CONSTRUCTION DECISION-MAKING USING VIRTUAL REALITY

by

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A Thesis

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science in Construction Management Technology

Department of Construction Management Technology

West Lafayette, Indiana

May 2020

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I dedicate this thesis to my family and friends for all their support and guidance.

ACKNOWLEDGMENTS

I’d like to thank Dr. Clark Cory for having faith in me and the undying encouragement he provides in all of my academic endeavors.

Dr. Emad Elwakil for his support and kindness.

Prof. James Jenkins for giving me valuable insight on a topic that interests me.

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GLOSSARY

AEC: An acronym for architecture, engineering and construction, the individuals involved in the procurement of an infrastructure project. Since their end result is to attain a common goal, they are integrated into a single industry (ImsCAD, 2019).

Building Information Modeling (BIM): A system-generated 3D virtual model of a building. This is becoming a standard aspect in construction and architecture. The AEC (United Kingdom) BIM Standard defines it as the compilation of project data to increase attention on design and also reduce blunders.

Client: The individual or organization in charge of commissioning a facility, including paying for the design and construction of it (BPF, 1983).

Coordinate: To combine several elements to work in coherence with one another (based on the *Oxford Dictionary*).

Deliverables: As defined by Bond Bryan Architects, "The specific requirements for the project which may be generated directly from the model or from other sources. They may include the building information model, drawings, fly-through, images, data, schedules or reports" (as cited in Cory, 2019, p. 25).

Design Team: The project architects and project-related engineers, including structural, electrical, mechanical, etc. ("Builder-Questions," 2019).

Immersion: The sensation of being in an environment. This could be physical (e.g., within a large stereo display system) or mental (e.g., deep engagement in a virtual world) (Burdea & Coiffet, 2003, as cited in Messner et al., 2006).

Immersive Virtual Reality: Device technology which creates an illusion of being present in a simulated world through use of sensorimotor devices (Biocca & Delaney, 1995, p. 64).

Non-immersive Virtual Reality: Also known as desktop systems. The virtual environment is viewed through a screen using a high-resolution monitor. Conventional means of interaction can occur with the use of the keyboard or a mouse (Costello, 1997).

Pre-construction stage: The stage associated with activities that are performed before the start of on-site construction (O'Neal, 2019). It can be subdivided into planning, designing and tendering (Nasir et al., 2016).

Prototype: An elementary model of a project that is a part of the design process and allows the user group to create, analyze, explore design options, test theories and confirm safety before large-scale implementation (TeachEngineering, 2019).

View: "A generated rendition of graphical or non-graphical information, such as a plan, section, elevation, schedule, or other view of a project" (as defined by AEC (UK) BIM Standard v2, p. 8, as cited in Clark, 2019, p. 32).

Virtual Model : A computer-based model depicting an aspect of the project. The model can be curated long before the project physically begins (Kunz & Fischer, 2009).

Virtual Reality: A computer-generated environment that creates a convincing illusion and a sense of presence in an artificial world (Castronovo et al., 2013). Without its physical existence, it conveys the information, properties and functionality of an actual environment (Jarkko & Kalle, 2000). The main feature of virtual reality is that the synthetic world responds to user input and is not static (Burdea & Coiffet, 2003).

VR Interaction: The user ability to interact with the virtual world in real time and receive feedback in the form of audio, video, smell, touch or taste (Burdea & Coiffet, 2003, as cited in Messner et al., 2006).

LIST OF ABBREVIATIONS

AEC: Architecture, Engineering and Construction

BIM: Building Information Modeling

HMD: Head-mounted displays

MEP: Mechanical, Electrical and Plumbing

Precon: Pre-construction

RFI: Request for information

VR: Virtual reality

ABSTRACT

We make decisions every day, some with the potential for a huge impact on our lives. This process of decision-making is crucial not only for individuals but for industries, including construction. Unlike the manufacturing industry, where one can make certain decisions regarding an actual product by looking at it in real time, the nature of construction is different. Here, decisions are to be made on a product which will be built somewhere in the near future. The complex and interim nature of construction projects, along with factors like time essence, increasing scale of projects and multitude of stakeholders, makes it even more difficult to reach consensus. Incorporating VR can aid in getting an insight on the final product at the very beginning of the project life cycle. With a visual representation, the stakeholders involved can collaborate on a single platform to assess the project, share common knowledge and make choices that would produce better results in all major aspects like cost, quality, time and safety. This study aims at assessing decision-making in the earlier stages of construction and then evaluating the performance of immersive and non-immersive VR platforms.

CHAPTER 1. INTRODUCTION

Construction as a whole involves making successive decisions. According to Faber & Rackwitz (2004) and Książek & Nowak (2011), as cited by Szafranko (2017), a decision is defined as a selection of one option amongst several others. The final shape of a building and the course of the building process are determined by the initial decisions made. The effect of these decisions can be seen for the duration that the building is utilized, potentially over a span of years.

A few construction projects might progress exactly as planned from start to finish, but most of them are not that predictable (Ashley et al., 1983). According to Leinonen & Kähkönen (2000), the primary reason for project defects is sourced at the design and engineering phase. According to Laitinen (1998), "It happens often that the design phase in a building construction project is realized without sufficient constructability consideration. Also, it has been found that the methods for decision support are ad-hoc and unsystematic. This is a root cause for many problems and disappointments in building construction projects" (as cited in Leinonen & Kähkönen, 2000, p. 1015).

To attain a more useful level of work practice, new techniques are required. Virtual reality technology is one of these new methods for construction management and planning (Alshawi, 1994, as cited in Leinonen & Kähkönen, 2000). By helping visualize construction information, the tool can help project personnel better understand the project as individuals and as a group by providing a consistent shared understanding (Shin, 2007). Visualization helps in understanding a design and also in scrutinizing it: according to Castronovo et al. (2013), "One method to improve the information representation is through the development of virtual prototypes that can be experienced in virtual reality (VR) environments" (p. 23). This study aims at analyzing the user attitude, performance and opinions toward two virtual reality tools.

1.1 <u>Statement of Problem</u>

Effective decision-making within AEC companies plays an important role in determining the final outcomes of construction projects. There are, however, uncertainties associated with construction projects that will have a large impact on the project life cycle.

Making right decisions at the right time is necessary for the project to be successful. It is important to make viable decisions at the beginning stages of a project to avoid impediments. Planning plays a critical part in the pre-construction phase, which makes it a top priority among stakeholders. The literature of this study identifies gaps in the field of pre-construction planning where good decisions are sometimes compromised. The reasons for such problems include lack of understanding, communication gaps, different perspectives among stakeholders and improper planning. Research suggests that VR tools and walkthroughs bridge these gaps by providing a common platform for the design team and stakeholders to collaborate. This allows them to evaluate design alternatives, share tacit knowledge, communicate ideas and help identify errors (Liu et al., 2014).

The objective of this case study is to examine the use of a VR design model to understand the challenges and benefits of the tool and evaluate the performance of immersive and non-immersive platforms. Eventually, the aim would be to bridge the research gap of good decision-making through the adoption of VR.

1.2 Research Questions

The research questions for this study are the following:

- How does virtual reality enhance the decision-making process in the construction industry?
- In decision-making for a client, is immersive VR better or non-immersive?

1.3 Scope

This research involves a qualitative case study of the user's opinion on decision-making using VR. Some of the important tasks involved in the design stage are coordination, error identification, design development, technical specifications and clash detection. The treatment will be a VR simulation which will expose the participants to the virtual building model. The medium used for visual representation will be both immersive and non-immersive VR platforms. The procedure would analyze the rating and data given by the users. The study would include participants from the construction management department of an educational institution. The outcome will produce an understanding of the technology based on user performance and opinion.

1.4 Significance

The construction industry is a multi-disciplinary team working together to achieve a common end result. With several individuals involved, work scopes sometimes overlap and the processes can get complex. Complications sometimes lead to disputes and delays, and it often takes days or even months to get important information to make decisions, inevitably causing loss of capital. Virtual reality has the ability to cater to several disciplines, presenting data in a simplified realistic manner. This study would focus on using 3D models as a common platform of collaboration during the pre-construction stage.

The demand for fast, cost-effective, high-quality and safe construction justifies the need for more effective decision-making tools. Companies that apply the suggested approach derived from the observations of this case study will be able to use better decision-making platforms best suited for them.

The final outcomes of this study would help the practitioners of this particular sector to select a tool that is appropriate for their project and collaboration needs. Stakeholders and managers can also use the outcomes of this study to evaluate a tool necessary for the improvement of their current setup of making construction decisions. For the researcher, the case study will help reveal critical opinions and areas in the VR decision-making process that previous researchers might not have explored. In short, issues that were overlooked before can now be addressed effectively.

1.5 Assumptions

This qualitative case study highlights the user's performance and experience and compares the results with other participants. The assumptions made for this case study are as follows:

1) This study will capture the essence of a real-life construction instance in the pre-construction stage. It will replicate a situation where the population sample is seen as "decision-making" professionals in the industry.
2) The views and opinions of the population sample are uninfluenced by their previous exposure to decision-making formats.
3) The selected sample is an ideal representation of the general user in the industry.
4) The participants will study the model, experience the animations and give honest answers in the questionnaire and interviews.

5) The participants have a basic knowledge of building construction.
6) Any assistance that the researcher provides during the experiment involving VR headgear adjustment or basic software help will be documented but not included in the overall data analysis.
7) Any computer-related mishap involving stalling of the software will be omitted.
8) The participants will take the interview on the same device.
9) The regulated environment and the time given to complete the assessments will minimize the risk of personal biases.
10) The participants will participate in the study voluntarily, under no external or internal pressure.
11) The participants' basic knowledge will be sufficient to identify shortfalls and gaps of the tool.

1.6 Limitations

1) The study is limited to the students of the construction management department and the ones who volunteered amongst them.
2) The study is limited to a particular pool drawn from a university's department of construction, and to participants age 18 or older. These factors might influence the applicability of this instance to the general public.
3) The observations in the experiment are limited to a particular project and depend on the model itself.
4) The study is limited to only two instruments, which are immersive and non-immersive 3D visualization.
5) This study only analyzes and presents the results of the ratings and interviews conducted within the set sample groups and therefore can't be generalized.

1.7 Delimitations

1.) Participants outside the university would not be included in the study.
2.) No other software other than AutoCAD and Revit will be used to create a base model in this study.

3.) Participants below 18 years of age will not be included in the study.
4.) The study will not develop any framework to assess the quality and setup of the interviewing environment.
5.) The participants will not need to update the model, only identify errors and provide a rating and their opinion on it.

1.8 Summary

This chapter provides an overview of the research topic and the case study. The subject group is identified as described in the scope. Narrowing down a large subject matter helps keep the case study plausible. By defining the limitations, delimitations and assumptions, the researcher defines the boundary of the study. Along with this, the elements beyond the researcher's control are clearly stated.

CHAPTER 2. LITERATURE REVIEW

2.1 <u>Introduction</u>

Decisions are an essential part of the construction industry at all stages. With several phases involved from the conceptual stage to project handovers, the decision-making process tends to be a difficult one: “As a rule, the decision-making process is made more complicated due to certain conditions specific for civil engineering. With such diverse decision situations, it is recommended to apply various decision-making support methods” (Szafranko, 2017, p. 1).

High project costs, deficient quality, delays and redundant productivity are the repercussions of inadequate planning and management, as per the results from several studies (Leinonen & Kähkönen, 2000). The activities that follow through in the construction process are to design, develop, coordinate and construct. Although certain elements may vary largely from one project to another, the activities and decisions are primarily the same (Hostick et al., 2003).

According to Poon and Price (1999), “The decision-making process is critical to the success of any construction project. Construction personnel have to make decisions on a daily basis and must be able to justify these decisions. Wrong decisions can be costly in terms of time, quality, cost and relationships” (p. 589). Based on the same paper, the authors coin the term “decision theory.” Decision theory states that in the construction field, it is common to be in a situation where a quick action or decision is required (Ashley et al., 1983). This means that in a real-life construction scenario, making informed decisions rather than relying on personal intuition is important. The practitioners and the stakeholders must be trained in the decision-making process to ensure success. Based on the articles by Poon and Price (1999) and Ashley et al. (1983), a gap in terms of having the right platform for effective decision-making can be identified.

According to a study by Liu et al. (2014), people perceive VR as a tool that brings value to a design review, conveys design intent and enhances the efficiency of meetings. When compared to stationary renderings and traditional drawings, the tool allows users to virtually walk through the building and understand its aesthetics in a flexible manner. Using a virtual environment to view a building allows individuals to get up to speed with the current design features and programs. Creating a common level of familiarity allows individuals to collectively view the model and enhances interdisciplinary, interprofessional and inter technical collaboration. It was noticed that design reviews involving VR sparked deep questions that uncovered unexpected design issues, which would have easily gone unnoticed in still renders or traditional models.

There is a need to establish effective frameworks to successfully implement the ideas of the decision theory. The idea of VR brings, in effect, a set of new technologies. This technology allows the practitioners to experience a simulated environment, providing a scenario to assess VR adoption. The objective would be to see if the adoption of VR could impact the opinion of the practitioners about using it for construction decision-making.

2.2 Complexities of a construction project

Bennett (1991), as cited in Baccarini (1996), mentions that the construction process can be regarded as the most complex undertaking in any industry. Baccarini (1996) states that construction-related projects are inevitably complex, and have progressively increased in complexity since World War II. According to Brockmann and Kähkönen (2012), the complexity of construction projects is mentioned in almost every text on project management or its adjacent fields.

Wood and Ashton (2009) suggest that increasing project complexity is the primary factor behind poor success rates of construction projects. Thus, there is a need for better understanding of project complexities at an early stage in order for a project to be managed efficiently.

In structured interviews of individuals involved in the construction industry, Gidado (1996) collected the following ideas about project complexities:

- A project is complex if it involves a great deal of intricacy. Such projects pose obstacles in terms of achieving desired goals within a set time.
- Secondly, complex projects have various frameworks that should be assembled with a substantial amount of coherence between steps.
- Thirdly, complex projects require effective coordination, supervision and organization from beginning to end.
- Lastly, complex projects have a series of tasks connected logically.

In recent times, the size and complexity of projects are increasing. Some of the factors that add to the complexity of a project include set timelines, unforeseen site conditions, structural complications and many more (Luo et al., 2017). A successful working team includes workers from diverse backgrounds. In addition to the impact of the complexity and its factors, workers often struggle to understand expectations. A few studies have also shown that traditional project management tools are deficient in addressing a project's complexity. This clearly means that decision-making strategy impacts complexity resolution within the working teams. This study thus focuses on narrowing down the limitations that cause issues with decision-making.

2.3 Uniqueness of the construction industry

This sector, unlike many other sectors, is labor driven. According to Colean and Newcomb (1952), "the products of construction, despite the wide diversity of the sectors within the industry and the heterogeneity of each product, share certain common characteristics: they are immobile, complex, durable and costly" (as cited in Nam & Tatum, 1988, p. 134).

A study conducted by Nam and Tatum (1988) compares construction with the manufacturing industry on five factors: complexity, immobility, costliness, durability and continuous improvement. The authors identify these five elements as critical success factors for the successful working of the construction sector.

2.4 Historical background

2.4.1 Evolution of technology in the industry

The construction industry incorporates knowledge of several visualization and sketching techniques to generate the desired output. This knowledge is essential for the practitioners to visualize and eventually execute successful projects. Over the years, the construction industry has had design information tools such as:

1.) 2D paper-based illustrations: Known as bidimensional graphics, visual representations in the form of plans, elevations and sections are used to analyze the building (Santos & Ferreira, 2008). Initially, this technology was used for data exchange in most engineering fields and enterprises. It is considered to be the conventional system and still used in instances where the workforce only has the knowledge to interpret 2D paper data. However, with advancement in computer technology, digital drawings are replacing 2D paper drawings (Ye et al., 2006).

2.) 2D CAD: The 2D CAD technology was an electronic version of the above format, with the added advantage of being able to modify and recover drawings easily. The presence of well-settled norms and simplicity made it a well-utilized CAD application. One of the demerits was the lack of clarity in showcasing complex 3D objects. It was these reasons that led to the inception and adoption of 3D CAD (Ye et al., 2006).

3.) 3D CAD: The emergence of 3D modeling has largely influenced the use of CAD application technology. According to Santos and Ferreira (2008), the above 2D CAD representation is said to be abstract and symbolic and demands on a designer/user to have more spatial visualization ability and technical knowledge when compared to 3D CAD. These traits are said to give 3D CAD users the advantage of fewer mistakes and earlier detection of design problems than with 2D CAD.

   3D CAD technology eased the design process for complex objects, which often required intensive use of surface modeling. Additionally, with the help of this technology, simple geometric shapes could be redesigned using simple solid-modeling software programs. Apart from model creation, physical properties such as mass, volume and center of gravity were also introduced into the model system to study their impact on the structure. This technology revolutionized the idea of modeling and brought in the idea of rapid prototyping (Ye et al., 2006).

4.) BIM: The objective of Building Information Modeling (BIM) technology is to build a centralized source with shared knowledge containing all the needed design and operational data on a project. Design proposals are submitted using 3D technology, with no true on-site implementation. BIM uses real engineering and architectural information to produce 3D models, as opposed to generating models with creative 3D design software. This allows a 3D model to be updated by altering the database that contains the requirements rather than the real model itself. BIM is used with this benefit to define and cut down on mistakes, resolve design disputes and fulfill requests for information (RFIs) before the project breaks ground. Centralizing the dataset also has the advantage of keeping a coherent data format (Rowlinson et al., 2010).

5.) 3D VR: According to Zikic (2007), VR is defined as “a computer-generated three-dimensional environment which responds in real time to the activity of the users” (p. 3, as cited in Liu et al., 2014, p. 1). Whyte (2002) summarizes VR as having three characteristics: interactivity, 3-dimensionality and real-time action to responses (as cited in Liu et al., 2014). Ye et al. (2006) mention that it is a technological tool whose function is to improve the flow of data from planners to owners. This is primarily done by producing simpler walkthroughs to test the design in a more natural way. Currently, the industry is gradually adopting the utilization of VR for various purposes. 2D and 3D illustrations are still the essential media for data communication. Few organizations use VR models as the primary mode of communication among all the stakeholders involved. According to Ye et al. (2006), the users of VR have experienced a proficiency gain of up to 30% in the development stages of construction. This depicts the importance of technology such as this to generate higher-quality outcomes.

2.4.2 Previous efforts in decision-making and gaps identified

According to Waly and Thabet (2003), the planning process is a crucial element in the successful execution of a construction project. Currently, teams make decisions manually, which poses a burden on the project team due to large amounts of information and interdependence (Laufer & Tucker, 1987, as cited in Waly & Thabet, 2003). The information exchange is primarily through paper documents, and visualization is communicated through paper-based 2D drawings, often leading to tasks and functions that are planned in isolation from one another. This is known as "silo" planning, involving large amounts of information that must be processed and pieced together manually by a project team to make a comprehensive plan. Efforts were made to completely or partially automate the planning process by the use of computer graphics and/or artificial intelligence. By doing so, the system relied on programmed knowledge and heuristics for decision-making, partially or fully eliminating the need for human involvement. Human involvement was indirect, limited to data input, which eventually became a drawback in the system. This led to reducing the use of this system in the industry (Waly & Thabet, 2003).

Taking the above literature review into account, this research seeks to tackle the information exchange gap, using a virtual tool that would involve the project team in the decision-making process and present the data to them in a joined platform.

2.5 Theory relevant to research questions: Benefits of VR

From previous literature and case studies, scopes have been identified where VR adoption addresses gaps in the construction industry. Taking excerpts from these literature reviews, the following benefits were gathered:

1. Improved collaboration/communication: VR adoption has the potential to impart plans to extensive audiences, as they would not need prior training to utilize the technology for basic discussions on project improvements and changes. A complete idea of the design and the viewpoints of stakeholders can be visualized, thus preventing ambiguity. The virtual model behaves as an information bank, providing a connection between stages, thus preventing information loss (Marshall-Ponting & Aouad, 2005). One of the most important benefits of VR is said to lie in design review. According to the case study by Woksepp and Olofsson (2008), VR was used as a tool in drafting at the design stage to find the best solutions for a project. The designers used VR technology to assess the impact of the project, make predictions and analyze potential options. With the help of this tool, the client was involved in periodic design work, which made it easier to make important decisions. This allowed the designers to congregate input from a more extensive audience, including the end users and support staff (Woksepp & Olofsson, 2008).
2. Increased stakeholder engagement: Many stakeholders who view the project and process from different perspectives are part of the design environment. They include industry professionals like architects, engineers, subcontractors, specialists, users and clients. VR provides a medium of 3D visualization to collaboratively explore design possibilities, manipulate the data in real time and simulate the construction stage by stage.

   Usually, some stakeholders who are not in the AEC field have little or no familiarity with conventional construction documents. A common problem is that the presentation of design concepts and information is not understood clearly by all stakeholders (Bouchlaghem et al., 2005, as cited in Zaker & Coloma, 2018). VR allows the users to experience, discuss and develop common perspective on things that don't exist yet. Users can work within a tangible framework rather than speaking in abstractions. The understanding gap is shortened between architects and clients and between visual and nonvisual thinkers (Bond, 2007, as cited in Zaker & Coloma, 2018).

3. Individualized experiences: VR’s ability to involve people in the different phases of construction and project development is another advantage. Project presentations and collaboration sessions can be a boring and burdensome process for participants. Utilizing head-mounted displays (HMDs) that detach the user from the real world can add an interesting factor, along the same lines as playing video games (Moss & Muth, 2011, as cited in Zaker & Coloma, 2018).

   VR offers advantages to its users in the way it “combines real-time 3D computer-generated graphics with feedback, enabling a participant to experience a simulated world quite vividly” (Pimentel & Teixeira, 1993, & Heim, 1994, as cited in Glicksohn & Avnon, 1997, p. 142). The building design process is closely associated with the user experience toward the end result, and the success of this process is often used to assess the architect’s performance. Architectural design is largely a user-centric process (Krukar et al., 2016).

   For digitally modeled architecture, VR has the potential to become an effective exploratory tool. Stereovision created by stereoscopic HMDs allows for depth perception in digital environments. The display responds to the user as the computer records the head and body movement, thus creating a spatio-temporal experience, which is a feeling of immersion and presence in the surrounding virtual environment (Dörner et al., 2013, as cited by Zaker & Coloma, 2018). The outcome of the design process depends on the interpretations, prejudice and perceptions of those involved (Colin & Hughes, 2007, as cited by Zaker & Coloma, 2018). According to Zaker and Coloma (2018, “This is aligned with one of the main concepts of BIM, to involve the project stakeholders in early stages of the design, and VR can be an appropriate medium for this purpose” (p. 4).

4. Understanding of space: Understanding how the user manages to navigate around the building is an important part of architectural design. For instance, by using VR it becomes possible to test emergency escape routes. This has often been tried by means of computer models. With VR, real people can interact with real-world scenarios, giving architects a better idea of how safe their design is and how to improve it (TMD Studio, 2017).
5. Fewer interruptions: Building involves many parallel tasks; a slight interruption or mishap can impact the work process of an entire chain of building schedule, resulting in cost increases and delays and taking a toll on the quality (TMD Studio, 2017).

6. Improved project predictability and outcomes: Adoption of VR in the construction sector reduces rework by providing a clear picture of the designed models. This advantage addresses the gap of conducting frequent reworks, which often costs immense time and money.

   The feedback process tends to be a bit more straightforward when the client is placed into a detailed virtual representation of a building design. Their likes and dislikes of certain elements of the design can be better determined than compared to viewing a 2D drawing or 3D model. This lowers the time spent on back-and-forth revisions and allows for real-time changes in the virtual world, giving clients the sense of specific aesthetic features (TMD Studio, 2017).

7. Improved safety: Many construction companies invest large amounts of money in safety training. Adopting virtual tools greatly reduces the risk of higher expenses. By portraying simulated real-life scenarios on site, these applications could give the client a lifelike feeling of a potential risk, thus improving safety by enhancing preparedness. Additionally, different types of trainings can highlight better decision-making by utilizing virtual technology. This results in improved and safer choices (Behzadi, 2016).
8. Reduced costs: The nature of a virtual model replaces the need for a separate rendered model. Avoiding expensive renders saves a company money, as the software provides both function and aesthetic quality (Haggard, 2017).

2.6 Current empirical literature reviews relevant to research

2.6.1 Potential of VR in construction-related work and gaps identified

Data handling in construction depends upon traditional media tools such as 2D drawings, written specifications, spreadsheets and Gantt charts (Kähkönen, 2003). These specifications are crucial to consider during data exchange. Additionally, computer-based graphical representations have changed the way work is done with possibilities such as:

- Creating a platform for collaborating and providing a 3D model to investigate options.
- Assembling models from a variety of departments and disciplines to check for discrepancies.

A study conducted by Westerdahl et al. (2006) assessed employees' evaluation of utilizing VR to experience a model of their soon-to-be-constructed workplace. That research argues that the usability concept of VR models' context has not been ventured into much. The findings show that the VR tool provided the team with good representation and helped in the decision-making process. That research involves those individuals who are not particularly affiliated with the construction industry. However, the current study will involve individuals involved with a construction-based education, possibly having industrial experience.

A qualitative field survey by Woksepp and Olofsson (2008) attempted to understand the impact of VR technology among construction professionals. The focus in this study was the adoption of VR at the planning process of a large pelletizing plant in northern Sweden. The construction of the facility began with an initial 3D setup model. This 3D model eventually developed into an effective 3D mockup model for visualization purposes. Essential 3D information such as the subsystems of the structure, equipment installations and other features were embedded to modify this 3D model setup (Woksepp & Olofsson, 2008). Connected by a common server, these modified models were shared amongst the teams, who extracted essential information for proper design, coordination and planning purposes. The 12 interviewees selected for the survey were mainly involved in the design and planning stage. The participants were interviewed individually in an informal setting, which essentially helped the researchers to systematically map the working procedure and to gather a deeper understanding of VR utilization.

The results show that adoption of VR models proved to be helpful, and the practitioners acknowledged this. The participants believed that the proposed VR model gave a concrete, holistic, organized approach to sort the data and allowed the team to explore different design alternatives. This sorted and organized data laid the foundations for clear 2D CAD illustrations. Using this setup, the team found it easier to help the investors and stakeholders navigate through the models. Moreover, this technology helped the stakeholders from all over the globe to participate in analysis of the models and contribute to decision-making process (Woksepp & Olofsson, 2008). Since the utilization of VR here was in an ongoing project, it was still looked at from an angle of project success, timelines, deliverables and execution deadlines. Though the planners appreciated certain aspects of VR, a large portion of the planning was done using conventional methods because these methods are still a deep-rooted system, the correct VR model was sometimes inaccessible, and there was not enough time to update the models to production level at every stage.

The current study would not involve an ongoing project, and the participants would be looking at the model purely to assess its viability. This eliminates the sense of urgency for project deliverables, and the participants' opinions and feedback will be solely on the performance of the tool.

According to Castronovo et al. (2013), VR systems can vary in immersion levels and in the experience they provide to the user. Choosing a particular type could be challenging. Their research collects user input from participants who use two types of display systems in design reviews. The statement "Very rarely do design review teams have the option to use two different types of display systems" suggests that the design review processes are not often compared in two different platforms (Castronovo et al., 2013, p. 28). In the Castronovo study, only one project team agreed to use two platforms (immersive and non-immersive) for design review. The participants' review experience was documented, and target questions were asked.

The current research is directed at helping future users make educated decisions when choosing a level of immersion for their projects. In this research, an attempt is made to compare two different immersion techniques/levels. To avoid the hasty nature of an ongoing project, the researcher chose a study model in which the participants would focus mainly on the quality and usability of the platforms, without having to construct the project.

The case studies by Westerdahl et al. (2006), Woksepp and Olofsson (2008) and Castronovo et al. (2013) concluded that adoption of VR technology provides an opportunity to simplify the complicated 3D models. These simplified models allow the stakeholders to visually analyze the situation and participate in the decision-making process. The focus of these case studies relies on the belief that a participant's knowledge about the modeling software would essentially lead to model simplification, thus leading to a better decision-making process. Hence, the VR adoption in both enterprises showed good improvement in the correspondence and collaboration between the stakeholders, which is essential for good decision-making.

2.7 Types of VR

In the construction sector, the term VR is often studied in the context of an immersive technology, although the level of immersion may differ depending on the setting of the virtual model. Immersion relates to the sensory depth that the observer experiences, which depends on display size/resolution, field of view and input equipment, among many other factors (Slater & Wilbur, 1997; Bowman & McMahan, 2007; Castronovo et al., 2013).

Virtual reality can be segregated into five main subcategories based on its adoption practices. The categorization is based on the display methods and its usability in the construction sector (Wang et al., 2018). Following are the categories that are typically deployed in a construction sector:

1.) Desktop/non-immersive VR: Widely adopted VR technology used in the early stages of construction engineering and training organizations. This was largely used from 1997–2001. Virtual activities were performed using a simple monitor as the basic platform (Chen et al., 2007). This type of VR relies on an individual's ability to study and understand the model. The hardware required involves a basic keyboard and a mouse. Due to its limited resource requirement, this type of VR is considered a relatively affordable setup (Wang et al., 2018).
2.) Immersive VR: For immersive VR, unique hardware is required to take users from the physical world into an immersive environment. This technology uses sensor gloves and a head-mounted device to create a high-tech immersive environment (Wang et al., 2018).
3.) BIM-enabled VR: In a BIM-related model, along with the 3D model, there is also a substantial amount of information in its properties, including the material type and cost associated with the model (Gheisari & Irizary, 2016). This model contains data from various fields. Fields such as mechanical, electrical and plumbing play a key role in impacting the successful working of this particular VR category (Wang et al., 2018).
4.) Game-based VR: In this model, the main objective is to create a computer-game-based training scenario, with technology that amalgamates visuals and multi-user operations for highly engaging virtual interactions (Wang et al., 2018).

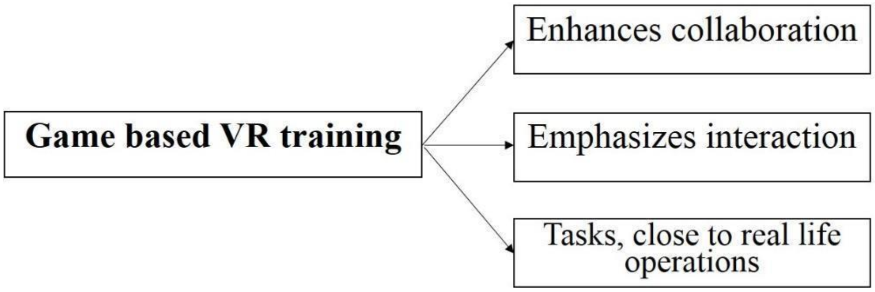


Figure 1: Benefits of game-based VR training (Wang et al., 2018).

2.8 Stages of construction

A systematic process is required for a project to progress from an initial point to a final product. The report by Ye et al. (2006) discusses the construction process as divided into the following stages:

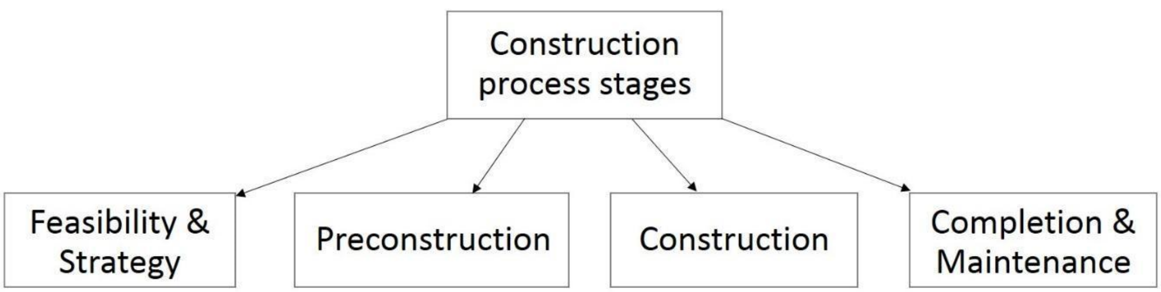


Figure 2: Construction process stages (Ye et al., 2006)

2.8.1 Pre-construction phase

Pre-construction phase is the amalgamation of several activities like developing objectives, planning future activities, procuring strategies, creating designs and defining organizational structure, among others. These activities require steady efforts and active decision-making throughout the process. Planning, design and tendering are the major stages in pre-construction (Nasir et al., 2016). To narrow down this research and VR usage, this study chooses to examine the pre-construction stage. The pre-construction phase of construction provides a basis for the study and analysis of the construction chain in the context of the virtual aspect. This helps practitioners to visualize information for the further steps. This acts as a virtual rehearsal session to make apt planning decisions (Waly & Thabet, 2002). Pre-construction involves sub-stages in the context of initiating the construction process:

1.) Planning stage: The majority of decisions in this stage pertain to cost, quality and the scheduling of critical tasks. Traditional decision-making procedures involve the usage of 2D drawings, blueprints, written specifications and Gantt schedules. These platforms provide a constrained data exchange between the stakeholders (Woksepp & Olofsson, 2008). With the advent of tools like task management software, virtual reality and cloud-based platforms, the decision-making approach is further simplified.

2.) Design stage: During this stage, the team makes decisions on the form, composition and material of the building, compiling data from a variety of departments to get a holistic idea of the structure (Nasir et al., 2016). The design stage can be further broken down into schematic, design development and construction document stages. Conventional decision-making practices in this stage share a close relationship with 2D graphical information. This relationship runs all the way from schematic development to the final documentation. The advent of computer graphics enhances the decision-making process with simulations to replicate a construction scenario (Woksepp & Olofsson, 2008). This study will further focus on the decisions made during the design stage.

2.8.2 **VR used in pre-construction research**

A case study conducted by Castronovo et al. (2013) reviewed two immersive VR display systems for construction designs. An immersive and a semi-immersive display environment were used and their similarities and differences assessed. To set up the virtual mockup, the research team used a VR generative tool to develop a 3D model that the architects designed. The design reviews were conducted using both immersive and non-immersive methods. After the design review processes, data from three surveys were captured and analyzed using Likert scale and open-ended questions. The first two surveys displayed minimal statistical differences between the two systems; however, the fully immersive system slightly outweighed the semi-immersive with regard to a higher sense of presence and a convincing sense of movement. The semi-immersive tool fared slightly better for the efficiency of updating material textures and for its higher screen resolution. The third survey demonstrated contrasts in the two labs for handling different tasks:

The results from the third survey however, indicate potential differences in the suitability of the two labs for conducting different tasks with different user groups. The project team rated a fully-immersive environment to be slightly more appropriate in conducting future design reviews for smaller groups of users, project teams and operational staff. for conducting future construction reviews, the project team found the semi-immersive system marginally more appropriate for larger groups of contractors and project teams. Similar to future design reviews, the team found the semi-immersive system to be better suited for larger groups conducting clash and coordination reviews. (Castronovo et al., 2013, p. 26)

2.9 Challenges of VR adoption for decision-making in the construction sector

Based on the previous literature, the adoption of VR in the construction sector can play a vital role in improving decision-making. However, the adoption of VR faces several challenges and obstacles:

1.) Collaboration and continuity: One of the biggest hindrances to VR usage is that the tool requires a base 3D model with detailed engineering components. When all the project participants work in 3D, it works out to be beneficial. If the model's scope and level of detail are not established at an early stage, then the benefits diminish. In the case of certain large industrial projects, the concept, design and engineering elements are modeled in 3D. Beyond this stage, the biggest hurdle is the owner handing over the project to the operator. In order to limit costs, the owner subcontracts each stage to the firm that bids the lowest. Thus, data is seldom passed forward to the next stage (Sheppard, 2004).

2.) Convenience: Since VR is a specialized platform, it requires a specific set of machinery, for example, headsets, which are not very practical, or appealing to the market (Scan2CAD, 2017). Such setups are usually missing two important factors for mass adoption, which are convenience and control. Availability and access are conveniences that are tied to choices, cost and functionality. The hardware and corresponding technology should be easy to use and attainable at a reasonable price (Pettey, 2018). In addition, VR primarily allows the user to be represented by one role in the virtual environment. Because there is no multi-role situation in the interactive environment, it does not deliver an entire project-human interaction (Li et al., 2018).

3.) Specialized skill set: One of the big hurdles of immersive technology is its difficulty, which necessitates a specialized skill set. Special training to use the equipment is required before it can be used to extract important data. A large amount of time and labor must be invested, which is difficult to accommodate in the construction industry. In addition, the industry is known to be slow in adopting technology (Jones, 2018).

4.) Complexities: The lack of streamlined software is one of the primary challenges for this technology. Starting with a Revit model, it will then have to be converted into several file formats in order to be uploaded in the virtual software (Haggard, 2017).

5.) Cost: Some reports state that the use of advanced visualization tools is seen by construction companies as a consumption rather than an investment (Woksepp, 2007). The cost is usually borne by the design development and construction team, since it is a benefit to display to the client. Thus, a smaller firm may choose not to make this investment, especially if their scope of construction is small-scale projects.

6.) Opinion in the industry: It is highly beneficial to use such technology in the industry. However, the usual trend is that the younger workforce picks up the technology at a quick pace, while older workers find the updating process inefficient and unprofitable. The mentality of the older workforce is reflected in the industry, as many site superintendents would like to retain the methods they have used in the past because they do not want to depreciate the skill set they have acquired over the years (Haggard, 2017; MacDonald, 2004).

2.10 Conclusion

Visualization tools in the AEC industry can cover the entire life cycle of a building from concept through execution into the maintenance stage. 3D models can be created from conceptual 2D sketches using VR techniques. These models can be used to convey the project intent for assessments and reviews from all parties involved. Amid further design development stages, the 3D model can aid in coordination, management and constructability. At the construction level, the 3D model is used as a platform of interpretation between the designers and site personnel.

With its utilization benefits seeming profitable, the VR type suitable for a project would be the next issue to be addressed. Projects can vary in genre, scale, location and capital, as well as other factors. A case study by Woksepp (2007), analyzed previously in this paper, shows that both immersive and non-immersive technologies have their merits and demerits. Which is preferable largely depends on what the managers and personnel would like to derive from each. This paper will look into comparing immersive and non-immersive virtual reality for a small-scale project. By doing so, the pros and cons of the two types will be assessed. The outcomes are expected to provide a fair idea for future project groups to pick a framework that suits their needs.

CHAPTER 3. METHODOLOGY

3.1 Introduction

The purpose of this study is to understand and compare the participants' opinions about using VR as a decision-making tool. The social/collaborative VR system framework was used to create a case study scheme to compare participant opinions on each of two VR decision-making systems. The difference between their opinions of these two tools demonstrates the impact of one over the other. The study particularly focuses on the decisions made during the pre-construction stage of the construction process.

Key highlights in this process were to gather user opinion regarding two VR systems, with a usability evaluation for inter-system comparison and a detailed open-ended questionnaire. According to previous examples, a small pool of participants studied in a qualitative platform allows a researcher to delve into the details of their experience; thus, qualitative methodology was used for this study.

3.1.1 Research Questions

As previously stated, the research questions for this study are the following:

- How does virtual reality enhance the decision-making process in the construction industry?
- In decision-making for a client, is immersive VR better or non-immersive?

3.1.2 Overview of Methodology

To gather possible results for the above questions, a case study was conducted in which users were exposed to two types of VR, after which their opinions and feedback were collected.

To do this, a workable building model was created, deployed using 3D generating software along with a VR engine/plugin and developed into two distinct platforms: immersive and non-immersive VR. The details of creating the model are not addressed in depth here, as it is not the focus of study. The participant pool was selected from volunteers. Participants were placed into three groups and exposed to the VR model. Group 1 had non-immersive VR, Group 2 had immersive

VR, and Group 3 had both types of VR. Following the experience, participants were given a usability evaluation Qualtrics survey, then an open-ended interview-type questionnaire.

The ideas and methodology flowchart in Figure 3, below, is adopted from the framework for a social/collaborative VR system from Le et al. (2015) and Castronovo et al. (2013). Here, the case study was divided into steps based on the three questionnaires in focus: namely, a pre-test demographic, a post-test usability evaluation questionnaire and a post-test open-ended interview/questionnaire.

Participation was voluntary. Volunteers were recruited from the graduate students in a construction management-based education department. The graduate student body was informed of the research and the deadline for application through a mass email from the administration department as well as flyers affixed to the notice board, and the faculty were asked to inform their students during interaction sessions/classes.

The interested candidates were given the pre-test demographic through an email. Based on the answers given, the researcher chose nine participants to equally distribute into three groups. This was done to eliminate the factor of skew and to get a similar amount of experience, academic background and VR knowledge to be represented in each group.

After the experiment was conducted, participants' opinions were gathered and analyzed. The objective of the study was to observe user opinion toward VR and decision-making. The outcomes of the process involved an exhaustive comparison between Group 1 and Group 2 and, in turn, a comparison of the amalgamation of Group 1 and 2 with the results of Group 3.

This research attempts to cover the questions pertaining to the improvement that VR technology has provided in the decision-making process in construction. It also captures the user attitude towards its adoption. The data used to create the model include information from multidisciplinary fields, namely the architectural, structural and support engineering fields.

3.2 Methodology selected

The methodology is qualitative in nature, with a case study approach. The framework utilized is 'Social collaborative VR framework' derived from the study by Le et al. (2015). That study involved using the framework by creating a construction site model and showcasing it to students in a classroom environment. The students were then observed during the construction "game," their performance recorded and feedback noted. This case study follows a similar path with a few refinements made for the context and content variation.

3.2.1 Justification of research design

To formulate a framework, case studies from Le et al. (2015) and Castronovo et al. (2013) were taken into consideration. These two studies involved exposing a set of participants to VR interaction and gathering their opinions and feedback through a series of closed-ended/open-ended questionnaires.

Reference case study 1: Le et al. (2015) used a social/collaborative VR system, with the flowchart of events as shown in Figure 3.

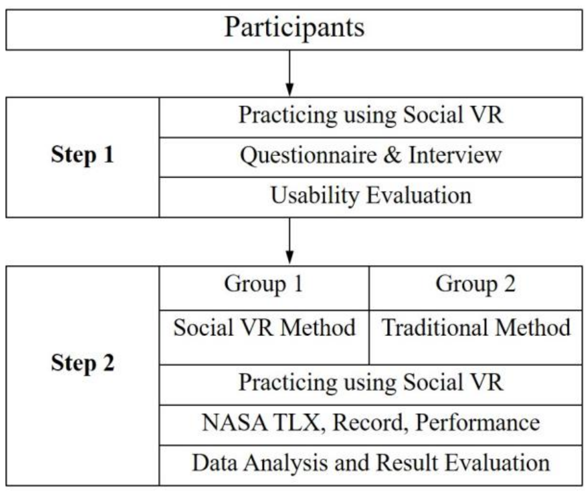


Figure 3: System evaluation process (Le et al., 2015).

The components taken from this framework are that each of the activities was divided into steps, and the participants were segregated into groups based on the system they were exposed to. Like the literature at hand, this research subjected the voluntary participants to a questionnaire: a pre-test demographic, considered as Step 1. Based on the responses given in Step 1, nine participants were chosen by the researcher and distributed into three groups. Step 2 involved exposing the participants of each group to the assigned VR system. A post-test questionnaire involving a Likert scale and a final open-ended interview-type questionnaire followed.

Reference case study 2: Castronovo et al. (2013) used a framework that involved their participants being exposed to two VR systems. Figure 4 represents their procedure using a flowchart. Two main components were taken from the study: first, the comparison of two VR systems, which is exactly what this research seeks to do, and second, the exposure of a participant group to two VR systems, which is relevant for Group 3 of this research.

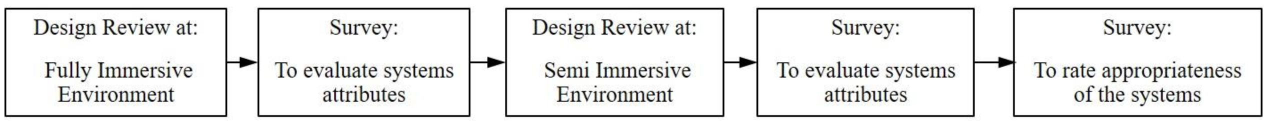


Figure 4: Design Review Procedure (Castronovo et al., 2013).

The results of this study offer a comparison of the two systems using a bar graph to display the average rating given by the users on a Likert scale. A limitation in the study states that the small sample size (n = 9) does not equate to a significant statistical inference — the numbers are only to compare the two systems in each subcategory. The graph in Figure 5 depicts the average user opinion.

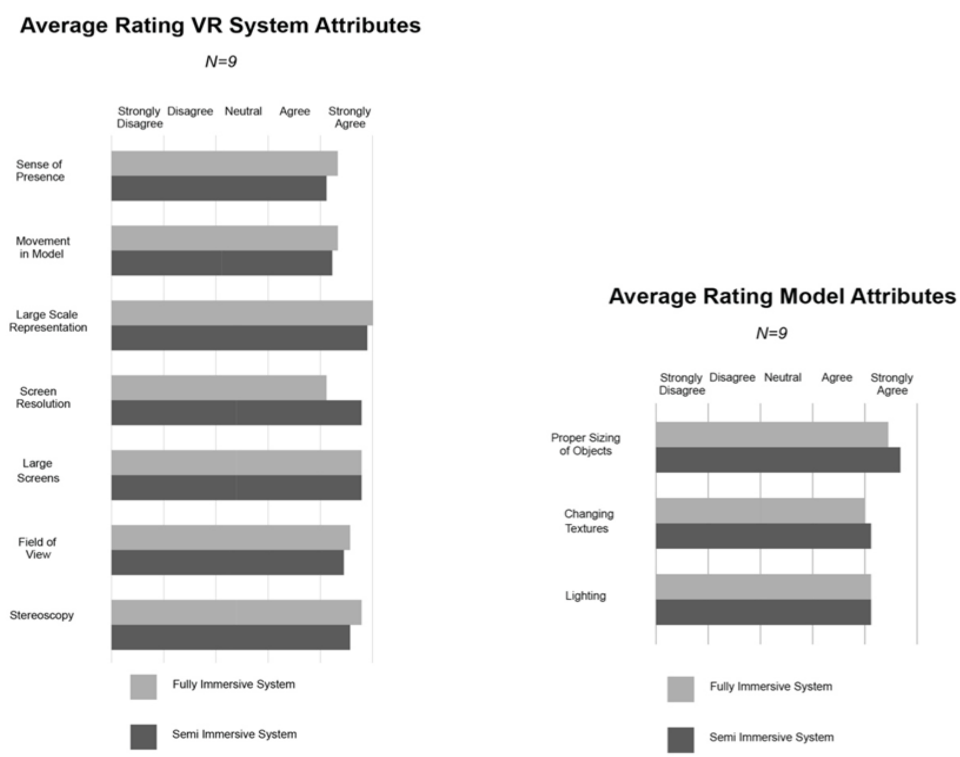


Figure 5: Rated helpfulness of the two systems' VR attributes, rated helpfulness of model attributes (Castronovo et al., 2013).

3.3 Researcher

3.3.1 Researcher's Background

I, the researcher, have conducted this case study in order to investigate the attitudes and opinions of the participants toward using virtual reality for construction decision-making. My interest in the complex and creative processes involved in built forms led me to pursue architecture as my undergraduate degree. After graduation, I worked in the industry for three years, my main role being a design manager. It was during this time that I was introduced to Building Information Modeling and its facets. I was involved in the modeling of aspects of the building such as architectural, structural, mechanical, electrical and plumbing. I quickly learned that technological advancement aided a project's development. Although a large portion of the workforce preferred conventional working methods, I was an advocate of modern technological systems.

Currently, as a graduate teaching assistant teaching graphics in construction, I instruct undergraduate students about construction-related software, its benefits and its uses. My interest in this field has led me to venture into virtual reality and its application in construction. During the summer of 2019, I received an opportunity to work with a general contractor that used VR, among other technological tools, to plan, develop and execute projects. While I was enthusiastic about VR in general, the factor that influenced me the most was its decision-making possibilities, leading me to pursue this case study.

3.3.2 Role of Researcher in data collection

The researcher's role was to coordinate with the volunteers and send over the questionnaire through email. Once the results were collected, the researcher computed the data on an Excel spreadsheet and narrowed the participant size. The next step was to coordinate with the participants.

The active role of the researcher was:

- creating Qualtrics, which documented the participants' responses and provided statistical graphs
- sending out emails with the questionnaire and answering participants' queries
- making observations during the VR display in the form of recordings and running notes

- asking the participants a series of open-ended interview-type questions which were recorded and transferred to a virtual format for analysis.

3.4 Participants

3.4.1 Selection of participants

The participants were graduate students enrolled in a construction management-related department. This pool was chosen in the hopes of finding participants who had already completed a formal undergraduate education and had a fair amount of knowledge in the field. With this set of participants, there was a possibility that they had worked in the industry before pursuing graduate studies, which would allow those with work experience to impart that knowledge into the study. This type of sampling technique is known as purposeful or selective sampling. It is usually done in qualitative studies, where the researcher selects participants who can provide in-depth information on the subject under investigation.

Nine participants were selected from a pool of volunteers (see Figure 6). The three A's (1A, 2A, 3A) were chosen based on their being enrolled in a PhD program or having greater than four years' work experience. The three B's (1B, 2B, 3B) were chosen based on their being enrolled in at least the second year of a master's program or having two to four years' work experience. The three C's (1C, 2C, 3C) were enrolled in at least the first year of a master's program or had up to two years' work experience.

3.4.2 Justification of participant number

The total number of participants used here is nine, following the approach of a similar study done by Castronovo et al. (2013) that involved conducting design reviews in two immersive display systems. The design of the study is qualitative case study approach, chosen because experiences are better represented by a qualitative study than by numbers (Gay et al., 2012). According to Yin (2003), one of the features of a qualitative study is representing the perspectives and views of participants. Another feature of qualitative research is presenting an insight into current or emerging concepts and observing human social behavior towards it (Yin, 2003).

3.5 Data collection

Taking a look at the flow diagram (Figure 6), there are three primary sources of data:

- Step 1: Pre-test demographic questionnaire
- Step 3: Post-test Likert scale questionnaire
- Step 4: Post-test open-ended interview-type questionnaire

Table 1: Steps involved and corresponding data collected

Steps	Description	Purpose	Data collected
1	Pre-test demographic questionnaire	To gather information on volunteers' academic background and previous experience; to hand-pick nine participants.	Answers gathered from a multiple-choice Qualtrics.
2	Testing/viewing the VR model	To exhibit the VR systems to the participants to get their opinions.	Observations and comments of participants (if any) documented using a recorder or running notes.
3	Post-test Likert scale questionnaire	To determine the systems' ease of use, visual output, model attributes and appropriateness for decision-making.	Opinions collected from a Likert scale–based Qualtrics.
4	Post-test open-ended interview-type questionnaire.	To gather in-depth details of participants' test experience and opinions.	Answers documented using a recorder and running notes.

The two questionnaires at Step 3 and 4 are the primary source of the data that were examined to arrive at a conclusion. The pre-test demographic (Step 1) was structured to give the researcher information about the volunteers in order to segregate them and pick ideal participants. Step 3 involved a post-test questionnaire in the form of a Likert scale, which was created on a Qualtrics and emailed to the participants soon after their exposure to the model. They were asked to respond to it during the lab session so that the researcher would be present to address any queries immediately. The answers from that questionnaire are regarded as the reaction of the participants towards the given statement on a scale of 1 to 5 (1-strongly disagree, 2-somewhat disagree, 3-neutral, 4-somewhat agree or 5-strongly agree).

The final source of data is an open-ended interview-type questionnaire involving a face-to-face conversation between the researcher and participant. Questions pertaining to the VR system were asked, touching base on each participant's experience; their opinion on the system's comfort level, clarity and utility; and their thoughts on using the system for decision-making. The conversation was recorded, with the participants' prior approval. Since this questionnaire was largely conversation-based, the researcher could ask more and different questions based on how the conversation unfolded. Apart from this, any queries and opinions other than the questionnaire were documented by running notes.

Since the participants were participating voluntarily, nonrespondents were not foreseen or encountered in this case study.

Table 2: Methods for data collection

Data collection method	Sample
1. Pre test demographic questionnaire	All volunteers involved before shortlisting participants
2. Observation/timeline documentation	9 participants involved/observations made by the researcher
3. Post test close end questionnaire	9 participants involved
4. Post test open end questionnaire	9 participants involved

Observation is a good approach for the collection of data here, as it allows a researcher to make a note of the important factors of the case study that don't involve the viewpoint of the participant. The researcher or observer should be able to clarify any areas of doubt using facts and avoid any personal opinions (Gay et al., 2012). There are two types of observing: the researcher can engage in the situation or observe silently (Gay et al., 2012). For new researchers, it is advised to observe passively in order to avoid any emotional connection to the situation, which might emerge in the observation (Gay et al., 2012).

There were no follow-up tasks the participants were required to do after the study. The participants were asked to share their contact details in case the researcher had any queries.

3.5.1 Variables

Before the case study, the demographic questionnaire formulated by the researcher was given to all volunteers with a closed-ended set of answers. The questions inquired about participants'

- current educational enrollment and previous education
- amount of practical experience in the industry
- previous exposure to VR technology
- personal opinion on adopting a new format
- opinion on VR and decision-making.

After experiencing the model, the participants were asked for their opinions towards a set of statements on a scale of 1 to 5 (from strongly disagree to strongly agree). These data were only used to compare user opinion between two VR tools and not for any statistical inference.

The main areas of post-experiment questioning were:

- Ease of using the tool (sensory)
- Sense of presence in the virtual model
- Visual output (sensory)
- Effectiveness of the model's/system's attributes
- Usefulness of the ability to administer design and the decision-making process

3.6 Procedures followed

Step 1: The first role of the researcher was to initiate the communication to the volunteer pool. Participation in this study was voluntary, and the target subject pool was graduate students in a construction management-based education department. The researcher created a poster with information about the study, which gave the subject pool a clear idea of the procedure, timelines, deadlines for application and name/contact details of the researcher. The administrative office was approached by the researcher and requested to send a broadcast email to the graduate student body with the poster attached. The same poster was affixed on notice boards and placed in common gathering areas. The graduate faculty were asked to inform their students of the study opportunity during classes/interaction sessions.

The interested candidates reached out to the researcher via email, text, phone call or in person. The candidates who did so before the deadline was accepted as volunteers and further requested to share their email addresses. The researcher sent an online pre-test questionnaire to the volunteers using a virtual Qualtrics, as shown in Figure 7. A deadline for completing the survey was indicated, and the responses received were assessed. This preliminary questionnaire determined participants' academic background, work experience in the industry, attitude towards decision-making in construction and previous VR knowledge.

Based on the answers given, the researcher chose nine participants out of the volunteer pool. These nine participants were distributed into three groups: Group 1, Group 2 and Group 3. The participants, designated as 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B and 3C, were selected meticulously in such a way that participants in each letter grouping (A, B or C) had a similar amount of work experience or similar educational background or gave a similar answer to most questions asked in the demographic questionnaire.

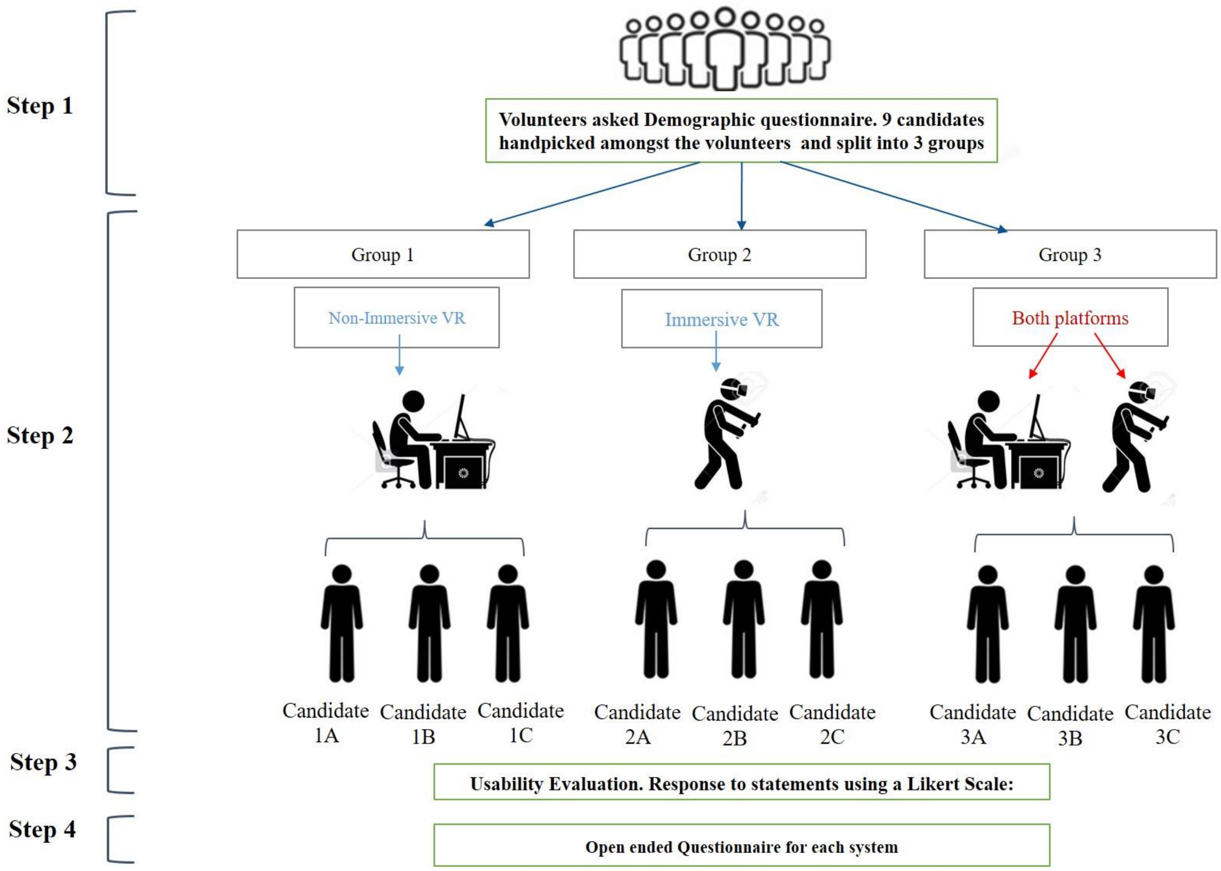
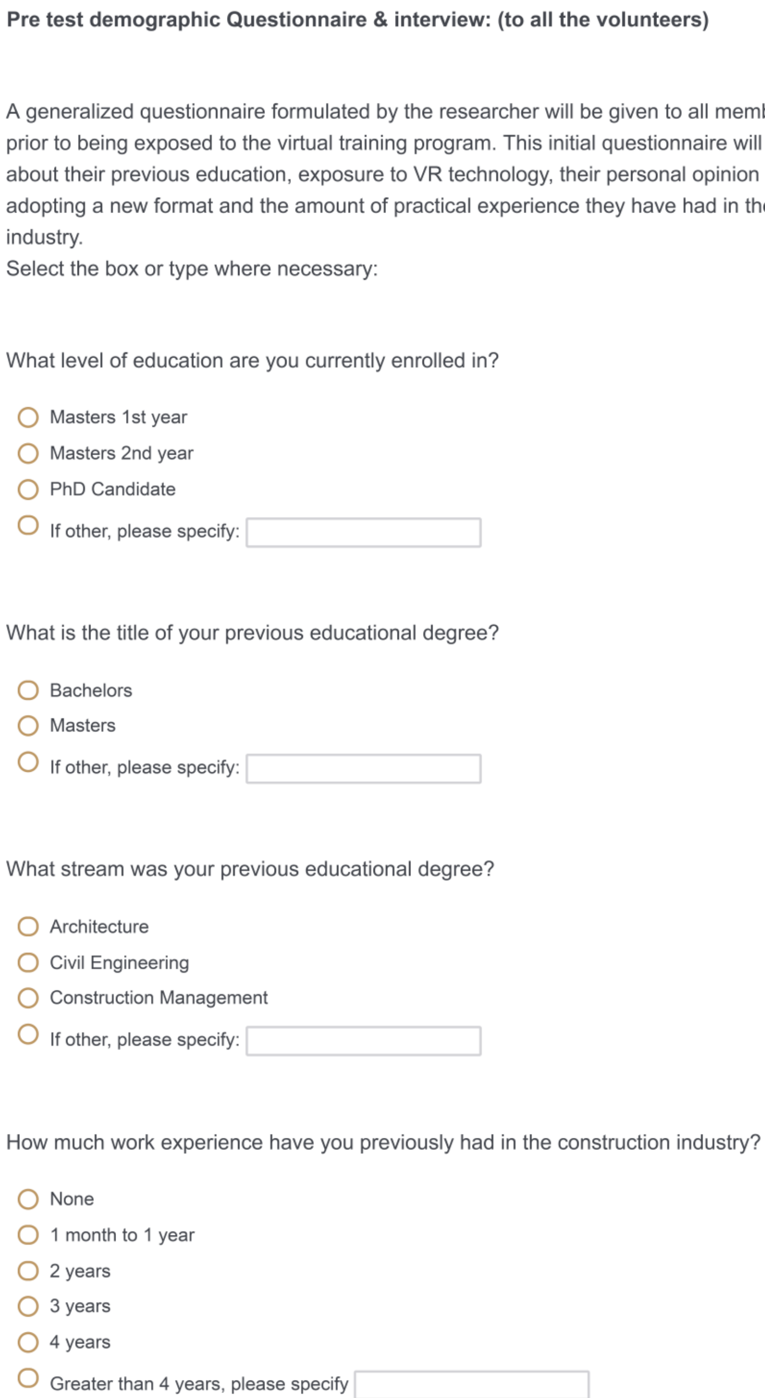


Figure 6: Methodology flowchart drawn by researcher

Step 2: Based on the researcher's allocation, Group 1 had three participants (1A, 1B and 1C), as did Group 2 (2A, 2B and 2C) and Group 3 (3A, 3B and 3C). The chosen candidates were informed of their shortlisting and asked for a convenient time and date to allocate two or three hours at the department computer lab. Meanwhile, a project was selected from the department archives and modeled up in a software called Revit, which is said to work seamlessly with quite a few VR applications (Corke, 2017). This software is widely used in the construction industry and often serves as a base point for collaboration. The model was then taken to a VR-producing platform and further developed to create an immersive and a non-immersive model.



Pre test demographic Questionnaire & interview: (to all the volunteers)

A generalized questionnaire formulated by the researcher will be given to all members, prior to being exposed to the virtual training program. This initial questionnaire will inquire about their previous education, exposure to VR technology, their personal opinion on adopting a new format and the amount of practical experience they have had in the industry.
Select the box or type where necessary:

What level of education are you currently enrolled in?

- ○ Masters 1st year
- ○ Masters 2nd year
- ○ PhD Candidate
- ○ If other, please specify: ________

What is the title of your previous educational degree?

- ○ Bachelors
- ○ Masters
- ○ If other, please specify: ________

What stream was your previous educational degree?

- ○ Architecture
- ○ Civil Engineering
- ○ Construction Management
- ○ If other, please specify: ________

How much work experience have you previously had in the construction industry?

- ○ None
- ○ 1 month to 1 year
- ○ 2 years
- ○ 3 years
- ○ 4 years
- ○ Greater than 4 years, please specify ________

Figure 7: Step 1, pre-test demographic questionnaire snippet, formulated by the researcher.

On the day of the experiment, participants were given a short set of instructions, based on the procedure they would follow. Next, each participant in a non-immersive group was given a PC to work on with a flash drive containing the model, and each participant in an immersive group was shown the model through a head-mounted apparatus. Once the model viewing was complete, the participants were given a post-test Qualtrics questionnaire, after which the interview-type questionnaire ensued. The details for each group are as given below:

Group 1: On the allocated day, they were each shown a building model on separate screens and asked to inspect, navigate and view it from all/preset angles and watch the walkthrough that the researcher had previously made.

Group 2: Candidates 2A, 2B and 2C each were asked for a convenient time and date to allocate two to three hours at the department computer lab. This group, however, did not have the display held simultaneously, due to the limited number of VR headgear available and the active attention of the researcher required on each individual. The candidates during their sessions were asked to wear VR headgear to view the model. The researcher guided the candidates and showed them the virtual model, directing them on where to move and how to use the apparatus and look at various aspects of the model.

Group 3: Participants 3A, 3B and 3C were asked to allocate two to three hours on two separate days to be exposed to both the systems. On the first day, they were each shown a building model on separate screens and asked to inspect, navigate and view it from all/preset angles and watch the walkthrough that the researcher had previously made. On the second day, they were assigned three separate times, due to the limited number of VR headgear available and the active attention of the researcher required on each individual. The candidates were given VR headgear to wear, and the researcher assisted them when necessary. The researcher did guide the candidates and show them the virtual model, directing them on where to move, how to use the apparatus and which elements to look at in the various aspects of the model.

The researcher guided the participants when asked for assistance and asked the participants of both platforms to follow a similar path around the model and focus on certain areas of interest to maintain some uniformity.

Step 3: After a model screening that lasted 30-45 minutes, each participant took the post-test Likert scale questionnaire (Figure 8) on their assigned computer. If any questions on clarification were directed towards the researcher, they were answered. Groups 1 and 2 took the Qualtrics post-test questionnaire only once, and Group 3 was given this test twice, once for each system. During this stage, the responses were fed into the computer assigned for that individual. A set of 16 statements was displayed to the participant, along with the options to strongly agree, somewhat agree, stay neutral, somewhat disagree or strongly disagree to each question.

Step 4: After the Qualtrics, the participant was asked to complete an interview-type questionnaire (Figure 9 and 10) to delve into the details of the system. This was a face-to-face interview, and the conversation was recorded by the researcher with the prior approval of the participant. The researcher was a part of the research setting and helped with the observation portion of the data collection.

All of the above-mentioned data were collected and processed to create comparisons using visuals. The average rating of the Likert scale was calculated to correlate the two systems. The open-ended answers at Step 4 were assessed by converting the audio to digital text, noting common words and opinions between participants, and considering each person's individual experience while making a conclusion. Field notes were taken during instances when the researcher observed interaction or reaction to the equipment and models. The researcher tried to maintain the data to be devoid of opinion and documented without bias.

Usability Evaluation. Response to statements using a Likert Scale:

Ease of use (sensory)

1. Interacting with the platform was a comfortable experience
2. It was it easy to navigate through the platform (Movement in model)
3. The user interface was easy to use

Visual output (sensory)

4. The information provided in the system was clear
5. The system reflected a realistic practical experience (Sense of presence)
6. The screens clarity was appropriate for my task

Model attributes

7. Was able to access the building with diagram/model/visuals provided
8. It was easy to comprehend material and textures
9. Objects in the model were properly sized
10. Was able to assess the magnitude of the building

Appropriateness for decision making

11. It helped me make decisions I was asked to make
12. I believe the system could improve the decision making process in a real construction project
13. The tools, graphics and visuals were useful for making decisions in building construction
14. This tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers to subcontractors)
15. This tool would be informative for a large project meeting group (10+ people)
16. This system could improve the decision making process in a real construction project

Each of the questions will be answered on a Likert Scale:

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
○	○	○	○	○

Figure 8: Step 3- Open-ended questionnaire for Group 1 & 2, formulated by the researcher

Open ended Questionnaire for Group 1 and Group 2

1. Did you experience nauseousness or disorientation at any point of this experiment?
2. Was the process of dealing with the equipment/navigation tools smooth, or did you find yourself struggling with trying to understand how to use something? If yes, why?
3. Is there anything you would like to change about this to make your experience better?
4. Was there anything unclear or ambiguous in the model? what was it?
5. Do you think this tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers), Why?
6. Do you think his tool would be informative for a large project meeting group or a small group, please explain
7. If you had the opportunity to work on VR would you choose this option and why?
8. Do you think this platform will aid in construction decision making and why?

Figure 9: Step 4- Open-ended questionnaire for Group 1 & 2, formulated by the researcher, adapted from (Castronovo et al., 2013) and (Le et al., 2015).

Questionnaire for Group 3: comparison of non immersive vs immersive:

1. Did you experience nauseousness or disorientation in either of the platforms. Please elaborate.
2. Which of the 2 systems do you think would be more informative to a variety of personnel involved in construction (From laborers to clients to designers)
3. Which of the two was more informative on materials and texture. In which ways
4. Which of the two had better clarity and lighting?
5. Which of the two better facilitated decision making?Why was it better
6. If you had the opportunity to work on a VR which platform, which would you prefer and why?

Figure 10: Step 4-Open-ended interview questionnaire for Group 3, formulated by the researcher, adapted from Castronovo et al. (2013) and Le et al. (2015).

3.7 Data analysis

The data documented are in the form of answers to a multiple-choice questionnaire, a Likert scale, open-ended feedback and study observations.

The data analysis method used here is narrative analysis, as this study involves analyzing content from a number of sources: interviews of participants, observations from the field and surveys. It focuses on the experiences and descriptions provided by people to answer the research question.

The stages and description of analysis of each step were as follows:

- Pre-test demographic: The data recovered from this stage are closed-ended answers provided via a Qualtrics. An Excel spreadsheet was created, and the answer data were inserted to create a visual representation for inter-volunteer comparison and to see areas of commonality. Each question was allocated a column, which was in turn broken down to smaller columns based on the number of answer options. Based on the answer provided, the researcher populated the columns with a ✓symbol. Using this as an analysis framework, the researcher located volunteers with similar answers and delegated them to the appropriate group.
- Post-test questionnaire on a Likert scale: The data produced from this questionnaire are the participants' response to 16 statements on a scale of 1–5 (1: strongly disagree, 2: somewhat disagree, 3: neutral, 4: somewhat agree or 5: strongly agree). After participants were exposed to the VR model, they were asked to log into the lab computer, and the questionnaire was emailed to them. The data were saved and stored in the Qualtrics, which the researcher could access for analysis. Groups 1 (exposed to non-immersive VR) and 2 (exposed to immersive VR) were given the questionnaire once, as they were exposed to one type of system each. In

this case, the average of Group 1's answer for each question was compared to that of Group 2; this is designated as Comparison 1 (Figure 12). In Group 3, the participants were given the Qualtrics twice, once after each system. The average rating of each question was taken and compared within the group but between both the systems. The comparison was made using a bar graph (see Figure 5 earlier in this chapter), similar to that used by Castronovo et al. (2013). Finally, for Comparison 3, the graph of Groups 1 and 2 was compared to that of Group 3 to see the comparison of the system rating.

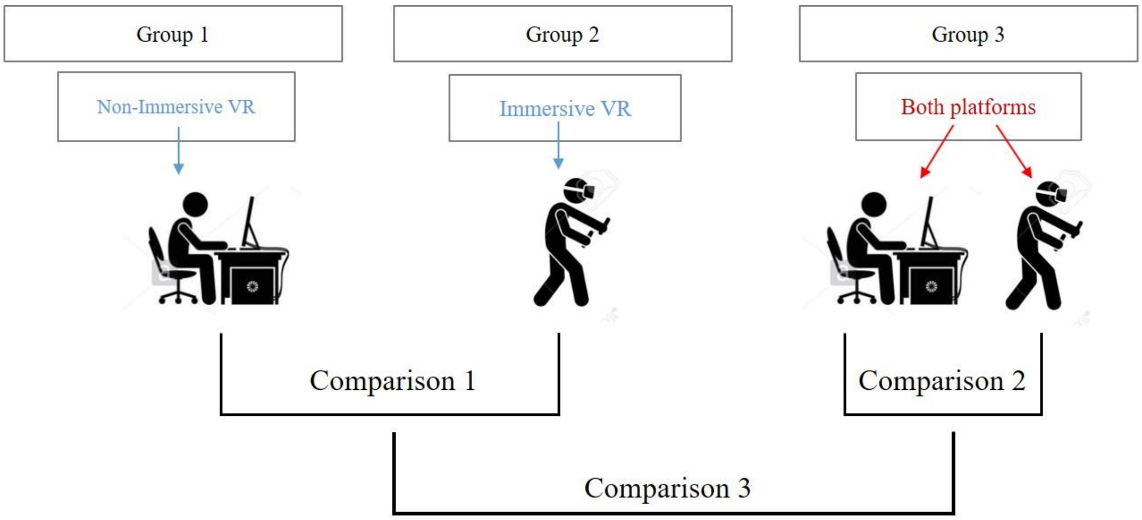


Figure 11: Intergroup comparison for data analysis

- Open-ended questionnaire: This interview-type questionnaire proceeded after the participant had finished filling out the online Likert scale questionnaire. The participant was approached individually by the researcher in the computer lab, and the recorder was placed on the table. In-depth questions were asked about their opinions, likes and dislikes, and their feelings about using the tool for decision-making. The researcher observed the subject's body language and made running notes on this. The recorded data were processed after the interview and converted to digital data. A software tool called NVivo was chosen to analyze the data. This kept the data organized and aided in computing the inferences. The acquired data were put into a Word document and an Excel spreadsheet to analyze holistically before separating into subtopics. Reoccurring and key words were noted and counted in the Excel spreadsheet.

The analysis was twofold, comparing Group 1 to Group 2 and collectively comparing those two to Group 3. The analysis was directed towards the elements that the research seeks to extract from this case study: the user experience/feeling toward the platform, the comparison of the two systems, and the user attitude and general opinion towards using these systems for decision-making. The rated responses were analyzed and compared between participants, leading to a conclusion.

The framework developed by the researcher would be considered sufficient based on the scope of this research study. The questions attempted to capture the responses based on the experience of the participants with respect to using VR and making decisions.

3.8 Trustworthiness

Connelly (2016), as cited in Cory (2019) mentions that the four factors that convey the trustworthiness of research are credibility, transferability, dependability and confirmability.

This study fulfills these requirements as follows:

- Credibility: All the participants were asked the same questions, from the pre-test demographic to the interview-type questionnaire. The only case where the questions were altered was to accommodate Group 3's experience with two different systems. Within that group, the participants were asked the same questions.
- Transferability: The sampling type used was selective sampling, as a specific subgroup was desired due to their understanding of the context of construction and the use of VR in it. Among the volunteers, nine participants were chosen by the researcher to make sure that volunteers with similar amounts of experience and educational background were represented in each group. This was done to limit skew and bias and to have a representative of a particular background in each group.
- Dependability: The information collected during the study is expressed as it is stated in the questionnaire, without altering its meaning. The open-ended answers have been directly translated to a virtual format and in no way refined or modified. All the data collected in this case study will be displayed for examination and investigation.
- Confirmability: Attention has been given to describing the methodology process systematically and distinctly along with flowcharts so that it is easy to read and duplicate. This research can be replicated by another researcher.

Yin (2015), as cited in Cory (2019), highlights these qualities to be associated with having a trustworthy study:

- Transparency: All questionnaires and data collected are listed in the appendix and available for examination for a reader.
- Methodicalness: Data are arranged in a systematic manner, allowing room for unforeseen situations and new findings.
- Adherence to evidence: The evidence here is the data and feedback input directly by the participant and the recordings made by the researcher. This evidence was collected and consistently studied to reach a conclusion.

3.9 Researcher Credibility

My responsibilities as a graduate student, with 3+ years of industry experience, include pursuing education sincerely, acknowledging and respecting peers/educators and working cohesively in a group environment. As a teaching assistant, my duties include instructing, mentoring and guiding students. With these multiple roles, I have gathered knowledge about professional conduct and graciously behaving in an academic environment. Now, as a researcher, guided by my chair and committee members, I have acquired a good understanding of how to manage case studies and interact with volunteers and participants, keeping in mind ethical conduct in tasks ranging from experimentation to analysis of data. I hope to bring these values to this study to generate a valuable outcome to the construction field.

3.10 Ethical concerns

Orb et al. (2001) was used to identify the key principles and framework for research ethics:

- Participant rights have been taken into consideration, recognizing their right to be informed about the study, right to decide if they would like to be involved and the right to withdraw from the study at any point without consequences.
- Importance is given to the participant’s point of view through observations, feedback and interviews. The researcher will listen to the participant’s concerns and opinions.
- Anonymity and confidentiality of the participant’s identity are maintained.
- Caution and care will be taken by the researcher to see that no harm comes to the participants.

According to the Economic and Social Research Council (ESRC), as cited in Cory (2019), the following principles should be addressed for ethical concerns:

- The data collected from the participants were accessed honestly without insinuating any personal bias into the analysis.
- Maintaining the independent and impartial nature of the study is taken as an important part of this research.

3.11 Conclusion

The findings in the case study and their implications answer the research questions. By computing the results, we determine the effectiveness of virtual reality for the current participants. The small sample size does, however, have to be kept in mind, as these results cannot be used as a generalized statistical inference. To get a better idea of the type of VR required for specific needs in the AEC industry, two platforms are compared, immersive and non-immersive systems. The results would let future project groups pick a tool that suits their needs. Future advances will include exploring different VR genres and participation groups in making decisions.

CHAPTER 4. ANALYSIS AND RESULTS

The purpose of this study was to analyze users' opinions towards using virtual reality for construction decision-making and see which of two platforms they preferred.

To revisit the research question:

- How does virtual reality enhance the decision-making process in the construction industry?
- In decision-making for a client, is immersive VR better or non-immersive?

In order to understand users' opinions, data were collected using a Likert scale questionnaire, an open-ended interview and running field notes. This chapter deals with organizing the information collected and assessing it.

The data collected in the Likert scale questionnaire was arranged in a spreadsheet. Columns were named using pseudonyms for the participants.

• **1A:** 1st-year master's student • **1B:** 2nd-year master's student • **1C:** PhD student	Exposed to non-immersive tool
• **2A:** 1st-year master's student • **2B:** 2nd-year master's student • **2C:** PhD student	Exposed to immersive tool
• **3A:** 1st-year master's student • **3B:** 2nd-year master's student • **3C:** PhD student	Exposed to both tools

4.1 Likert Scale questionnaire

Table 3: Participants' responses on a scale of 1 to 5 (1-Strongly disagree, 2-Somewhat disagree, 3-Neutral, 4-Somewhat agree and 5-Strongly agree.)

Likert Scale questionnaire	Single System						Dual System					
	Non-immersive			Immersive			Both					
	(1A)	(1B)	(1C)	(2A)	(2B)	(2C)	(3A)		(3B)		(3C)	
							Non-immersive	Immersive	Non-immersive	Immersive	Non-immersive	Immersive
Q1 Ease of use (sensory)												
Interacting with the platform was a comfortable experience	5	4	5	4	4	4	5	4	4	5	3	4
It was it easy to navigate through the platform (Movement in model)	4	2	4	4	5	4	4	4	2	5	2	5
The user interface was easy to use	4	5	5	5	4	5	5	5	2	4	2	4
Q2 Visual output (sensory)												
The information provided in the system was clear	4	3	5	5	4	5	5	5	4	5	4	5
The system reflected a realistic practical experience (Sense of presence)	5	4	5	5	5	5	5	5	2	5	1	5
The screens clarity was appropriate for my task	5	5	5	2	5	5	4	5	4	4	4	4
Q3 Model attributes												
Was able to access the building with diagram/model/visuals provided	4	3	5	5	5	4	5	5	4	4	2	4
It was easy to comprehend material and textures	5	4	5	4	4	4	4	4	2	5	4	5
Objects in the model were properly sized	4	5	4	5	5	5	5	5	4	5	4	5
Was able to assess the magnitude of the building	4	5	4	5	3	4	5	5	2	4	2	5
Q4 Appropriateness for decision making												
It helped me make decisions I was asked to make	4	5	4	5	5	5	4	5	2	5	5	5
I believe the system could improve the decision-making process in a real construction project	5	5	5	5	4	4	5	5	4	4	4	5
The tools, graphics and visuals were useful for making decisions in building construction	4	5	5	5	5	4	5	5	4	4	4	5
This tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers to subcontractors)	4	5	4	5	5	5	4	4	4	2	4	4
This tool would be informative for a large project meeting group (10+ people)	3	5	5	5	5	5	4	4	5	1	4	4

Participants' ratings, comments, behavior and expressions will be examined in the segments below. This information will be sourced from the notes made by the researcher during the experiment.

4.1.1 **Q1 Ease of use (sensory)**

4.1.1.1 Statement: Interacting with the platform was a comfortable experience.

Non-Immersive:

The single-system participants gave the tool a score between 4 (Somewhat agree) and 5 (Strongly agree). The dual-system participants ranked the tool between 3 (Neutral) and 5 (Strongly agree). All participants rated the tools 4 and above, except 3C who scored it a 3. During the experiment, 3C stated, “The VR goggles in the immersive system are easier to use than walking through the model (using the keyboard and mouse) as this needs practice to navigate.” This participant had not regularly interacted with a gaming platform or one that involved navigating with a keyboard/mouse and stated that they had only seen their children playing video games. The individual described the system as being “hard” and “complex” and often held the arrow keys down longer than required, resulting in speeding into a wall and unknowingly entering another room.

The immersive tool had only one method of navigating, a pointer, which allowed the participant to point and click on a location to be transported here. To look around, they had to turn their heads and bodies. Such movements are closely related to a natural human-environment interaction. The non-immersive platform involves maneuvering a keyboard/mouse, which would require practice in order to smoothly use it. To those lacking familiarity with keyboard/mouse navigation, the non-immersive tool could be challenging.

Immersive:

Single- and dual-system participants gave the tool a score between 4 (Somewhat agree) and 5 (Strongly agree).

Single and dual system:

Participants of the single system provided ratings of 4 and 5 for non-immersive, and all chose 4 for immersive. The non-immersive received a larger average rating in the single system, while in the dual system, immersive received a larger rating. The levels dropped for non-immersive in the dual system primarily due to participant 3C’s response of 3.

Overview:

When correlating opinions of non-immersive vs immersive in the single system to those in the dual system, there are mixed responses, and no one system stands out as a clear preference.

When a tool delivers a comfortable user experience, it enhances the decision-making process. With this advantage, less attention would be directed towards accustoming to a tool, leading to more attention towards identifying errors or refining the building.

In decision-making for a client, no tool stands out with a rating higher than the other between single and dual system.

4.1.1.2 Statement: It was easy to navigate through the platform (Movement in model).

Non-Immersive:

The single- and dual-system participants gave the tool a score ranging between 2 (Somewhat disagree) and 4 (Somewhat agree). During the experiment, participant 3A, who used both the systems, favored non-immersive over immersive in this aspect, stating, "Navigating is easier in non-immersive than fully immersive—moving throughout the building is a lot easier!" This participant mentioned their familiarity with video games and spoke of interacting closely with a roommate who is an avid gamer, often engaging in it socially in recent times. It would seem that this exposure and practice could have something to do with their ease in using the non-immersive system (with the keyboard and mouse) for navigation. Another factor that could have influenced the participant to choose non-immersive over immersive could be the individual's difficulty in walking past doors in the immersive system. They found themselves getting stuck within the door model, preventing them from choosing a clear floor space to teleport into, hence remaining stationary. In contrast, in the non-immersive platform, they could easily pass through the door by holding down the forward arrow key and walking through. This door experience could have influenced the participant to rate immersive as being low.

However, participant 1B, who gave a non-immersive a lower rating of 2, was noted saying "I don't know how to go to a specific location" and often made swift movements, passing through walls and exiting the building accidentally. This happening several times made the participant voice their concerns, saying, "If I received the model via email and the researcher wasn't here with me to help navigate, I'd get lost." Participant 3C, who also gave a rating of 2, stated "It's complicated to get where you want." They mentioned that they had not worked with the non-immersive platform before. If this were a new navigation tool at a job, using it for the first time would have been a cumbersome process.

Immersive:

Single- and dual-system participants gave the tool a score between 4 (Somewhat agree) and 5 (Strongly agree). The system did prove to have a few shortcomings in navigation, some of which involved participant 2C stating "The navigation is frozen," which prevented them from moving momentarily. The issue did pass in a minute or so, either by the researcher taking control or the system de-freezing. The participant was not fazed by this process, however, and rated the system a 4 (Somewhat agree). This could have to do with the fact that they, having worked on construction-related software, which can often freeze, are lenient due to being used to these minor technical hindrances and thus did not let this affect their overall impression of the tool.

Single and dual system:

The average scores show that immersive exceeded non-immersive in this area. This occurred due to participants pointing out their difficulties in using the keyboard and mouse to navigate. Difficulties in getting a certain angle of view proved a demerit in the eyes of the viewers, leading them to assign a lower score.

Overview:

Looking at the overall survey, some participants gave immersive and non-immersive an equal score, and some felt that the former surpassed the latter with regard to mobility in the model. The bar graph in figure 12 shows the comparison, with immersive being the forerunner for this statement, both in single and dual systems. In order for users to engage in efficient decision-making, the tool involved should be able to offer efficient navigation, allowing the user to focus on locating error-prone areas and not on maneuvering the software. In decision-making for a client, based on the ratings and comments of the participants, immersive stood as the forerunner with its versatile hand controller. This makes it easy to adopt even for those who do not have familiarity with video-game-based navigation.

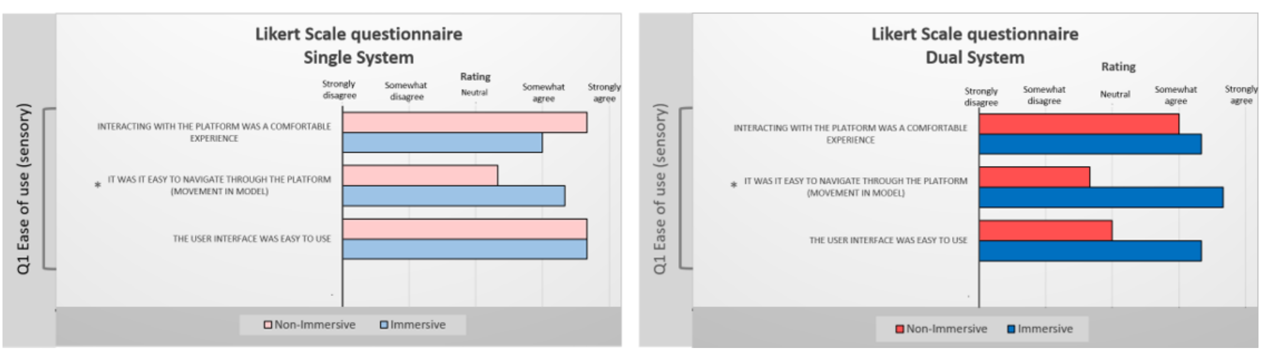


Figure 12: Graphical representation of Q1 responses of single-system participants vs. dual-system.

4.1.1.3 Statement: The user interface was easy to use.

Non-immersive:

The participants gave scores ranging from 2 to 5. Participants 3B and 3C gave the lower rating of 2, 3B stating "It is much more interesting in the Immersive experience." Participant 2B mentioned a need for the application to, before starting, show a short set of instructions on how to use the tools and access the tool tab.

Immersive:

The participants rated it between 4 and 5. During the experiment, the immersive system did hesitate to respond to certain participant input, like "undo" and swiping to new options. However, the immersive did score better overall, perhaps because the menu option hovers over the pointer at all times and was visually accessible. In contrast, in the non-immersive, the options appeared only if the participant explored the screen and found a tiny arrow on the top left corner. This could have something to do with the individuals preferring the immersive interface, even though it proved to be unresponsive at times.

Single and dual system:

The participants in the single system gave a score of either 4 or 5. This could have been because they were looking at the tool in isolation and compared it to none. The participants in the dual system were more critical with their tools as they compared the two types. Non-immersive received a low score of 2 by 3B and 3C, dropping the overall average and giving immersive the greater score.

Overview:

Overall, in the single system, both tools were rated equally, but the dual system favored immersive. The user interface refers to the toolset the VR system offered, which allows the user to change materials, insert objects and change the season, among other options. Giving the user the opportunity to try variations and options in the model enhances the decision-making process, as they have a sense of control in the model. In decision-making for a client, keeping in mind the reviews and ratings the dual-system participants provided, immersive seems to be the notable option. The reason the dual system's verdict is highlighted is because the participants who worked with both the tools selected immersive as their preference.

4.1.2 **Q2 Visual Output (sensory)**

4.1.2.1 <u>Statement: The information provided in the system was clear.</u>

Non-immersive:

Participants' ratings were from 3 to 5 in the single system and 4 to 5 in the dual. Participant 1A mentioned being "not sure what the size of the auditorium is," and 1B said that "not all equipment is showing the accurate representation of material."

Immersive:

The rating range was from 4 to 5. Participant 2A said the walls looked slanted and the heights were not clear. They also made statements such as "Do I get to see which direction I'm facing?" and "I don't know exactly what this material is," and when they clicked on a concrete slab, they stated, "It says 'bare concrete' when I click on this, but when I click on ceilings, it doesn't give me a specific type name." This participant's point suggests a need for the system to better inform individuals on details such as material type and cardinal directions. But with immersive allowing the participant to appear present in the model, they had a clearer idea of objects and elements with regard to their eye level, which could be the reason this system offered better clarity than viewing it through a computer screen.

Single and dual system:

Participants in the single-system non-immersive gave scores between 3 and 5, and single-system immersive gave scores between 4 and 5. The dual-system non-immersive received scores between 4 and 5, and immersive received a unanimous 5. In both cases, immersive surpassed non-immersive in the rating score. This could largely have to do with the immersive interface being straightforward while the non-immersive interface contained features that were hidden to the eye.

Overview:

In both systems, participants brought to the researcher's attention the need for a few features:

- A key or plan to show them where they were.
- A tag to show which room they were entering.
- A measuring tool to check levels and heights.
- A properties tab or identification for equipment and materials once selected.

Consequently, immersive was ranked higher in single and dual systems, possibly due to the clarity observed in identifying material and also through observation in a more human environment and natural manner.

When information is modeled in the building, it allows users to make tangible choices based on the available resources. Hence, it is an important factor that enhances the process of decision-making. In this area, immersive seems like the forerunner and is the participants' choice of tool with regard to clarity in the information modeled.

4.1.2.2 Statement: The system reflected a realistic practical experience (Sense of presence).

Non-immersive:

The single-system participants rated it between 4 and 5, whereas the dual-system rating ranged from 1 to 5. This can be explained by comments like "There should be a button to turn your head," which 1A said when they were having difficulty getting a good view of the ceiling. Participant 1B said, "How do I check out the upper view? Can I look up? I'd like to add the option to get a full view from my position." This hinderance could be taking away from the sense of presence. Also, looking through a PC screen could inhibit the feeling of actually being "there."

Immersive:

In this category, immersive received a unanimous 5 score. Participant 3A made comments such as "Whoa! This is so good!" shortly after putting on the head-mounted goggles, and later, they compared the immersive experience to the movie *Inception* (in which people were transported to a dreamlike world that seemed real). After the experiment was over and they took off the headgear, they exclaimed, "I was in some other world—it felt so good."

Single and dual system:

The participants of the single system gave scores between 4 and 5, with non-immersive receiving scores between 4 and 5 and immersive achieving a perfect 5. In the dual system, the participants were critical when comparing the two tools, and in comparison, non-immersive received 1, 2 and 5, while immersive received an impeccable 5. With immersive receiving a full score in both situations, it would be safe to say that the participants preferred it to viewing a model through a screen.

Overview:

Overall, the immersive scored the maximum rating in both single and dual systems. This could be due to the fact that immersive by definition offers a more comprehensive sense of presence.

4.1.2.3 <u>Statement: The screen's clarity was appropriate for my task.</u>

Non-immersive:

Participants scored this statement between 4 and 5. The Dell 49-inch screen utilized for this experiment provided a high-quality picture. The laboratory (in which the experiment was performed) had focused lighting, which did cause a glare on the screen, which a participant pointed out. This, however, did not originate from the tool and can be disregarded as a demerit.

Immersive:

Participants scored this statement between 2 and 5. Candidate 2A gave a score of 2 after saying, "The model is blurry in the distance." They had difficulty in identifying objects that were far away, such as a connection detail between a column and slab on a level above the one they were standing at. The participant did mention that they didn't know if it was their poor eyesight or the system itself. This concern wasn't brought up by other participants, so this opinion could be specific to the individual's condition.

Single and dual system:

The single-system reports show immersive having a higher rating. This could be due to the participants' contentment with the Dell 49-inch computer screen. Having looked at this screen in isolation, they could have believed it to be a good experience.

The dual-system participants gave immersive a better score. This could be linked to their comments saying that materials and lighting appeared better through the VR headset. The brightness level of the computer screen was set at a standard value, and the room's glare could have made the non-immersive option slightly less appealing when compared to the immersive one.

Overview:

Overall, a unanimous response was not recorded, as the single and dual system, on an average, preferred different tools. Hence, a generalized assumption cannot be made for the participants. Having a comfortable visual experience would aid in the decision-making process. In order to be an acceptable tool, the favorable tool would cater to a variety of individuals, echoing the demographic in the construction industry. Comparing the two, we see that they both scored an average of 4 and above. There would be no clear tool that is ideal for this statement, based on comparing single and dual systems. If the input of the dual system were taken into consideration, immersive would be the tool of choice.

4.1.3 **Q3 Model attributes**

4.1.3.1 <u>Statement: Was able to access the building with diagram/model/visuals provided.</u>

Non-immersive:

The single-system participants gave scores from 3 to 5 and dual-system participants from 2 to 5. Participant 1B mentioned that they weren't able to access the complete building, and a key or a plan of the building on the side of the screen would help give an overall idea. 1A said, "Instead of having an entire model to navigate through, we could have had floorwise navigation. Or if we could cut the model and visualize the overall first floor, would be helpful. Otherwise, it's like we are entering the second floor by going through the slab." From this feedback, it would appear that the participants had trouble getting a holistic idea of the building, and the navigation issues added to this obstruction. This could be a drawback in using this tool with stakeholders/end users who haven't been in constant touch with the design and planning process. As they might not have attained a clear picture, their opinions and feedback might not be best suited for vital decision-making.

Immersive:

The participants gave scores of 4 to 5. Participant 2C said, "The good thing about VR is that it's understandable by everyone. So it's not like you need to know everything." They did, however, also mention that they'd like a plan of the building showing where they were at that instant.

Looking at what participants had to say about both systems, it seems that they would need a key or plan to give a synopsis or broader idea of the whole building. But looking at it on a room-to-room basis, both the systems do have benefits over conventional 2D drawings and blueprints.

Participant 3C made an interesting point: "Non-immersive, you see, is not so realistic, but it allows you to click and get a lot of information. So, this is helpful. I think both the systems are complementary."

Single and dual system:

In both systems, immersive received scores of 5, 5 and 4, higher than non-immersive. The immersive participants in both systems were noted saying that they felt like they had walked through the building. This could have given them a better idea of the overall model.

Overview:

Looking at the overall rating, immersive does fare better than non-immersive, which could largely be linked to its convenient navigation, which reduces the feeling of being lost, and its better representation of visual data. With its ability to provide graspable data to a viewer, it could enhance the decision-making process, as the individual would have a cognizant idea of the building.

In decision-making for a client, a tool with these traits will be helpful, as the aim would be to give stakeholders and clients a clear understanding of the entire building in order to make pragmatic decisions. Immersive would be the tool of choice.

4.1.3.2 Statement: It was easy to comprehend material and textures.

Non-immersive:

Ratings were given from 2 to 5. A low rating of 2 was given by participant 3B, who, when questioned about materials and textures, said, "Immersive is better for it because you can visualize it by entering a room physically and viewing it through any perspective you want. So, I think that will aid in making better decisions rather than non-immersive." They gave an opinion based on comparing both the systems. This participant had previously used PC software called Navisworks, which could be used to walk through a building. There is a possibility that they see the non-immersive tools as similar to this software and the immersive tools as a refreshing and new venture.

Immersive:

Ratings ranged from 4 to 5. 2C called the interiors "nice," and 3C said, "Immersive does not allow you to click on the material and get its information, but it's easier to see how the material really looks like."

Single and dual system:

The single and dual system have contradicting results of comparison. The non-immersive tool provides certain abilities, like scaling of material, that create an adjustable and practical approach, whereas the immersive offers a multi-angle perspective of the space. It could be due to these reasons that there isn't a clear forerunner.

Overview:

Material and texture are important parts of a building, and being able to identify them correctly enhances, or even creates, accuracy in the decision-making process. With a tool that provides lifelike ambience, the viewer would be able to judge a virtual building as they would a real one.

In the responses and ratings provided here, in isolation (the single system), both tools achieved a 4 and above rating. The conversations made it evident that the participants were comparing the systems to their conventional counterparts, namely 2D drawings and still renderings. So in order to get a factual comparison of the two tools, the dual system can be utilized here. Immersive does seem to be the choice of tool for those who compared it to non-immersive. This could lean the overall verdict towards immersive.

4.1.3.3 <u>Statement: Objects in the model were properly sized.</u>

Non-immersive:

Scores of 4 or 5 were given by participants, who seemed to relate this to video games with the same controls involved. This comparison could be because, although users were overall satisfied with the output of the tool, the controls did not allow for free head movement or adjustment of the eye level. This could have reduced the respondents' enthusiasm for the tool.

Immersive:

Participant 2A commented on the appearance of objects: "The wall looks like it's slanting. There's something wrong. It doesn't look perpendicular." However, they did rate it a level 5. The flooring pattern was noticeably crooked, which could have created the illusion that the walls were tilting. Overall, this didn't seem to be a factor of concern, as the participant found other objects to be proportional and rated the system a 5. When changing materials in the model, participant 2A noticed that immersive does not have an option to scale the material—for example, to modify the size of granite floor tiles. This is a necessary feature, as it reflects how material is actually available in the market. Non-immersive, however, does have this feature.

Single and dual system:

Both the single and dual system received 4 and above regarding this statement. On average, however, immersive surpassed non-immersive. The reason for this could be that in immersive, the size of objects is adjusted in relation to the person immersed, while in non-immersive, objects are not in scale with the user's body.

Overview:

Overall, no participant explicitly called out any object as being sized incorrectly. Immersive did receive a higher rating, which again could be due to the multi-dimensional perspective it offers and its similarity to a real human-object interaction. Having well-scaled objects and proportionate surroundings allows the participant to gauge the dimensions as they would in a real-life situation. Given that viewers found few to no errors in the scale of materials, this tool could enhance decision-making, as it allows users to identify incorrectly sized objects. The aim would be to minimize the inaccuracy of a tool so that if a user does find a mistake in the size of an object, the problem lies with the actual object rather than the graphics.

In decision-making for a client, in the area of object proportion and scale, immersive received a unanimously better ranking. However, it is worth noting that non-immersive did offer a feature regarding this that immersive lacked.

4.1.3.4 Statement: Was able to assess the magnitude of the building.

Non-immersive:

Participant 3C rated the system a meager 2, with the comment, "It's hard to get an overview of the building." This could have to do with the fact that the movement is restricted to forward, sideways, and back, whereas in the immersive system, the user can jump/teleport from place to place to get a good vantage point from which to gauge the building.

Immersive:

Participant 2B said, "Maybe if I start from a bird's-eye view, I'd have a better idea of the spaces. I'd know the shape and form of the structure." They felt that walking through the building wasn't sufficient for understanding its magnitude. Thus, they assigned a rating of 3. This could be related to the participant's background in architecture and experience working on 3D models and sketches, which allows control of the model and the viewing angle. The immersive tool, does not give the flexibility to twist the entire model to get a desired view. The lack of control of the model could be the reason behind their response.

Single and dual system:

Non-immersive scored higher in the single system, while immersive received a higher rating in the dual system. Ratings in the single system did not go below 4. In the dual system, non-immersive received two scores of 2, which could be because of the restrictions of movement in the tool. Those using the forward and back arrows on the keyboard may have felt they were not able to identify the full scale of the building on a human-interaction level.

Overview:

Overall, there is no clear frontrunner for a preferred system for this criterion. Both had flaws, as highlighted by participants 2B and 3C. A possible indicator of preference is that the dual-system participants rated immersive higher, as they felt aware of the building's entirety.

During the decision-making process, having a clear idea of the building in its entirety could help individuals provide holistic input, not just input based on the room or area they navigated through.

For decision-making for a client, neither of the tools clearly stands out. However, dual-system participants did rate non-immersive lower. This could be interesting to consider, as they have seen both the systems and found this one lacking in giving them an idea of the entire building.

4.1.4 **Q4 Appropriateness for decision-making**

4.1.4.1 <u>Statement: It helped me make decisions I was asked to make.</u>

Non-immersive:

This was rated from 2 to 5, with participant 1C saying, "It's more informative than 2D drawings. It provides a 3D form of the object you are going to build or construct. It helps in decision-making and understanding the outcome of our project." This participant said that they had three or four years of experience but hadn't worked on 3D tools. They selected "not sure" when asked the pre-experiment question "Do you believe that using VR would help making decisions in the preconstruction/construction process?" After exploring the tool, they seemed positive about its impact in the industry. They compared it to conventional planning and decision-making methods and believed it was more helpful than those they had previously worked with. This does not confirm whether the non-immersive tool is the ideal one, but this participant did prefer it in comparison to 2D. Participant 3B chose a score of 2, perhaps because they expected more content/objects and asked if we could download more from the internet. This participant was exposed to both systems and was, overall, inclining towards immersive.

Immersive:

The score here was unanimously 5. The participants seemed influenced by the effectiveness of the tool. Comments included 2A's statement "We were able to find so many errors, which would help in decision-making." Participant 3C said, "For getting a better idea of space and clashes and everything, I think the immersive one was better for me, because it was easy to navigate. I had problems with the other one, but immersive allows me to see details and ceiling connections. So, I think it's like walking a real building." This feedback could have to do with the realistic feeling of the immersive tool, which could have given them a sensation of looking around the completed building and made them feel able to critique and make clear decisions.

Single and dual system:

The average ranking of immersive was higher in both the systems.

Overview:

Both systems allowed the participants to notice and call out errors in the building with regard to safety, aesthetics, and details, among other aspects. Collectively, in both the single and dual system, immersive seems to have gathered a higher rating.

Most of the participants gave ratings of 4 and above. They believed that the tools helped them make decisions such as changing material, analyzing layouts, and locating safety hazards. In decision-making for a client, the participants ranked immersive above non-immersive.

4.1.4.2 Statement: I believe the system could improve the decision-making process in a real construction project.

Non-immersive:

Ratings ranged from 4 to 5, with participant statements like "Non-immersive can be helpful for architects and engineers as such," from 1A, and "I'd choose this for general topics and issues, not for detailed. As an engineer, I will be looking for software or modeling systems that provide more detailed information," from 1C. The building itself and the scope of this experiment do not involve specific engineering details like mechanical, electrical and plumbing. This could have given 1C the false impression that it is not possible to include these details.

Immersive:

Participant 2C said, "Some things, like stair railings, you can add later. But things like kitchen hoods is something you can't. The tile in the kitchen flooring you can change, but you have to pay a lot to get rid of the previous one. Like the hood, you have to tear up the whole ceiling.

It’s better to see here than later in construction. If it’s going to happen, it will cause delays. That costs money.” For this participant, the tool created a situation very comparable to walking a job site or a project on the verge of completion. This would allow people to draw on their tacit knowledge and previous experience to find and tackle mistakes at an early stage. Immersive got scores ranging from 4 to 5.

Single and dual system:

The single system rated non-immersive higher than immersive, and the dual system did the reverse. However, all ratings for this statement were 4 and 5.

Overview:

The participants voiced their concerns and what they believed to be limitations of the tool. Some acknowledged it for its help, and some called it out for its perceived lacks. Either way, non-immersive leads in the single system, and immersive leads in the dual system. It is not necessary to say from this that either one is favored; rather, it could be said that the participants felt that the tool overall helped in decision-making and could do so in a real construction project.

The participants allocated high scores, demonstrating that both the systems would be helpful in a decision-making scenario.

4.1.4.3 Statement: The tools, graphics and visuals were useful for making decisions in building construction.

Non-immersive:

Participants scored it between 4 and 5. Based on this response, it can be said that they somewhat agreed, if not strongly agreed, about the toolset in the system and the benefit it brought to decision-making. A sample response, from 2C, was “Limited number of (object) families. Easy to use but limited options.” Participants did have suggestions during the experiment that they believed would increase the tool’s use. For example, participant 2A said they would appreciate being able to click on an object or surface and access its technical details—for example, technical details of the glazing, such as single or double glazing or heat insulation.

These kinds of details could be available in more depth in the parent Revit model, so if the places of ambiguity were noted during the viewing and later checked in Revit, it would clear some gaps in the viewer’s mind. However, they were expecting a more dynamic software that elaborates on the material, which in this case is yet to be implemented.

Immersive:

Scores of 4 and 5 were recorded by participants, with comments on the interactive display occasionally "freezing," "objects being blurred," and "difficulty in distinguishing material." Other participants, like 2A, browsed through the material options and experimented with textures and patterns. Changing and trying different options in real time gave the participants control of the building and allowed them to provide feedback on areas of improvement.

Single and dual system:

The single system had equal average scores for immersive and non-immersive. The dual system, however, favored immersive by a fractional amount. This equates to the fact that participants felt that both the tools, pros and cons alike, had features to complement each other and provide an overall platform for enhanced decision-making.

Overview:

Comparing the two systems, non-immersive does allow an option to add objects and families into the model. Immersive does lack in this. However, participants did mention that they preferred the visual quality that immersive provided. According to opinions gathered through this survey, there is no obvious preference over one tool, as they both scored equal scores in the single system, and immersive only mildly surpassed non-immersive in the dual system.

4.1.4.4 Statement: This tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers to subcontractors).

Non-immersive:

The tool was rated between 4 and 5. Participant 1A had a few statements to add, saying that they would occasionally feel lost or find an object unidentifiable, which could largely be due to the fact that they were seeing the project for the first time, but if they had a fair idea of the project's background, then it would not be a big issue. 1A suggested that for those project personnel seeing the model for the first time, they should be guided by room tags or by someone who is well aware of the building.

This concern is something to be noted, as showing the model in isolation would not necessarily generate results, especially when dealing with a variety of personnel. Giving a synopsis of the project and then exposing the workforce to the model would possibly generate better feedback to make efficient decisions.

Participant 3C said, “For laborers, I think the experience in the screen (non-immersive) is OK, because we can show them the details”—in order to explain a certain complicated fixture, if the situation does arise on a construction site, the non-immersive model can be loaded on a computer screen, and the detail’s location can be navigated to and explained to the individual. This seems scenario seems both likely and achievable on a construction site. 3C has 22 years of experience in the field, so their thoughts reflect their pragmatic approach to a real construction situation.

Immersive:

Participants in the single and dual systems gave ratings between 2 and 5. Participant 3B rated the dual system 2 (Somewhat disagree) after saying, “Laborers are not the decision makers, so might not be feasible to show them.” Participant 3A said that most people don’t know about the immersive system and might take some time to get used to it. In contrast, “You could ask anybody to take a look at [the non-immersive system], and it’s easier for them to do so.” This participant’s response suggests they believe that time and social outlook are factors in selecting a tool. 3B said that the tool would not be of much use for labor personnel, probably due to this individual’s field experience. It is possibile that the project they were engaged with during their practical training had a strict hierarchy in which decisions were exclusively made by upper management. Another participant brought up that the sudden introduction of a modernized tool might not be in the personnel’s comfort zone. With strict project timelines and lack of time for exploration of a new tool, non-immersive might be easier to incorporate due to its familiarity.

Single and dual system:

The single system had a higher rating for the immersive and the dual system for the non-immersive tool.

Overview:

Taking a look at single system and dual system, the ratings seem to contradict each other. Single system puts immersive ahead, and dual, non-immersive. In such a situation, dual system seems like a helpful participant pool to look at because the two systems are explicitly compared. However, in the minds of the participants, the comparison in the single system could be between the VR tool (immersive or non-immersive) and conventional methods (2D drawings). In that case, the participants might consider any VR option as more informative for a larger variety of individuals, as opposed to stacks of blueprints and technical CAD drawings.

Also, taking into account the virtual communication and information exchange, tools such as headsets to accommodate immersive VR might not be readily available and would involve setting up in a remote location. Due to these inconveniences, non-immersive VR might seem like a suitable option for a variety of personnel involved.

4.1.4.5 Statement: This tool would be informative for a large project meeting group (10+ people).

Non-immersive:

Participants scored the system from 3 to 5. All participants (single and dual system) rated it between 4 and 5, except 1A, who gave it a 3. Participant 1A said, “Non-immersive can be helpful for architects and engineers and such.” Their reason for giving this tool a lower score than other participants could be the navigation difficulties they faced during the experiment. Participant 1A made comments like “It’s hard to navigate” and “Where are we?” and had moments where they ran into walls and suddenly exited the building, which could have affected their opinion on incorporating this to a large group. They could have envisioned a project meeting with 10+ people having navigation difficulties at the same time. Such a situation could prove bothersome for everyone. However, in a meeting, if the tool is navigated by someone who is competent, it could prove to be useful. A participant in the dual system had a few things to say regarding this area: “Non-immersive would be suitable for a large number of people. There will always be older individuals around, nagging that the immersive tool is not working. This will be annoying for those people, and time-consuming. So it’s better to go for non-immersive in such a situation.” This could be a valid point: setting up the immersive system is more time-consuming, and if the meeting room lacks a powerful computer, the tool may not run smoothly. Older and more experienced project personnel might become impatient towards this tool, given the hurried nature of construction and its deliverables. With this in mind, non-immersive seems to be more convenient than its counterpart.

Immersive:

Participants gave this a rating ranging from 1 to 5. Participant 3B gave the immersive system a rating of 1 in this segment, as they believed that the other option, non-immersive, would be helpful in getting more people educated in less time. According to them, immersive would lack in this aspect and give the individual wearing the headset the benefit. Having to do so in a meeting would be time-consuming if the project were being shown to each person individually. And if it were to accommodate several people at once, there would be a need for 10+ headsets. Another factor to keep in mind is coordinating several individuals who are immersed in the system, which could pose a unique challenge. Another perspective came from participant 2C, who said that immersive could be considered an option for a large meeting group, having one individual immersed via the headset and the others watching the computer screen and experiencing the system vicariously.

Single and dual system:

The single system conveyed a higher rating for the immersive tool. The dual system, however, presented a higher rating for the non-immersive system.

Overview:

Looking at both systems, there is no universal forerunner between them. The single system has participants favoring immersive, while the dual system favors non-immersive. It should be noted that there is a chance that participants of the single system compared the tools to conventional methods. We know this because during the experiment, participants compared the given system to 2D blueprints. In the dual system, participants are explicitly comparing the two systems and favoring the one they deem best for the situation, which in this case was non-immersive. For decision-making for a client, in a scenario where there are a large group of individuals to address, there is no clear preference. But those participants who tested both systems preferred non-immersive.

4.1.5 **Conclusion of the Likert Scale Questionnaire**

In the previous segments, each statement is taken into consideration and scrutinized based on the participants' ratings and input. There were several instances where the ratings provided in the single system contradicted those provided in the dual. The below graphical representation categorizes and addresses it more holistically.

The two systems (immersive and non-immersive) will be compared using 2 different approaches:

Approach 1:

Comparing immersive and non-immersive in the single- and dual-system environments.

When comparing the two sets of charts, the common results are denoted with a star ‘*’ symbol. This approach tries to pick out what graphs generate a similar result, disregarding the ones that show contradictory data.

The statements that received a unanimous response between the single and dual system are:

Q1: Statement 2: It was easy to navigate through the platform (Movement in model).

Here immersive seems to be the choice of tool. This could be largely resting on the fact that the handheld controllers provide a virtual loop for teleporting the participant to the desired location. This requires the participant to just aim and shoot to the spot they want to move to.

Q2: Statement 1: The information provided in the system was clear.

Immersive seems to be the forerunner for this statement. This could be due to the fact that it provides a more relatable human-environment situation, close to a lifelike situation. And the clarity in being able to identify materials and objects would have had participants favoring this tool.

Q2: Statement 2: The system reflected a realistic practical experience (Sense of presence).

Immersive scored a higher rating for this statement, predominantly due to the comprehensive sense of presence that it offers. Several participants claimed that it gave them the sense of actually being “there.”

Q3: Statement 1: Was able to access the building with diagram/model/visuals provided.

Participants claimed that immersive is more accommodating to individuals who do not know the building in its entirety. The ease of navigation and response of the system to bodily movements could have led to immersive surpassing its counterpart in this area.

Q3: Statement 3: Objects in the model were properly sized.

Due to the dynamic human-system interface and adjacency to a regular human-environment interaction, immersive could have scored better.

Q4: Statement 1: It helped me make decisions I was asked to make.

Immersive turned out to be the system favored here. This could be the case due to the realistic feeling experienced and the sense of evaluating a real building. The tool’s ability to mimic a real-life site visit could have its merits, as the participants could momentarily forget that they are using a tool and focus their attention on identifying mistakes and improving the building.

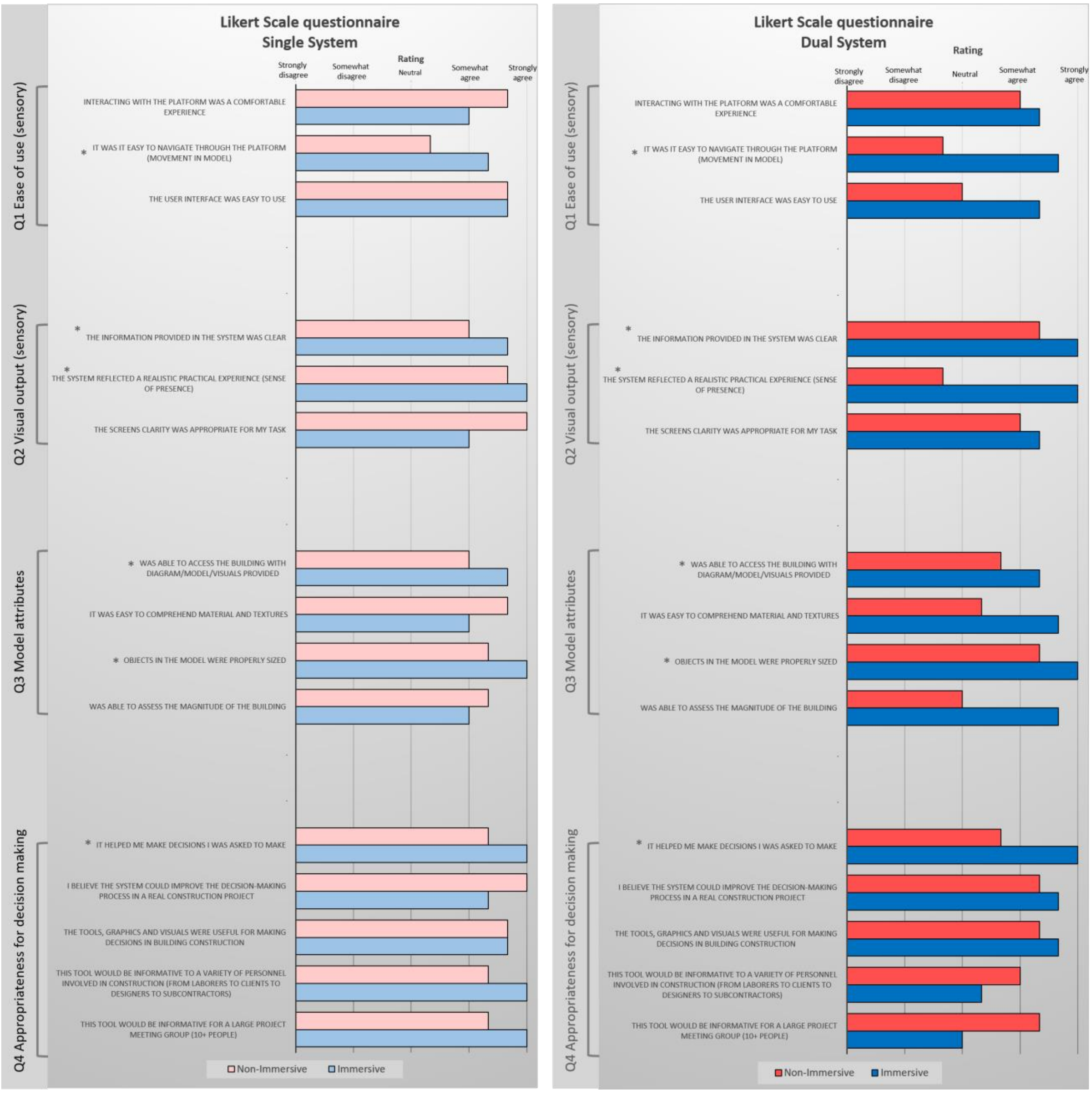


Figure 13: Graphical representation of responses of single-system participants vs. dual-system.

Approach 2:

Comparing immersive and non-immersive in the dual-system environment.

This would involve considering the dual system's graphical comparison, mainly because it is in this system that the two tools are compared solely to each other. In the single system, the participants are exposed to either only immersive or only non-immersive. This could bring into consideration that they are assessing the tool in isolation or in comparison to the kind of decision-making tools they are/were previously exposed to.

Examining the graphical comparison, we see that all the statements favored immersive in the dual system, except for:

Q4: Statement 4: This tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers to subcontractors).

Non-immersive stood as the forerunner in this situation, which could largely have to do with the participants believing that it is familiar to a large variety of personnel, as it involves looking at a model through a screen. A participant also brought up the prospect of sharing the model through email, in which case non-immersive would be a straightforward option for the receiving end, in contrast to the need for head-mounted goggles and time to set them up. With the convenience and simplicity of non-immersive, some participants believed it would be a pragmatic choice in instances where it would be shared with a real construction site.

Q4: Statement 5: This tool would be informative for a large project meeting group (10+ people).

Non-immersive was favored here, owing to the fact that a larger number of people can be educated/informed at once. If immersive were to be chosen as a tool of communication for a meeting involving 10+ individuals, it would require the same number of head-mounted goggles. Showing the model to each person in turn would be time-intensive and inconvenient.

Between the two approaches, the first calls for identifying the common intersystem forerunners, which in this situation seems to be immersive. In the second approach, immersive scored an overall high rating, except regarding the diversity of construction personnel and the needs of large project meeting groups.

4.2 Open-ended interview-type questionnaire

After the participants used the tool, they were asked a series of open-ended questions and engaged in conversation to gather their impressions and general concerns. The questions are elaborated in full detail in Appendix C. In order to analyze their conversation, a technique called thematic analysis is used. Here, each answer or response is given a "code." Examples of codes include "visual appeal," "system deficiency," "ease of learning," "navigation issues," and "equipment issues," among others shown in Table 2. The common codes are then collectively assigned to a category. The categories are created based on previous studies by Castronovo et al. (2013): ease of use (sensory) and visual output (helpful), among others as displayed in Table 2. The categories are then placed into three broad "themes": pros of the system, cons of the system and suggestions. And finally, participants' opinion on improvement in construction decision-making is asked and assessed.

On a case-by-case basis, participants' thematic summary is computed in the form of figures and compared among them.

Table 4: Thematic categories for coding of data

Codes	Sub-category	Themes
Previous exp/comparison	Ease of use (sensory)- easy	pros of the system
system deficiency	Ease of use (sensory)- difficulty	cons of the system
visual appeal	Visual output (sensory)- helpful	suggestions/improvements
ease of learning	Visual output (sensory)- issues	
visual output inaccuracy	Model attributes-material, textures	
navigation issues	Appropriateness for decision making- use in industry	
equipment issues	Appropriateness for decision making- adoption issues in industry	
improvement suggestions	Previous experience	
Visual output-materials	suggestions	
use in industry		
adoption issues		
affirmative		
benefits		
benefits- financial		
not decision making		
unconvinced		
unconvinced- for interiors only		
mildly convinced		
convinced		
Limitations		
difficulty in use		
benefits		
Limitations		
adoption issues		
benefits-time		
ease of use-lacking		
benefits- selling/marketing		
affirmative		
visual output-immersive better		
visual output-problems with non-immersive		
use in industry-non immersive for crowds		
use in industry- non-immersive		
use in industry-immersive		

4.2.1 Individual participant-based analysis

A figure is computed individually that presents the system's pros and cons and the participant's suggestions, determined by thematically analyzing their statements. These data will be compared between participants, and repeating statements and patterns will be identified . These repeating elements will be organized to reach a conclusion and, eventually, linked to the research question.

4.2.1.1 <u>Participant 1A</u>

The participant is a first-year master's student in the Department of Construction Management Technology. They have an undergraduate degree in civil engineering, having pursued a master's degree immediately after, with internship-based work experience. They have previous experience in using tools like AutoCAD and Revit and also work with these on a daily basis. They also mentioned having played video games before, namely the Wii and Xbox.

The pros, cons and participant suggestions were tabulated, as in Figure 14. To better understand each segment, they are elaborated, starting with the pros. The remote navigation of a building was one of the first statements to be brought up. With stakeholders situated in multiple locations, geographically, it could help save the time and effort of traveling to the construction site or the project meeting.

When cost was brought into the conversation, they believed the benefits attained would outweigh the initial cost for using the tool. They also believed that the tool had marketing potential, unlike Revit, which could not be used directly for marketing the project. They spoke in regard to advertising, saying, "The human psychology is targeted" as a selling point, probably having to do with the higher-quality visuals created.

Focusing on the cons of the system, it is noted that during the course of the interview, 1A often compared non-immersive VR with Revit. This was highlighted when they selected objects and surfaces. When doing so they noticed that material properties did not display like in Revit, which details the type, material composition, length, width and height. Along with this, they brought up navigation as a point of significance. They mentioned feeling "lost" at times in the model, with navigation tools accidentally transporting them through the walls and outside the building when they did not intend to. They suggested that the rooms be tagged so that the viewer did not need a designer or a mediator to guide them, especially when seeing the building for the first time. 1A said they would prefer looking at the model floorwise instead of tackling the whole building. This could have to do with this participant's navigation issues, which caused them to often unknowingly move from the first floor to the second through the slab. Another navigation concern was the lack of flexibility to virtually "turn your head" in order to see at various angles. Lastly, the participant focused on the tool's benefit to a company, noting that in order for it to be a feasible investment, the tool has to be used for multiple projects due to the need to set it up, train individuals, and allocate time. 1A's input is shown as a graph to understand the pros, cons and suggestion percentage. Their overall opinion of the tool was positive, with them saying it would definitely help in the decision-making process, not just in identifying building errors but also in safety training.

Figure 14: Thematic composition of Participant 1A’s response to an open-ended interview.

4.2.1.2 Participant 1B

Participant 1B is a second-year master’s student in the construction management department. They have a background in civil engineering and 1–2 years of internship experience.

They commented positively that they were able to point out safety-related faults and issues while exploring the model, such as gaps in railings, weak glass wall locations and potential injury/fall hazards. According to them, safety also extended to the on-site process and safety hazard training for laborers. For visual aesthetics, they believed that this tool could be used to showcase the building to individuals without a background in construction. They also believed this tool would be helpful in a large meeting group, particularly with the guidance and maneuvering done by a design expert. This participant said that with regard to requests for information (RFI), if there's any ambiguity in the model, the user could look into the model and get clarity, as opposed to reaching out to the design team every time. They also brought up location, which provides the flexibility for people to work remotely.

Some of the drawbacks of the tool are navigation, as mentioned by others. A lack of a location pin or key plan proved to be a concern for 1B. They were also concerned about middle-aged people in the industry and their possible skepticism towards tools like this.

Their suggestions included "hardening" of walls, like in the software Navisworks, which prevents an individual from passing through walls and avoids navigation blunders. They also voiced the need for a measuring tool, as did other participants. 1B also suggested the use of a key plan to provide a general sense of direction, an introduction by the system on how to use the navigation and available toolset, and a documentation tool to keep note of areas that were identified as problematic. When asked for their verdict about the tool's use in decision-making, the participant said they did believe it was a helpful tool. The graphical representation of this participant's feedback and opinions appears in Figure 15.

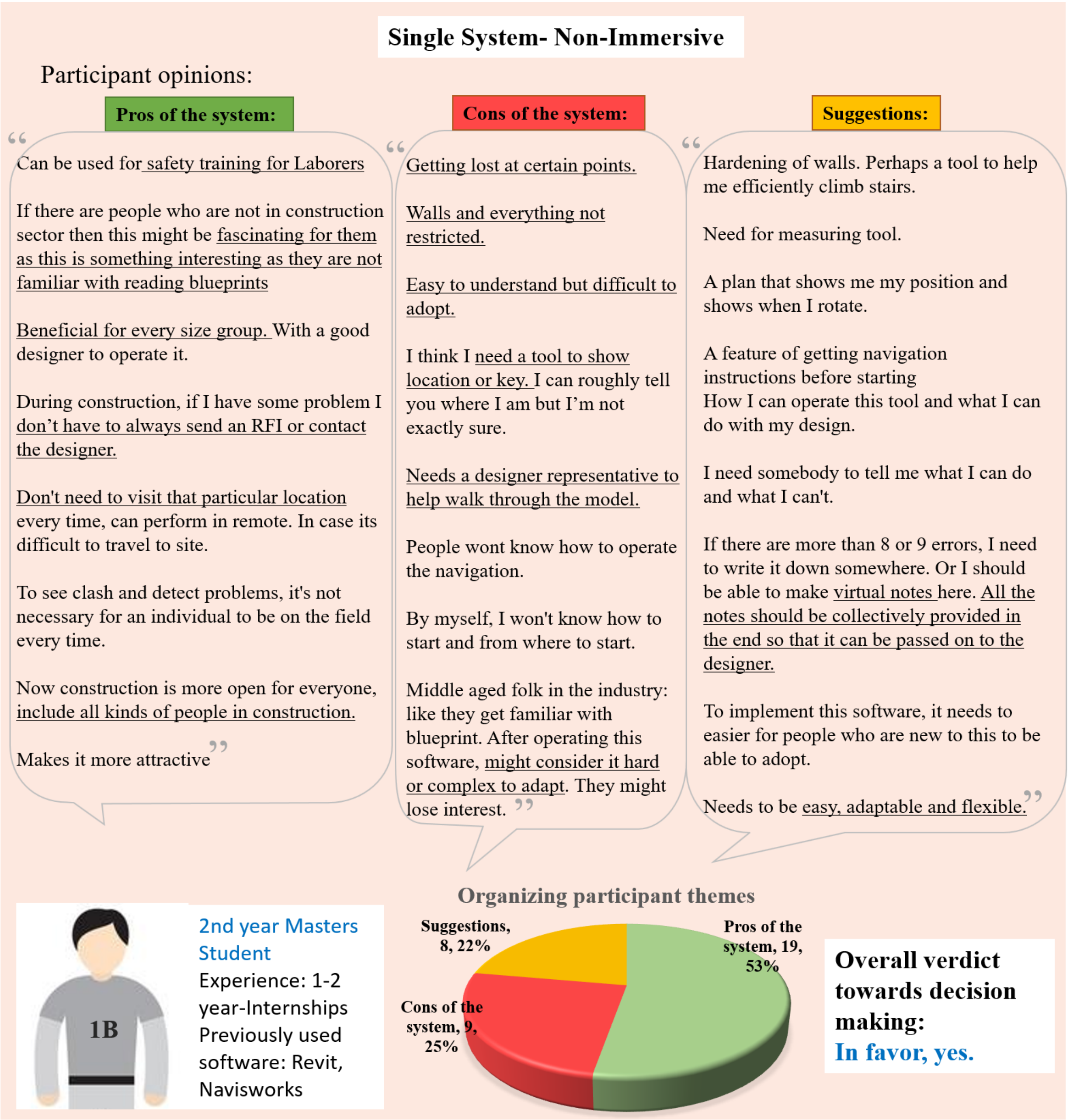


Figure 15: Thematic composition of Participant 1B's response to an open-ended interview.

4.2.1.3 Participant 1C

The participant is a PhD student who has 3–4 years of industrial experience. Their background involves an undergraduate degree in civil engineering and a master's degree in construction management. According to their demographic information, they have experience with using Revit and Navisworks. According to them, the pros of the tool involve the ease of use: "In four or five minutes, anyone can learn how to use it." They compared it to 2D blueprint drawings and said it is more informative, especially for people with no past knowledge. With regard to using the tool for large and small meeting groups, they believed it is versatile and can be utilized for both.

When talking about the cons of the tool, a concern did arise when they were exploring the model. When material of one object was changed, other objects with the same material type changed too. Their comment on this was that it would cause confusion if the materials are not separated. 1C also mentioned that the available tools for changing interiors lacked elements from an engineer's perspective. They said that they would need to look behind wall surfaces and inside the false ceilings, among other places, to see the building services. This participant said that they would use this tool, but not for details; as an engineer, they would prefer a software or modeling tool that provided more detailed information. It is true that the tool is not designed with MEP elements in mind and hence lacks those families and options; a software including those would immensely help the engineering side of stakeholders. With a background in civil engineering, this participant is bound to look at the model with that perspective and identify those shortcomings. However, the model was not created to highlight those aspects, and this research deals with architectural and structural elements.

Suggestions put forward by this participant included having the option to break blocks and groupings of families and materials in order to isolate changes only to specific ones. They also recommended a summary tool that reaffirms a change made in the model during its viewing. Figure 16 displays the participant's response in a thematic arrangement.

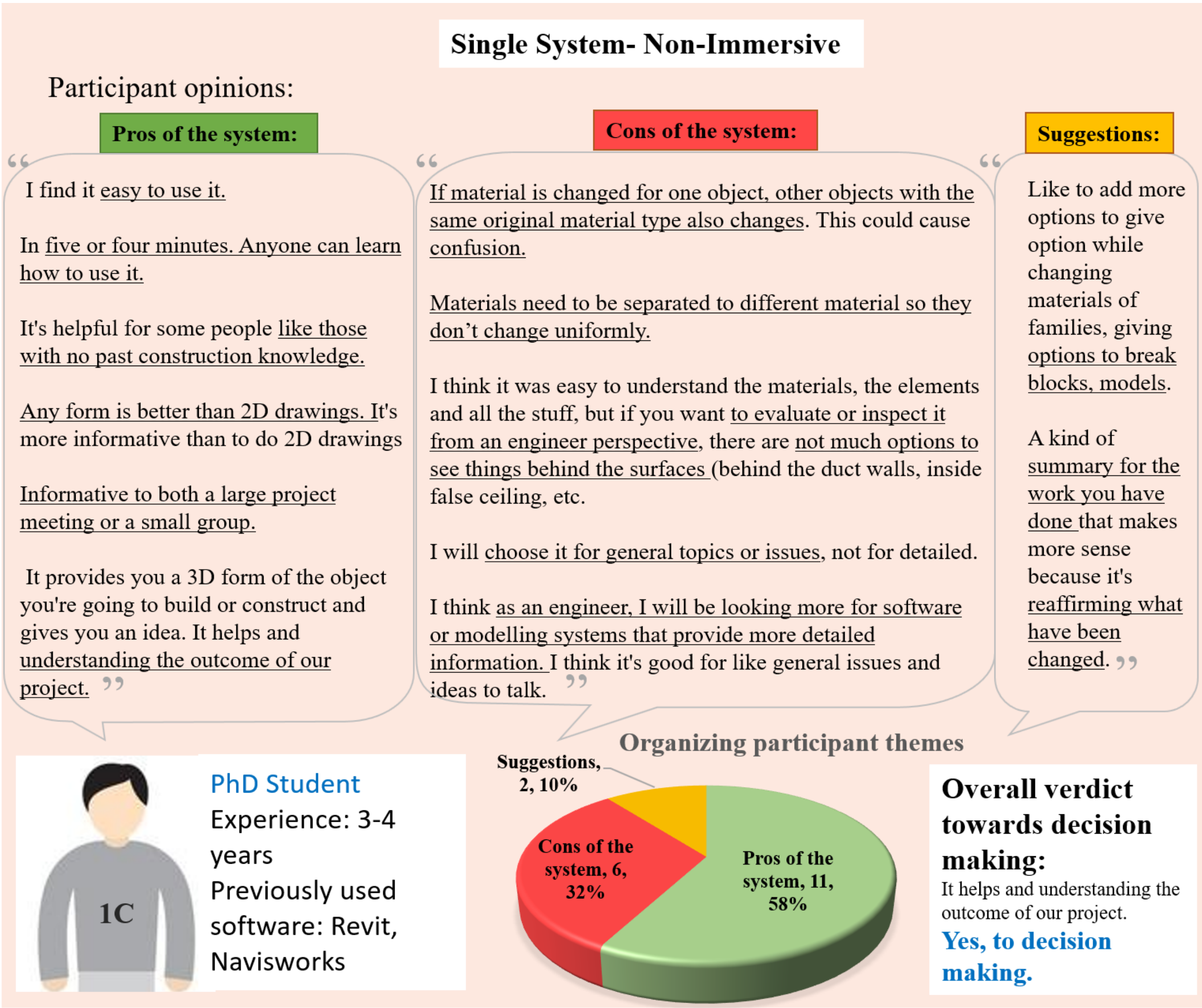


Figure 16: Thematic composition of Participant 1C's response to an open-ended interview.

4.2.1.4 Participant 2A

2A is a first-year master's student in the construction management department and has a bachelor's degree in architecture with 1–2 years of industry experience. They have interacted with virtual models like Revit, ArchiCAD and Sketchup before, although not in a professional setting. Having been exposed to VR-based gaming, they said they see potential in this tool for using it for other purposes. Their statements acknowledged the tool in aspects such as its worthiness of time and effort. They said that models are often made in Revit, and taking these to a VR format would not necessarily take a lot of effort, as the tool is a plug-in to Revit itself. With regard to addressing a large meeting group, they believed one person could be wearing the head-mounted goggles with others watching and taking notes. This, however, could not be considered a complete immersive experience for all the attendees, as they would be looking at the screen and have non-immersive involvement. When comparing the immersive tool to non-immersive, 2A said that a company might think that non-immersive would do for their project needs, but that immersive is "much more interactive." They believed this tool could be a good selling point for a design-build company. This was mentioned repeatedly by participants, largely because, some being in the architecture field, would have observed how models progress until they are rendered for marketing. The process generally involves exporting the Revit model to a 3D enhancing software like 3DS-Max, for which an individual has to perform post-processing to enhance material, texture, lighting and other elements. The software used to generate the immersive VR is a plug-in to Revit itself, and requires little to no post-processing. Consequently, less effort would have to be directed towards treating the model in order for it to be ready for marketing.

Drawbacks of the tools that 2A pointed out were the navigation and the interface. The participant reported feeling nauseous occasionally, and selecting options had problems with the options freezing. They mentioned that the laboratory in which the experiments were held could have had more free space to facilitate bodily movements and prevent running into surfaces. From the standpoint of adoption, they believed that some people would be reluctant to use the tool. Possibly, their 1–2 years of work experience has allowed them to understand the dynamics of a workplace and notice how construction can be stagnant, as a convention-based industry with experienced individuals adhering to tried and tested ways.

2A's recommendations included the need for documentation to view activity/changes at the end of the procedure. A legend, orientation, or bubble for navigation could reduce confusion for the user, and a demonstration, 2A believed, would help people using this for the first time.

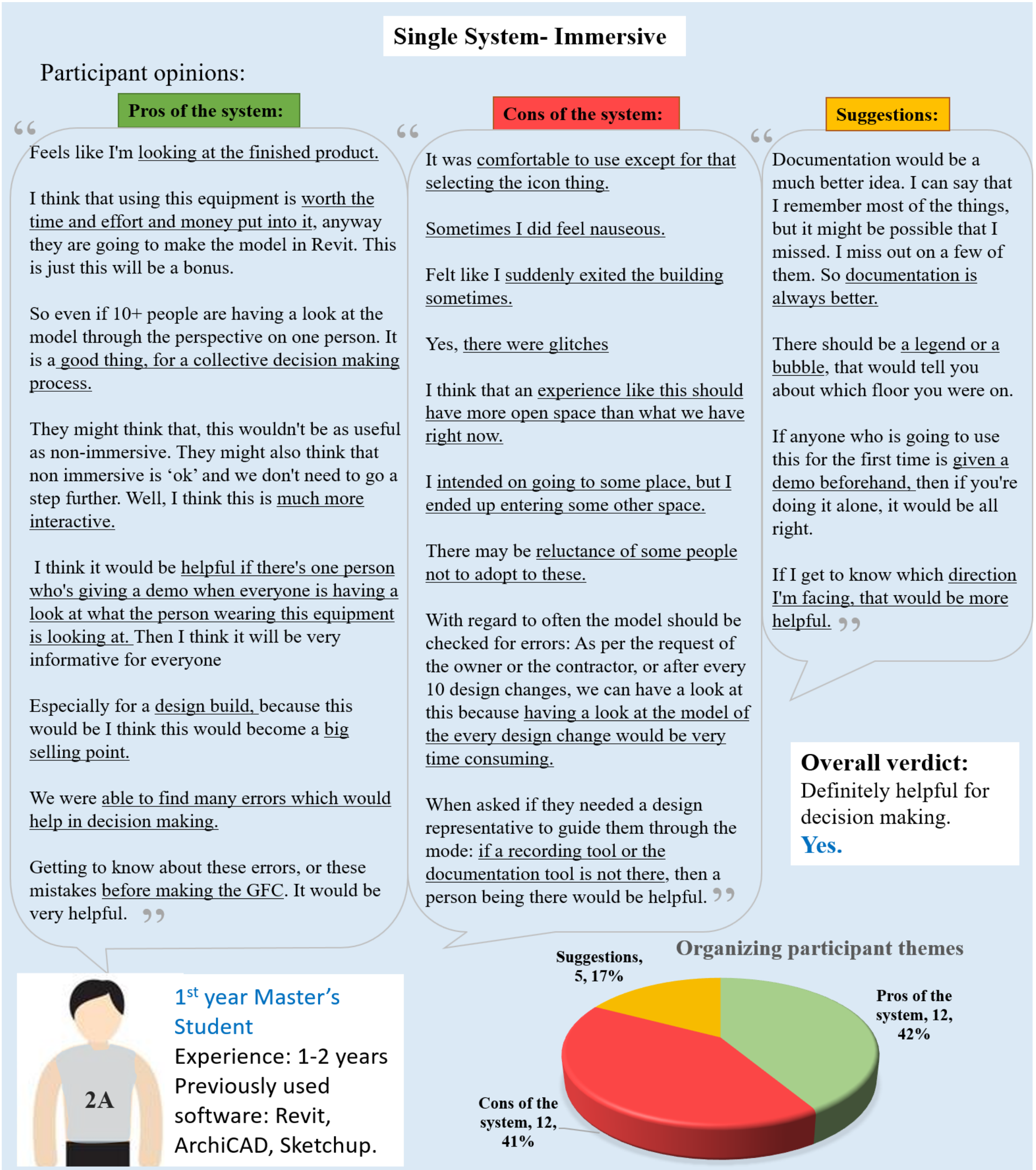


Figure 17: Thematic composition of Participant 2A's response to an open-ended interview.

4.2.1.5 Participant 2B

This participant is a second-year master's student in the construction management department. With 3-4 years of work experience in a civil engineering-based firm, they considered the model from that perspective. They mentioned they were able to visualize the building. This could be a substantial pro of the system, as although they have a background in civil engineering, they worked primarily on infrastructure projects and were not familiar with commercial construction. They were able to identify errors during the model exploration. They also noticed design errors that would essentially become a safety hazard, such as a ledge that could be accessed by jumping a low railing, which could become a fall hazard as it overlooked the floor below. Another advantage, mentioned repeatedly, is the potential for the system to attract clients and be a useful marketing tool.

Some of the disadvantages or areas for improvement involved navigation, such as a feeling of "flying" or being "out of place" when the viewer was standing in the corner of the room. There were times when the participant felt uncomfortable. This could be because they are not accustomed to using a tool such as this. When asked if they would consider this tool a good option for a large meeting group, they said that it would not be ideal and is more suited for one or two people. This participant mentioned a possible limitation of the project genre, as they believed that this tool would be suited for commercial projects but not "heavy-civil" ones. Their perspective could be linked to their lack of exposure to these tools during their professional experience. With their infrastructure projects proceeding with conventional methods such as blueprints and 2D drawings, they could believe there is no need or room for VR-related tools.

They suggested the need for more head-mounted goggles in order to accommodate a large meeting. On a general note, they believed the tool would definitely help in the decision-making process. Figure 18 shows thematic information from the interview with 2B.

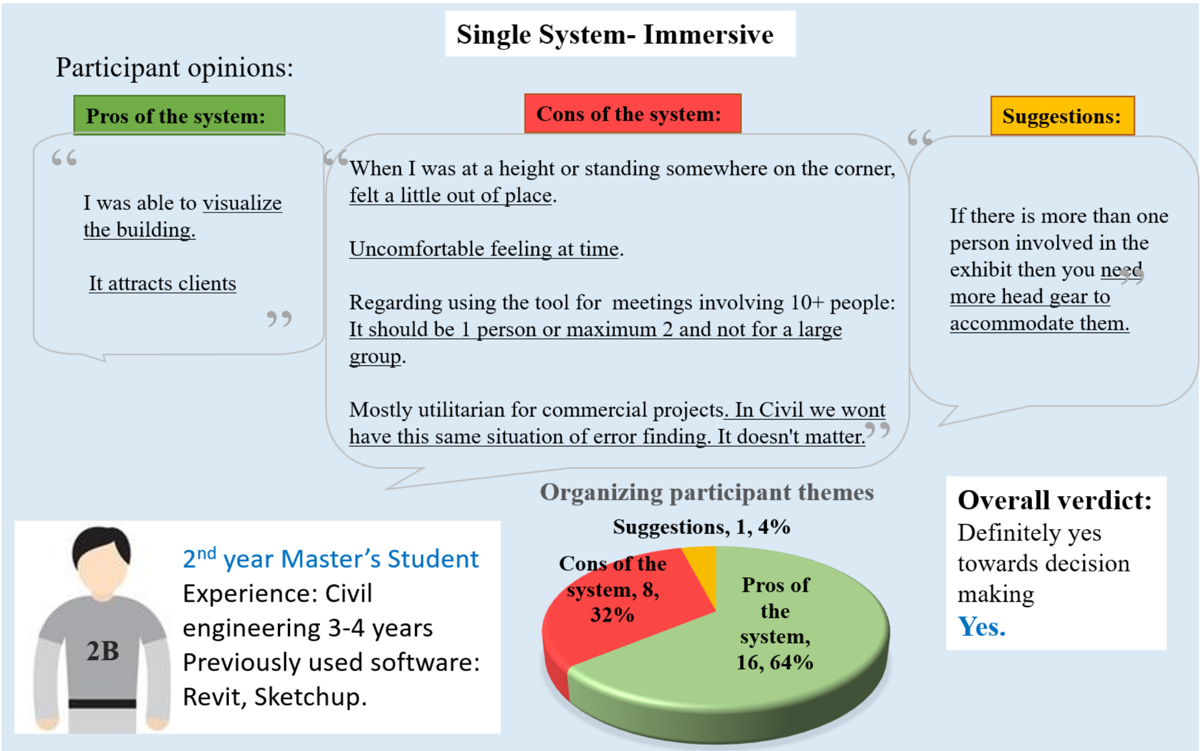


Figure 18: Thematic composition of Participant 2B's response to an open-ended interview.

4.2.1.6 Participant 2C

This individual is a PhD student in the construction management department with previous experience in the field of architecture. They have a master's degree in architecture and have used BIM tools such as Revit and Navisworks. Their responses, arranged thematically, are portrayed in Figure 19. They were skeptical of whether this tool could be seen as useful for decision-making for the broad spectrum of construction, and they believed it would favor decisions based on interiors. When the researcher explained the limitations of the model—that this particular one had not been populated with MEP and other services—they hesitantly believed it could be suitable. For the defined scope of this study, the current model had only architectural and structural elements modeled. Participants including 2C mentioned their concerns regarding this. The model is not meant to be an absolute executable one, but in fact depicts a building in the design development stage with only architectural and structural portions input. This experiment hopes for participants to conceptualize possibilities of further details and give their opinion. However, some participants did interpret the limited model elements as the tool not having the capability. This would not necessarily be an accurate response.

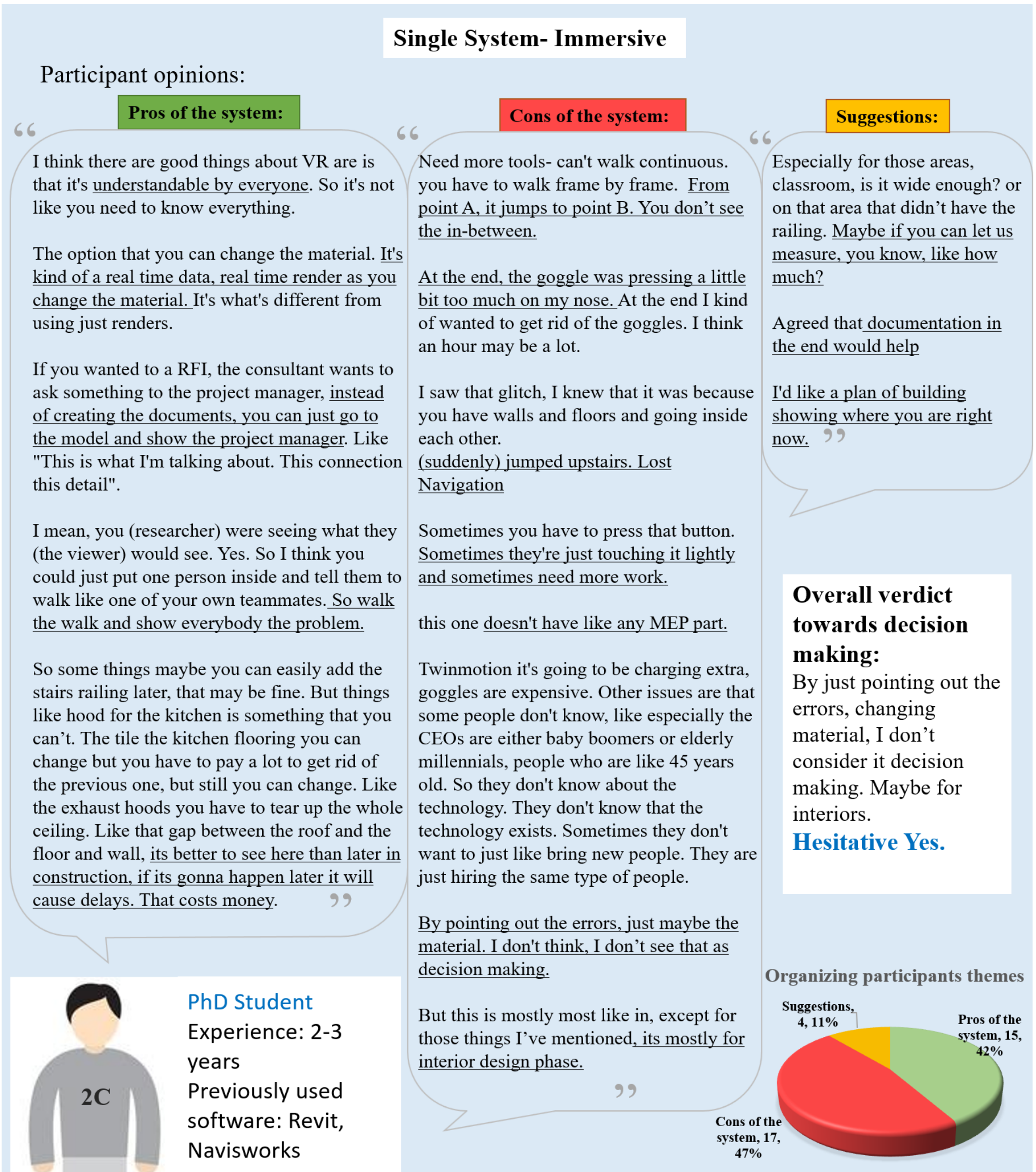


Figure 19: Thematic composition of Participant 2C's response to an open-ended interview.

4.2.1.7 Participant 3A

The participant is a first-year master's student in the construction management department with a background education in civil engineering. With work experience of less than a year, they seemed enthusiastic when shown the immersive system. This participant was shown both the systems, immersive first and then non-immersive. To begin with their positive comments, they said the VR model gives the viewer a clear view of how things would look after construction.

Cons of the system they mentioned involved navigation issues, which caused them to exit the building unexpectedly. They mentioned that the system would be more suitable for the aesthetics of a building rather than for structural identifications, as those would require the user to know comprehensive information such as thickness of slab and distance between columns. This participant said they were concerned about the difficulty of bringing in new things and having people accept them. Time and monetary investment in the tool seem influence, the use especially toward new technology. When marketing and advertising were discussed, the participant said that they were aware of residential construction companies making a "demonstration apartment" to show to the client. They were not aware of VR being used for these purposes and were skeptical about its usability when compared to other options. The point mentioned is a valid one with regard to multi-level residential/apartment projects, as layouts are repeated and a person can take a look at one of those and get an overall picture. However, for commercial or projects involving little or no layout replication, VR could be a feasible tool.

Since the group 3 participants were given two tools to compare, their inputs on each will be addressed:

Non-immersive:

Participant 3A felt the navigation in this tool was "totally smooth." They said that if they were familiar with using the keyboard and mouse for navigating on a computer interface, then it would be easy. For the case of a large number of people in a meeting group, they vouched for non-immersive, as people are used to working with a computer screen, and they said that older and more experienced individuals would be more accepting of non-immersive, as immersive would be too drastic a change for them. Non-immersive would also work as a time- and budget-friendly option. It certainly would be an economical option, as there are no head-mounted googles required.

Immersive:

Pros of the system involve better clarity in identifying materials and texture. The participant believed that immersive better facilitated decision-making, as it creates a sense of being present in the building.

Cons of the system included navigation issues, such as the sensation of flying or the feeling of being stuck within an object. The controller seemed to have frozen at times, causing a pause in the experiment. The headset was heavy, especially if it is to be used for a longer time. Looking at the navigation and usage of tools, these could require practice, and since the participant is working with them for the first time, they could have considered it tedious.

They did have suggestions to offer, based on factors they noticed during their exposure to the tools. As previous participants mentioned, they said they would appreciate being able to mark the errors in the model and leave comments on them. This participant had a unique take on the idea of having a map as a key or legend. They believed that having it would create more confusion, as one might accidentally enter a wrong room while trying to figure out their location on the map. When an object is selected, such as kitchen equipment, the participant suggested that the tool could elaborate on features like the capacity and power. An interesting thing they mentioned is the need for previous corrections to be documented in the form of tags as participants enter the rooms. This could be a valuable suggestion, as a documented log of previous changes and pending changes could create a systematic approach towards decision-making and refining a project.

Finally, when asked which tool they would prefer for decision-making, the participant picked immersive. They saw potential in this tool even though they felt non-immersive offered helpful features. They did mention that for situations with a larger group of people, non-immersive would be advantageous.

Dual System- Non-Immersive vs Immersive

Participant opinions:

Pros of the system:

"Yeah, this would be a great option. It'll give them (users) a clear view. Like how the thing would look after it constructed.

If they want to give some suggestions, this would be perfect because they have multiple options.

You could make corrections so quickly and add and delete things."

Cons of the system:

"I accidentally exited and entered the building.

If I can afford to hire someone to do the visuals for me I would rather have someone else do it. If I'm just starting my career and it's really necessary for me to learn, ill learn.

For structural elements, I don't think it would help much. For Aesthetics its perfect. But for the structure It's hard to see where the column should be, where the slab should be. It's hard to see the structural glitches in this. Just how the thickness of the slab etc.

It's difficult without measurements to gauge how far the columns are from each other, or the thickness it should be. Pointing out this stuff would be a problem and difficult without measurements.

Some people are just afraid to bring in new things. They don't want to invest too much time and money into it.

Most of the companies just wanna get things done. If something is working out, they think-why bring change, why invest so much time and money doing it. And most people are just outright reluctant to a product and new technology.

Advertising. What I have seen is, if a company is building ideas on what is essential, they just build a demo flat. They would give all kind of fixtures that would make it look as luxurious as possible. So all the clients would come in and look at that. It would have the exact same dimension as the apartment inside. I've never seen them using this kind of, you know, kind of things to attract clients."

Suggestions:

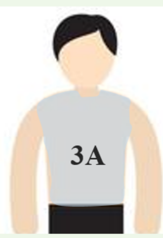
"Marking the model and leaving comments would be helpful.

By having a map or a key plan, might not necessarily help, it might make it even more confusing. Because you might accidentally enter and get inside the wrong room when you're just trying to figure out where you are on the map.

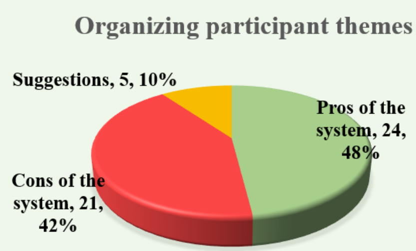
There should be an option if you if you're using the immersive model. If you point the joystick towards it and click on it. It should give the details about it. Like what's the capacity what's the power all that stuff. And for the non-immersive one, when you point your cursor and click on it, it should give the details. It's not necessary that everybody should know what all equipment they have by just looking at it.

The person who is looking at it for the second time, shouldn't have to go thro every single thing. You have to write it down or could just put on put on a map and give some kind of designation to it like: room1, room2. And on that you could just write down by the side of that as: Room1 requires this correction, Room2 requires this correction.

This would save a lot of time instead of having to go through the entire structure again. The person could just go to that specific spot, look at the connections that need to be made. And get done with it."



1st year Master's Student
Experience: Civil Eng., 0-1 years
Previously used software: none



Overall verdict:
Helpful for decision making?
Yes.

Figure 20: Thematic composition of Participant 3A's response to an open-ended interview.

Dual System- Non-Immersive vs Immersive

Participant opinions:

Non Immersive

"Pros:
Non immersive was totally smooth.

If you know how to use the buttons and mouse. Navigating through the structure was totally smooth.

Non-immersive is appropriate for a large number of people, because most of the people, they don't know much about the immersive system. And it might take them some time to get used to it. And non immersive one, people are habitual to it. You could just ask anybody to take a look at it.

If there is a shortage of time and a shortage of money, can just go with the non-immersive one.

For a large project meeting Non-immersive will be better to project, as there will always be some old people around nagging that the immersive tool is not working. That will be time consuming and annoying for people, so better to go for non-immersive"

Immersive

"Pros:
I would say immersive was more informative on the materials, texture. Not completely but would it be a little better than the non-immersive. Even for lighting and shadow

Immersive better facilitated decision making. Because it gives you kind of a clear picture. It feels as if it is right in front of you. It feels 3dimentional and it makes it easier for you to spot minute differences and any faults. 2D It feels like a normal thing, hard to point out any gaps in between minute gaps in between structures that way, immersive is way better

Cons:
Sometimes when using the immersing model, I was flying, you know when I was trying to go thro the door it'd just lift me up instead of letting me thro the door.

I exited and accidently entered the building as well.

Sometimes in the middle I thought the joystick wasn't working. Maybe it was a little technical glitch. If the joystick Works perfectly fine, then with practice, then definitely, easy to use.

And I even had trouble in undoing what I did.

Headset was kind of heavy on my eyes maybe because I'm wearing glasses. I don't know what it'll be for other people"

Overall verdict:
Immersive better facilitated decision making

Figure 21: Thematic composition of 3A's non-immersive vs immersive feedback.

4.2.1.8 Participant 3B

This participant is a second-year master's student in the construction management department. Prior to enrolling in graduate school, they had 2–3 years of industry experience in a civil-related firm. Their educational background is in civil engineering. Highlighting the pros of the system, they mentioned that they largely worked on heavy civil-highway projects, which involved complex underground utilities. They said that incorporating a tool like VR could help trade professionals identify aspects such as excavation zones. Training and safety did also emerge as potential uses, as they believed showing working staff these visuals would be more effective than giving them a theoretical speech. They said that with visual tools, hazardous work like electrical cables could be more systematically planned with safety in mind. Having users enjoy the display as they would a video game could be an attractive point. With several errors being identified, those that could be expensive could be given preference. This is a point that could be elaborated more, as which errors to be given preference could be linked to the estimates of the project.

Cons of the system were discussed, and the participant voiced their concerns about the construction industry as a whole, calling it relatively stagnant in adopting new techniques. They mentioned the demographic involved, saying the "older" generation is unconvinced of new technology and mainly rely on their hands-on experience and don't want to change that. 3B was also concerned about the cost of implementation. They said that the cost of training and of purchasing the gear would seem like an investment of questionable worth to some companies. If they do use the system, it would be preferred to have wireless headgear. This participant's concerns aligned with those of the other participants, and could primarily stem from their previous work experience and management. There could be managers who are welcoming to such tools, but the general verdict by the participants is that managers will be skeptical.

Questions regarding individual tools were asked and categorized to identify the strengths and weaknesses of the tools:

Non-immersive:

For a discussion or meeting with a large number of people, this participant preferred non-immersive, as they mentioned that time is always an issue in construction. A system that could get more people educated in less time would be preferable.

Immersive:

They mentioned that the immersive experience is more enjoyable for the viewer due to material, texture, light and shadow, among other aesthetic qualities. The “sense of presence” offered was also highlighted as a major selling point, as it allows the participant to react and behave as if they were exploring an actual building. 3B believed that this tool would aid users in making better decisions than the non-immersive tool.

Overall, when asked for their verdict, they said they would prefer immersive for their design estimation team. When showing the model in a client meeting, they would prefer non-immersive, as this would save time and deliver a quality product.

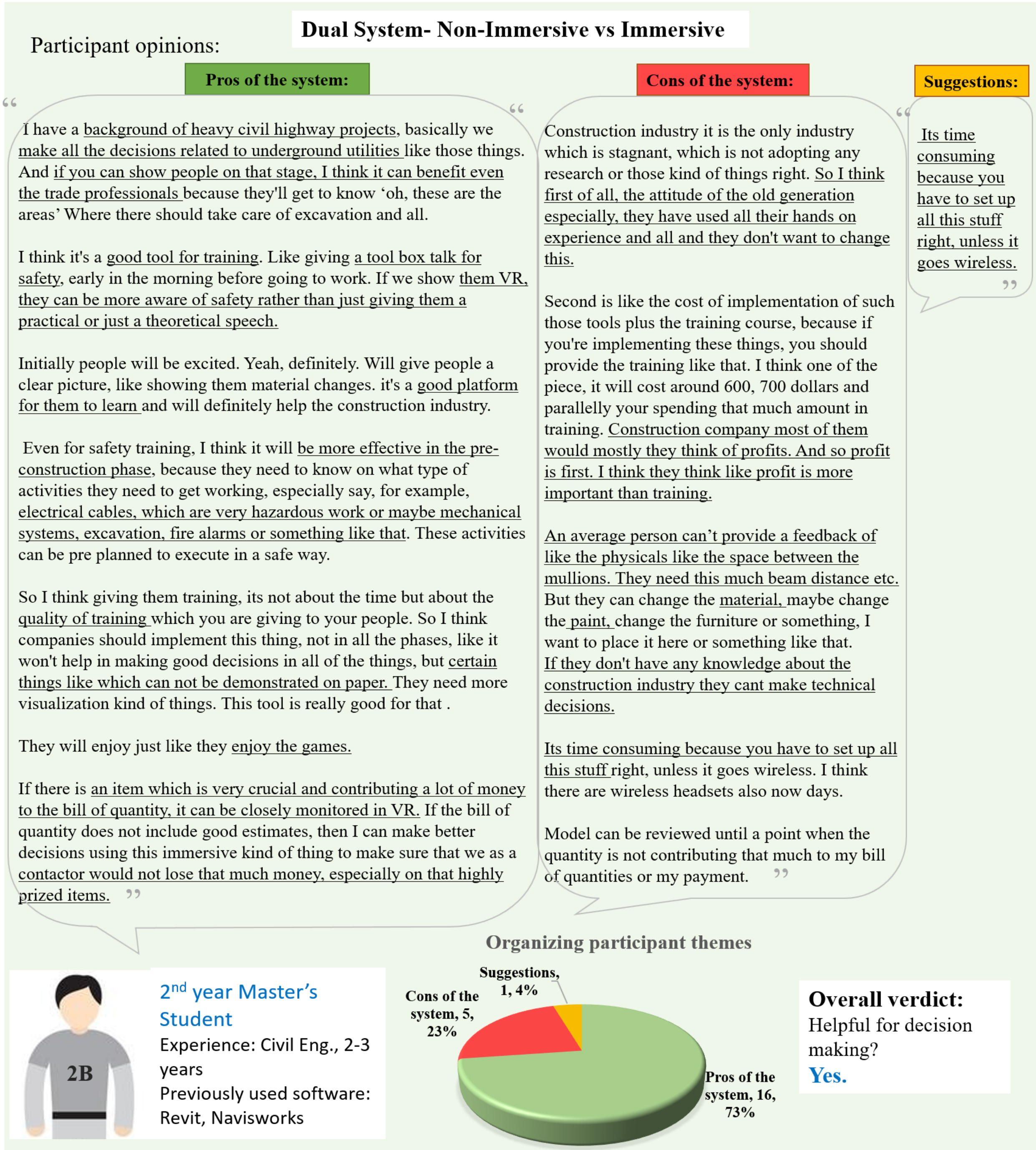


Figure 22: Thematic composition of Participant 3B's response to an open-ended interview.

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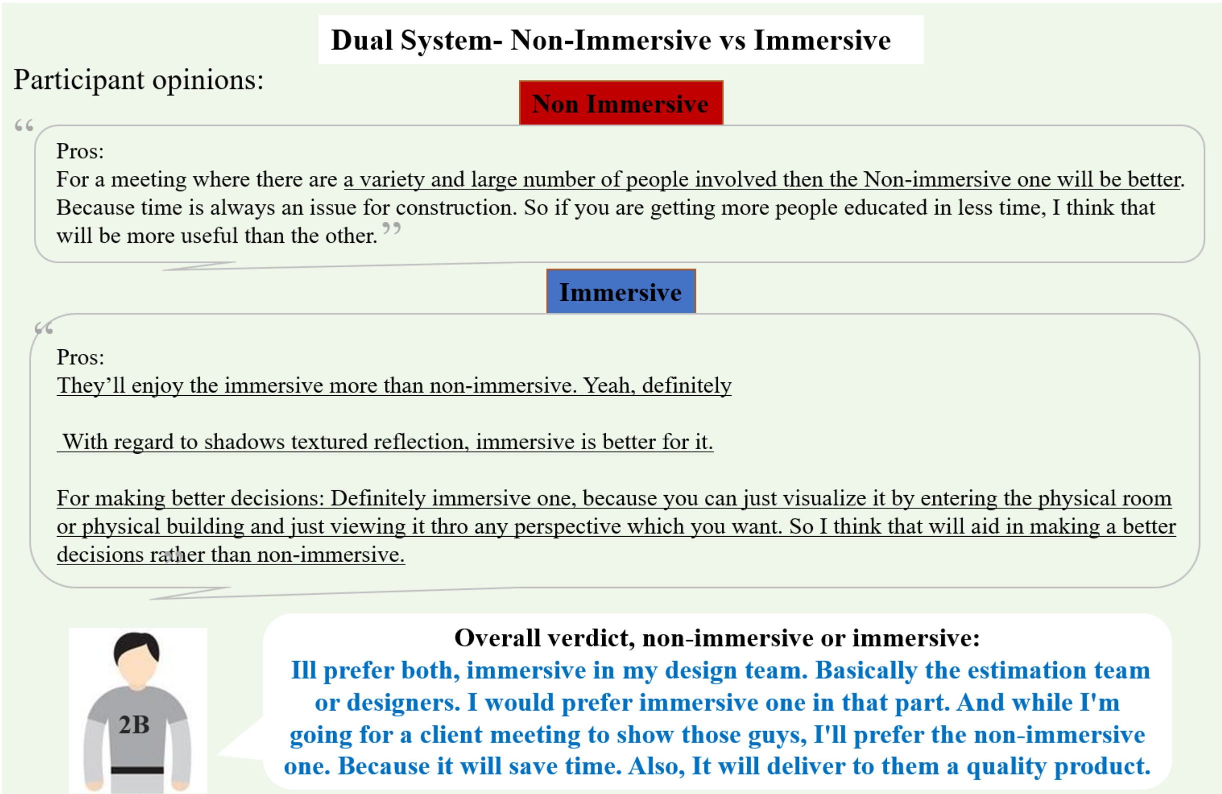

Figure 23: Thematic composition of 3B's non-immersive vs immersive feedback.

4.2.1.9 Participant 3C

Participant 3C is a PhD student in the department of construction management, with 22 years of experience in the industry and a bachelor's degree in architecture, followed by a master's degree in environmental technology. They have used BIM-related tools like Revit, ArchiCAD and Sketchup, as well as phone-based VR goggles for entertainment. They were shown both the systems and asked to provide their feedback.

They experienced "dizziness" and said that they were feeling sick during the viewing. They admitted to having this sensation even while visiting amusement parks with their children. When the topic of advertisement and marketing was mentioned, they believed this would be a versatile tool for people to see their finished product before deciding on a purchase or investment.

Both tools were discussed to assess the pros and cons of each system.

Non-immersive:

When asked which tool would be better to show the labor crew, they chose non-immersive, as they would prefer information through a screen, but they also said the tool lacked a sense of realistic appeal.

Immersive:

Although they believed that the two tools were complementary, 3C said that immersive provided an intensive view. For identifying clashes and looking at the ceiling, they said they preferred immersive, owing to the fact that they found navigating easier. They said they had not played video games, and the immersive tool proved to have a straightforward navigation command. Cons of the system included nausea and the fact that the tool did not allow the participant to select objects and retrieve their details.

They believed that both the tools are complementary to each other, one offering one set of conveniences and the other offering an alternate set. Overall, they believed there was use for both the tools.

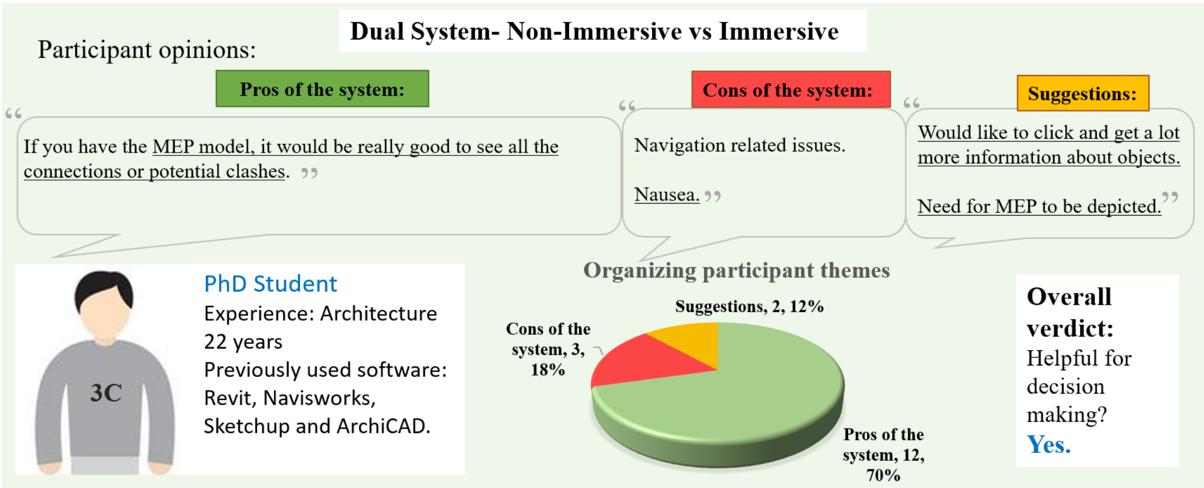

Figure 24: Thematic composition of Participant 3C’s response to an open-ended interview.

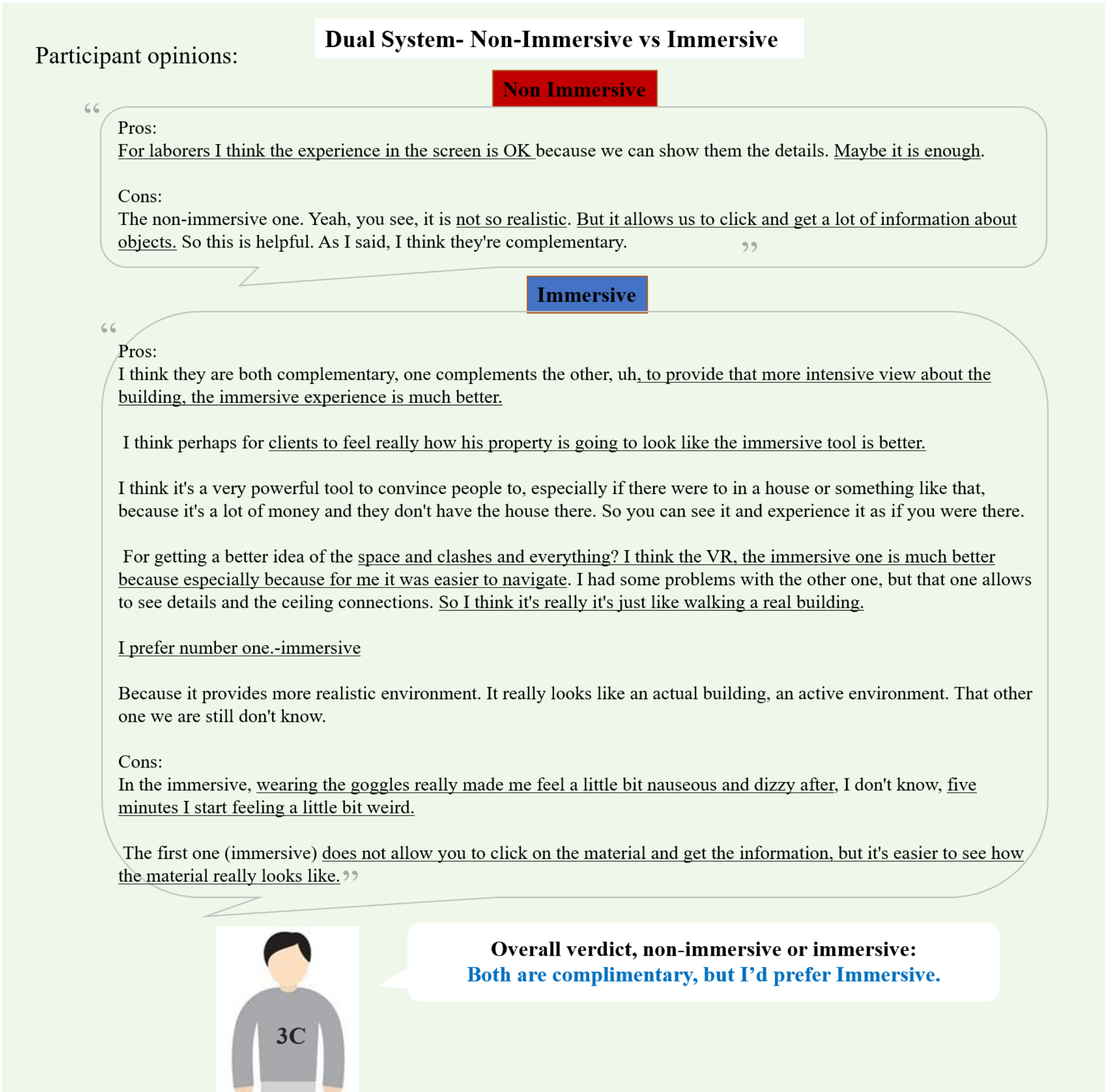

Figure 25: Thematic composition of 3C's non-immersive vs. immersive feedback.

4.2.2 Concluding the open-ended interview analysis

With a variety of data provided by the participants, some feedback and suggestions overlapped, and some were unique to the individual. Here, those statements that were repeated will be organized to get an overview of the participants' feedback.

Repeated statements about VR:

Pros:

- The tool would allow construction to be informative to a wide variety of people, even those who do not have a background in construction.
- In case of ambiguity or information gaps in the project, individuals can view the model and verify by themselves. This reduces the need for comprehensive RFIs.
- VR would be useful and informative as a tool for safety training for workers.
- It could be used as a marketing and advertising tool in order to attract clients.
- It is more informative than 2D drawings/blueprints, as it showcases views and angles that would go undetected in 2D representations.
- It can be used to help identify errors at an early stage, saving time and money.
- The construction site can be viewed remotely when physically traveling is inconvenient.

Cons:

- In order to assess the building holistically, information and a toolset for MEP services would be needed.
- There is a need for labels or tags for objects and equipment in order to identify their properties, parameters, manufacturer, material composition, etc.
- In order to properly assess elements like structural and architectural, it is necessary to measure distances, gaps, etc. A visual analysis is not sufficient.
- Navigation issues arise, such as users suddenly exiting the building and moving from room to room.
- The tool might receive some skepticism based on its use in the industry, especially by those individuals who are accustomed to conventional methods.
- The tool lacks accommodation for heavy-civil based projects and may be more suitable for architecture and interior design.

Repeated statements about the non-immersive tool:

- Non-immersive would be more helpful than immersive for educating more people in less time, for such situations as large meeting groups.
- Non-immersive would take less time to set up and avoid the need to invest in head-mounted goggles.

Repeated statements about the immersive tool:

- The toolset did freeze at times and required several attempts before it became effective again.
- The viewer may enjoy immersive more than non-immersive.
- Immersive creates a sense of walking through a real building and thus may be better suited for decision-making.

Repeated suggestions:

- There should be a legend or a key in order to identify the user's location on the building plan.
- Having a tag or a room name would help users understand the spaces better.
- A document showing the markings and zones to be refined and the item changes would help keep a log for the project team.
- Being able to get material, object and equipment properties and details directly from the system would be helpful for users so that they could have their questions answered without having to open the Revit model and navigate to the specific equipment.

The data collected from the two rounds of questionnaire are synthesized in order to address the research question in the conclusion, Chapter 5.

CHAPTER 5. CONCLUSION

5.1 Introduction

The purpose of the experiment and study was to understand the participants' opinions about VR and assess their feedback in order to answer the following research questions:

- How does virtual reality enhance the decision-making process in the construction industry?
- In decision-making for a client, is immersive VR better or non-immersive?

In order to understand the users' opinions and address the above questions, the experiment was broken down into two categories:

- A Likert Scale closed-ended questionnaire: The participants were asked to rate the system(s) on a scale of 1 to 5. Their ratings were analyzed and reinforced with data collected in the form of field notes by the researcher.
- An open-ended interview-type questionnaire: The participants were asked a series of open-ended questions, and the data were classified into codes, categories and themes. This helped sort their statements about VR into pros, cons and suggestions.

Data gathered from these methods helped answer the questions and assess the users' attitudes towards elements like:

- The pros and cons of the tool
- Areas of improvement for VR
- The parts of the tool that the participants found worthy to invest in and adopt
- The barriers that would hinder the adoption of the tool by a user or company
- The beneficial features that would encourage users and companies to use and promote the tool.

This conclusive chapter will display the information organized from the previous chapter in order to answer the research question.

Following what Yin (2011) says, here in the conclusion, we will be connecting our findings with the larger picture by comparing it to a higher conceptual level or to a broader idea. As a researcher, I choose to use my liberty to make an inference from the research and data collected. This does not necessarily mean rephrasing the findings, but rather taking it further to explain. The following chapter will address the research question and express the researcher's journey and exploration.

5.2 Reflection

When I envisioned this research, I had a fixed idea of the goal and the process I would pursue. The course of this study has revealed information that I had not expected to accumulate. During my professional experience, I have been exposed to virtual design tools and people's response to them, with me being one of the users. I have noticed that people discuss their opinions differently in regular life than when they're participating in a study. With a rough idea of the presence of the VR tool in the industry, I moved forward, learning with each stage about how to accurately set up a VR tool, run an experiment and analyze data. With the study by Castronovo et al. (2013) to guide me on the framework, I had a fair idea of how to pursue mine. My research began with my need to understand VR's support of construction. Decision-making being a vital part of a project, not to mention an area that can get complicated easily, it was an aspect I wanted to delve into. Based on what I've learned, VR is not completely utilized, and not as widespread as one would imagine. The individuals involved in the study revealed their excitement as they had not worked with the tool, either at all, or this closely, before.

A qualitative approach was used, as we were not looking for validation through a statistical number, but instead wanted to get an idea of the participants' journey so far and how it affected their perspective of the tool. During the interviews and conversations, participants opened up about their work experience, their colleagues and a general work synergy. Windows like this into the past of a participant would be best viewed and synthesized using a qualitative study. In this respect, Deacon (2000) is correct in saying that in any study, it is important to consider the context in which the topics we are researching occur. The participants were selected using "Purposeful" sampling. According to Yin (2011), the aim of this technique is to have those participants who will provide plentiful and relevant information on the topic. The graduate student participants elaborated on their previous work experiences, their educational degrees and their peers' opinions too. At times, the viewpoint of one participant contradicted that of others. According to Yin (2011), as cited in Campbell (2009) and Yin (2000), good research is conducted with a critical frame of mind. By doing so, possible rival explanations are tested and identified, integrally becoming a part of the study's process. Abiding by these guidelines, there were topics that came about during the data collection that generated colliding opinions. This contradicting feedback is addressed in order to mold a robust outcome and to find new perspectives on the tool.

The experiment began with giving the participant a brief idea of the project and offering to elaborate on any areas they found unclear. Proceeding to show them the model, I found it an important practice to take running notes and sketch out instances as they spoke, reacted and exclaimed. This technique was taken up actively after coming across the advice of Yin (2011), which says that like a typical photographer, who always holds a camera in case a photo opportunity happens, a researcher should always be prepared to write something down while doing research. These notes were referred to when validating a participant's survey response. It was sometimes noticed that participants would critique certain aspects of the system when they were viewing it, but when they were asked to fill out the survey, they were less vocal about their opinions. The field notes came as an essential tool to connect their response to their actual feelings. Bar graphs were created using the survey response, to create a graphical interpretation for comparison.

The next step in the research was gathering their feedback through an interview-type questionnaire. During the interview, it was observed that the participants repeated some of the statements they made when they were viewing the model. Noticing this, I made more accurate notes at the viewing, as this turned out to be their first and genuine impression of the tool. Some had an architecture-related background, and some had a civil-related background. It was interesting to see the variation in approach that was related to this background. Those with heavy civil background particularly questioned the use of the tool for their field. One participant went as far as to say that the tool would be mostly beneficial for an interior design kind of project, and not for civil-related. Some brought up the lack of MEP systems. Based on the opinions received, it is true that the tool investigated did not have MEP-related families, commands and toolsets. This finding needs to be addressed so it can be used in the future by software developers to understand and fulfill the needs of an industry. If a tool only caters to one sector of construction, then it loses out on versatility and credibility to the larger stakeholder pool.

The participants, however, met the model with appreciation and optimism towards its use in the future. They suggested ways to improve it to fit their needs and fill the gaps between construction and technology.

What I know that nobody else does

Technology is making its way into the construction industry. With departments allocated for technology like VDC (virtual design and construction), its impact is noticeable. What I noticed is that VR has reached a point where the graphics and tools are admirable. When I created the entire model, I myself was surprised how enduring the model turned out to be, even though I had done this for the first time. But what I believed was lacking was the toolset to cater to the other facets of construction other than architecture and design. However, the base tool Revit does support those aspects, and if necessary, the modeling part can be done in Revit and then converted to VR. Currently, however, the VR tool, Twinmotion, does not have such features. I believe that it is a matter of time before these features are implemented. With people giving their feedback to these companies and with research papers such as this one, software companies will take the cue to proceed further.

Importance of the research to the research question

According to Castronovo et al. (2013), project reviews are very rarely done using two separate display systems. Looking at the previous studies involved, a limited number of them involve participants comparing two different tools. Often, it is a single system examined in isolation. In reality, owing to the plethora of options available in the market, one could feel confused when selecting the program best suited for their task.

By narrowing it down to the system at hand and organizing participant feedback, this research offers constructive criticism in order to facilitate the evolution process of construction software. I believe that at certain checkpoints and milestones in tech advancement, it is important to confer with the user group, and this research does just that. We have included participants with diverse educational backgrounds, years of experience and age to gather their take on VR's contribution towards decision-making.

But we didn't want to blatantly ask them questions without giving them the gist of the software. We refrained from sending them a survey through email saying "Do you think VR is helpful for decision-making?" or "Do you think non-immersive is better or immersive?" Frankly, it would have been easier to do so, to send out a survey to a lump sum of people, gather their response, draw a graphical curve and conclude with a statistical inference. But we believed that it would only be a fair assessment if we showed our participants a working VR model so that they could give educated responses, not responses based off their sparse (if any) previous encounters with VR. In order to arrive at a quality product of research, we limited our participant numbers and increased the depth and involvement in the interview process. What we gain here is a deeper understanding of each answer, the liberty to question the source of their opinions and a chance to extract their feelings underlying every rating or judgement. What we lose in the process is the ability to reach a statistical inference due to the small participant group. I believe that to derive a user attitude, quality is more valuable than numbers, which led us to choose the qualitative route.

During the course of the experiment, it was noticed that the participants included their work and previous/current educational experiences in their answers. This added to the richness of the data and sometimes resulted in conflicting opinions. According to Campbell (1975) as cited in Yin (2000) and Yin (2011), one of the signs of valid research is having “rival explanations.” Giving the rival information due recognition and refining your original interpretation to acknowledge it only strengthens your research. Those points of contradiction were highlighted and given due assessment. Largely, the participants’ response to how they felt VR would enhance decision-making was in their own terms, particular to their diverse background. Most, if not all, of their answers were backed up with explanations and were not treated as a single point of answer to a survey. To address the research questions and perform the experiment, guidance was taken from previous research papers, faculty and books on qualitative study.

5.3 Reflecting on the research questions

How does virtual reality enhance the decision-making process in the construction industry?

- Involves a variety of individuals in construction

Deriving input from the gathered data, it was noticed that most participants felt that the tool allowed those not closely involved in the construction industry to understand the building and provide their opinions and feedback. This was, for the most part, compared to using conventional blueprints, which they pointed out can be difficult to understand.

- Reducing the number of RFIs

With the VR model available for a variety of team members to take a look at, and the navigation designed for all individuals alike, people can view the model and clarify an area of ambiguity by themselves, thus reducing the number of times they contact the designer and generate RFIs.

- Highlighting safety and integrating its aspects at an early stage of construction

Participants noticed instances in the model that they believed would be a safety hazard during construction and for the end user. Safety-related decisions are important, and most companies pride themselves on prioritizing safety. This tool could help identify, communicate and rectify these concerns during the planning stage. The model could also be used for training laborers and site personnel about safety concerns such as fall protection, electrocution and sharp edges. It would give them familiarity with the building and help them understand zones of potential risk.

- Allows project decisions to be made in remote

For those individuals who would not be able to visit the construction site, this tool could help them communicate with the on-site team and to identify and tackle issues. It adds a level of convenience for the decision-making participants and allows an avenue for them to give their input.

- Project estimates can closely be monitored with the model to reach a financial consensus.

Participants identified portions of the model that had more equipment than required and flooring that was not suitable. Such refinements would change the estimates and the subcontractors/vendors involved. The model can be tackled from an estimate kind of perspective, with decisions made based on the procurement of material, objects and equipment.

In decision-making for a client, is immersive VR better or non-immersive?

Strong evidence of VR’s benefits has come from more than just spectacular visual presentations. Studies show that different immersion components have other benefits and complete immersion is not always required, as per Bowman and McMahan (2007).

According to Castronovo et al. (2013), for decision-making and identifying errors, a high-quality visual tool can provide significant benefits. With a variety of tools available that vary in features and the nature of immersion, it could present a challenge for users to select an appropriate tool for their task.

This study uses the input of the participants from the Likert scale questionnaire and the open-ended interview and cohesively analyzes the two to find a response. The participants who were exposed to both systems rated immersive relatively high on the ease of use, visual output and model attributes. Key variations were found when group sizes and task were considered. For instance, based on the feedback given by the participants, it was observed that the immersive tool is more suited for smaller groups who want a higher level of immersion. Working in smaller groups, according to them, would allow the individuals to take turns viewing the model. To educate and train larger groups, and for those who would find it easier to use a standard computer-screen operation, non-immersive turned out to be the preferred choice. With regard to sharing the model with partners working from a distance, non-immersive was said to be a better choice, as there could be no guarantee that the receiving end has the equipment required for immersion.

In comparison, it was observed that the non-immersive tool, which has a lower degree of immersion, is more suitable for larger audiences for different use situations. If there are a large number of people, head-mounted apparatus would be needed for all. Another thing to consider is that if they were all wearing headsets, the tool would not support them to see each other and work together to reach a consensus.

5.4 Potential Limitations

Some of the identified limitations of the study are:

- Only two types of VR are addressed in this research, immersive and non-immersive. That does not imply the sole presence of only two options, as there are variations of the same available to the user.
- The sample size is purely for qualitative analysis, and a statistical inference cannot be made for a general population.
- The effectiveness/ineffectiveness of VR is not limited to the variables defined in this study. The areas of focus, especially in the Likert scale questionnaire, are ease of use, visual output, model attributes and appropriateness for decision-making.
- A few of the questionnaire items were adopted from literature study in order to capture the viewpoints of participants and see if they were in track with the findings of a previous study.
- The interviews were done with graduate students from the department of construction management. It is possible that the opinion of persons of a different university or degree stream might generate an outcome that differs from this one.
- The opinions of participants are not differentiated based on the level of experience, current academic status or level of education previously attained.
- According to Meier (2003), and as assumed in this study, participants' responses are assumed to have used unbiased retrieval strategies (where the individual uses information

from their memory directly and without bias to answer questions). However, there could be a possibility that the responses are derived from generative strategies (where the individual produces responses that are not based on accurate recall due to an unwillingness or inability to derive relevant information from their memory). In this research, it would be difficult to identify the retrieval strategy of their responses.

5.5 Reliability and Validity

Reliability

According to Lincoln and Guba (1985), reliability involves producing results that are consistent, time after time. In qualitative research methods, the standards that ensure the reliability of a study are credibility, transferability, dependability and the confirmation of the findings. Research is said to be credible if it has used established research methods; this research has adhered to using such methods in aspects such as participant sampling (purposeful/selective sampling) and data analysis (narrative analysis), among others. Addressing transferability, the findings of this research are specific to a small number of participants. It is not possible to showcase its applicability to other populations and situations. The strategy followed to make it transferable is to describe not just the experiences and behavior of the participants but also the context, making it meaningful to the reader. To highlight dependability, the experiment is reported in detail, allowing a future researcher to evaluate or replicate the study, if not necessarily attain the same result. And finally, the findings can be confirmed, as they are results derived from the participants' ideas and experiences. The research has reached a conclusion that considers evidence gathered from the interviews.

Validity

According to Maxwell (1996) as cited in Yin (2011), validity of a research is essentially its quality control. Valid research has obtained and interpreted the data correctly so that the results accurately reflect and depict the real world (or laboratory) that was studied. According to them, there are 6 ways of addressing a validity challenge:

1. Intensive field involvement: the study involved close communication and involvement of the researcher.

2. Rich data-detailed interviews: An extensive interview was held and different types of data were collected from it.
3. Validation of the respondents: Participant feedback was directly taken from the participants and placed into codes, categories and themes without altering the source itself.
4. Testing rival/competing explanations: Negative evidence and contradicting opinions were highlighted and addressed.
5. Triangulation: With the process of thematic coding, converging evidence was gathered from different participants and literature sources as well.
6. Quasi-statistics: Numbers associated with the Likert scale responses are utilized when associating with claims.
7. Comparison: Comparisons are made between participants and focus groups.

5.6 Recommendations

Our findings show that certain parts of the VR tools need to be refined to be a more robust platform for users. According to Takki (2019), the degree to which construction companies actually use digital technologies varies, and the prospect of adopting such technology is often met with indecisiveness and uncertainty. This was noticed for the most part, as the participants, even those with work experience, had not previously been exposed to a tool such as this for construction. This was also demonstrated in a pre-test demographic survey, where the majority of the participants said they had not engaged in construction related VR. During the course of the experiment, the participants were enthusiastic about experiencing the tool. Their input involved positive feedback, constructive criticism and suggestions, with almost all believing it to be a beneficial tool. In order to direct these findings to the construction companies and VR developers, a segment has been allocated to each, in hopes that these ideas would be included in their future plans and ventures.

5.6.1 **Implications**

Since this is a qualitative study with an open-ended questionnaire, the data collected address more matters than just the research questions. The data include suggestions for developing the user interface and offer advice to construction companies.

5.6.1.1 <u>For VR developers</u>

The AEC industry is seeing a variety of options of VR-based software and plug-ins, such as Twinmotion, Enscape and Unity 3D. With professionals in the industry having a diverse educational background, job description and project needs, a tool with versatility would best cater to their needs. This research offers user feedback and suggestions to help enhance their experience. According to Pagano and Brügge (2013), user input provides valuable information for developers, helps to enhance software quality, increases the consistency of the tool and helps identify missing features. Suggestions mentioned in Section 4.2.2 could be addressed and adopted by a VR developing company in order to make their tool more fitting for the industry.

5.6.1.2 <u>For construction companies</u>

Implementing new technology is important in the construction industry. According to National Information Economy Office (NOIE, 2000) as cited in Stewart et al. (2004), information technology (IT) is growing increasingly, and in the near future, it is expected to become the dominant tool for communication between organizations. Moreover, information from NOIE reveals that in adopting IT, the construction industry lags far behind other industries. This study has acquired data from participants who have a variety of educational backgrounds. They also have varied degrees of work experience. The majority had not seen or been involved in activities such as VR during their experiences. These statements support the data from NOIE (2000). They believe in several benefits such as the ones listed in segment 4.2.2 under "Pros" and address how VR can create a feeling of inclusion, reduce ambiguity/number of RFIs and increase safety.

5.6.2 **Recommendations for Future Research**

The results collected during this experiment can help construction teams select an immersive tool that best fits their project needs. A few factors to be kept in mind regarding this research would be the small participant number (*n*=9), hence we are not reaching a statistical inference with our results. The participants involved are graduate students and are not involved in the project. The project shown to them is an institutional building modeled in Revit and developed into VR using Twinmotion. Further studies could include increasing the participant numbers, choosing a different genre of project and recruiting participants of a different background. Involving new variables in the study would generate data that are unique, and would gather a well-rounded set of feedback by individuals who could represent a user of the tool in the near future. By doing so, gaps in the tool and its adoption could be addressed and used to create a robust tool.

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APPENDIX A. PRE-TEST DEMOGRAPHIC QUESTIONNAIRE

Pre-test demographic questionnaire: (to all the volunteers)

A generalized questionnaire formulated by the researcher will be given to all members prior to being exposed to the virtual training program. This initial questionnaire will inquire about their previous education, exposure to VR technology, their personal opinion on adopting a new format and the amount of practical experience they have had in the industry. Select the box or type where necessary:

Q1 What level of education are you currently enrolled in?

- ○ Masters 1st year
- ○ Masters 2nd year
- ○ PhD Candidate
- ○ If other, please specify: ____

Q2 What is the title of your previous educational degree?

- ○ Bachelors
- ○ Masters
- ○ If other, please specify: ____

Q3 What stream was your previous educational degree?

- ○ Architecture
- ○ Civil Engineering
- ○ Construction Management
- ○ If other, please specify: ____

Q4 How much work experience have you previously had in the construction industry?

- ○ None

○ 1 month to 1 year

○ 2 years

○ 3 years

○ 4 years

○ Greater than 4 years, please specify: ____

Q5 If you do have experience, did your company(s) use VR or any BIM tools on projects?

○ Yes

○ No

Q6 If yes, which one?

○ Revit

○ Navisworks

○ ArchiCAD

If other, please specify: ____

Q7 Have you personally interacted with virtual models before? (Revit models, ArchiCAD models, Sketchup, or any in the BIM platform)

○ No

○ Yes

Q8 If yes, please specify which software:

○ Revit

○ Navisworks

○ ArchiCAD

○ Sketchup

○ If other, please specify: ____

Q9 Have you previously enrolled in VR related academic coursework?

○ Yes, specify: ____

○ No

Q10 Have you used Virtual reality for academia?

○ Yes, specify: ____

○ No

Q11 Have you been exposed to VR based entertainment?

○ Yes, specify: ____

○ No

Q12 Would you call yourself optimistic with adoption of a new tech format?

○ Yes

○ Not sure

○ No

Q13 Do you believe that integrating a new technology with construction will be beneficial?

○ Yes

○ Not sure

○ No

Q14 Do you believe that using VR would help making decisions in the preconstruction/construction process?

○ Yes

○ Not sure

○ No

APPENDIX B. POST-TEST USABILITY EVALUATION: RESPONSE TO STATEMENTS USING A LIKERT SCALE

Q1 Ease of use (sensory)

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Interacting with the platform was a comfortable experience	○	○	○	○	○
It was easy to navigate through the platform (Movement in model)	○	○	○	○	○
The user interface was easy to use	○	○	○	○	○

Q2 Visual output (sensory)

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
The information provided in the system was clear	○	○	○	○	○
The system reflected a realistic practical experience (Sense of presence)	○	○	○	○	○

The screens clarity was appropriate for my task	○	○	○	○	○

Q3 Model attributes

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
Was able to access the building with diagram/model/visuals provided	○	○	○	○	○
It was easy to comprehend material and textures	○	○	○	○	○
Objects in the model were properly sized	○	○	○	○	○
Was able to assess the magnitude of the building	○	○	○	○	○

Q4 Appropriateness for decision making

	Strongly disagree (1)	Somewhat disagree (2)	Neither agree nor disagree (3)	Somewhat agree (4)	Strongly agree (5)
It helped me make decisions I was asked to make	○	○	○	○	○
I believe the system could improve the decision making process in a	○	○	○	○	○

real construction project					
The tools, graphics and visuals were useful for making decisions in building construction	○	○	○	○	○
This tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers to subcontractors)	○	○	○	○	○
This tool would be informative for a large project meeting group (10+ people)	○	○	○	○	○
This system could improve the decision making process in a real construction project	○	○	○	○	○

APPENDIX C. OPEN-ENDED QUESTIONNAIRE FOR GROUP 1 AND GROUP 2

The interview takes around 30-45 minutes.

Date and time of Interview____

Person interviewed____

Location of Interview- description of space__________________________________

Researcher announces the following points before the interview:

Letting you know that the participation is voluntary and you can decide to stop at any point.

I will be recording your answers, please let me know if you have any issues about this.

Do you have any questions before we begin with the questions?

This interview could take us 30-45 minutes; shall I begin?

1. Did you experience nauseousness or disorientation at any point of this experiment?
2. Was the process of dealing with the equipment/navigation tools smooth, or did you find yourself struggling with trying to understand how to use something? If yes, why?
3. Is there anything you would like to change about this to make your experience better?
4. Was there anything unclear or ambiguous in the model? what was it?
5. Do you think this tool would be informative to a variety of personnel involved in construction (From laborers to clients to designers), Why?
6. Do you think his tool would be informative for a large project meeting group or a small group, please explain?
7. If you had the opportunity to work on VR would you choose this option and why?
8. Do you think this platform will aid in construction decision making and why?

APPENDIX D. QUESTIONNAIRE FOR GROUP 3: COMPARISON OF NON-IMMERSIVE VS. IMMERSIVE

The interview takes around 30-45 minutes.

Date and time of Interview____

Person interviewed____

Location of Interview- description of space__________________________________

Researcher announces the following points before the interview:

Letting you know that the participation is voluntary and you can decide to stop at any point.

I will be recording your answers, please let me know if you have any issues about this.

Do you have any questions before we begin with the questions?

This interview could take us 30-45 minutes; shall I begin?

1. Did you experience nausea or disorientation in either of the platforms? Please elaborate.
2. Which of the 2 systems do you think would be more informative to a variety of personnel involved in construction (From laborers to clients to designers)
3. Which of the two was more informative on materials and texture. In which ways
4. Which of the two had better clarity and lighting?
5. Which of the two better facilitated decision making? Why was it better
6. If you had the opportunity to work on a VR which platform, which would you prefer and why?