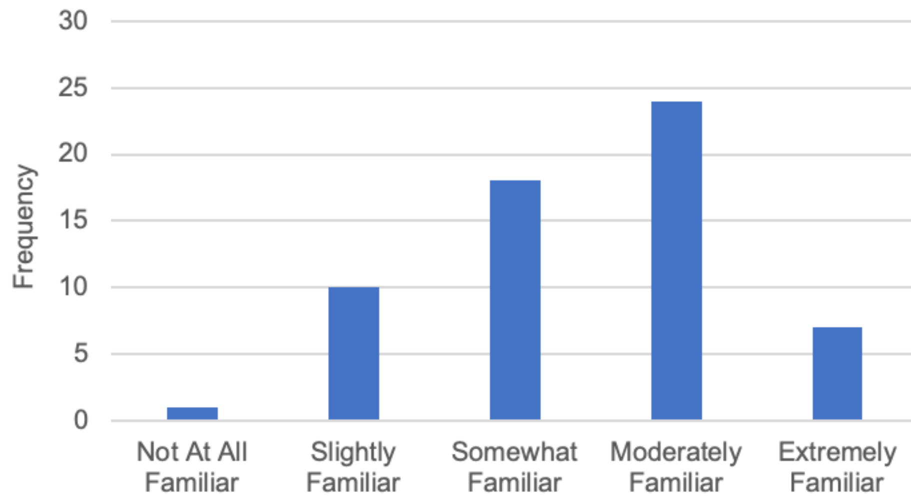


Figure 4.3: Familiarization with VT prior to the COVID-19 pandemic

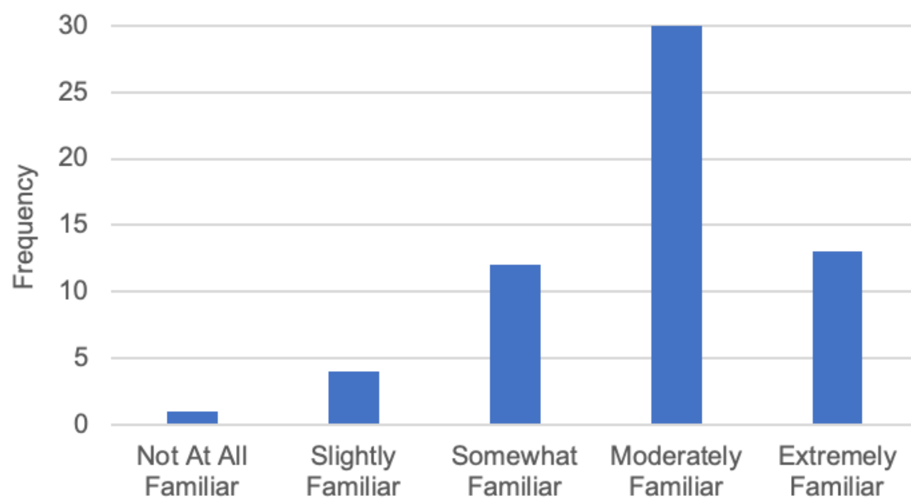


Figure 4.4: Familiarization with VT after the onset of the COVID-19 pandemic

Frequency of remote work performed

The questions "How often did you perform remote work prior to the COVID-19 pandemic?" and "How often have you performed remote work since the onset of the COVID-19 pandemic?" were designed to see if the amount of remote work done by the respondents increased after the onset of the COVID-19 pandemic. Figures 4.5 & 4.6 show that more respondents shifted to having more work done remotely after the onset of the pandemic, as seen by the large increase in the number of respondents who worked remotely very often.

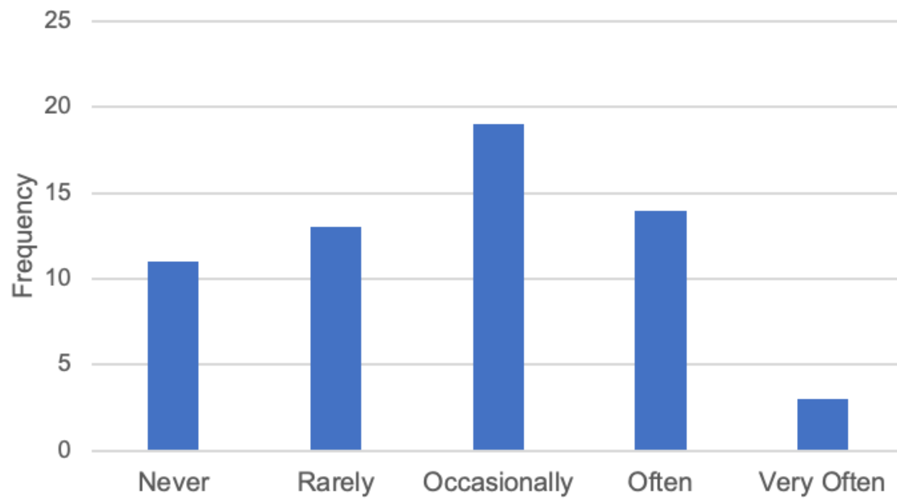


Figure 4.5: Frequency of work performed remotely prior to the COVID-19 pandemic

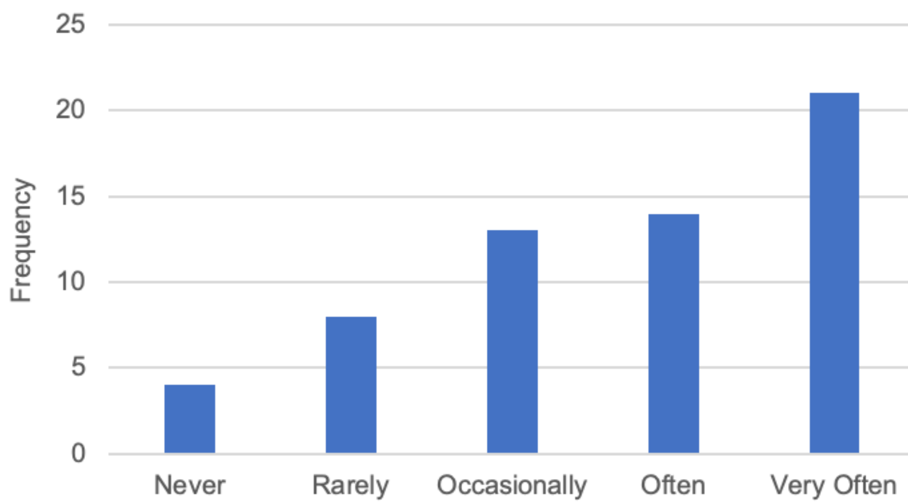


Figure 4.6: Frequency of work performed remotely after the onset of the COVID-19 pandemic

Frequency of remote work performed with a form of VT

Questions were designed to see the difference in how many respondents performed work remotely with the use of a form of VT in doing so. Respondents were asked the questions "how often did you perform remote work with a form of VT prior to the COVID-19 pandemic?" and "how often did you perform remote work with a form of VT since the onset of the COVID-19 pandemic?" rating their use of VT for remote work on a scale ranging from Never to Very often. As seen in Figures 4.7 and 4.8, the responses to these questions show that there has been a drastic increase in the number of people now performing remote work with a noticeable increase in the number of people now performing remote work often and very often.

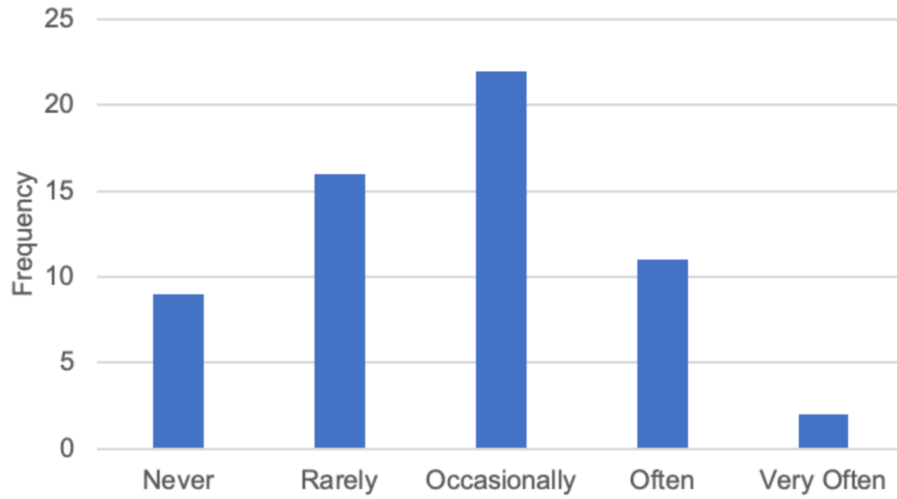


Figure 4. 7: Frequency of work performed remotely with a form of VT prior to the COVID-19 pandemic

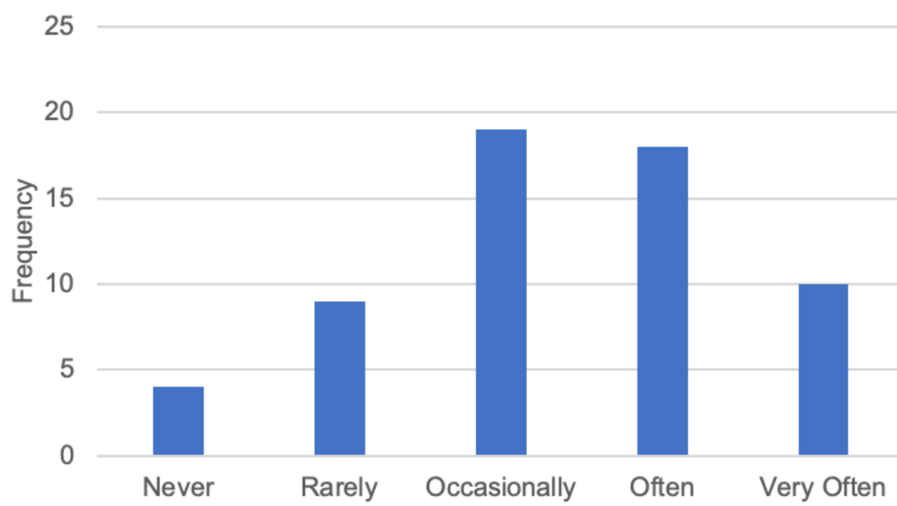


Figure 4. 8: Frequency of work performed remotely with a form of VT after the onset of the COVID-19 pandemic

Remote engagement on an AEC project since the onset of the COVID-19 pandemic

This question sought to find out the number of respondents who had been engaged in an AEC project since the onset of the COVID-19 pandemic. Of the 60 survey respondents, when asked the question "have you been engaged remotely on an AEC project after the breakout of the COVID-19 pandemic?", 66.67% (40 respondents) of the respondents indicated they had been involved with an AEC project remotely, while 33.33% (20 respondents) have not been engaged remotely on an AEC project, as seen in Figure 4.9 below.

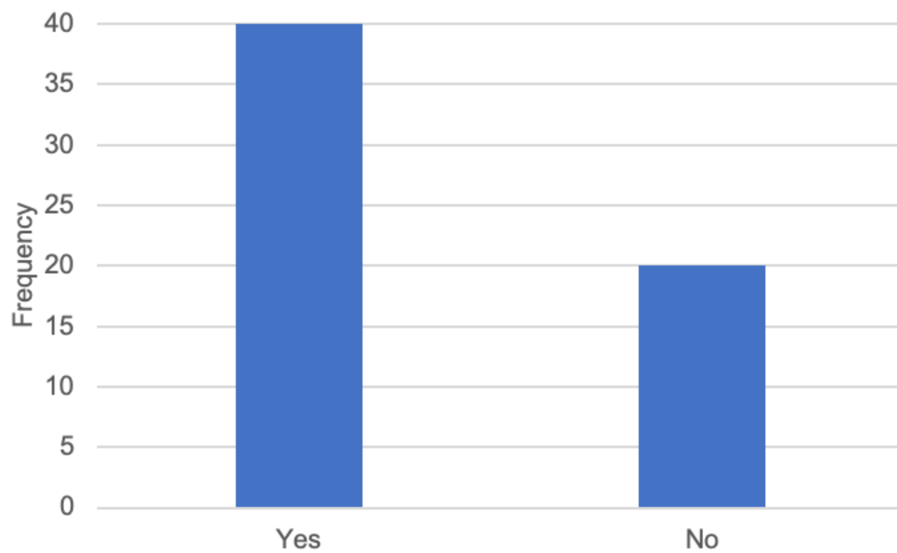


Figure 4.9: Remote engagement on an AEC project since the onset of the COVID-19 pandemic

Visualization technologies use for AEC activities

Relative Importance Index (RII) has been used to rank the various uses of visualization technologies among the respondents both collectively and among the different categories of respondents.

The formula for relative importance index:

$$RII = \boldsymbol{\Sigma} W / A * N'$$

Where W = Weighting to each factor by respondent

A = Highest weight

N = Total number of respondents

These remote-uses of VT within the AEC sector have been ranked from highest to the lowest according to the numerical scores assigned to the responses collected from the respondents to the survey in response to the question “please rate your usage of Visualization Technologies for the following activities?”. On-site VT use-cases ranked higher than off-site site cases, with the top three ranked use-cases been on-site use-cases. In contrast, the bottom three ranked use-cases were off-site use-cases. When asked to “rate your usage of Visualization technologies for the following activities,” the results of this survey ranked “Virtual conferencing/meetings” with an RII of 0.782 as the highest use-case among the respondents. “Space planning and visualization” ranked 2nd with an RII of 0.733. The results showed that while members of groups 2 & 3 rank this use-case highly, members of Group 1 only rank it as the 5th use-case. “Clash detection” and “Progress monitoring” both ranked third with RII’s of 0.684. At the bottom end of the rankings, “Site supervision/maintenance support” ranked 7th with an RII of 0.540.

Furthermore, the results from the survey ranked “Inspection walk-throughs” as the second least used use-case of VT for remote with a rank of 8th and an RII of 0.530. “Safety training, planning and management” ranked as the least use-case among the respondents of the survey with an RII of 0.491. The ranking of the VT use-cases for remote work and their rankings are in Table 4.5 below.

Table 4.5: Relative Importance Index of VT uses for remote work in the AEC

S/No	Use-Case	Overall RII	Rank	Group 1 Rank	Group 2 Rank	Group 3 Rank
1	Virtual conferencing/meetings	1	0.782	1	2	1
2	Space planning and visualization	2	0.733	5	1	2
3	Clash detection	3	0.684	4	3	6
4	Progress monitoring	3	0.684	3	5	3
5	Surveying and site mapping	5	0.639	2	6	4
6	Value Engineering/ design reviews	6	0.632	6	4	8
7	Site supervision/ maintenance support	7	0.540	7	7	9
8	Inspection walk-throughs	8	0.530	8	8	4
9	Safety training, planning and management	9	0.491	9	9	7

The mean RII's among the various groups show that the use of off-site VT use-cases is higher than the use of on-site use-cases. As seen in Table 4.6, the results indicate that while Group 2 members have the highest mean RII among the off-site use-cases, they have the lowest mean RII among the on-site use-cases. Group 3 members have the highest mean RII among all categories.

Table 4.6: Mean Relative Importance Index by categories of VT use-cases for remote work in the AEC

Groups	Mean RII	Mean RII (off-site use)	Mean RII (on-site use)
1 Project Manager/Owner/General Contractors	0.604	0.655	0.564
2 Designer/Architect	0.575	0.691	0.482
3 Engineer	0.647	0.680	0.621

Barriers to VT in the AEC

RII has been used to rank the barriers to adoption of visualization technologies used in the AEC among the respondents both collectively and among the different categories of respondents. These uses have been ranked from highest to lowest according to the numerical scores assigned to the responses to the question "Please select your level of agreement to the barriers of implementing visualization technologies for remote work in the AEC sector", collected from the respondents to the survey to show what barriers are considered more important both collectively and among the different categories. As seen in Figure 4.7, the results from the survey show that "Cost of technology" with an RII of 0.847 is the most prevailing of all barriers to VT usage in the AEC with a general consensus among the different group categories. Responses to the survey ranked "Access to software and hardware required" as the 2nd most important barrier identified. Respondents also indicated that not having the people with the technical know-how on how to use VT is a top barrier as "Lack of skilled personnel" ranked 3rd in general with an RII of 0.733. "Lack of standardized processes and procedures" in the industry for using these technologies was ranked as the 4th highest barrier with RII of 0.727 highlighting the need of a standard in guiding the use of these technologies. At the bottom end of the rankings, the results indicate that despite the numerous possibilities of using VT for remote work in the AEC, the respondents do not see it as a threat to their job roles with "Seen as a cause for job insecurity" ranked the least important barrier with RII of 0.510.

Table 4.7: Relative Importance Index of Barriers to Visualization technologies in the AEC

S/No	Barriers	Overall Rank	Overall RII	Group 1 Rank	Group 2 Rank	Group 3 rank
1	Cost of Technology	1	0.847	1	1	1
2	Access to software and hardware required	2	0.790	2	2	2
3	Lack of skilled personnel	3	0.733	3	5	3
4	Lack of standardized processes & procedures	4	0.727	4	4	5
5	Cost of training personnel	5	0.723	6	3	4
6	Management aversion to new technology	6	0.680	4	6	7
7	Lack of interest from owners	7	0.643	7	7	6
8	Security of data	8	0.593	8	8	7
9	Seen as a cause of job insecurity	9	0.510	9	9	9

According to the survey results, the respondents in Group 3 agree more with the barriers to VT for remote work than a member of the two other groups with a mean RII of 0.710. Members of Group 1 have the lowest mean RII of 0.687

Table 4.8: Mean Relative Importance Index of Categories to Barriers to VT

Group	Mean RII
1 Project Manager/Owner/General Contractor	0.687
2 Designer/Architect	0.691
3 Engineer	0.710

Kruskal Wallis test

Responses from the different professional categories of respondents are tested to see the level of agreement between the groups using the Kruskal Wallis test, which compares the mean rankings of the respondents. The test is a non-parametric test performed to see if the median responses of different groups to particular questions are the same or not. Table 4.9 shows the p-value of the test for responses to VT use-cases among the respondents, while Table 4.10 shows the p-value of the test for responses to the barriers to VT in the AEC sector.

Hypothesis 1- There is no statistically significant difference in the mean responses between the respondent group categories to the use-cases of visualization technologies.

The Null Hypothesis H_0: $p > 0.05$ – There is no statistically significant difference between groups.

The alternate Hypothesis H_1: $p < 0.05$ – There is a statistically significant difference between groups.

The results of the Kruskal Wallis test for the VT use-cases in Table 4.9 show that 7 out of the 9 mean ranks of the use-cases among the groups do not have a statistically significant difference. However, there is a significant difference between the mean rankings among the various categories for inspection walk-throughs and safety training, planning and management as $p < 0.05$ in both cases; hence, we reject the hypothesis for them.

Table 4.9: Kruskal Wallis test for VT Use-cases.

Applications	P-value	H-Stat
Inspection Walk through	0.010	9.141
Site-supervision/ Maintenance support	0.151	3.781
Progress Monitoring	0.458	1.564
Safety training, planning and management	0.001	13.812
Space planning and visualization	0.103	4.552
Clash detection	0.364	2.024
Value Engineering/Design reviews	0.482	1.460
Surveying & site mapping	0.580	5.678
Virtual conferencing/ meetings	0.824	0.387

Hypothesis 2: There is no significant difference in the mean responses between the respondent group categories to the barriers and constraints to visualization technologies.

The Null Hypothesis H_0: $p > 0.05$ – There is no statistically significant difference between groups.

The alternate Hypothesis H_1: $p < 0.05$ – There is a statistically significant difference between groups.

The test results in Table 4.10 below shows that there is no statistically significant difference between the mean rankings of the barriers among the various groups. This shows a high level of agreement between the responses of the various groups.

Table 4.10: Kruskal Wallis test for VT barriers

Cost of technology	0.624	0.943
Access to software and hardware required	0.786	0.483
Lack of skilled personnel	0.640	0.892
Lack of standardized processes & procedures	0.981	0.038
Cost of training personnel	0.498	1.395
Management aversion to new technology	0.579	1.093
Lack of interest from owners	0.992	0.016
Security of data	0.564	1.144
Seen as a cause of job insecurity	0.414	1.766

Interview sessions

Based on the industry survey results, four specialists were interviewed on a range of questions to help develop a framework to successfully implementing VT in the AEC. The questions ranged from factors influencing the top barriers ranked by the survey to proposed strategies to combat these barriers.

Interviewee 1

Respondent 1 agreed that the use of VT within the AEC had increased since the onset of the COVID-19 pandemic as people are looking for ways to manage and interact with worksites remotely. He also noted that drones and 3D scanners are becoming mainstream in the industry, particularly for surveying and topographical purposes.

Respondent was of the opinion that the first strategy in getting more firms and AEC professionals to use VT for remote was awareness. He suggested that many people, while being aware of these technologies on the surface, are not aware of how they could potentially make their work much easier in performing various tasks.

The second strategy suggested in getting VT for field use to be more utilized was a need for firms to allocate budgets to these technologies and incorporate them as requirements on their projects, which would subsequently increase adoption rates of these technologies on projects. He also suggested that owners would also have a role to play by requiring such technologies to be used.

Respondent was of the view that as more people adopt VT, the cost would inevitably go down. However, he noted that only very few companies actually have expertise in this field due to the engineering, design, construction, and technical expertise required. Therefore, he suggested the cost of VT would inevitably drop as the gap of skilled personnel in the industry increases.

Another strategy suggested particularly for small and medium companies to adopt these technologies is for these firms to first utilize these technologies on a few projects by way of outsourcing which eliminates the need for high initial investment while affording them the benefit of determining whether to develop an in-house team or stick to an outsourcing strategy.

Interviewee 2

The respondent noted that while there has been an increase in remote work performed in the AEC and movement of activities such as progress meeting, which happens traditionally on-site to online spaces, there hasn't been a significant increase in the use of visualization technologies such as BIM usage as a direct result of this.

He noted that on occasions where companies used high-resolution cameras for project monitoring, owners of those projects required such technologies to be used, highlighting the roles that owners can play in fast-tracking the use of these technologies for remote work.

The respondent was of the opinion that industry-wide, there will always be a lack of standardization of procedures and processes, especially in BIM. This stems from the fact that every project is unique and has different requirements, and these technologies are constantly evolving. And in the case of BIM, various programs in use would lead to inconsistencies and discrepancies. He suggested that such processes and procedures, rather than being standardized for the industry, in general, should be project and team-based and made to cater to the particular project's needs in question. Having a BIM execution plan on a project would be a good start point to standardize the processes and procedures on a particular project.

The respondent suggested that the main reason why the use of these technologies for off-site use-cases is not yet as widespread as the on-site use-cases is due to the fact that most on-site activities are still performed by humans (not automated). He was of the opinion that as the construction industry becomes more automated, we will also witness an increase in these technologies being used for activities such as progress monitoring and inspections which would lead to an increase in VT for remote work.

The respondent said there were a few factors influencing the lack of skilled personnel in the AEC industry. He mentioned that the biggest hurdle that has to do with training the current workforce and the willingness to use these technologies. He mentioned that professionals who have been in the industry for a long period of time might not be willing to change tried and trusted methods of doing things for new innovative methods. Another factor influencing the lack of skilled personnel especially is the low demand for such personnel currently in the industry. For small and medium companies, the cost-benefit ratio of hiring in-house BIM personnel, for example, doesn’t appeal to them as they have few jobs which require the use of these technologies, which in turn leads to them outsourcing as a stop-gap for projects that require these technologies. The respondent also cited the lack of a clear career path, especially to new college graduates as a factor leading to shortage of skilled personnel.

The respondent was of the opinion that the long-term strategy to tackle this barrier was for more projects to require the use of these technologies. This would create a need for companies to have in-house professionals in this field and also more people willing to fill in that need.

Interviewee 3

In relation to the lack of skilled personnel being a barrier to VT being implemented in the AEC sector, the respondent was of the opinion that for the younger members of the workforce, education had a role to play. She noted that the academic side is similar to the professional side of the AEC in being slow to adopt new methods while relying on tried and trusted ones. She was of the opinion that when exposed to these technologies in the classroom, recent graduates do not only take these skills with them into the industry but serve as advocates due to their exposure to these technologies.

Strategies put forward by the respondent in responding to that barrier are:

1. Updating current curriculums to include teaching new technologies and systems by way of performing use-cases, being innovative with assignments and projects being given to students. Although she recognized that there might be some form of push back from heads of departments, deans and accreditation bodies.

2. By encouraging more undergraduate research in this field, which encourages students to learn more on their own and develop genuine interest in these technologies alongside soft skills.
3. Collaborations between academia and industry. She noted that this would be a good learning experience for students as they learn how to apply these use-cases to practical scenarios while providing services to companies who choose to collaborate.

On lack of standardized procedures and processes as a barrier, the respondent opined that it would prove difficult to have a blanket standard practice across different companies and countries. Instead, guides can be used to help companies adopt the use of these technologies. She highlighted research as important part academia could contribute to this process. Research would help both educational departments and construction companies develop helpful guides and get the best value out of technologies they decide to incorporate into their operations.

The respondent noted that the emergence of the pandemic has made professionals in the industry reimagine and change the way they perform work, particularly remotely, and is a trend that would continue as things return to normalcy. She highlighted the rise in the use of online management systems such as BIM 360 and the gradual use of VR and AR to conduct site inspections and visits.

Interviewee 4

The respondent stated that while his company had used AR and VR recently on their projects, the main issue they encountered, which has limited the use of these technologies, is data binding, i.e., linking relevant information to the visuals. He pointed out that MR had been used for virtual conferencing where a Microsoft HoloLens device had been used to show project members the status of construction works ongoing at a nuclear plant.

He noted that while these technologies possess a lot of potentials, they haven't yet gotten to the level where they can be used extensively due to the specialty skills such as programming, unity attaching, and linking to Azure database that some of them require to perform certain use-cases.

As the use of most VT for remote work is internet and cloud-based, the respondent stressed security of data as a major constraint among big clients as an important barrier in using VT. Fears of sensitive data & information being leaked on top-secret or government projects prevent the use of these technologies being utilized and only big companies have the resources to be able to have their own database to allay these concerns

The interviewee was of the opinion that general standards and processes in VT would be hard to achieve due to the rapid changing nature of technology. He mentioned two approaches in addressing this. The first approach is to have project-based standards and processes between teams working on the same project to achieve uniformity across all collaborators. The second approach was for companies to have their own standards and procedures which they used on their projects which periodic reviews made it to it as necessary. However, he noted that the second approach was only viable for big companies that undertake huge projects and have the financial resources to support it. Small and medium companies which do not have adequate resources would find this approach tough to implement.

The interviewee believed that a lack of willingness to learn new ways of doing things and people being comfortable in the tried and trusted methods were factors influencing the shortage of skilled personnel in the AEC as a barrier to VT. He also noted that this isn't as much of an issue in architecture as it is in engineering and construction due to the artistic nature of architecture. He was of the opinion that the main way to tackle this barrier is by having a champion for these technologies, which drives awareness and encourages learning by actively showing how they function. He believed that as more of the tech-savvy generation get into management roles in the near future, we would notice an uptick in the use of these technologies.

Another factor identified by the interviewee was the unwillingness to share information as they feel they would become less important if more people become more competent at that skill.

Lastly, he acknowledged that the manufacturers of these technologies have important roles to play in driving their quicker adoption. He recommended specific research in exact requirements needed by end-users as opposed to generalized functions that would attract more people in the AEC in adopting these technologies.

From the responses of the interviewees, a framework for the implementation of visualization technologies was developed as seen below in Figure 4.10

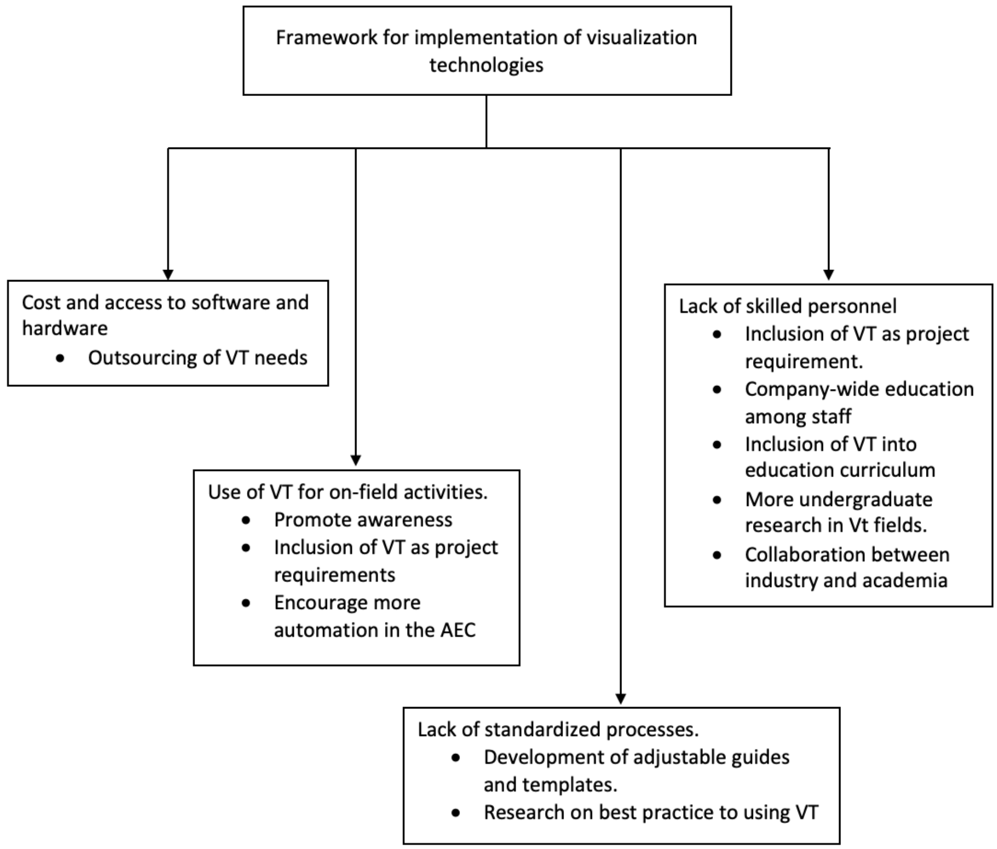


Figure 4.10: Framework for implementation of visualization technologies

Use-case experiment

The main purpose of the use-case experiment was to test and assess the use of MR in performing remote supervision. The device used in performing the use-case experiment was the Microsoft HoloLens. The use-case experiment involved on-field personnel performing an installation process guided by a remote supervisor. Participants took an average time of 10 minutes to get used to the MR device interface, which shows the short learning curve involved and approximately 15 minutes in completing the task. Several questions relating to the suitability of MR in performing remote supervision were asked via the use of a pre-test and post-test survey. The responses from the respondents were analyzed through the use of descriptive statistics.

The pre-test survey gathered demographical data from the respondents and their previous use of Visualization technologies for construction activities.

Respondent category

This question provided information about the participants of the experiments. As seen in Table 4.11, 83.3% (5 participants) were full-time students in an AEC program of study, while 16.7% (1 participant) was a part-time student in an AEC program of study with a part-time job.

Table 4.11: Respondent Category

	Number of Participants	% of Total
Full-time student in an AEC program of study	5	83.3%
Part-time student in an AEC program of study with a part-time job	1	16.7%

Utilization of a form of visualization technology for a construction activity or class

In response to the question "Have you used any form of Visualization Technologies such as Virtual Reality, Augmented Reality, or MR for a construction activity or a class?", the vast majority of participants, 66.7% (4 participants) indicated that they did not have any prior experience of Visualization technologies. In comparison, 33.3% (2 participants) had some form of experience using VT for either construction or class activity.

Table 4.4: Utilization of a form of Visualization technology for a construction activity or class

	Number of Participants	% of Total
No	4	66.7%
Yes	2	33.3%

Type of Visualization technology used

When asked "what type of technology have you used?" as a follow-up question to find out the type of visualization technology used by the participants who indicated they had some form of experience in the previous Question 2 indicated that they had used XR, which was the same number for persons who had used BIM. UAV/Drones and High-resolution cameras both had just one participant that indicated a prior use, as seen in Figure 4.10

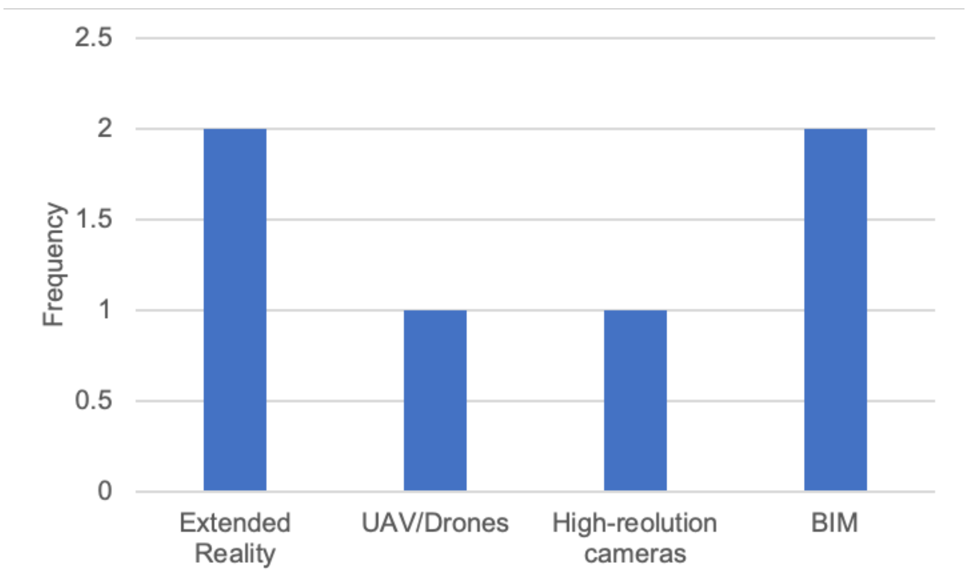


Figure 4.11: Visualization technology used

Prior use of the Microsoft HoloLens or any HMD

The question was asked to determine how many of the participants had prior experience with the MR device selected for the Use-case experiment. The majority of the participants (83.3%) had no experience with the Microsoft HoloLens HMD, which was the MR device selected. Only 16.7% (1 participant) had prior experience with the Microsoft HoloLens prior to the Use-case experiment, as seen in Figure 4.10.

Table 4.5: Prior use of the Microsoft HoloLens or any HMD

	Number of Participants	% of Total
No	5	83.3%
Yes	1	16.7%

Performance of a construction activity remotely before (either as a supervisor or a field worker)

The responses to the question "have you performed a construction activity remotely (either as a supervisor or field worker)?" provided information on the number of participants who had performed a construction activity remotely prior to the experiment. According to the results in Table 4.14, the majority of the respondents, 66.7% (4 participants), had not remotely performed a construction activity, while 33.3% (2 participants) had performed an activity remotely.

Table 4.6: Performance of a construction activity remotely before (either as a supervisor or a field worker)

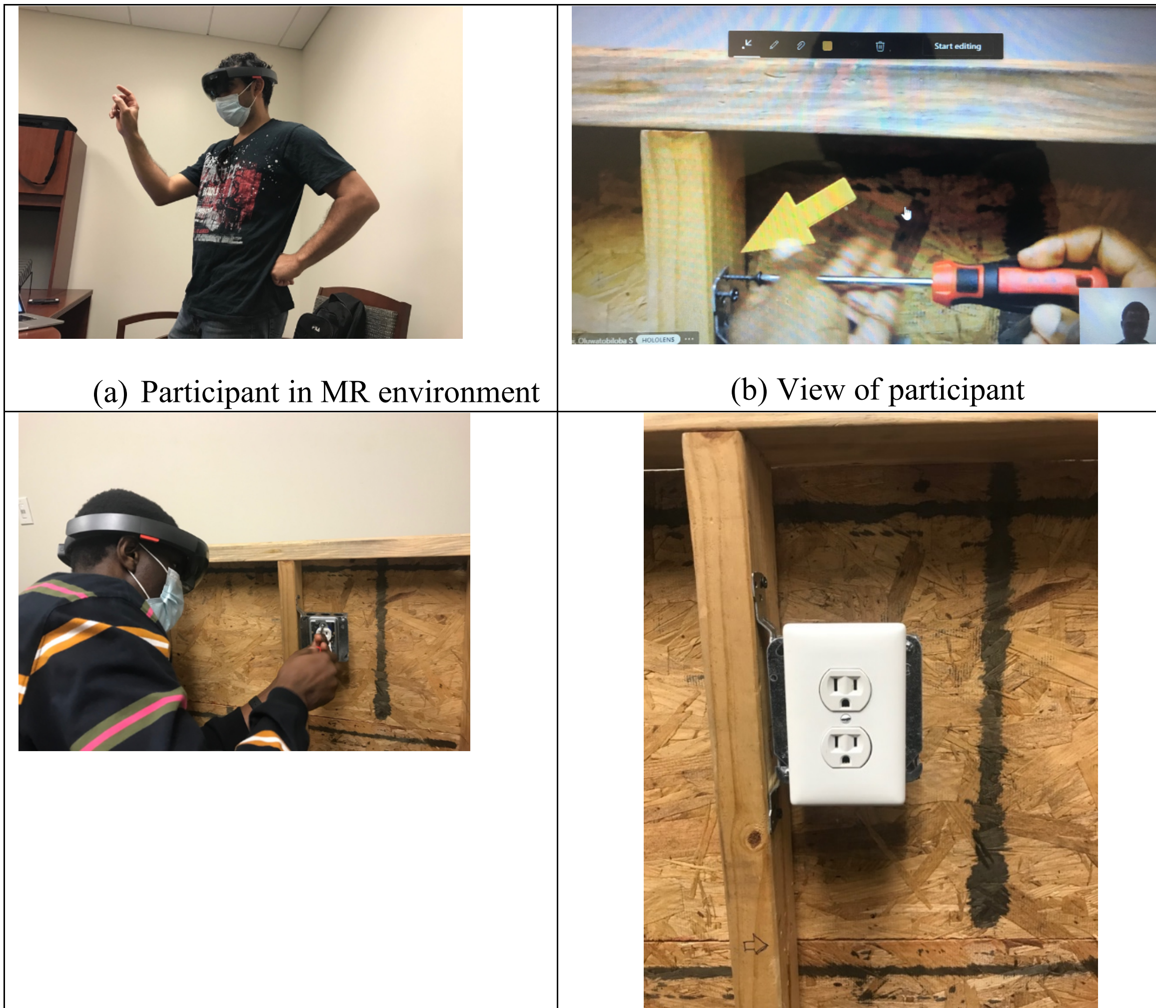
	Number of Participants	% of Total
No	4	66.7%
Yes	2	33.3%

Use of Visualization technologies in performing the construction activity remotely

This question asked the participants in the previous question who had answered yes (had remotely performed a construction activity) whether they had used a form of VT in performing that activity. Both participants (100%) indicated that they had used a form of VT in performing the construction activity remotely.

Table 4.7: Use of Visualization technologies in performing the construction activity remotely

	Number of Respondents	% of Total
Yes	2	100%
No	0	0%



(a) Participant in MR environment

(b) View of participant

(c) Participant performing experiment

(d) Completed installation guided by remote expert

Figure 4.12: Participants performing use-case experiment

The post-test questionnaire assesses the participants' perception of using MR to perform remote supervision. Respondents' responses are measured on an ordinal scale and data analyzed via the use of descriptive statistics to draw conclusions and inferences.

Ability to carry out the instructions given adequately

The question “were you able to adequately carry out the instruction given to you?” was asked to determine the number of participants who were able to adequately follow instructions delivered remotely to perform and complete the use-case experiment. According to the data in Table 4.16, 100% (6 participants) indicated that they were able to adequately carry out the instructions given to them, indicating the use of the MR device as an effective means of communication between the user and the remote expert.

Table 4.8: Ability to carry out the instructions given adequately

	Number of Participants	% of Total
Yes	6	100.0%
No	0	0%

Understanding the interface and capabilities of the MR device

The question “the interface and capabilities of the MR device was easy to understand” aimed to find out participants' thoughts about the user-friendliness of the device and the ease at which the participants learned how to navigate the interface. According to Table 4.17, 66.7(4 participants) strongly agreed that the interface and capabilities of the selected MR device were easy to understand, while 33.7% (2 participants) agreed to the question.

Table 4.9: Understanding the interface and capabilities of the MR device

	Number of Participants	% of Total
Strongly Agree	4	66.7%
Agree	2	33.3%
Neutral	0	0%
Disagree	0	0%
Strongly Disagree	0	0%

The remote expert supervised the process adequately through the platform

The question was designed to access the use of MR as an effective means of communication between the remote expert and the on-site user (the participant). The participants were asked to select options on an ordinal scale ranging from strongly agree to strongly disagree in response to the question "The remote expert supervised the process adequately through the platform." From Table 4.18 below, all of the participants were of the opinion that the process was adequately supervised by the remote expert, with 83.3% (5 participants) strongly agreeing while 16.7% (1 participant) agreed.

Table 4.10:The remote expert supervised the process adequately through the platform

	Number of Participants	% of Total
Strongly Agree	5	83.3%
Agree	1	16.7%
Neutral	0	0%
Disagree	0	0%
Strongly Disagree	0	0%

Problems experienced in using the HMD

The question "Did you experience any problems in using the Mixed Reality device for this experiment?" was asked to the participants to find out the problems encountered during the use of the HMD device in the use-case experiment. Table 4.19 shows that 83.3% of the use-case participants did not experience any problems using the MR device, while 16.7% (1 participant) experienced a problem with the device during the experiment.

Table 4.11: Problems experienced in using the HMD

	Number of Participants	% of Total
No	5	83.3%
Yes	1	16.7%

Type of problem experienced during the course of the experiment

Out of the six participants involved in the use-case experiment, only 1 participant (16.7%) experienced an issue during the course of the experiment. The participant experienced a blurry display, as seen in Table 4.20 below.

Table 4.20: Type of problem experienced during the course of the experiment

	Number of Participants	% of Total
Poor internet connectivity	0	0%
Latency	0	0%
Blurry Display	1	16.7%
Difficulty in communication with remote expert	0	0%
None	5	83.3%

Effectiveness and viability of MR for experts to carry out remote rather than on-site supervisions

The question, "Do you think this would be a viable and effective alternative for experts to carry out remote supervisions rather than on-site supervisions?" sought to find out if the participants agreed that MR would be a viable and effective alternative for experts to carry our remote supervisions rather than on-site supervisions based on their experience on the use-case experiment. According to Table 4.20, out of the 6 participants, 83.3% (5 participants) agreed, while 16.7% (1 participant) was not sure that MR would be an effective alternative for experts to supervise work remotely rather than on-site supervision.

Table 4.12: Effectiveness and viability of MR for experts to carry out remote rather than on-site supervisions

	Number of Participants	%
Yes	5	83.3%
Maybe	1	16.7%
No	0	0%

Recommendation of MR for remote supervision

Participants were asked, "Would you recommend Mixed Reality for remote supervision of construction work?" as a follow-up to the previous question to get the participant opinions on if they would recommend MR for remote supervision. The majority of the participants (83.3%) indicated that they would recommend MR for remote supervision, while just 1 participant was undecided. As seen below in Table 4.22, the overall responses suggest that MR is a good technology for remote supervision.

Table 4.13: Recommendation of MR for remote supervision

	Number of Participants	%
Yes	5	83.3%
Maybe	1	16.7%
No	0	

Rating of MR experience for remote work

Participants were asked, "How would you rate your experience of using Mixed Reality for remote work?" on an ordinal scale ranging from very dissatisfied to very satisfied with a midpoint of neutral. As seen in Table 4.23 below, the majority of the participants (66.7%) indicated that they were satisfied, while 33.3% (2 participants) were very satisfied with the use of MR for remote supervision. None of the participants were dissatisfied. This suggests that the use of MR was effective in the use-case.

Table 4.14: Rating of MR experience for remote work

	Number of Participants	% of Total
Very satisfied	2	33.3%
Satisfied	4	66.7%
Neutral	0	0%
Disagree	0	0%
Strongly Disagree	0	0%

Concerns or recommendations on MR use for remote supervision of construction activities.

One respondent out of six had a recommendation regarding how to better use MR for remote work. The respondent recommended that files that could provide more understanding for the on-field worker be shared during the interaction to better the experience.

This chapter contains the findings of the different phases of this study. Sixty respondents participated in the industry survey. The results of this survey have been coded, analyzed, and explained. 4 subject matter experts from industry and academia were interviewed on the top barriers to the implementation of VT in the AEC to develop a framework for VT adoption. The interviews have been analyzed and transcribed in detail in this chapter. The last phase of this study involved a use-case experiment that involved 6 participants. The participants filled a pre-test and post-test questionnaire in accessing the suitability of Mixed Reality for remote supervision.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The pandemic has hard hit the AEC sector like other sectors. It has had to reimagine innovative ways and methods to achieve project objectives. One such way has been the use of visualization technologies (VT). Although some forms of VT have been present for a while, particularly in the last decade, these technologies have been used sparingly in the AEC sector compared to other industries. This thesis study was designed to examine the use of VT in the AEC sector, with a focus on five research objectives. The findings of this study are discussed in this chapter, while limitations and recommendations for future studies are provided.

Results in relation to research objectives

The following section discusses the findings of the study in achieving the research objectives. This study comprised five research objectives.

1. Identify the various types of visualization technologies currently in use in the AEC industry.
2. Identify and evaluate the current use of visualization technologies in the AEC industry both in the field and in the workplace prior to and after the outbreak of the COVID-19 pandemic.
3. Identify and assess the barriers to the utilization of visualization of technology in the AEC industry.
4. Propose a framework for the implementation of visualization technologies in the AEC industry.

5. Demonstrate the potential use of at least one visualization technologies (Augmented Reality) for remote work.

Visualization technologies in the AEC industry

In achieving the study's first objective, an extensive literature review was carried out to identify various visualization technologies in use in the AEC for remote work. Technologies identified include Virtual Reality (Kaushal, 2013; Wang et al., 2018; Woksepp, 2007), Augmented Reality (Alsafouri & Ayer, 2019; Wang et al., 2018), BIM(Alizadehsalehi et al., 2020b; Aslani et al., 2009), High-resolution cameras (Bohn & Teizer, 2009; Silva et al., 2009) and Drones/UAVs (F. Ahmed et al., 2018; Ciampa et al., 2019; Zaychenko et al., 2018). Among the different VT identified, BIM was the most utilized by the survey respondents for remote work.

Visualization technologies adoption before and after the COVID-19 pandemic outbreak

While the outbreak of the COVID-19 pandemic brought about a sharp increase in the number of people working remotely, the use of the technologies for remote work has yet to be embraced by all.

The study found that the level of familiarity among AEC members to these technologies had increased since the pandemic outbreak, which suggests that people became more aware of ways that these technologies can be leveraged to make their work more efficient. The VT mostly used by the majority of the respondents of the industry survey was BIM which indicates its maturity in the AEC sector. Conversely, AR was the lowest used VT among the respondents, which tends to agree with studies suggesting that AR has a very slow rate of adoption in the AEC sector (Davila

Delgado, Oyedele, Beach, et al., 2020). Also, the findings of this study show that there was a sharp increase in the amount of AEC professionals who embraced remote work. However, the number of respondents who used a form of visualization technologies to perform remote work did not increase at a similar rate.

The study found that the use of VT was mostly for off-site use-cases such as virtual conferencing, clash detection, and space planning and visualization, and off-site uses ranked higher than on-site use-cases like inspections and safety training and management. In addition, among the three categories of respondents in the study, engineers were found to be the category that used VT for remote work the most.

Barriers to visualization of technology adoption in the AEC sector

Key barriers to the adoption of VT were identified, and respondents were asked to rank their importance. The cost of technology and access to hardware and software of these VT devices ranked as the top two barriers to their adoption in the AEC, especially among small and medium firms. A lack of skilled personnel was also ranked as a top barrier, with respondents agreeing there is currently a skill gap of personnel who have the required knowledge and competencies required to get the best benefits from these technologies. The barrier ranked the least by the respondents was "seen as a cause of job insecurity," which suggests that there is a willingness among the survey respondents to learn these technologies and be more welcoming to how they can help.

Framework for the implementation of visualization technologies

This phase of this study involved interviewing industry experts in this field to develop a framework to the top barriers to VT adoption in the AEC sector selected by the respondents of the survey. As a result of the interviews carried out with the experts, a proposed framework on implementing VT in the AEC successfully has been developed based on the responses of the interviewees.

Cost and access to software and hardware.

A strategy for overcoming this barrier would be outsourcing VT needs by small and medium companies on the first few projects. This eliminates the need for high initial cost investment. A cost-benefit analysis can then be conducted, and a decision on whether to hire an in-house team or stick with the outsourcing strategy is made.

Use of VT for on-field activities.

Several strategies were suggested to promote the use of VT for more on-field remote activities. The first strategy identified is to promote awareness among industry professionals on the benefits of these technologies in making their work processes better and more efficient. Another strategy to consider is the inclusion of visualization technologies into project requirements by owners. This would make companies allocate budgets for the use of these technologies and increase their use. Finally, a long-term strategy is to encourage more automation for tasks in the industry.

Lack of standardized processes and procedures.

Two strategies were suggested in overcoming this barrier. First, the development of guides and templates for various projects, which can then be adjusted to cater to the needs of particular projects, was identified by the interview respondents. Second, at the same time, more research on best practices to using these technologies from academia would be beneficial.

Lack of skilled personnel.

A few strategies were suggested in addressing this key barrier. The first strategy focuses on the need for projects to include the use of VT as requirements which creates more demand and encourage people to develop the skills required. Company-wide education among existing staff to encourage and build their interest in VT is also recommended.

On the academic side, the inclusion of the use of visualization technologies into the education curriculum makes students more familiar with how these technologies work in various scenarios. Also, more undergraduate research to get future graduates interested in these technologies is recommended. Finally, collaborations between the industry and academia are suggested. This would expose students to real-world problems in the AEC which they can implement the skills already learned in the classroom.

Demonstration of visualization technologies for remote work

The final phase of the study focused on assessing the use of Mixed Reality for remote supervision by performing a use-case experiment in achieving objective 5. Site supervision ranked low on the list of VT use-cases for remote work in the industry survey conducted in the first phase. The results of the experiment suggest that the use of the HMD for remote supervision via MR was successful as the majority of the participants indicated that they would recommend the use of MR for remote supervision

Recommendations for future study

This study was aimed to assess the use of VT in the AEC sector for remote work. Based on the results of this study, the following are recommendations for future research in this area.

Future research in this area should attempt to understand the underlying factors influencing the low use of Augmented Reality for construction activities in the AEC sector. Such a study would be beneficial in developing specific strategies to accelerate and improve the adoption of AR into the AEC, especially for remote work.

A detailed cost-benefit analysis study utilizing these technologies for remote work in the AEC sector should be performed, particularly for on-site activities. The results of this study would aid in convincing small and medium companies of the long-term benefits these technologies could offer.

A control group and intervention group approach should be used in further studies to find the benefits of the MR approach.

Research on the use of VT for remote work for the identified use-cases individually before and after COVID-19 is also recommended to gain further insight on how the attitudes of professionals toward these technologies has changed.

Limitations

During the course of conducting this study, a number of limitations in achieving the study objectives were encountered. A key constraint was recruiting participants to participate in the use-case experiment. Due to the ongoing COVID-19 pandemic, access to students who were the main target audience was limited to emails rather than physical interactions. As a result, the sample size for the use-case experiment was small, making it difficult to generalize the results.

Also, the sample for the use-case experiments consisted mainly of students in the AEC, limiting the target audience. Extra steps should be made to consider and include construction workers in the AEC who would be the main target for this use-case (remote site supervision).

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APPENDIX A: IRB APPROVAL LETTER

UNIVERSITY of HOUSTON
DIVISION OF RESEARCH
Institutional Review Boards

APPROVAL OF SUBMISSION

March 2, 2021

Oluwatobiloba Sowunmi
ossowunmi@uh.edu

Dear Oluwatobiloba Sowunmi:

On February 26, 2021, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	An investigation of the use of visualization technologies for remote work in the AEC sector.
Investigator:	Oluwatobiloba Sowunmi
IRB ID:	STUDY00002774
Funding/ Proposed Funding:	Name: Unfunded
Award ID:	
Award Title:	
IND, IDE, or HDE:	None
Documents Reviewed:	• Email request for study participants (industry survey).pdf, Category: Recruitment Materials; • HRP-502a (interview).pdf, Category: Consent Form; • Industry survey.pdf, Category: Study tools (ex: surveys, interview/focus group questions, data collection forms, etc.); • Email request for study participants (interviews).pdf, Category: Recruitment Materials; • HRP-502e-Consent cover letter.pdf, Category: Consent Form; • Post-test survey.pdf, Category: Study tools (ex: surveys, interview/focus group questions, data collection forms, etc.); • Pre-test survey.pdf, Category: Study tools (ex: surveys, interview/focus group questions, data collection forms, etc.); • IRB Protocol document, Category: IRB Protocol; • Recruitment Flyer, Category: Recruitment Materials; • citiCompletionReport9390190 (2)a.pdf, Category: Other; • Interview questions.pdf, Category: Study tools (ex: surveys, interview/focus group questions, data

UNIVERSITY of HOUSTON
DIVISION OF RESEARCH
Institutional Review Boards

	collection forms, etc.); • citiCompletionReport9390190 (1).pdf, Category: Other; • Recruitment Email, Category: Recruitment Materials; • Consent Form, Category: Consent Form;
Review Category:	Expedited
Committee Name:	Non-committee review
IRB Coordinator:	Maria Martinez

The IRB approved the study on March 2, 2021; recruitment and procedures detailed within the approved protocol may now be initiated.

As this study was approved under an exempt or expedited process, recently revised regulatory requirements do not require the submission of annual continuing review documentation. However, it is critical that the following submissions are made to the IRB to ensure continued compliance:

- Modifications to the protocol prior to initiating any changes (for example, the addition of study personnel, updated recruitment materials, change in study design, requests for additional subjects)
- Reportable New Information/Unanticipated Problems Involving Risks to Subjects or Others
- Study Closure

Unless a waiver has been granted by the IRB, use the stamped consent form approved by the IRB to document consent. The approved version may be downloaded from the documents tab.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system.

Sincerely,

Research Integrity and Oversight (RIO) Office
University of Houston, Division of Research
713 743 9204
cphs@central.uh.edu
http://www.uh.edu/research/compliance/irb-cphs/

APPENDIX B: QUESTIONNAIRE SURVEY

VISUALIZATION TECHNOLOGY FOR REMOTE WORK IN ARCHITECTURE, ENGINEERING & CONSTRUCTION

You are invited to participate in a survey about the use of visualization technologies for telework in the AEC industry. The data analysis results from this survey will help in providing much needed insights about the use of Visualization Technologies in the AEC industry, which will be of importance to professionals and members of academia. This survey would take approximately 10 minutes of your time, and responses to this survey would be completely anonymous.

If there are any concerns or questions regarding the completion of this survey, kindly reach out to either me via my email ossowunm@cougarnet.uh.edu (mailto:ossowunm@cougarnet.uh.edu) or my thesis advisor Dr. Zia Ud Din at uziauddi@uh.edu (mailto:uziauddi@uh.edu)

I would like to thank you for taking time out of your schedule to consider this invitation to take part in this survey.

Best regards,

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* Required

1. ELECTRONIC CONSENT: Please select your choice below. Selecting the "agree" button below indicates that:

   You have read and understand the above information.
   You voluntarily agree to participate.
   You give us permission to use your input for research purposes.
   You are at least 18 years of age. *

   ◯ Agree

   ◯ Disagree

DEMOGRAPHICS SECTION

2. Age *

- ◯ 20-30
- ◯ 31-40
- ◯ 41-50
- ◯ 51-60
- ◯ > 60

3. Number of years in the Architecture, Engineering & Construction industry *

- ◯ 0-5 years
- ◯ 5-10 years
- ◯ 10-15 years
- ◯ 15-20 years
- ◯ 20-25 years
- ◯ > 25 years

4. How would you classify your role in the AEC industry *

- ◯ Owner
- ◯ General Contractor
- ◯ Designer
- ◯ Architect
- ◯ Engineer
- ◯ Sub-contractor
- ◯ Other

5. Do you have experience with Visualization Technologies (such as BIM, Augmented Reality, Virtual Reality, Drones, 360 Degree & Hi-resolution Cameras) on AEC projects? *

- ◯ Yes
- ◯ No

6. What type of visual technologies have you utilized in your projects? *

- [ ] Virtual Reality
- [ ] Augmented Reality
- [ ] Drones/UAV
- [ ] Building Information Modelling
- [ ] Hi-resolution Cameras
- [ ] Other

7. How would you rate your familiarization with Visualization Technologies prior to the COVID-19 pandemic? *

Not at all familiar	Slightly familiar	Somewhat familiar	Moderately familiar	Extremely familiar
○	○	○	○	○

8. How would you rate your experience with Visualization Technologies since the onset of the COVID-19 pandemic? *

Not at all familiar	Slightly familiar	Somewhat familiar	Moderately familiar	Extremely familiar
○	○	○	○	○

9. How often did you perform remote work prior to the COVID-19 pandemic? *

Never	Rarely	Occasionally	Often	Very Often
○	○	○	○	○

10. How often have you performed remote work since the onset to the COVID-19 pandemic? *

Never	Rarely	Occasionally	Often	Very Often
○	○	○	○	○

11. How often did you perform work remotely with a form of Visualization Technology prior to the COVID-19 pandemic? *

Never	Rarely	Occasionally	Often	Very Often
○	○	○	○	○

12. How often have you performed work remotely with a form of Visualization Technology since the onset of the COVID-19 pandemic? *

Never	Rarely	Occasionally	Often	Very Often
○	○	○	○	○

13. Have you been engaged remotely on an AEC project after the breakout of the COVID-19 pandemic? *

- ◯ Yes
- ◯ No

APPENDIX C: INTERVIEW QUESTIONNAIRE

1. Which of these professions best describes you?

- ○ Engineer
- ○ Designer
- ○ General Contractor
- ○ Sub-contractor
- ○ Architect
- ○ Academia
- ○ Other

2. What do you think are the underlying factors to these top three barriers to visualization technology use in the AEC?

3. In your opinion, what strategies can be employed to effectively tackle these top barriers?

APPENDIX D: USE-CASE PRE-TEST QUESTIONNAIRE

1. Kindly put in the randomly generated user identifier number assigned to you in the box below

2. How would you describe yourself

- ◯ Full-time student in an Architecture, Engineering and Construction program of study
- ◯ Part-time student in an AEC program of study with a part-time job in the AEC sector.
- ◯ Part-time student in an AEC program of study with a part-time job not in the AEC sector.
- ◯ Full-time professional in the AEC sector.

3. Have you used any form of Visualization Technologies such as virtual reality, augmented reality, or mixed reality for a construction activity or a class?

- ◯ Yes
- ◯ No

4. What type of Visualization Technologiwa have you used?

- ☐ Extended Reality (Virtual, Augmented or Mixed Reality)
- ☐ UAV/Drones
- ☐ 360 Degree Cameras/ Stationery Cameras
- ☐ Building Information Modeling (BIM)
- ☐ Other

5. Have you used the Microsoft HoloLens before?

- ◯ Yes
- ◯ No

6. Have you performed a construction activity remotely (either as a supervisor or field worker)?

- ◯ Yes
- ◯ No

7. Did you use Visualization Technology in performing the construction activity remotely?

- ◯ Yes
- ◯ No

APPENDIX E: USE-CASE POST-TEST QUESTIONNAIRE

1. Please input your assigned random generated number

2. Were you able to carry out the instructions given to you adequately?

- ◯ Yes
- ◯ No
- ◯ Not sure

3. The interface and capabilities of the MR device were easy to understand.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

4. The remote expert supervised the process adequately through the platform

Strongly disagree	Disagree	Neutral	Agree	Strongly agree
◯	◯	◯	◯	◯

5. Did you experience any problems in using the Mixed Reality device for this experiment?

- ◯ Yes
- ◯ No

6. Which of these problems did you experience during the course of this experiment?

- [ ] Poor internet connectivity
- [ ] Latency (delayed user experience)
- [ ] Blurry display
- [ ] Difficulty in communication with remote expert
- [ ] Other

7. Do you think this would be a viable and effective alternative for experts to carry out remote supervisions rather than on-site supervisions?

- ○ Yes
- ○ No
- ○ Not sure

8. Would you recommend Mixed Reality for remote supervision of construction work?

- ○ Yes
- ○ No
- ○ Maybe

9. How would you rate your experience of using Mixed Reality for remote work?

	Very dissatisfied	Somewhat dissatisfied	Neither satisfied nor dissatisfied	Satisfied	Very satisfied
Statement 2	○	○	○	○	○

10. Do you have any concerns or recommendations for the use of the Mixed Reality for remote supervision of construction activities?

- ○ No
- ○ Other

APPENDIX F: GROUP 1 RII USE-CASE RANKINGS

Project Managers/Owners/General Contractors

USE-CASE	RII	RANK
Virtual conferencing/meetings	0.713	1
Surveying and site mapping	0.696	2
Progress monitoring	0.661	3
Clash detection	0.609	4
Space planning and visualization	0.600	5
Value Engineering/ design reviews	0.557	6
Site supervision/ maintenance support	0.548	7
Inspection walk-throughs	0.539	8
Safety training, planning and management	0.513	9

APPENDIX G: GROUP 2 RII USE-CASE RANKINGS

Designers/Architects

USE-CASE	RII	RANK
Space planning and Visualization	0.791	1
Virtual conferencing	0.755	2
Clash detection	0.718	3
Value Engineering and design reviews	0.645	4
Progress Monitoring	0.609	5
Surveying and site mapping	0.500	6
Site supervision/ maintenance support	0.436	7
Inspection walk-throughs	0.400	8
Safety training, planning and management	0.318	9

APPENDIX H: GROUP 3 RII USE-CASE RANKINGS

Engineers

USE-CASE	RII	RANK
Virtual conferencing/meetings	0.773	1
Space planning and visualization	0.707	2
Progress monitoring	0.693	3
Inspection walk-throughs	0.627	4
Surveying and site mapping	0.627	4
Clash detection	0.613	6
Safety training, planning and management	0.613	6
Value engineering and design reviews	0.600	8
Site supervision/ Maintenance support	0.573	9

APPENDIX I: GROUP 1 RII RANKINGS OF BARRIERS TO VT FOR REMOTE USE

Project Managers/Owners/General Contractors

S/No	Barriers	Rank	RII
1	Cost of Technology	1	0.817
2	Access to software and hardware required	2	0.783
3	Lack of skilled personnel	3	0.730
4	Lack of standardized processes & procedures	4	0.713
5	Management aversion to new technology	4	0.713
6	Cost of training personnel	6	0.687
7	Lack of interest from owners	7	0.635
8	Security of data	8	0.600
9	Seen as a cause of job insecurity	9	0.504

APPENDIX J: GROUP 2 RII RANKINGSOF BARRIERS TO VT FOR REMOTE WORK

Designers/Architects

S/No	Barriers	Rank	RII
1	Cost of Technology	1	0.864
2	Access to software and hardware required	2	0.809
3	Cost of training personnel	3	0.745
4	Lack of standardized processes & procedures	4	0.736
5	Lack of skilled personnel	5	0.718
6	Management acersion to new technology	6	0.673
7	Lack of interest from owners	7	0.645
8	Security of data	8	0.555
9	Seen as a cause of job insecurity	9	0.473

APPENDIX H: GROUP 3 RII RANKINGSOF BARRIERS TO VT FOR REMOTE WORK

Engineers

S/No	Barriers	Rank	RII
1	Cost of Technology	1	0.867
2	Access to software and hardware required	2	0.773
3	Lack of skilled personnel	3	0.760
4	Cost of training personnel	4	0.747
5	Lack of standardized processes and procedures	5	0.733
6	Lack of interest from owners	6	0.653
7	Management aversion to new technology	7	0.640
8	Security of data	7	0.640
9	Seen as a cause of job insecurity	9	0.573