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Feasibility of Using Virtual Reality in Requirements Elicitation Process

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Feasibility of Using Virtual Reality in Requirements Elicitation Process

A Thesis Presented To

The Faculty of the Software EngineeringDepartment

by

Aman A. Bhimani

In Partial Fulfillment

of Requirements for the Degree

Master of Science in Software Engineering

December 2017

Feasibility of Using Virtual Reality in Requirements Elicitation Process

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Contemporary Virtual Reality (VR) technologies offer an increasing number of functionalities including head-mounted displays (HMD), haptic and sound feedback, as well as motion tracking. This gives us the opportunity to leverage the immersive power offered by these technologies in the context of requirements elicitation, especially to surface those requirements that cannot be expressed via traditional techniques such as interviews and focus groups. The goal of this thesis is to survey uses of VR in requirements engineering, and to describe a method of elicitation using VR as a tool.

To validate the methodology, a research plan is developed with a strong empirical focus. According to this plan, after an identification of VR technologies in the market, the most appropriate hardware and software is selected for experimentation based on the degree of immersion. An experiment is designed and conducted for gathering landmarks for a navigational system (e.g., buildings, point of interest,), in addition to distance and time, to provide directions to users. The experiment aims to: gather these tacit components of the navigational system, and gather the usability of VR methodology compared to other traditional elicitation methods. Overall, this research will clarify and understand the usability of VR in a requirements elicitation setting. The methodology will be useful when highly immersive VR technologies - currently expensive for consumers - will become available at limited costs, and a more widespread exploitation will be possible for requirements elicitation.

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1 Introduction

In recent years, *Virtual Reality* (VR) has been used in many industries such as entertainment, medicine, and education; this technology has been a great asset in all these fields and shows all the potentials to be *a great support* in the Requirements Engineering (RE) process, especially in requirements elicitation. The key proposal of this thesis is to utilize VR technology for requirements elicitation. Indeed, there are numerous opportunities offered by VR which can provide a great deal to the elicitation (and possibly validation) of requirements. One of the main aspects which is very promising about VR is that 3D environments offers a controlled immersive environment in which it is intuitive to monitor and analyze the behaviors of the participants without interfering and possibly making the participant forget about the fact that he/she is being observed.

In this thesis, the feasibility of using VR technology for elicitation of requirements will be explored. It is my general hypothesis that using this elicitation technique, alongside others in certain projects, will benefit the project greatly in terms of the quality and quantity of requirements collected from stakeholders. However, before investing the time and effort required to build a formal elicitation technique, which may involve developing environments, an observational experiment can help determine whether the effort is necessary. The initial results from the data collected in this thesis, is used to determine it is actually worth investing the time, effort, and money in this endeavor.

VR can be used as an advanced observation technique without the typical limitation of observations. Indeed, in-field observations, which guarantee the immersion of the participant, can be very time consuming, while observations in a controlled environment might be biased by the lower level of immersion. However, in addition to observation, VR can also provide varying levels of interactivity between the system and user.

Although Virtual Environments (VEs) have already been explored in RE [1, 2, 3, 4], their focus does not include the development of a new elicitation technique; rather, focuses on virtual prototyping, validation of requirements, and safety-critical systems. A set of requirements that is closer to complete is far more beneficial to have, as analysts often miss requirements due to miscommunication between stakeholders and analysts, which may be more prevalent in natural language communication such as English. However, some requirements require visual cues; the subject may not be able to explain it in traditional method such as interviews or focus groups.

The scope of this thesis also includes a literary review for the state of art in VR technology. Literature review will also include all similar works found in the recent years, and a summary of their findings. Furthermore, I will also describe preparation steps, roles and responsibilities of stakeholders, analysts, and the technology. In order to determine whether using VR as a tool in eliciting certain requirements, an experiment will be developed using Google Maps, Street View, and Google Earth VR technologies, and performed using participant stakeholders from Kennesaw State

University (KSU). The results from this experiment will be a partial proof that the elicitation technique can be quite useful in the act of elicitation of requirements.

Concluding the study, based on the results found in the experiment, a determination of the future fate of the study is made. In order to further eliminate the threats to internal and external validity, there is a need for further experimentation, preferably in several different domains; as well as a documentation of the method of duplication for the use of VR.

1.1 Motivation

The RE process entails the elicitation of requirements, their modeling, analysis and specification, integration, and validation [5]. In this process, requirements elicitation is considered to be one of the most important phases. An error or an incompleteness introduced in this phase, even if discovered later during the software life-cycle, might considerably affect the success and the cost of a project. Statistics report that around 70% of all errors in a system are due to incorrect system specification, and 30% revolve around design issues [6]. Therefore, inadequate requirements elicitation is responsible for most of the errors in implementing the system.

At the same time, elicitation is also one of the hardest to successfully accomplish since it requires several people to collaborate from varying backgrounds towards a particular goal. There are two main populations that participate in the elicitation process: stakeholders and requirement analysts. The stakeholders are generally comprised of customers, personnel in the business domain, final users, and financial supporters of the project under development (e.g., clients, external sponsors) [7]. On the one hand, stakeholders have the domain and the functional knowledge of the end product. Requirement analysts, on the other hand, need to understand and model this knowledge into functional and non-functional requirements. Creating a complex software solution for a problem may also require many different types of requirements. Being able to elicit all of them can become quite difficult and, to be successful, requires both communication and technical skills of the analysts and adequate supporting techniques.

The information exchanged and collected during the requirements elicitation phase can be complex and the difference in the domain knowledge between analysts and stakeholders makes the process even more difficult. On top of that, relevant information for the system to be could be present in form of tacit knowledge [8], which represents knowledge possessed by the stakeholders, of which the analyst is not aware of. This knowledge might also represent procedural knowledge, which includes sequences of actions that are second nature to the stakeholders, and are performed in an automated way. While eliciting tacit knowledge, there is a significant amount of information transferred non-verbally as seen in past research and experiments [9].

Using traditional techniques of requirements elicitation (e.g., interviews, questionnaires, focus groups, and workshops [7, 10]), or even a combination of these techniques, can result in information that is missing essential content and ambiguity in the information that is collected [5][11][12][6]. However, traditional techniques, and among them especially requirements elicitation interviews [13, 14, 15, 16] are still prevalent in the industry, and very little has been done to introduce innovative techniques in traditional companies[1]. Traditional techniques usually use a spoken or written language such as English, which introduces many different meanings for phrases and words. Some stakeholders or analysts may not have a common language that they are most fluent in as well; for example, stakeholder prefers to communicate in English, and the analyst in Spanish. This disconnection between the two parties can create a miscommunication that is reflected in the set of requirements collected.

For this reason, I believe that VR could provide an out-of-the-box technique that will elicit requirements not achievable through the traditional techniques mentioned earlier. Due to it's visual and interactive nature, there are certain types of requirements for which VR works very well for. Although VR has been used in other sectors of Requirements Engineering (RE), elicitation phase has yet to be explored using VR.

To be clear, the purpose of this study is to develop a technique that can very reliably elicit a subset of requirements for a system. A complete set of requirements can be obtained, for certain projects, by using this technique along with other elicitation techniques already available. This thesis will be the first step in describing an elicitation technique that uses VR as it's main tool; with an experiment that

---

[1] This is not true in innovative companies, which at least manipulate traditional techniques depending on the faced problem [17].

explores it's feasibility.

1.2 Thesis Direction and Research Questions

The thesis is a part of a bigger study of creating an elicitation method using VR as a tool; it is only the first step of evaluating whether or not VR is worth delving into. Since immersive VR is a much newer technology than Requirements Engineering, it is crucial to first recognize the compatibility of VR in an elicitation setting. Is it worth developing high-cost environments and investing in further immersive hardware for RE? These questions are not answered simply, and preliminary research is necessary to get started.

In order to create an elicitation technique, an evaluation of the feasibility of the technique is needed; an extensive literary review of the related fields; and a survey of new VR technological field is necessary. I will also need to select certain hardware, software, and experiment ideas that are feasible enough to run experiments and prove that the elicitation technique can provide significant results.

Figure 1 describes the flow of the research plan and activities needed for a successful research study. Nodes that are on the same horizontal plain can be worked on concurrently, and the arrows represent sequential tasks. In order to traverse through a node, every incoming arrow must be completed beforehand. For example, for the experiment to be started, "Virtual Environment Development", "Requirements Suitable for VR", and "Observations in VR" must be completed.

Figure 1: Research activities to be completed for the success of this study

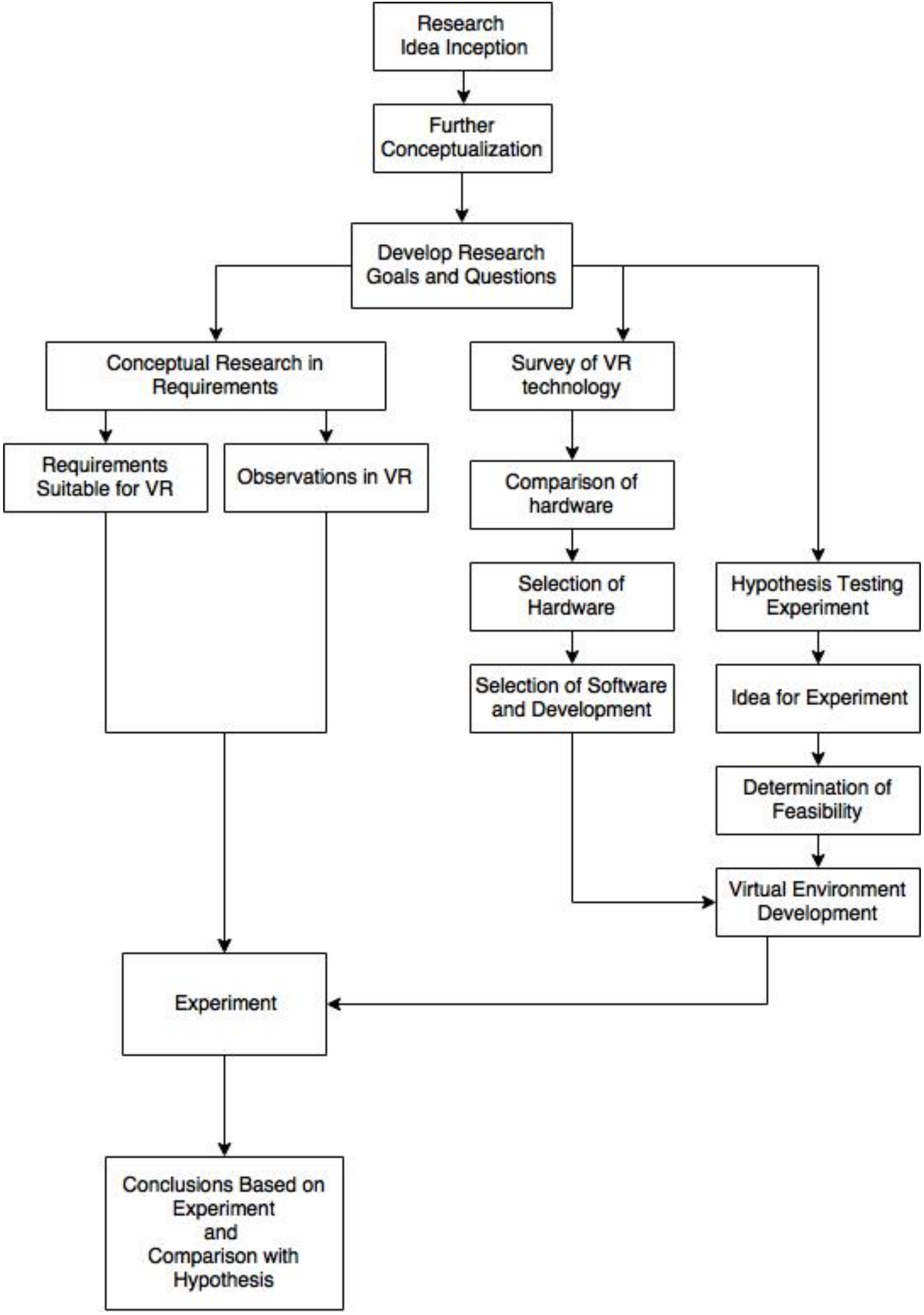


Figure 2: Further describes the Experiment node in Figure 1

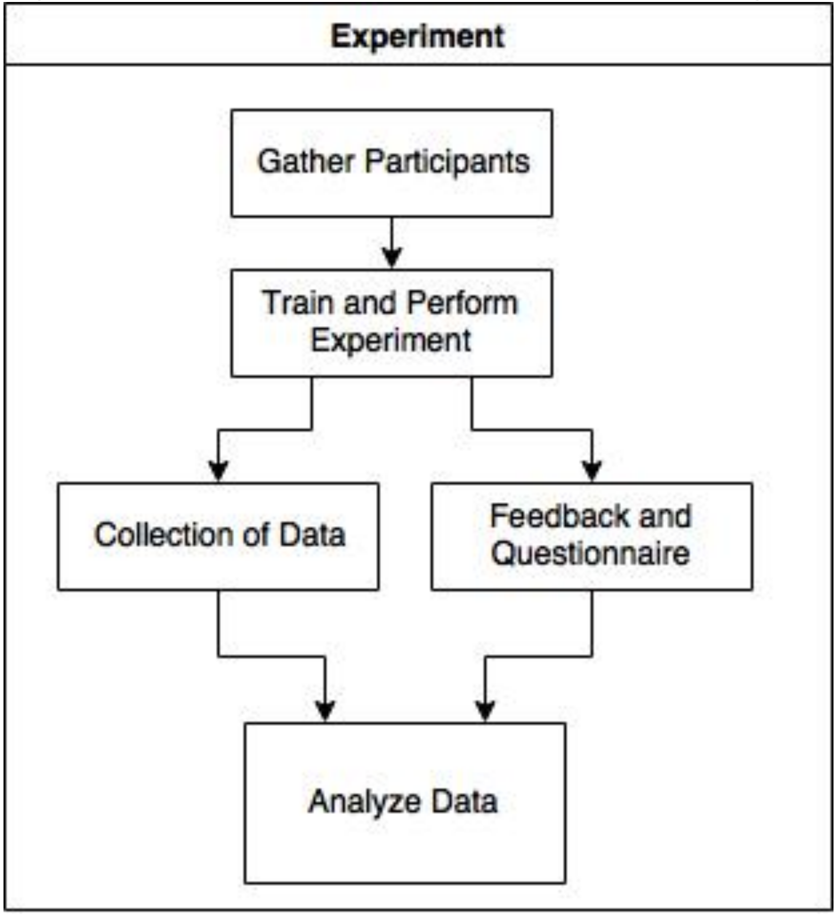


Figure 2 expands the “Experiment” node further to explain the sub-steps in this phase of the research study.

Research Questions: Depending on the results for these questions, further controlled experiments may need to be conducted to provide a concrete theory and generalized method of using VR in requirements elicitation.

- RQ1: In it’s current state, is using VR as a tool for requirements elicitation feasible?
- RQ2: Does using VR as a tool for eliciting certain requirements provide significant benefits over eliciting the same information with traditional methods (eg. interviews, questionnaires)?
- RQ3: Does VR technology still have significant usability issues to be detrimental for using it as a tool for requirements elicitation?

In particular, the main objectives of this thesis are to:

- survey the current state of VR technology including previous research, hardware, and software, related to Requirements Elicitation
- determine and describe the types of requirements suitable for elicitation using VR tool
- develop and test an example environment by eliciting information from participants to determine feasibility of using VR

- analyze the information collected to determine the current feasibility and successfulness of VR for elicitation
- determine the initial usability of VR in a requirements elicitation setting

1.3 Section Summaries

The rest of the study can be summarized as follows: a literature review, preparation of VR for the elicitation technique, documentation for the elicitation technique, an exploratory experiment to evaluate VR, data collected, the threats to validity of this study, and results and conclusions that can be drawn.

Section 2 reviews the methodology used for finding related works to this study. Although I am unable to find closely related studies, there are several domains related to the development of this VR elicitation technique. Namely, elicitation of requirements, VR and it's usability, immersion in VR, and various other subfields of requirements including virtual prototyping, validation of requirements, and safety-critical systems. The most prominent works are listed and information learned from these works is summarized. Referring to the flowchart of this study in Figure 1, the comparison and selection of hardware is also done in this section.

Section 3 describes the method development for requirements elicitation using VR. This includes a preparation phase including steps needed in order to perform experiments of your own. This may include: determining the level of immersiveness needed for the elicitation technique; determining the hardware and software required;

roles and responsibilities of stakeholders, analysts, the environment and technology; and various requirements of the VR hardware. Furthermore, the elicitation protocol, and data collection is presented.

Section 4 describes an experiment developed in order to validate usability of VR. This experiment tries to elicit landmarks for a navigational system for directing users along with distance and time information. Along with collecting landmarks as requirements for navigation, a usability evaluation for this technique is also conducted.

Lastly, Section 5 discusses some positives and threats found during the experiment and development of this VR-Elicitation technique; along with future work to advance this technique and concludes the thesis.

2 Literature Review

This section presents a review of all the research conducted before the inception of the idea in this paper.

In order to find relevant articles for the purpose of this literature review, the following keywords have been used: Virtual Reality, Virtual Environments, Requirements Elicitation, Requirements Engineering, Immersion, and Challenges. A permutation of these keywords were used in order to find works that are similar or closely related to ours, potentially with research that adds knowledge to this one. For example, (VIRTUAL REALITY) AND (REQUIREMENTS ELICITATION) could be one such permutation of keywords.

The databases and publishers that articles were found in include (but not limited to): IEEE Xplore, Science Direct, ACM, IET Softw., and Eurographics Association. Surprisingly, there were no works found that directly correlated to the work being done in this study. Since VR technology is very new, there is hardly any research being done in the field of requirements elicitation; however, there were works found in the fields of requirements certification [3], validation [4, 18], negotiation [1], and process elicitation [2].

The rest of this section describes the current state of art in Virtual Reality, how VR and Requirements Engineering are related, and statistics for the classification of works found in the literature review. Previously conducted research has an important role in this research as it enables us to focus on the main objective: to successfully use VR as a requirements elicitation technique.

2.1 State of Art in Virtual Reality

In order to understand how VR can be effectively used as an elicitation technique, I must first understand what makes VR effective in itself. There are many attributes of the hardware and software currently available including the capability to project highly immersive virtual environments, several tracking mechanisms to track subject movements, and other output capabilities including sound and haptic feedback.

VR is a large technology field that encompasses many different types of environments, with different immersion levels. However, many researchers in the past have found that high-fidelity immersive environments are far better in many aspects [19][1][20]. As an umbrella term, VR encompasses text-based, 2D, and 3D environments [21]. Although they are still considered to be VEs, in this study, environments within text-based or 2D mediums were not considered due to the lack of achievable immersion and they are out of the scope of this research.

Since the real-world is three dimensional, 3D environments are the closest form to achieve immersion with VR. Immersion can be defined as the extent to which technology can deliver an inclusive, extensive, and vivid illusion of reality to the human senses [22]. Visual, auditory, haptic, vestibular (sense of motion), smell, and taste are the sense that have been explored in immersion of VEs [23]. Visual and auditory immersion have been quite popular in recent industries and due to this popularity, it is becoming easier to incorporate visual immersion in VEs. In contrast, it is still far too costly to create VEs with sense of vestibular, smell, and taste immersion; therefore, this research will focus on visual and haptic attributes of VR.

Display technology is one of the main reasons for VR's excellence. The display in the Head Mounted Display (HMD) is also the only visual object the participant can see while immersed in the virtual environment; therefore, it is crucial that the display is of high quality. There are three main aspects of the display in question: pixel resolution, field of view (FOV), and the screen refresh rate. It is important for the screen resolution, measured in horizontal and vertical pixel (px) count, to be high enough to be clear; the desired resolution in today's standards is 4000x4000 px [23]. Another main attribute of visual displays is the virtual camera's Field of View (FOV), "the angular area in the physical world within which the user can see the virtual world at any instant in time" [19]; with a wider FOV, an actor in the VE is able to compare it to the real world. A healthy human eye's FOV is roughly 140 degrees horizontally; the binocular FOV being around 190 degrees [24].

Obtaining higher FOVs is also one of the main ways to increase the immersion of VEs, which is crucial in obtaining better feedback for certain types of requirements elicitation. However, some of the downfalls for higher FOV include distortion of images and heavy load on host system's resources [23]. When the FOV is increased, there is much more of the scene in sight of the display's camera; which means many

Table 1: Comparison of VR Enabled Technologies

VR Technology	**Resolution (px)**	**Refresh Rate (Hz)**	**FOV**	**Tracking (ft x ft)**
HTC Vive	2160 x 1200	90	115	12x12
Oculus Rift	2160 x 1200	90	115	15x15
Google VR	Upto 2560x1440*	Varies	90	N/A

more calculations need to happen in real-time to render models. The optimal way to increase FOV without distortion would be to increase the virtual viewing angle along with physical screen real-estate; this can be accomplished by adding more screens, or having a wider physical screen. Surround-screen systems such as the C2 have partially resolved this issue by creating a $12'$x$9'$x$12'$ display which spans across three walls of a room [3].

Due to the popularity in VR in the past few years, there are several options to consider for the hardware to be used. As discussed earlier, visual qualities affect the VR experience greatly, as such, Table 1 compares some of the most popular HMDs in production at the time of writing. The HTC Vive and Oculus Rift are displays that must be connected to an external system such as a computer. Since both of these devices have only one screen, the resolution listed is for both eyes, therefore, the final resolution per eye is 1080x1200 px. Google has also launched two versions of VR headsets, however, they are not displays in itself. Google VR requires a display to be placed in the head-mounted band, usually a smartphone. Applications running within the device then simulate a stereo display that can be seen through the lenses. The refresh rate and screen resolution depend on the capabilities of the device.

From the list of VR enabled technologies compared in Table 1, the HTC Vive was selected for this research due to it's extensive tracking technologies and competitive attributes. In addition to the ability of running high-fidelity environments in real-time, it enables us to track the participant's hand, head, and body movements in a small room (12ft x 12ft).

The main reason for us to understand these attributes of VR hardware and software is presence and immersion. There have been several works that describe the importance of immersion in a VE; however, it is quite recent that a significant level of immersion is achievable. Slater et al. describes the highest level as "Matching" immersion as the head, arms, and body movements inside the VE "match" the person in real life [22]. Immersion is a way to self-represent yourself in the environment. This is achieved via a HMD, sensors in a room, and hand-tracking technologies.

Since the participant is holding a device in both their hands, namely controllers, it is possible to achieve this matching level of immersion. Sensors in the VR system enable us to track the user's head, arms, and body very accurately. Haptic feedback is also provided via vibration motors in the controllers. Therefore, the matching immersion is achievable with HTC Vive and Oculus Rift. This technology has been used in video games for decades, and it is being translated towards VR.

Presence is the psychological state of being inside a VE. The participant must forget the fact that he or she is in a VE. The participant must perceive the virtual body as theirs, and act as if both bodies are one [25]. This has become increasingly easy ever since technologies such as Oculus Rift, and HTC Vive have been released. Kilteni et al. describe this fact of presence in the following senses: self-location, agency, and body ownership. However, the HMD that the participant must wear is still very heavy, and has wires running from the display to a host computer, which is a threat to it's validity. Future revisions of such headsets are bound to make it possible to have wireless capabilities.

2.2 Virtual Reality and Requirements Engineering

As mentioned previously, there have been many works that use VR in related fields, and no works directly related to the elicitation of requirements. However, a lot was still able to learnt from the effort and results of these different works; therefore, they are described here and mentioned with their separate lessons. The following are a subset of all the works read for preparing this study, starting with works most related to elicitation techniques.

Harman et al. has proven that virtual environments indeed provide an effective platform for knowledge elicitation [2]. The study experimented with using virtual environments for process elicitation from experts of the fields (stakeholders). These experts hold tacit knowledge, unknown to the analyst, which needs to be extracted. A virtual environment was proven to prime the stakeholder's memory; therefore, they remembered more tasks in the entire process; using a VE identical to the stakeholders' working environment, their memory was refreshed. The participants were able to more clearly remember the process in the virtual environment rather than on paper. It was also found that while using VR, documenting the process was much faster. Although the study was closely related to elicitation of information from stakeholders, it did not involve any VR equipment or immersive environments. The stakeholders used environments on a computer screen, and traditional input devices such as keyboard and mouse. As researched from previous studies, an environment with higher level of immersion increases the performance in the tasks performed [19].

Sutcliffe et. al describe a technique named Immersive Scenario-based Requirements Engineering (ISRE), which uses virtual prototypes for validation of requirements [18]. A focus on presence, immersion of the environment, and validation was emphasized, however, no elicitation technique was described in the study. Sutcliffe describes a good classification of requirements errors distinguished from usability problems that inherently exist in VR. However, some of the drawbacks of VR mentioned by the study have since been fixed and improved upon; for example, lack of haptic feedback and inadequate graphics as described by Sutcliffe have since been improved to an acceptable level for an immersive experience in VR.

Similarly, validation of requirements for safety-critical scenarios where human life or large monetary value is in danger is quite popular [3, 4]. Virtual Environments were proven to significantly narrow the range of test cases to be performed, and ultimately the cost for a large project. Humans can understand and verify three-dimensional models of a specification much more than formal specifications or implementation code. As long as the virtual environment can replicate the domain-specific features and constraints, it can be used to simulate highly accurate versions of the real-world. For an example, VR can be used to test the safety of a car while keeping costs to a minimum for repeated testing [3].

Another divergence important to mention is that researchers have been exploring virtual worlds, whether they are immersive or not, to complete the gap between distant analysts and stakeholders. The Internet has enabled us to utilize it's potential for requirements engineering across the globe. Erra et al. compared the effectiveness of different distributed techniques for requirements elicitation - including text-based interaction, and a 3D virtual environment [1]. It was found that the 3D environment was more engaging and resulted in a higher quality of requirements than text-based communication. However, there was no immersion in any of these environments, which is proven to be beneficial for enhancing the VE; the environment was merely used to fill the distance gap between participants.

2.3 Summary of Related Work

After extensive search, it is known that there is a lack of including VR in requirements elicitation techniques. Currently, there are virtually no methods previously described that use this high-fidelity technology to our advantage, and therefore, this study plans to complete that gap. It is highly important that we, the RE community, take advantage of VR technology to improve the elicitation process. The rest of the paper

Table 2: Related studies considered as a knowledge base

Requirements Engineering	[5], [6], [7], [10], [15], [26]
Ambiguities in Elicitation	[12], [13]
Stakeholder Tacit Knowledge	[8], [9], [16]
Distributed Elicitation	[27], [1], [28]
Process Elicitation	[2]
Immersion in VR	[19], [22], [25], [20],
State of Art in VR	[21], [23]
VR for Safety-Critical Systems	[22], [29]
VR for Validation	[30], [3], [4], [18]
Usability of VR	[31], [32], [33], [34]

will describe on how the study plans on doing that, and describe the technique as well, in detail.

From all the works found and read previously to this study, Table 2 summarizes each of the main fields considered as a knowledge base. Please keep in mind that even though some of these studies were not listed and described in the Section 2.2, much was still learnt from each one of them in order to describe the process of using VR for elicitation.

3 Requirements Using Virtual Reality

This section will focus on the idea and theory of collecting requirements using Virtual Reality technology. The main goal of any RE process is to successfully elicit and document all requirements for the final product. Since recording a complete set of requirements is next to impossible to achieve with a single elicitation technique, analysts must pick and choose the methods and match them with the types of requirements.

Using VR as one of these methods, an analyst may accurately be able to elicit certain types of requirements. An elicitation technique is described as a "series of steps along with rules for their performance ... sometimes includes a notation and/or a tool" [35]. The technique described as a result of this research and experiment will include a series of steps, an experiment, and VR tools that assist you in collecting certain requirements.

Section 3.1 describes the general details about this technique, which should help understand the types of requirements this technique can cover. Since this technique will be one of the first to use VR tools, a documented preparation phase which covers technology, stakeholder, and analyst preparation (Section 3.2). The execution phase (Section 3.3) covers the main activity of the elicitation; lastly, example projects and types of requirements this method may be useful for is covered in Section 3.4.

3.1 Strategy Overview

The main goal of VR-Elicitation technique is to collect requirements that are unable to be collected using other traditional techniques. VR is a tool for requirements collection - a new perspective for a project for which another subset of information already exists An ideal scenario would be a partial set of requirements collected for a certain project, however, more requirements are needed to successfully fulfill the needs. These needs may be related to a physical aspect of a project, such as selection of landmarks, selecting points on a graph, placing furniture around a room, and other physical requirements.

Strategy Scope: The scope of this technique goes as far as using VR as a tool for collection of requirements. The technique will also recognize requirement types that are comfortably elicited via VR, which fulfills the second research objective of this study. Example environments and suitable projects are thoroughly described in Section 3.4.

Before using VR as a strategy to collect requirements, a lot of preparation needs to happen; analysts, participants, and technology, all need to be prepared. The preparation phase includes several aspects of: analyst preparation, stakeholder preparation, role of technology, responsibilities of hardware and software. There may also be a large gap in understanding the technology from the participants since it is quite new with all new display and input devices. For this reason, there are many drawbacks to this strategy along with benefits - largely discussed after the experiment in Section 4.

Types of data and information collected will complete the third objective of this research. Since the VR elicitation technique immerses the participant in the VE, the analyst is free to observe externally or within the environment without interfering. This can result in valuable information that is otherwise unattainable. Furthermore, the requirements collected will be the main data collected via this technique, along with supplementary data that can help the technique in the future.

3.2 Preparation Phase

Virtual Reality is one of the most innovative technologies of not only this generation, but the past as well. Being in development for nearly 40 years, there are many challenges that the users face in creative fields[36]. In order for any RE process that uses VR as a medium to analyze requirements, there is a need to fully understand and prepare for problems that the stakeholders or analysts may face. Since the technology is very recently started to become popularized, there are many usability issues as well, which are discussed in Section 3.2.4.

Since there has been no significant previous work done regarding elicitation of requirements using VR, I believe that the users and analysts may need some direction before incorporating this technology in their requirements life-cycle. Although VR has been in development and use for the last 40 years, there are still many challenges that users face regarding usability, preparation, and expectations. To eliminate these, there are certain theoretical standards that virtual reality hardware and software must conform to. These may or may not be achievable currently, but it is our hope that the technology will move in the right direction.

In addition to technology, a preparation phase is needed for both participants: analysts and stakeholders. Both parties must understand the extent to which the technology will help them, and meet their expectations. The requirements elicitation phase, after all, is not a technological activity but rather an interaction between two participants. The analysts and stakeholders must adapt properly to use new technologies to their advantage.

3.2.1 Analyst Preparation

The analyst must understand both, the technology being used (VR) and also the stakeholders that are selected for participation.

Full Understanding of Virtual Technology: The analyst must be responsible for the whole knowledge about the technology selected for the elicitation process. Since the stakeholders will rarely be experienced in VR technology, they may have many questions about usability or interaction with the environment itself. If the analyst is not experienced with the hardware and software, the usability issues can be detrimental for the project.

According to Sherman et al. virtual technologies have four key elements: the virtual world, immersion, sensory feedback, and interactivity [37]. The virtual world is the content of the medium itself; what is actually displayed on the screen inside a HMD. It is the space that the virtual body of a stakeholder will be placed into, to interact and experience the world. The immersion relates to the sense of being in a certain place, which feels like reality [22]. Sensory feedback is the virtual world interacting with one's body using senses other than visual. For example, touching a jackhammer inside a virtual world may trigger haptic sensors in the controller that the participant is holding, which in turn makes the participant 'feel' the vibrations. On the contrary, interactivity deals with the virtual world reacting to the user's actions; an example can be flipping a light switch in the world actually turns the lights off in a room. An understanding of all options and scenarios in a virtual world is the responsibility of the analyst.

The selection of VR as an elicitation technique must be justified in any project - the role of the VR technology must be stated in order for it to be successful. Since VR may not be beneficial to all projects, there is a great cost if the role of virtual worlds in the project is not recognized. An improved understanding of what needs to be performed greatly affects the success of analysts in their elicitation efforts[35]; ultimately reducing project development and rework due to changes in requirements.

Selecting and Training Stakeholders: Ultimately, the process of requirements elicitation is an interaction between two types of people, in which information leaves one, and into the other. There may be cause for miscommunication between the two parties, or one of the two parties may not be correct for the scenario selected.

The analyst must choose from a pool of stakeholders (end-users, legislators, decision makers, etc.) [38]. Selecting the wrong type of stakeholder may result in a sub-par elicitation via VR.

The types of stakeholders selected may depend on each particular project, but there are two key components when it comes to selection of stakeholders: project definition, and stakeholder. The final goal of the project plays a great role on which stakeholders are necessary for the project, along with the domain knowledge each type of stakeholder may hold. Stakeholder's role in the project, along with the project definition is a major aspect as well - the two must combine for a healthy selection of stakeholders Anwar et al. have compiled a great list that project analysts can use when selecting stakeholders [39]. However, with an additional layer of VR, there are many other aspects that pertain to the selection of stakeholders: adaptability to new technology, open mindedness, clumsiness, level of risk regarding nausea. After considering all factors, it is possible to select the correct stakeholders for any given project.

After the selection, it is necessary for the stakeholder to partially understand the technology in question, in order to complete the task on hand. The analysts must use their understanding of technology and convey their knowledge appropriately. Although the stakeholders must understand how to use VR, they may not need to know everything in great details. In part, this is also the responsibility of the technology itself, to be considerably usable and easy to understand, described later in this section.

Requirement Types: Since this study is not focusing on a silver-bullet approach, there are a set of requirements that are attainable via VR. Some of these requirements are discussed below:

- **Architectural Requirements**: This involves any physical requirements that are needed such as placement, scale, and rotation of objects.
- **Geographical Requirements**: Requirements that involve many different geographical locations - visiting these locations in real life may be impossible or very costly.
- **Visual Requirements**: Any visual aspects of software or items related to a software project; such as color, shape, and consistencies of objects.

3.2.2 Stakeholder Preparation

In addition to analysts being responsible in their duties, it is highly important that the stakeholders, whether they are end-users or otherwise, are participating properly and efficiently in an elicitation technique. Requirements engineering, including the elicitation phase, is a team effort, and the stakeholders are one of the most important part of this team. For the scope of this research, the study will focus on the responsibilities that pertains to the VR technology itself; stakeholders, in general, will have more responsibilities than what is mentioned in the following.

User Characteristics: The users of the system need to have an open mind for them to learn the new ways of moving, interacting, and using a system. However, having an open mind may not be enough in the case that the experience level of the user is lacking [40]. Technical aptitudes of the individual affect this matter as much as anything else - if the user does not have a good spatial understanding of their surroundings, they may not be suitable for the task on hand. Users may get “lost” in using the system, which enhance the usability issues of the system for that particular user.

The user must also understand the limitations of the system to be successful at using VR to it’s full potential; otherwise, it may impose the system with exaggerated limitations [40]. Having more expectations than the system can deliver can become an issue that is neither the user or the technology’s fault. Considering a majority of projects benefit from end-user involvement in the requirements engineering phases [41], it is important for the user to be involved in this scenario. Much of the knowledge of the users can become tacit, no longer available to the conscious mind, and therefore inherently difficult to elicit with traditional techniques. High-risk projects such as ones where human life is in danger, may require specialists or an expert’s opinion rather than an end-user.

3.2.3 Virtual Environment Preparation

The virtual environment is one of the key aspects of VR development; without it, there is nothing to be seen. The hardware, discussed in the next sub-section, is just a paperweight when it is not paired with good software engineering principles. It is crucial to note that the development of this software (the environment itself) is only an effort to assist the requirements engineering phases for your actual project. For example, in our pilot experiment described in Section 4, the main project is to develop a navigational system that uses landmarks, as well as distance and time information to direct the users. However, in addition to the development needed for the landmarks-enabled navigational system, there may also be development efforts needed to create the virtual environment in which the stakeholders can interact to select landmarks. The creation of such an environment can in fact be considered as a brand new project in itself, which is one of the threats to the validity of this method. For some projects, the development cost of the requirements engineering virtual reality environment can outweigh the benefits.

Usability of VE: The virtual environment must also be designed in a way that is suitable for the experience level of the user [40]. If the user is unable to understand the user interface or is confused by the environment interactions, the use of this environment may not be helpful for the overall project. Kalawsky et al. has compiled a special questionnaire, VRUSE, which is designed for determining the usability of VR hardware and software [32]. Using methods like this, there is potential to improve upon the existing VR projects. The questionnaire splits itself into 10 main sections, by which the participant (the person using the VR equipment) is asked questions to judge certain aspects from 1 (strongly disagree) to 5 (strongly agree). For the purpose of this study, the sections that I will consider from VRUSE to be valid include: functionality, user input, system output, consistency, flexibility, simulation fidelity, error correction/handing and robustness, sense of immersion/presence, and system usability.

Environment Graphics and Interaction: One of the key aspects of a virtual environment is the immersion it offers. Higher levels of immersion can turn into presence, in which the user "feels" as if they are present in the environment, rather than looking at a screen. Photorealism is one of the easiest ways to achieve immersion in an environment. With the growing capabilities of video cards, we are certainly able to achieve photo-realistic environments on monitors with 1080p screen resolutions (1920 horizontal and 1080 vertical pixels). However, a VR setup usually has 1080p resolutions for each eye, as found in the HTC Vive; therefore, the system must process twice the amount of data and pixels. Achieving photo-realistic environments with VR is not quite possible for the highest level of immersion, but it is very close to being achievable. In addition to photo-realistic environments, the rate at which the input and outputs are processed, more commonly known as frame-rate, must also be considered. Usually, video games and virtual environments process information 60 times a second (60Hz), which is also the supported refresh rate of popular monitors; this offers a smooth experience for the user. However, achieving such high frame-rates, with double the information to process, is one of the reasons that it is hard to achieve photo-realistic environments in VR. The hardware (compute graphics specifications) is currently not capable of processing such high amounts of information so quickly. A secondary portion of immersion also includes hardware that provides immersion, discussed in Section 3.2.4

Interaction is another way of adding immersion for a virtual environment. There are several meanings of interaction, for the scope of this section, interaction is between the user and the system's components. For example, a button pressed on a controller held by the user, simulates a button that physically exists in the environment, triggering an event that the user can see. This level of interaction can provide the user with objectives, tasks, and a simulation of their real life - which adds to the level of immersion. Human-computer interaction does not just end at pressing buttons, it can span from walking in the virtual world, to eye tracking that responds to a scenario in the virtual environment [42]. Every single peripheral for the virtual device can be considered as an interaction with your virtual environment; the HTC Vive has the following: haptic feedback, sound, tracking hands, tracking movement in a room, and head tracking.

Development Effort and Environment Selection: Considering that each project is different, there will be some development efforts required to create an application and environment. Developing an environment requires knowledge of 3D modeling, photo-realistic textures, and physics knowledge. A collection of highly knowledgeable people may be required to build an environment that has the correct immersion requirements for the given project.

To make the development effort worth-while, a proposal of this research study in the future work is to create a more general set of environments that are customizable. For example, for all the requirement types discussed in Section 3.2.1, a generic environment can be created that can be customized by the developer in a much shorter time than creating it from scratch. This will reduce the cost of development and move the idea forward with more projects.

As an example, architecture requirements usually require creating sets of buildings, rooms, and walls. This requirement can be fulfilled by a user interface (UI) within the VR experience; the stakeholder can select any amount of artifacts such as walls and rooms, and place them directly into the environment. There could be an option to add artifacts such as furniture. A texture changer could also be utilized to mimic changing paint, along with photo-realistic textures.

Once the project is developed further, there may be some general environments that are usable for multiple scenarios. In this situation, the analyst must select from a pool of environments; one that is most suitable for the scenario in question. Although the thesis is not yet to this point, it is part of the method and preparation to select the appropriate environment.

3.2.4 Responsibilities of Hardware

For the scope of this research, the hardware includes the HMD, controllers, and trackers for the immersive experience. The desktop computer is out of the scope, and it is a given that the hardware in the computer must be able to process the images being displayed. Since the user will be wearing a HMD on their head, it is responsible for the immersion and being comfortable throughout the experience.

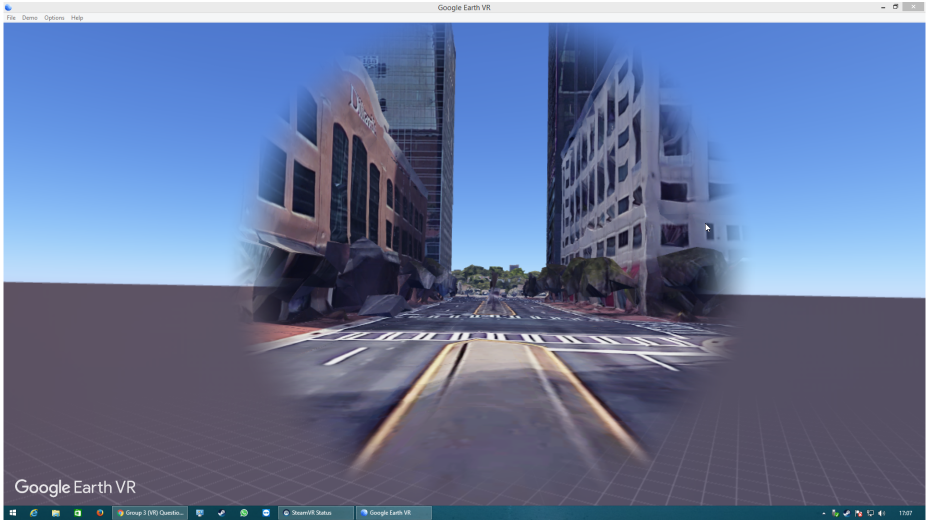
Immersion: Along with the VE, the hardware has a certain responsibility as well - depending on the immersion level required for the project. For the best-case scenario, all the immersive elements of your environment must be projected out to the user - whether it is in visual format or otherwise. The graphical elements of the environment must be displayed on a screen that can handle such details, the sound coming from the environment must output through speakers or headphones, and the haptic feedback must go through any controllers that the user is holding.

For the highest level of immersion, the hardware's responsibility is to maintain a *matching* level of immersion [22]. In matching immersion, the movements that the participant makes in real life are reflected exactly into the projection of their body in the environment. For an example, turning your actual head to the right by 10 degrees, must be reflected by a camera angle change by 10 degrees in your virtual body; similarly, moving your arms forward should be reflected as well.

There are several other types of immersion that have not been explored in VR devices currently. These include vestibular (located under your ears), smell, and taste [23]. Although these immersion techniques have not made it as far as popular VR technologies, there is much room for improvement with the immersion techniques that do already exist. For example, after experiencing some of the VR technologies first-hand, the lower FOV is quite noticeable and creates a non-immersive environment. Although, the HTC Vive has a much higher FOV than the less expensive hardware, it is not close to the actual FOV of the human vision.

Comfort and Usability: Judging how comfortable certain devices are is definitely difficult, and almost considered an opinion; there is extensive data needed in order to understand what is comfortable and usable for certain people. VRUSE usability method has been extraordinary for it's time, with 100 questions that test VR hardware and software usability issues that includes comfort [32]. Further testing and surveys may be needed to determine the comfort of using a VR headset or tracking devices for large amounts of time. Software solutions have already been implemented by companies such as Google for their products including Google Earth VR, that use a vignetting effect while moving, called 'comfort mode'. A visual for this effect can be found in Figure 3; this effect is only visible while moving in any direction. The user will be able to see the full view while stationary. According to Google Earth VR, this tends to reduce nausea while using the device for long periods of time. After the pilot experiment, the data will represent whether or not the participants feel nauseated after using the system which is one of the questions in the questionnaire taken at the end of the session.

Figure 3: View of Group 3's participant while picking landmarks on a route.



3.3 Requirements Elicitation and Data Collection

After the exhausting phase of preparation, the analyst should be ready for an elicitation session with a stakeholder. Considering that ample amounts of time was spent for the preparation for this session, it will complete without many problems. In this session, the analyst will gain requirements from the stakeholder, as well as other data such as motion tracking, time spent on each task, mistakes or corrections needed per task, and more.

Generally, in this phase of the elicitation session, the analyst will ask the stakeholder to perform certain tasks or configure some requirements in the VR environment. The environment would typically be similar to a real-life scenario such as driving a car, walking on a road, being in a room, or any scenario that is similar to the project. The benefit that VR provides to this project will be monetary cost savings and risk mitigations.

For example, if the project requires you to be in multiple locations in order to complete the requirements, it will be much easier and cheaper to travel through space via VR rather than in real-life; the same applies to traveling through time, whether you need to elicit requirements for a night-time or day-time scenario, or both. These examples give you the monetary savings for spending less time and money in order to achieve the same results. Immersion is key during these scenes as well, as discussed in the preparation phase. The more the participant feels as if they are in the environment, the better your participants will perform [19].

The elicitation phase will largely depend on what the project is on hand. If the project is architectural based, there may be functionality needed in the environment to change architecture such as the height of a building or room; placing objects around the room; changing paint color, and more. In this scenario, the final result, whether it is a room or a building, will be the final requirements specification. The architecture or construction team can then use the specifications provided by the stakeholders via the VR environment and make suggestions or changes for the final product. This in turn, saves the effort required to draw, model, or even create an entire building or room in real-life and change requirements later on. Other techniques use for eliciting certain requirements can lead to rework in the either the design or execution phases [12].

During the elicitation phase, the following is recommended from the analyst and user. The analyst must: instruct the user to perform certain tasks; record results and reactions of the user; record the requirements displayed by the user; record any comments, discomforts, and other data expressed by the user. The user must: perform all tasks required to complete the requirements set; follow directions from the analyst. An example elicitation session can be found in Section 4 where an experiment includes an elicitation session protocol in which the duties of analyst and user are described in detail for eliciting requirements for an navigational system.

Data Collection: The first and foremost collection of data happens to be the requirements for the current project. Using VR as a tool, the analyst can collect and record the data that is suitable to be collected. For example, the experiment in Section 4, the actual data collected are landmarks for a specific set of routes. Other than the collection of requirements needed for the current project, there may be other useful data collected from the session. This will be referred to as 'secondary data' moving forward. Some of this data can help improve future sessions with other stakeholders; and some of the data can be used for historical lookups and statistics.

Some secondary data can be for record keeping and billing purposes, such as time spent. Since data storage is not too expensive, being as granular as possible will benefit the organization in the long run. Collection of different types of secondary data, in conjunction with the requirements can include the following:

- Time required for training
- Time spent for each task

- Total time spent for experiment
- Time spent on Questionnaire/Survey
- Number of mistakes made during each task
- Number of times asked for help during experiment

When comparing these statistics to methods other than VR, it is possible to objectively judge whether or not it is worth creating a VR environment for your project requirements elicitation. For example, for certain scenarios it may take VR twice as long to elicit the same requirements. However, it can be much harder to determine the quality of requirements elicited.

Another popular way of collecting secondary data for the betterment of future experiments and sessions are questionnaire after the session. For this purpose, some great research has already been conducted by Kalawsky, who has developer a 100-question survey to document usability of VR equipment and software [32]. This questionnaire is taken right after the participant is done with the VR session so the content is still fresh in their minds. As discussed earlier, the questions focus on 10 different aspects of VR technology; which can be seen in the Appendix in Section 6.2

3.4 Example Environments and Projects

This section discusses some example environments and projects that are suitable for VR-Elicitation technique. Since the purpose of this research study was not to find a silver bullet for elicitation techniques, these projects are deemed to have a subset of requirements that can easily be elicited via the proposed VR elicitation technique. Virtual reality is a very physical medium of communication, therefore, most of the requirements are easily attainable using this technique are related to the real world in some way.

Landmarks for Navigational Systems: There have been several studies that focus on using landmarks for navigational guidance - walking and driving navigation [43, 44, 45]. Landmark navigation has even proven to be beneficial and useful for daily use for visually impaired users [46]. Using VR for this experiment could be beneficial in certain ways: using immersive VR environments to select landmarks. This very example will be our pilot experiment for this study; therefore, detailed specifications can be found in Section 4.

Landmark selection for indoor navigation has been done previously using picture-based object recognition, where the user is able to look at the picture of a scene for a few seconds and select the most recognizable object [44]. However, considering the importance of immersion, the participant may select different landmarks if presented with the scene in real-life. The cost of moving participants to different scenes that may be far away is out of question, rather, it is much more efficient to bring the scene to participants using VR. In this experiment, the scope of requirements collected via VR would be the selection of landmarks. If the navigational application is for a mobile phone, all other requirements can be collected via other elicitation techniques such as interviews or focus groups.

Color Picking: Picking the color of a large object or surface, such as a wall in a room can be difficult. The general practice is to pick up small color cards at paint shops and compare them. However, this is not advisable for expensive color options or large projects. When colors are compared on a small piece of cardboard paper, it fails to exemplify the intensity of the color when it is painted on a wall [47]. Currently, there is not much evidence of larger color sample cards being available at paint stores; therefore, a large project for painting carries risk in purchasing the wrong shade of a color.

Unfortunately, it is well known that screens cannot accurately represent colors either - even the same brand of screens can differ in color presentation to the human eye. Color calibration is hard to accomplish accurately with the exception of Pantone colors which can be accurately represented on a screen and painted or printed with the same exact shade. Due to the lack of complete accuracy in representing colors on a display, this experiment was not considered for this study - however, a preliminary experiment plan was developed which is attached in the appendix in Section 6.1.

Placement and Size of Objects: This is a general topic that relates to physical requirements of certain objects. Architecture may need this type of requirements to review and confirm the size of certain objects and how they fit into a building or scene. Portman et al. discusses the possibility of implementing VR into architecture, landscape, and environmental design [48]. These technologies do not yet exist, however, Portman describes a way to move forward with their plans. For example, Unreal Engine technology has embraced VR and has a VR editor for developers to use. Essentially, you are able to build environments while you are in a VR environment. The VR editor by Unreal Engine allows the user to place, move, and scale any number of objects to their liking. Instead of using a traditional mouse and keyboard to place objects, developers can pick up objects with their hands (controllers), and place them in a certain position. This has never before been seen in the development community, and can be extended to architectural requirements as well.

For an example, consider the following scenario: a businessman buys a storefront, however, it is completely empty with just a few rooms. The store owner needs to buy several types of furniture: desks, cupboards, and cash registers in order to make the store functional. Deciding where to put each piece of furniture can become confusing if you are using your imagination. Using VR, you are able to see and experience the placement of these objects and find the perfect setting. The placement of these furniture is considered to be a requirement, and needs to be elicited with a technique. A contractor could use traditional techniques such as interviews, or graphical interviews with drawings of the placement of furniture, however, the stakeholder may not be able to imagine what the final product would look like. VR gives a way for the stakeholder to confirm these requirements before spending large amounts of money hiring contractors and buying furniture. There has also been case studies on end-user involvement in building design [49]. The impact of decisions taken for the requirements of a building is the highest during the design stages; therefore, many models and visualizations are created to confirm and validate. Furthermore, VR can be used to create these sets of requirements rather than validating them; users themselves can place objects in a room or change the dynamics of a building in order to create specifications.

4 Experiment: Navigation with Landmarks

Traditionally, navigation has been interfaced with distance remaining for your next turn, and street names, along with visuals such as a line on a map. Navigation with smart phones now has the capability of being anything that developers choose it to be. The proposal of this experiment is to create an environment in virtual reality with an experiment protocol to further develop the idea of a navigational system that uses landmarks as well. For instance, 'turn left after the white clock tower', is a much better description for a human to keep track of while traveling at high speeds.

The purpose of this experiment is to find *landmarks*, besides distance and time, to suggest directions to users, as well as determine whether VR can be beneficial for this task. Sefelin *et al.* [44] has studied the problem to select landmarks for navigation. The elicitation process for collecting landmarks involved a traditional interview with visually impaired persons.

Recent studies have also provided solutions to incorporate landmarks in navigational systems for visually impaired people [46] and indoor navigation [43]. Similar to these studies, the goal of our application will be to select landmarks within an area, and determine which landmarks are the best for certain locations.

With the experiment, the plan is to determine whether or not using VR as a tool in an elicitation technique will bear a higher quantity or quality of requirements in certain scenarios. Therefore, there is a need for a control, Group 1, which will be conducted as an interview; the amount of visuals will be minimal, the interview will take place along with only a map. Group 2 will go through the same tool-assisted interview process as Group 1, however, using Street View with access to photorealistic images of maps; the final experimental Group 3, will go through the same routes in a VR environment with the HTC Vive (Group 3). All groups will complete the same tasks, selection of landmarks for a navigational system, but will defer in the method of elicitation used by the analyst.

4.1 Experiment Overview

The experiment designed has a main purpose: determine the usability and performance of VR for requirements elicitation. However, to have somewhat of a comparison between different techniques, it includes three different tools for eliciting these landmarks. For the rest of the experiment, ‘requirements’ and ‘landmarks’ can be used interchangeably because the landmarks itself are the requirements intended to be collected in the experiment. Without VR, there are several ways to collect these requirements using traditional techniques such as interviews or questionnaires. One such method will be used: a tool-assisted interview using Google Maps and another using Google Street View. The experimental group being the one that uses VR for selecting the requirements of navigational landmarks.

Research Questions:

- EQ1: Is Group 3 (VR) able to collect more or less requirements when compared to Group 1 and 2?

- EQ2: Are there significant usability issues for Group 3 which are detrimental to the act of collecting requirements?

Groups Structure: The main difference between the groups will be the method of exploring the routes that have been selected for the experiment. All groups will follow the same protocol, and attempt to provide the analyst with the same requirements, being landmarks; however, their view and information about the world and routes is different.

Group 1 will experience the act of providing requirements (landmarks) using a top-down view of a 3D map on a computer monitor. In this view, they have the ability to move around by clicking and dragging with the mouse pointer, and rotate the map to their liking. While in comparison, Group 2 will go through the same routes and select landmarks using Google Street View. This group will also have a top-down view of the route to follow. Lastly, Group 3 will experience the same routes and select landmarks while in the VR system. This group will have no top-down view of the map and will be fully immersed in the artificial world.

There is a clear difference of information between the groups; Groups 1 and 2 receive a top-down view of the map, while Group 3 does not. Group 3 also has a 3D view of the world in VR, which the other two do not. This difference in information for the groups was deliberate and was chosen for the main purpose of the study - collecting requirements using VR. There may be several other adaptations needed as well if VR is used for the elicitation of requirements, including taking some information away in order to increase the immersion and presence of the user, such as the mini-map provided to Groups 1 and 2.

Experiment Hypothesis:

- H1: There is no difference in the quantity of requirements (landmarks) collected between Groups 1, 2, and 3.
- H2: There are significant usability issues in Group 3 that hinder the usability of VR in a elicitation setting.

4.2 Preparation Phase

As noted in the previous section, there are several levels of preparation needed for holding an elicitation session using VR. The preparation needed for this experiment includes: selecting the environment and hardware, preparing stakeholders and analysts, and preparing the data collection phase.

Environment and Route Selection: An investment was made in the equipment, HTC Vive and a video card, Nvidia GTX 1070, and it is capable of: photo-realistic environments; display of high resolution images; head, arms, and body tracking; haptic feedback; and sound. It has a resolution of 2160 x 1200 px, 90 Hz refresh rate, and a field of view of 110 degrees. Specifications are similar to Oculus Rift, but HTC Vive was considered more mature. It should be noticed that a highly-immersive VR technology also allows us to turn off any features if found to be not necessary, such as sound or haptic feedback. This provides us the control to choose the level of immersion for a given domain.

With the use of the HTC Vive, upcoming technologies such as Google Earth VR and WRLD 3D can be utilized for developing our environment. Although the customized application developed in WRLD3D will help with usability, the graphical fidelity of maps is quite low. Due to this reason, Google Earth VR will be used for our experiments. It provides photo-realistic images, and also has the ability to view spherical panoramas of actual images with Street View.

Table 3: All routes and basic meta-data about the routes.

Route	Area	Type	Turns
Route 1	Midtown Atlanta	Urban	6
Route 2	Downtown Atlanta	Walking complex	7
Route 3	Marietta	Suburban	8
Route 4	Midtown Manhattan	Very Urban	8
Route 5	Griffin, GA	Rural	7

The experiment will consist of 5 routes that each participant will go through and select landmarks. The reason for having multiple routes is so that if the participant needs a break from the virtual experience, they are able to end after each route. Any VR experience has some people feeling nauseous, therefore, the routes have been kept relatively short and concise while still leaving us with data. With longer routes, there is also a possibility of the participant being bored or not paying attention to the environment as much. Each participant will go through the same routes using one of the techniques, depending on the group they belong to, and the analyst will record data as needed. The experiment structure and data collection can be found in the next two sections. Table 3 represents some meta-data about the routes: route number, area on Earth, area type, and the number of turns in the route. A varied selection of types was considered while picking routes around the United States. The following Figures 4,5,6,7 and 8 represent the view and directions of all 5 routes around the United States.

Figure 4: Route 1 of the experiment

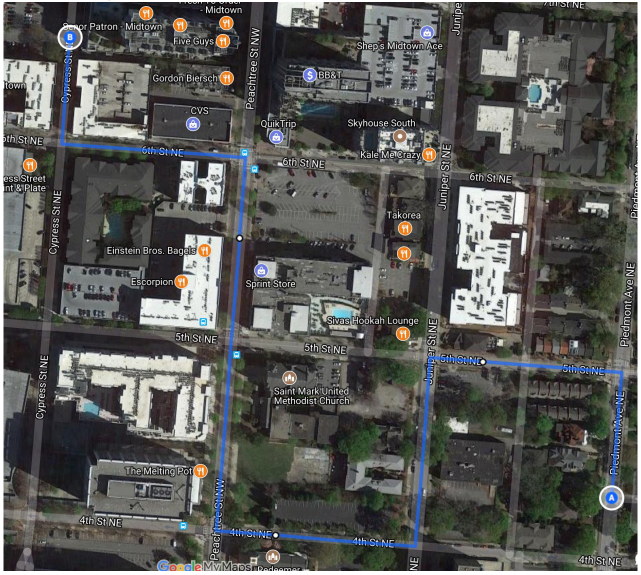


Figure 5: Route 2 of the experiment

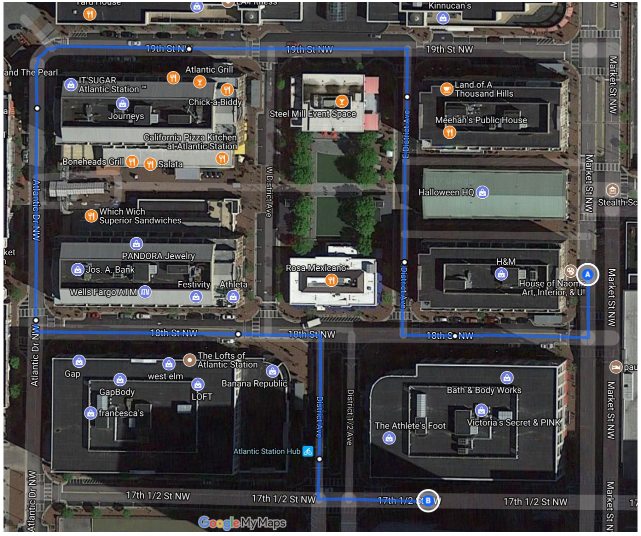


Figure 6: Route 3 of the experiment

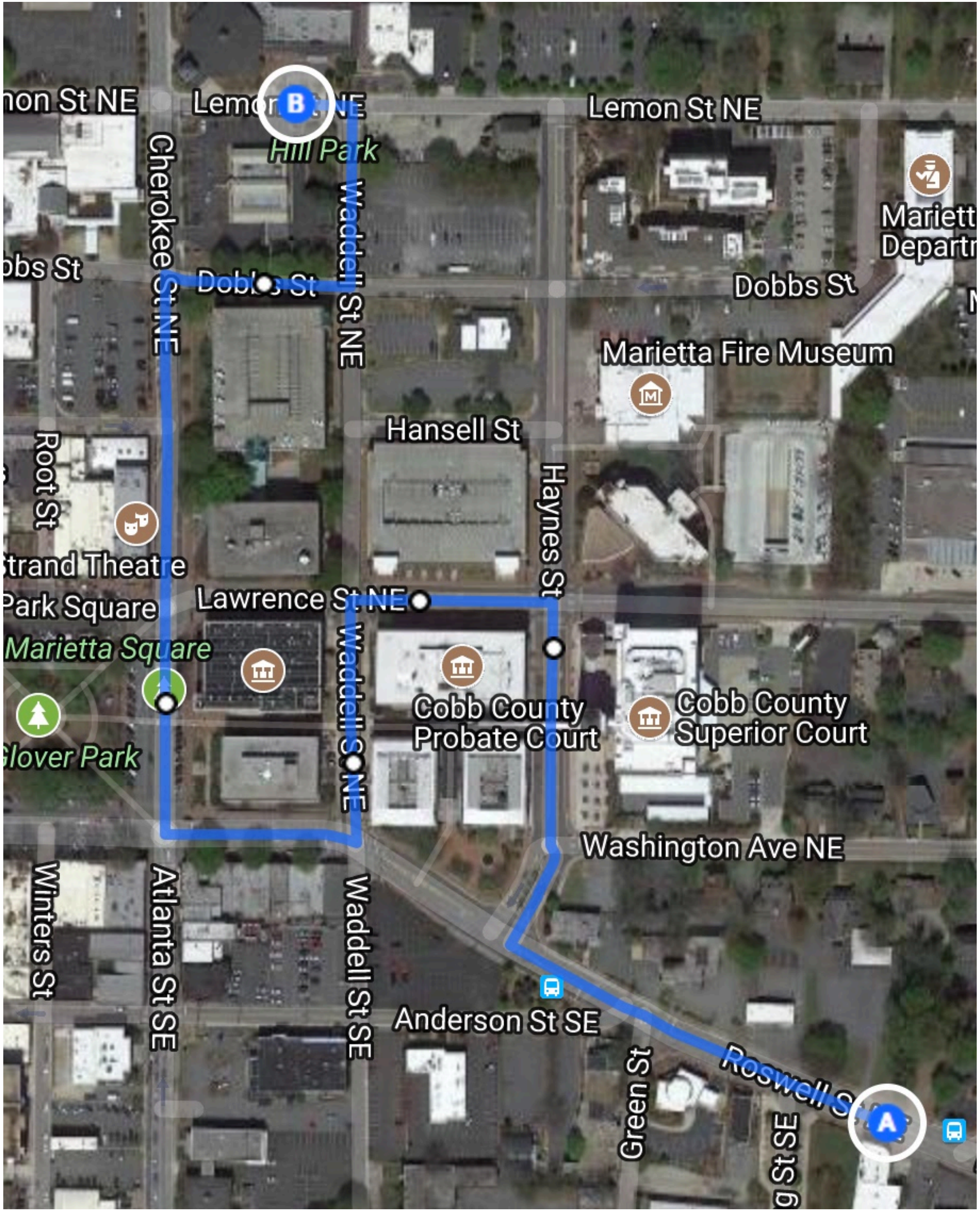


Figure 7: Route 4 of the experiment

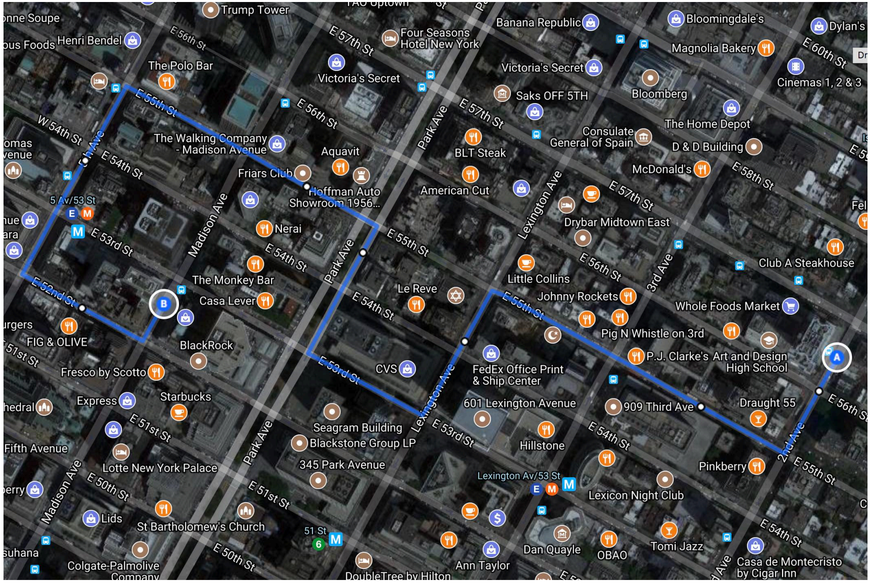
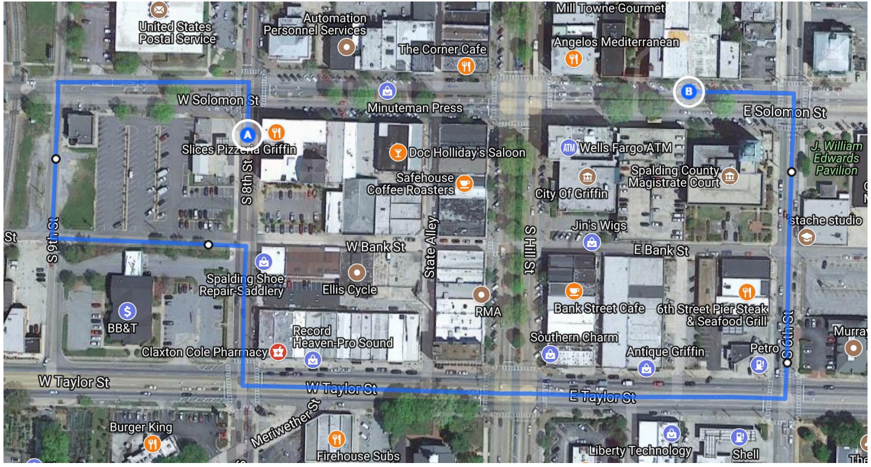


Figure 8: Route 5 of the experiment



4.3 Experiment Structure

Each participant in the experiment, regardless of which group they belong to, will go through the same protocol. There are some inherent differences, which separate the two groups, however. For data collection, 12 participants were gathered for Group

Table 4: Background of participants

Group 1	Group 2
Nursing	Computer Science
Public Relations	Electrical Engineering
Computer Science	Architecture
Software Engineering	Mechanical Engineering
Electrical Engineering	Industrial and Systems Engineering
Electrical Engineering	Business Management
Mechanical Engineering	Commications
Electrical Engineering	Culinary
Mechatronics Engineering	Mechanical Engineering
Game Development	Mechanical Engineering
Mechanical Engineering Technolgy	Software Engineering
Industrial Engineering and Supply Chain	Graphic Design
Group 3	
Mechanical Engineering	
Mechanical Engineering	
Mechanical and Automotive Specialties	
Electrical Engineering	
Game Development	
Interactive Design	
Computer Science	
Computer Science	
Mechanical Engineering	
Business Management	
Finance	
International Business	
Music	

1; and 13 participants each for Group 2 and 3. Table 4 represents the background of these groups with regards to their knowledge. All participants are students of the Kennesaw State University with an age between 18 and 28.

Experiment Protocol for Group 1 and 2: The following is a series of steps that will be followed for the successfulness of participants in Group 1. Figure 9 displays exactly what Group 1 will be able to see while going through all the routes.

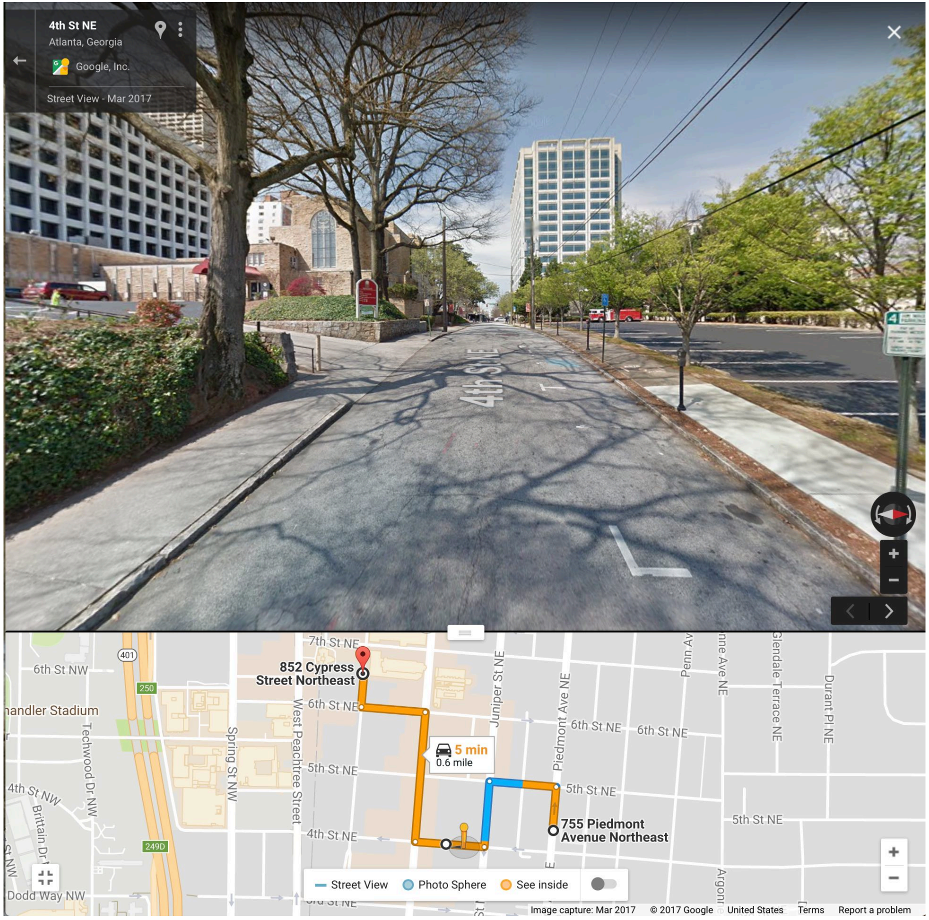
In addition to looking at the map, participants can also rotate the map as needed.

1. Analyst must prepare a computer for Group 1's use: navigate to Google Maps with a web browser, and load each of the 5 routes in separate tabs.
2. Enter Map View (Group 1) or Street View (Group 2) on each of the routes.
3. On a separate machine, keep track of what the participant considers a landmark for each turn, for each route.
4. Once the participant arrives, provide a summary of the experiment and make sure they understand any risks.
5. Ask their experience with Google Maps and Street View, and give them ample time to get acquainted with the system.
6. Once ready, have the participant start route 1.
7. Analyst makes notes about what the participant thinks is a landmark
8. A screen shot for each landmark can be take if the computer allows to do so.
9. Repeat steps 6 - 8 for the remaining routes.
10. Once all routes are finished, hand the participant the final questionnaire, either via paper or electronically.

Figure 9: View of Group 1's participant while picking landmarks on a route.

Group 2 will go through the same experiment protocol as Group 1, however, during the interview, the maps will be in 3D with an option to use Street View photo realistic images for reference. There will be no immersion in this scenario as the participant will still use the computer monitor as a display device, and keyboard and mouse as an input device. Figure 10 displays exactly what Group 2 will view while moving through the routes.

Figure 10: View of Group 2's participant while picking landmarks on a route.



Experiment Protocol for Group 3: The third group (experimental) will experience the same routes as Group 1 and 2, however, within the VR headset. Figure 11 displays exactly what Group 3 will see while moving through the routes; along with the option to see the photo-realistic image displayed in Figure 12. As you can notice, the photo-realistic is a lot more detailed than the 3D models viewed in the regular view. The participant is able to move around in the regular view and look for details in the photo-realistic view mode. Since the participant is unable to see any routes in the VR view and able to move in any direction possible on Earth, the analyst has to interact with participants and direct them through the route. Table 5 were used as instructions for each route, from the starting location.

Following is the experimental protocol for Group 3:

1. Analyst must prepare the VR experience and save the 5 route's starting locations for the participants
2. Once the participant arrives, review the material with him/her and describe the risks and benefits.
3. Describe the participant of the protocol you will take throughout the experiment and what they will be doing.
4. Have the participant wear the HMD and look around. Give the participant at least 10 minutes to get used to being inside a virtual world.
5. Once the participant is ready, have them go to the starting point of the first path using the menu system.
6. Direct the participant to the first intersection
7. Have the participant enter Street View if necessary
8. Have the participant look around the area and select any landmarks.
9. Repeat steps 6 - 8 for each intersection or turn of current route.
10. Repeat steps 5 - 9 for each route you plan to accomplish

Table 5: Directions used for Group 3 - VR

Route 1: Midtown Atlanta 1. Next Intersection, Left 2. Next Intersection, Left 3. Next Intersection, Right 4. Next Intersection, Right 5. Skip 1 Intersection, Left 6. Next Intersection, Right	Route 2: Atlantic Station 1. Next Intersection, Right 2. Next Intersection, Right 3. Skip 2 Intersections, Left 4. End of Road, Left, 5. Next Intersection, Left 6. Next Intersection, Right 7. Next Intersection, Left
Route 3: Marietta 1. Next Intersection, Right 2. Next Intersection, Left 3. Next Intersection, Left 4. Next Intersection, Right 5. Next Intersection, Right 6. Skip 1 Intersection, Right 7. Next Intersection, Left 8. Next Intersection, Left	Route 4: Midtown Manhattan 1. Skip 1 Intersection, Right 2. Skip 1 Intersection, Left 3. Skip 1 Intersection, Right 4. Next Intersection, Right 5. Skip 1 Intersection, Left 6. Skip 1 Intersection, Left 7. Skip 2 Intersections, Left 8. Next Intersection, Left
Route 5: Griffin 1. Next Intersection, Left 2. Next Intersection, Left 3. Next Intersection, Left 4. Next Intersection, Right 5. Next Intersection, Left 6. Skip 1 Intersection, Left 7. Skip 1 Intersection, Left	

Figure 11: View of Group 3's participant while picking landmarks on a route.

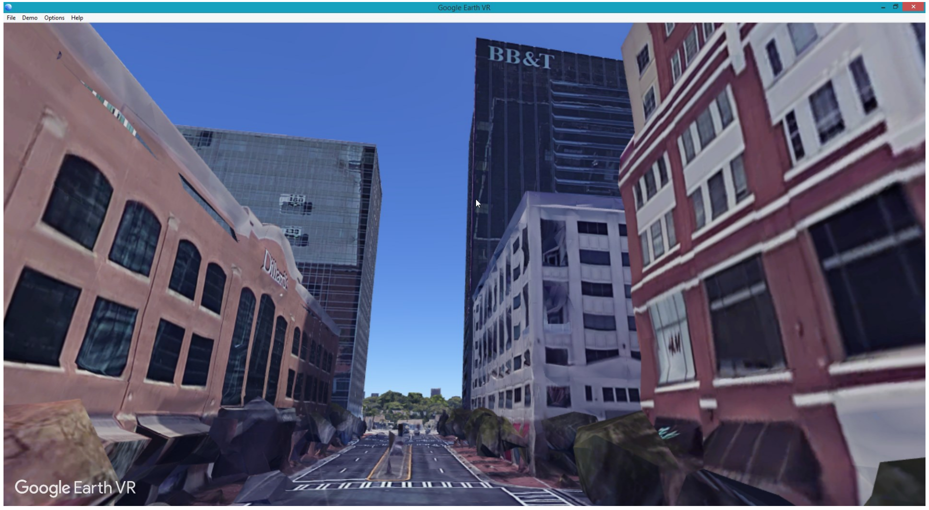
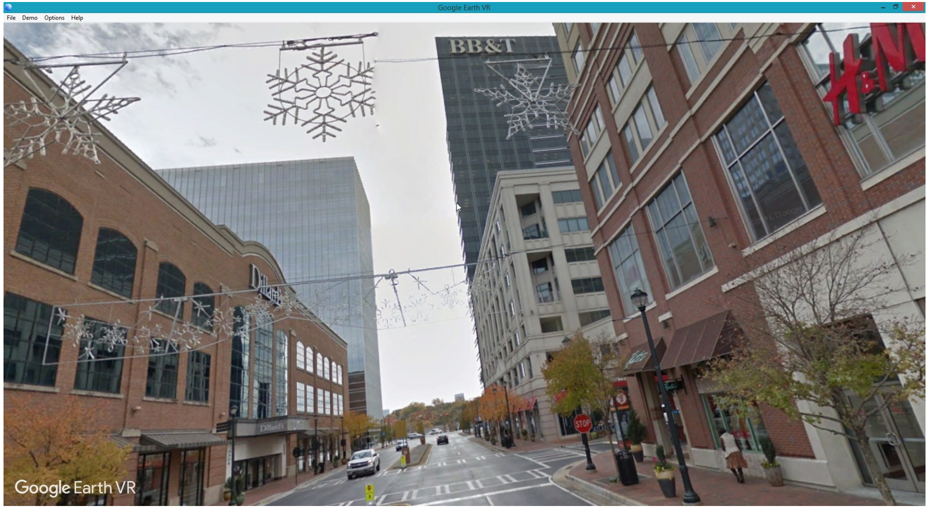


Figure 12: View of Group 3's participant while picking landmarks on a route with photo-realistic images.



4.4 Collecting and Analyzing Data

The main purpose of this experiment was to collect landmarks at each intersection of each route; this is the primary requirement that needed to be collected with the use of VR. Other than the primary requirement, the study was able to collect many different forms of secondary data via questionnaires and notes by the analyst while conducting the experiments.

Requirements Data: Landmarks: During all groups' sessions, the analyst records what the participants consider as landmarks. For example, in Group 3, when the participant is going through the route in VR, and lands on an intersection - they are asked to select landmarks that are suitable for this turn. The participants look around and point out any appropriate landmarks; the analyst makes a note of the landmark for this specific turn.

Table 6: Data collected from one participant in Group 3.

Participant ID	304
R1-T1	Tower
R1-T2	Parking Lot
R1-T3	Skywalk
R1-T4	Church
R1-T5	Quick Trip
R1-T6	No Landmark
R2-T1	Dillards
R2-T2	American Apparel
R2-T3	Regal Cinema
R2-T4	Yard House
R2-T5	Atlantic building
R2-T6	Mistake
R2-T7	BB&T
R3-T1	Clock Tower
R3-T2	City of Marietta Building
R3-T3	Parking Entrance
R3-T4	No Landmark
R3-T5	Antiques
R3-T6	BoA
R3-T7	BoA
R3-T8	No Landmark
R4-T1	Good Nature
R4-T2	Church/Religious building
R4-T3	Lifted up building
R4-T4	Statue
R4-T5	Rustic Looking
R4-T6	No Landmark
R4-T7	Red Roof building
R4-T8	No Landmark
R5-T1	Saki Sushi place
R5-T2	No Landmark
R5-T3	Griffin Package
R5-T4	Gas station
R5-T5	Burger King
R5-T6	Shell
R5-T7	Courthouse

Table 6 is an example of collected data during one participant's session in Group

3. R1-T1 refers to ‘Route 1 - Turn 1’, ‘R2-T1’ refers to Route 2 - Turn 1, and so on. A full set of data is included in the appendix, Section 6.3, which includes all participants in all 3 groups.

Along with collecting what the participant thinks is a landmark, the analyst is also able to collect when the analyst gets confused, makes a mistake, gets lost, or has trouble with the system. Noting down these events during the experiment helps track down the usability issues and easiness for each method of elicitation, notably the VR elicitation method.

To get a varied types of data from the experiment, routes that are different from each other were selected and can represent different scenarios. For each route and each group, it was noted when: there were no landmarks found for a particular turn; the participant made a mistake in following directions or the route; and when the participant was confused as to what they need to be doing. However, due to the difference in information between the groups, an analysis on this information was not conducted.

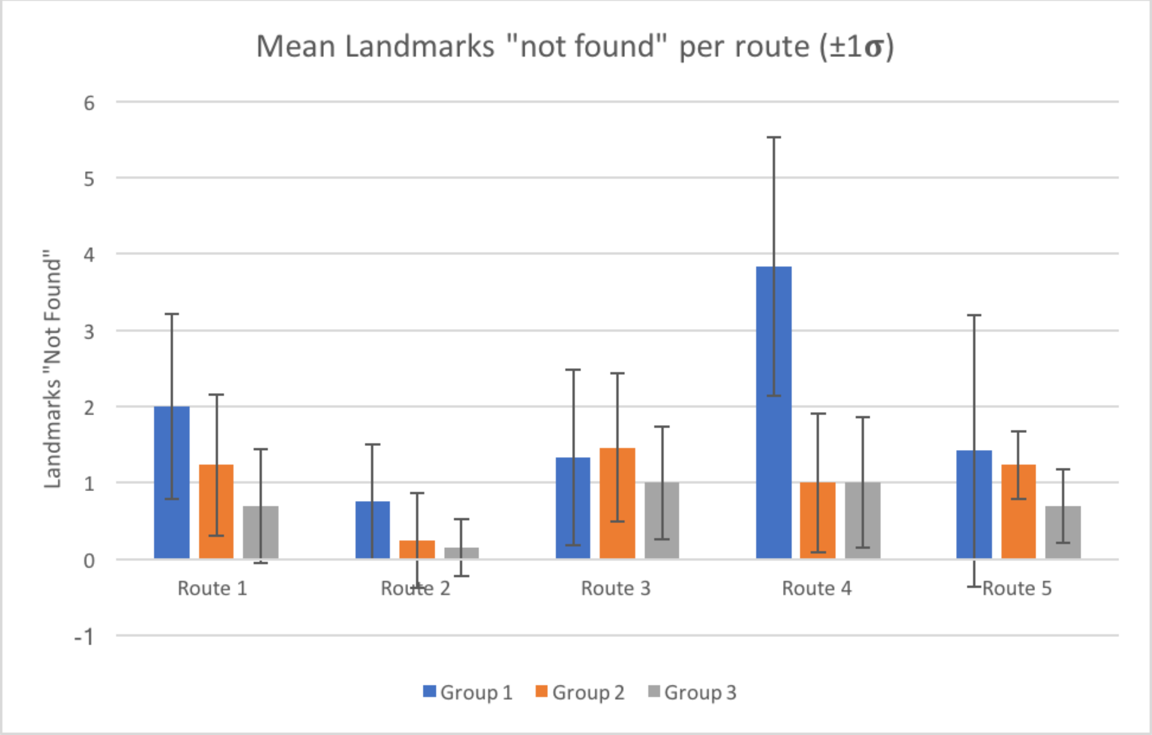
Compiling the data recorded about the landmarks during the elicitation session, Table 7 is a summary of observations in each route and in each group; blank cells are represent an average score of 0; lower numbers are better in this table. “Not Found” refers to when the participant was unable to find any landmarks for the a particular turn. Average column has the header ‘$\overline{\mathrm{x}}$’; standard deviation has the header ‘σ’; and the median column has the header ‘$\tilde{\mathrm{x}}$’.

	$\bar{\mathbf{x}}$	$\boldsymbol{\sigma}$	$\tilde{\mathbf{x}}$
Route 1			
Group 1	2.00	1.206	2.000
Group 2	1.231	0.927	1.000
Group 3	0.692	0.751	1.000
Route 2			
Group 1	0.75	0.754	1.000
Group 2	0.25	0.622	
Group 3	0.154	0.376	
Route 3			
Group 1	1.333	1.155	1.000
Group 2	1.462	0.967	1.000
Group 3	1.000	0.739	1.000
Route 4			
Group 1	3.833	1.697	4.000
Group 2	1.000	0.913	1.000
Group 3	1.000	0.853	1.000
Route 5			
Group 1	1.417	1.782	0.500
Group 2	1.231	0.439	1.000
Group 3	0.700	0.483	1.000

Table 7: Summary of data of landmarks “Not Found” per route in all groups

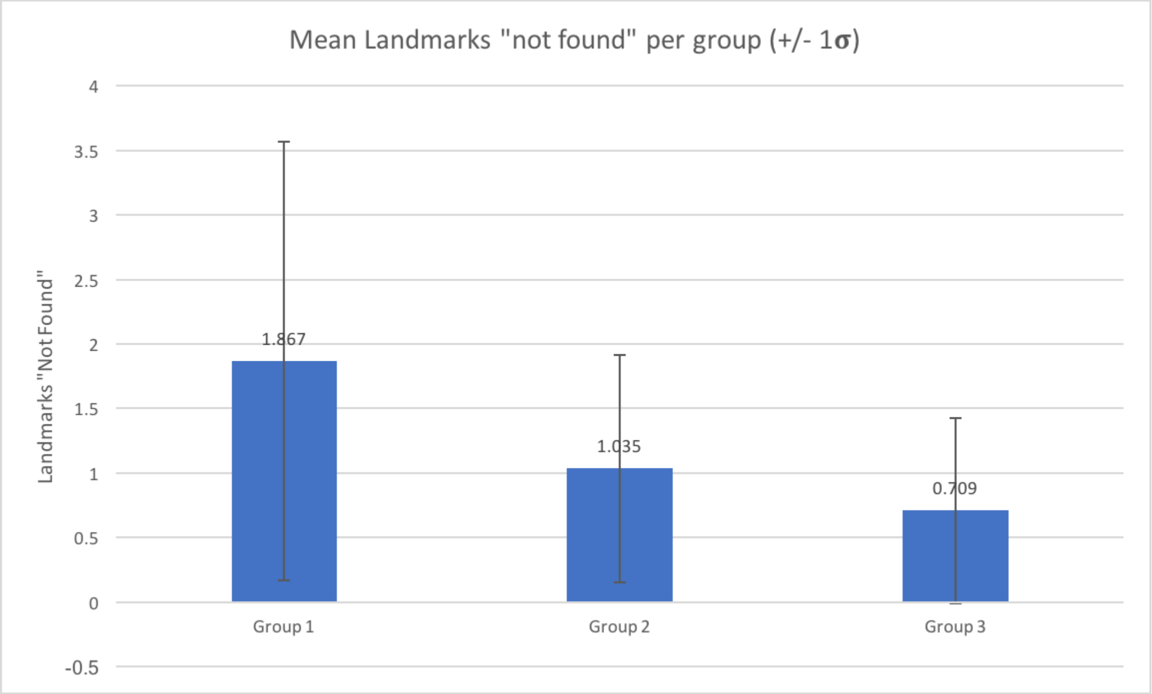
In Figure 13, you can see the averages of how many landmarks participants were able to find per route. The standard deviations for Route 2 Group 2 seems to be invalid due to the fact that one standard deviation below the mean is less than zero. This suggests that there are some threats to internal validity, discussed further in Section 4.5 of the experiment that need to be worked out in the future experiments. However, some preliminary conclusions can be made using the data collected on the usability and interoperability of VR with requirements elicitation.

Figure 13: Landmarks not found per route, per group +/- 1 standard deviation.



Abstracting further, all information has been averaged between groups for all routes in Figure 14; in other words, the first bar represents an average of all routes in Group 1 along with one standard deviation error line. Lower numbers in the graph once again represent a lower number of landmarks "not found"; hence, more landmarks (requirements) found. On average across all routes, the number of turns is 7.2 turns. Group 1 on average, for all routes, was not able to find landmarks for 1.867 turns; Group 2 was not able to find landmarks for 1.035 turns; and Group 3 was not able to find landmarks for 0.709 turns. However, visually looking at the standard deviations on the graph presents a threat to the validity of the experiment, therefore, generalized statements about VR and it's performance for picking landmarks cannot be made. More discussion on the threats to validity of the experiment and results obtained are discussed in Section 4.5.

Figure 14: Landmarks not found per group for all routes with +/- 1 standard deviation.



All Routes			
	$\bar{x}$	σ	$\tilde{x}$
Group 1	1.867	1.702	1.5
Group 2	1.035	0.881	1
Group 3	0.709	0.72	1

Table 8: Summary of landmarks “not found” per group for all routes.

One advantage of either using VR or Street View compared to the top-down map view is exemplified with Route 4 Turn 3. A majority of Group 1, almost 70%, expressed the landmark as being the bank of ‘BB&T’ since it seems that it can clearly be seen from the intersection; however, upon further inspection, the BB&T building cannot be seen from the intersection at all. This is realized in Group 2 and 3’s data of which 0% of the people that attempted the route selected a landmark for this turn (no landmark). This can clearly be seen by comparing the two images in Figure 15; the top part of the figure shows the as being seen from the intersection, and the bottom part contradicts as it is not seen from the street at all. The red arrow on the top part of the image represents the camera's direction in the bottom portion. The lack of immersion and sense of direction is misrepresented for Group 1, which makes it harder to pick landmarks that are actually visible from the intersection. With a top-down view, the participants are obviously forced to guess what the user may be able to see while standing in the intersection.

This phenomenon happened multiple times, especially in Route 5 with Turns 1 and 2; and with route 3, turn 4. Participants were obligated to pick landmarks that were not very obvious when standing on the street. For example, with Route 3 Turn 4, there is a church right in front of the street, which is easily visible and readable from the top-down view; however, even when closely examined from the street view or VR, participants are unable to see the church. This is illustrated in Figure 16; the red arrow on the top portion of the image represents the direction of the camera in the bottom portion (street view).

Figure 15: Comparison of map view (top) and Street View (bottom) of Route 5, Turn 3.

Figure 16: Comparison of map view (top) and Street View (bottom) of Route 3, Turn 4.

While participants were performing the experiment in Group 1, there were several negative comments noted down. Some of these phrases include (paraphrased): ‘the view is not very detailed to see landmarks’, ‘the textures are loading too slowly’, ‘controls are finicky’, ‘I can’t really see anything’. It seems clear that the usability of using just the Google maps tool, without Street View or VR, is too unusable. Participants had trouble moving around, looking at landmarks, and controlling themselves in the environment. Participants in this group also had the most trouble finding landmarks, considering the highest number of landmarks “Not Found”. In contrast to Group 2 and 3 which had access to Street View, Group 1 was also unable to see landmarks very far away. This is due to the fact that this Group 1 had to drag the map with their mouse, and they did not want to move too far. Another drawback of Group 1 seems to be that the labels are clearly visible from the top-down view. Without the help of these labels on the map, it is difficult to pick the same landmarks since they are not very obvious; therefore, do not make for a good landmark.

Both, Group 2 and 3, were able to see landmarks further away because of the line of vision. Both groups were placed in the environment as if the participant is actually standing in the street; this gives them the vision to look around as far as possible, which the first group lacked. However, one advantage that Group 3 has is the intuitiveness to look around the area while in Street View. Instead of moving line of sight by dragging the mouse across the screen, the participant can simply look around with their head. This is made possible due to the immersion provided by wearing the HMD; the participants could effortlessly look around as they would in their daily life.

Data from Questionnaire: Using the VRUSE Usability Questionnaire [32], the usability of the VR system can be evaluated, along with other attributes. The questionnaire asks the user to rate the statements in the question from (1) Strongly Disagree to (5) Strongly Agree, and the middle being Disagree, Neutral, and Agree, respectively. Due to the length of the questionnaire, a summary of the most notable questions and their results is displayed here instead.

Group 1 and 2 had the same questions in their questionnaires, however, there are some differences between their answerers; due to the fact that Group 1 did not have access to Street View. Table 10 in the Appendix summarizes the results from the questionnaire that Group 1 and 2 took after the experiment experience; and Table 12 summarizes the information collected with the VRUSE Usability Questionnaire [32].

With regards to previous research on higher levels of immersion, almost 50% of Group 1 remarked that they did not feel as if they were really “there” while picking landmarks for the routes as seen in Figure 17; and 100% of Group 1 felt that they would benefit with higher levels of immersion while picking landmarks as seen in Figure 18.

Figure 17: Group 1 Presence Question

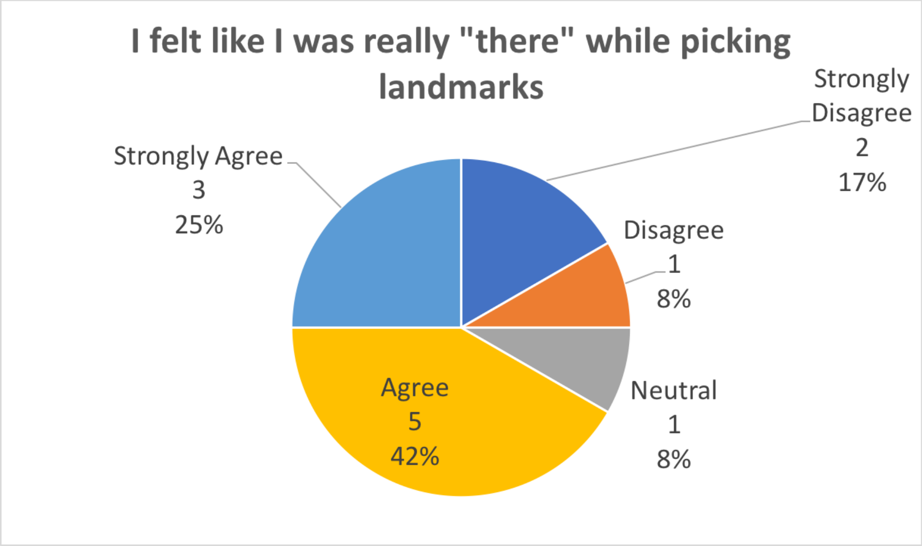
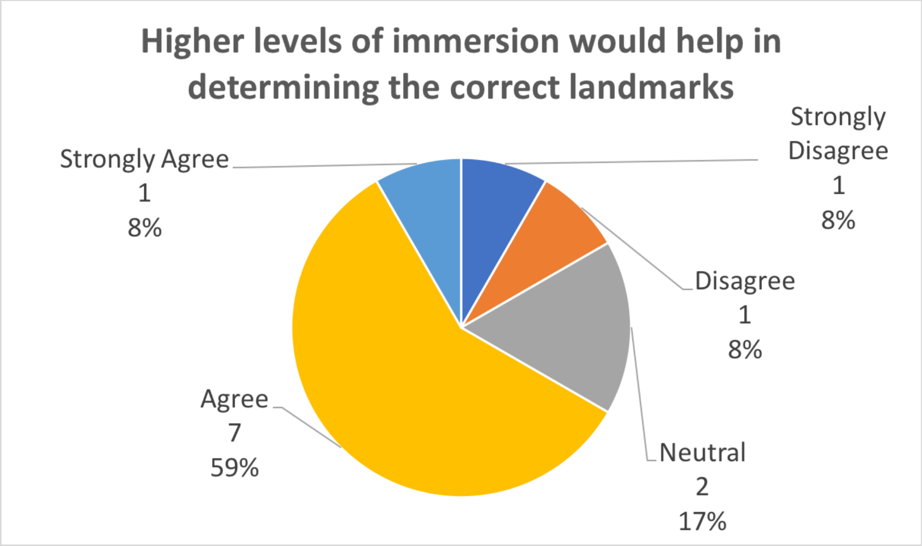


Figure 18: Group 1 Immersion Question



As a summary of the VRUSE Usability Questionnaire [32], more than 50% of the participants in Group 3 (in no particular order):

- thought it was easy to select and move objects in the virtual environment
- thought that display resolution was adequate for the task

- thought quality of image did not affect the performance
- thought there were glitches in the display
- said their eyes did not feel uncomfortable after using the system
- said objects in the virtual environment were not very realistic
- said the update in the image after moving their head was acceptable
- did not feel nauseous after using the system
- did not feel objects moved in a natural manner
- thought the quality of the simulation enhanced their performance
- did not feel the system would protect them against trivial errors
- felt it was easy to make silly mistakes
- thought the VR system was reliable
- felt the quality of the image reduced the feeling of presence
- felt they would be comfortable using the system for long periods
- felt in control of the system

And, as an extreme response, more than 80% of the participants in Group 3:

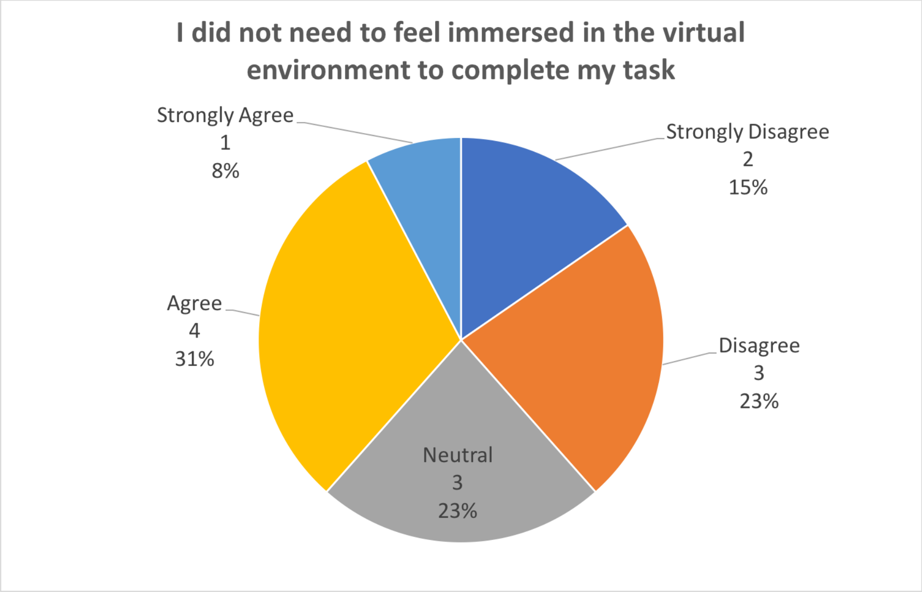
- felt the level of functionality (control) provided by the system was appropriate for the task

- found it easy to access all the functionality (control) of the system
- difficult to remember all the functions available
- understood the meaning of the control interface
- found the overall VR experience satisfactory
- found the input device to be easy to use
- would not have preferred an alternative input device
- found the system response to user input was acceptable
- found the input device was ideal for interacting with a virtual environment
- felt it was easy to move and reposition themselves in the environment
- understood the meaning of menus when displayed
- found it easy to perform tasks in the order they chose
- impressed with the way they could interact with the system
- had the right level of control in the simulation
- had a good sense of scale in the virtual environment
- had a clear idea of how to perform certain functions
- felt the overall VR system did not affect their performance negatively

- enjoyed working with the system

In Group 3, more than 50% of the participants did not feel that the display resolution was adequate enough for the task. Almost 70% of the participants did not answer positively to the question about objects moving in a natural manner in the environment. This could be due to a static world that the participants were presented with. An interesting situation with Group 3, even though more than 70% of participants felt completely immersed in the environment, around 38% thought they did not need the immersion to finish the task on hand as seen in Figure 19. This creates a scenario where the costs of immersion (implementing the environment, buying hardware) is not justified. However, it does not guarantee that other tasks may not require the immersion to successfully complete them.

Figure 19: Group 3 Immersion Question



Following are some questions that gave us interesting results about VR (Group 3) along with statistics such as mean, median, mode, and standard deviation from the 13 participants. Same as the charts above, the questionnaires represent statements rated by the participants from 1 - 5, of which the higher the score, the better the participant felt about the statement. In the chart labels, the prompt is at the top, with the actual number of responses for that question next, and the percentage of total answered below that. The mean, median, mode, and standard deviation of these questions listed below can be found in the table following in 9.

Figure 20: VR: Level of Functionality

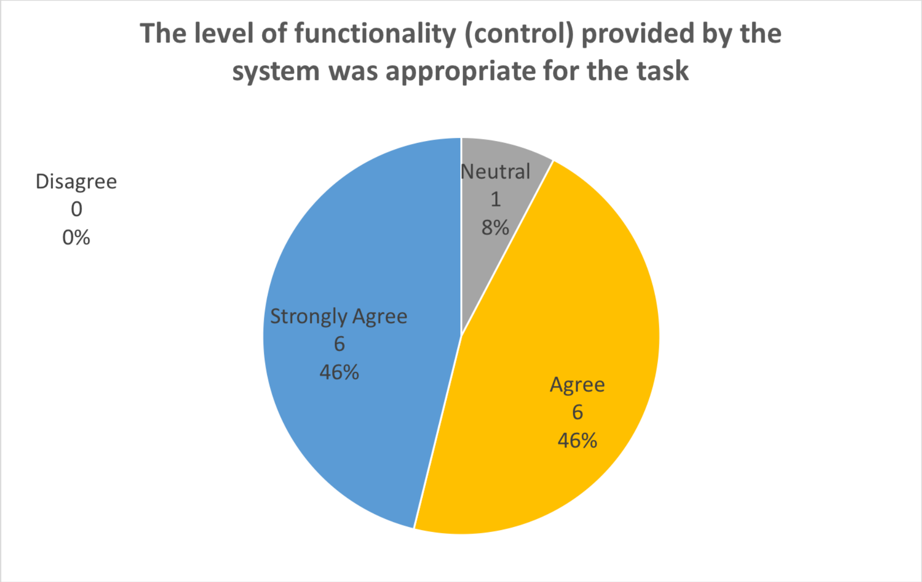


Figure 21: VR: Immersion Question

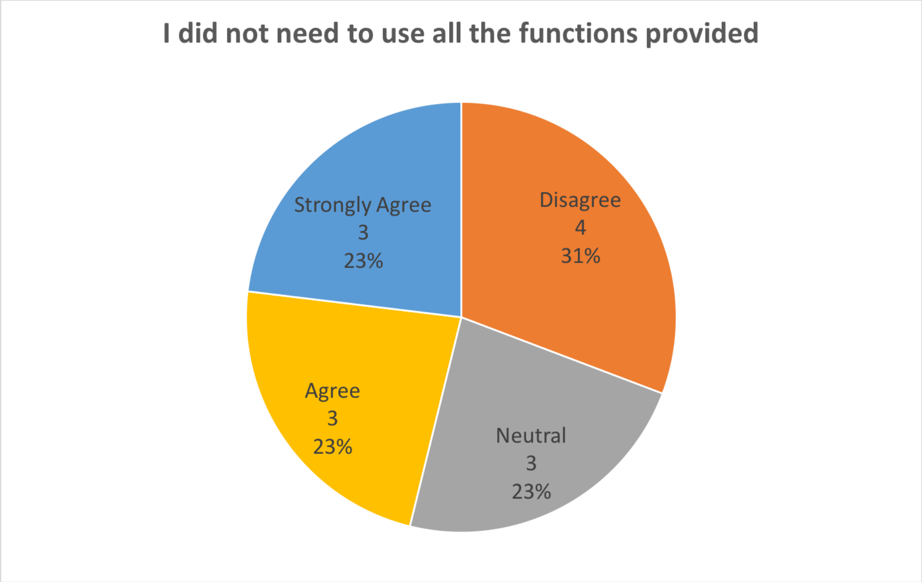


Figure 22: VR: Number of Glitches

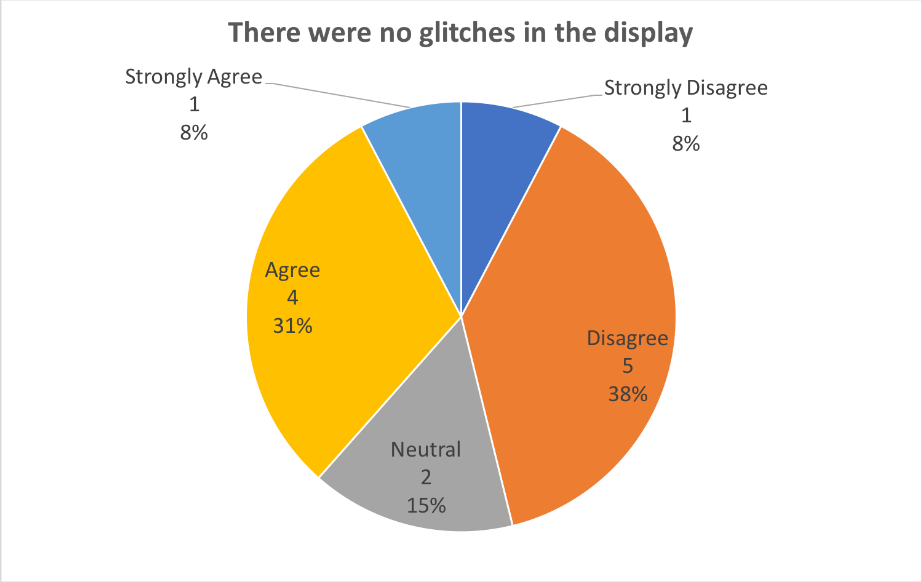


Figure 23: VR: Consistency in System

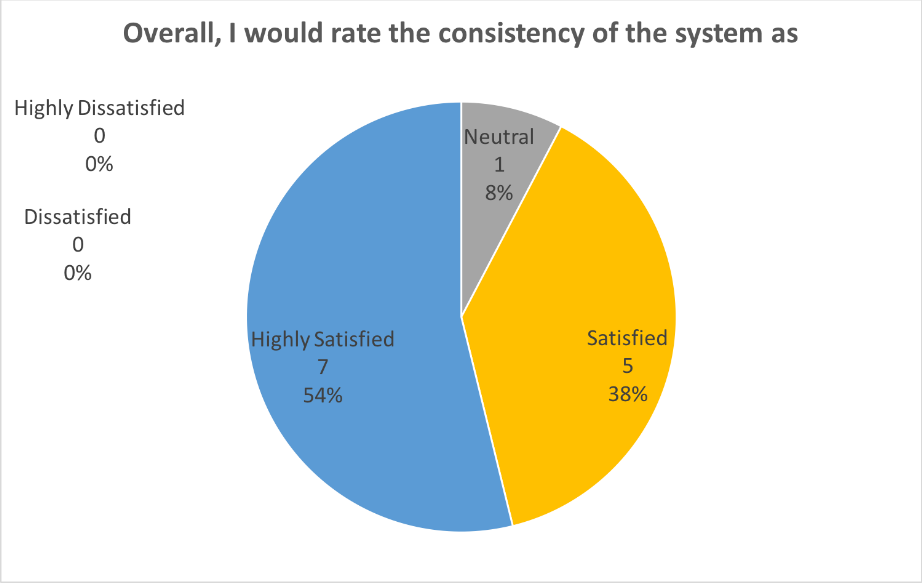


Figure 24: VR: Complications of Input Devices

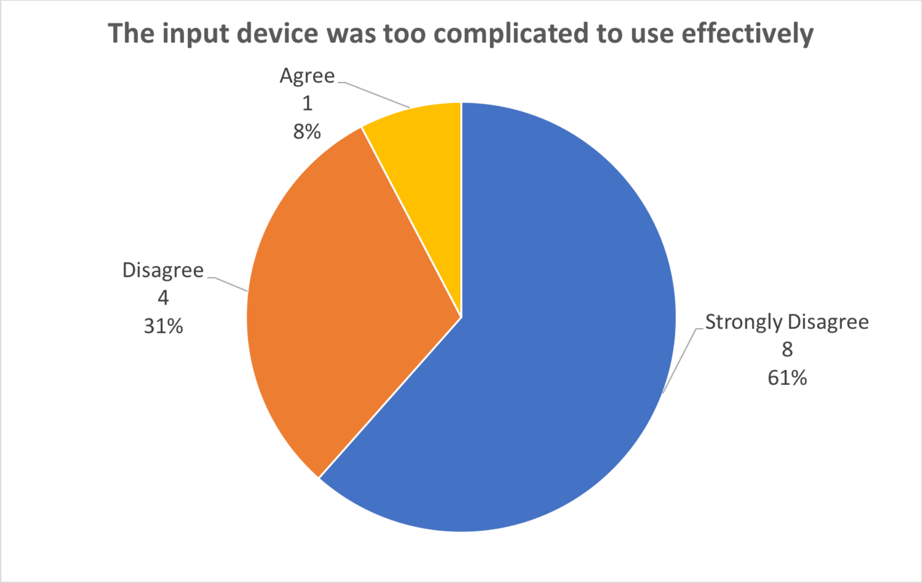


Figure 25: VR: Level of Nausea in Participants

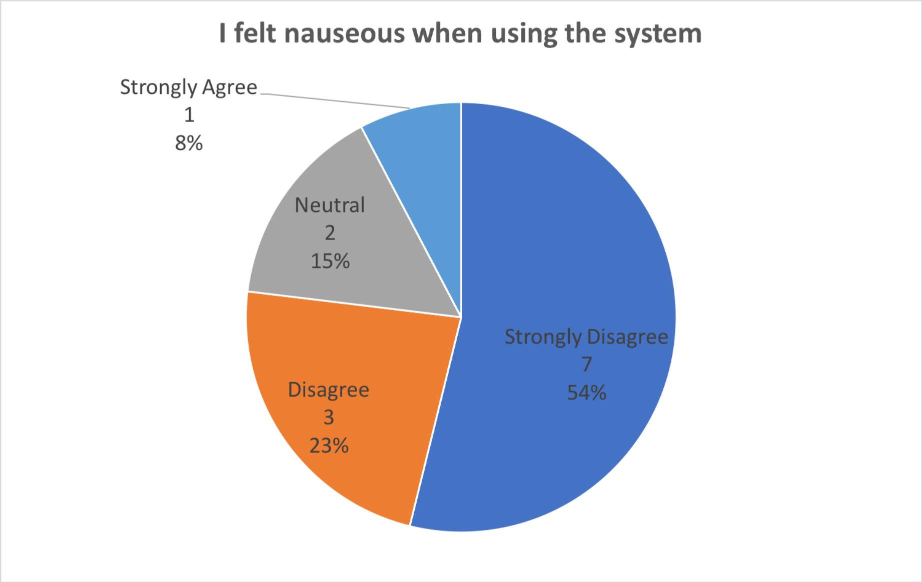


Figure 26: VR: Learn-ability of System

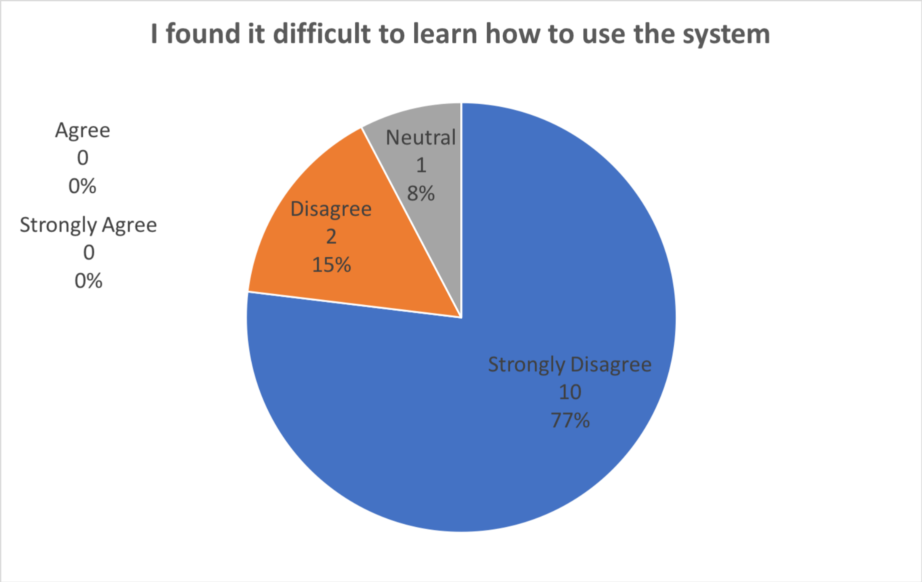
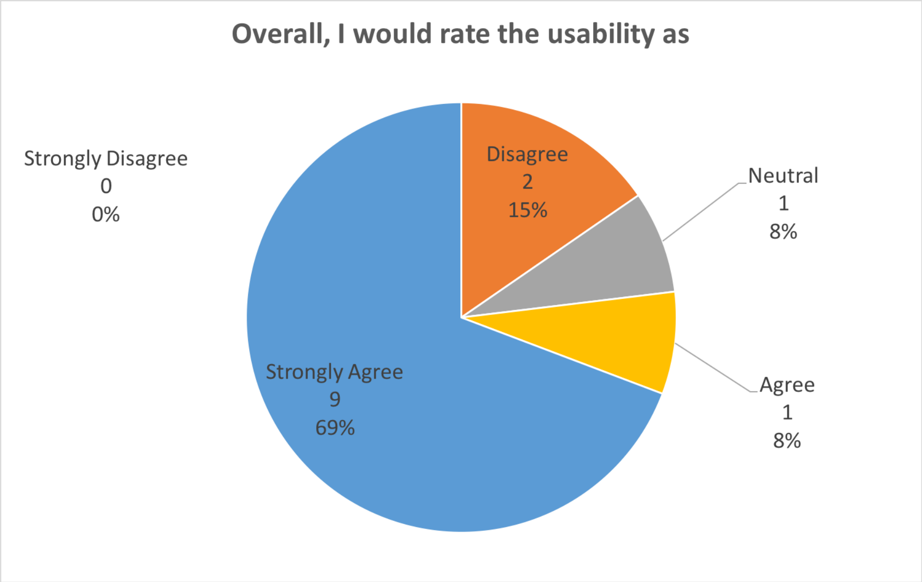


Figure 27: VR: Overall Usability of System



Question	$\bar{x}$	σ	$\tilde{x}$	*Mo*
The level of functionality (control) provided by the system was appropriate for the task	4.38	0.650	4	5
I did not need to use all the functions provided	3.38	1.193	3	2
There were no glitches in the display	2.92	1.188	3	2
The input device was too complicated to use effectively	1.54	0.877	1	1
I felt nauseous when using the system	1.85	1.214	1	1
I found it difficult to learn how to use the system	1.31	0.630	1	1

Overall, I would rate the usability as	4.31	1.182	5	5

Table 9: Statistics for questions in Graphs

4.5 Discussion and Threats to Validity

The discussion and threats mentioned in this section are only for the experiment, not the entirety of the thesis or study. Section 5.1 discusses the threats for the entire thesis as a whole.

Discussion: Looking at the research questions presented before the experiment, in *EQ1* the idea presented was “Is Group 3 (VR) able to collect more or less requirements when compared to Group 1 and 2?”. After the experiment and looking at the landmarks collected, it is not possible to reject the null hypothesis *H1* due to the internal and external validities mentioned below. There are too many variables in the population that can create different results depending on the sample taken. However, for this particular sample, the landmarks were easily found using VR. Further experimentation is needed to really understand whether or not VR is beneficial for certain requirements elicitation sessions when compared to traditional techniques.

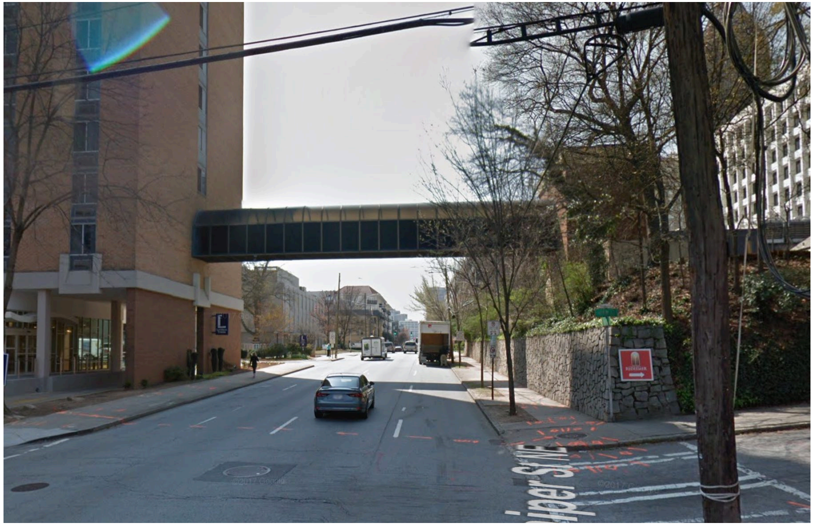
The second research question *EQ2* stated, “Are there significant usability issues for Group 3 detrimental to the act of collecting requirements?”. After analyzing the questionnaire data, most of the participants part of Group 3 enjoyed working with the system overall, and did not notice any detrimental usability issues. However, this question may not be generalized to the entire population until a significant sample is taken into consideration which follows a normal curve. The sample was also taken from a niche selection of college students, which may have more experience with newer technologies than the rest of the population. This hurts the validity of this data as well due to the seclusion from the entire population. However, since there was great positive responses in the usability questionnaire, it is worth moving forward with future research in the area of using VR for requirements elicitation.

Threats to Validity: As far as the structure of the experiment and groups, there is a known gap between Group 2 and 3 - the overview map. Both Groups 1 and 2 received an overview of the route on a top-down view, which was lacking from Group 3 (VR). This led to a disadvantage for Group 3, and the information given to all three groups was not equal. Group 3 also gets a different layer of information that is not seen in Group 1 and 2 - the VR 3D models view; a computer generated 3D view of the world. However, Group 3 was still able to perform in the act of selecting landmarks, which contributes to the main objectives of the study. Group 3 is still able to find a significant amount of landmarks, which is what the study pursues to find; whether VR can be usable for certain tasks such as finding landmarks on a route. Having this gap does affect the experimental validity of the data; for this reason, a fourth group of participants has been designed - more discussed in Section 5.2.

Another threat to the experiment is the low number of participants per group; the demographics of the group do not represent a normal curve of the population. This is also the reason a good statistical analysis was not done for this experiment data. Because the participants were not enough to have a sample with a normal curve, many statistical analysis tests cannot be considered, and the standard deviations calculated will also not be representative of the overall population. Hence, any statements about VR and it's performance in selecting landmarks in comparison to other methods used in this experiment cannot be generalized. However, VR does provide some practical benefits over using a mouse and keyboard. The immersiveness of looking around using your body may be confusing at first, but provides an intuitive way of moving and looking into an environment. Quantified results of this fact will be observed and calculated in the future of this study.

Even though the same landmark may be selected by multiple participants, there is still the threat of ambiguity in language. An observation made during the elicitation sessions is that in Route 1 Turn 3, the same landmark was selected by most participants, however, multiple different words were used: bridge, sky-bridge, catwalk, walkway, sky-walk, overpass, pedestrian bridge, walkway over road. All these words describe the same object in front of the user as seen in Figure 28. Even though selecting the best word for a landmark was not in the scope of this experiment, it is important to realize that different cultures and types of people may associate landmarks with different keywords.

Figure 28: Walkway over road at Route 1, Turn 3.



There is also a threat that there were not enough participants per group. Group 1 had 12; group 2 and 3 both had a total of 13 participants each. Almost all participants were also between the ages of 18-28, being college students at the Kennesaw State University. This may be a threat since most college students are easily adapted to newer technologies. Audiences from other colleges or age groups may find the VR technology harder to use because of their detachment to the change in technology culture. There may be a need to further generalize the results with broader demographics and more participants. For this reason, I am also unable to run any statistical analysis on the data found yet, which can be resolved in a future, more controlled experiment.

Overall, there are definitely some drawbacks for using VR, however, the freedom to move and intuitiveness of looking around an area seems to provide benefits after an appropriate amount of training.

5 Discussion, Future Work and Conclusions

Based on the results of the experiment, immersive VR technology for requirements elicitation seems to unveil more information from the stakeholders than traditional techniques. The group that used VR for going through the routes was able to find more valid landmarks that are visible from the street; qualitatively, this makes it a better landmark. Even though Group 2, with Street View access, could see exactly what Group 3 could, the controls for moving around seems easier in VR, as found from the questionnaire

Participants in the VR environment were able to experience the true feeling of ‘being there’ and selecting landmarks. This provides information to the participant that is otherwise only available by visiting these landmarks which could take days to complete. VR gives us access to places that are impossible or not feasible visit in real life because of time or monetary costs. The intuitiveness of moving around in a VR environment may be very beneficial to requirements elicitation as well, as it is to many other fields, in technology and otherwise. There is much more evidence needed to prove this theory into a fact, though this was the first step in that direction.

In the introduction, research questions RQ1 and RQ2 were presented - RQ1 being “In it’s current state, is using VR as a tool for requirements elicitation feasible?”; which can definitely be answered that it is quite usable for an elicitation session. There is quite a lot of preparation and cost involved in order VR to be successful in an elicitation setting; however, it is quite usable. The questionnaire presented to the students turned out return positive results. However, The selection of candidates may not relate to the population, and the sample size may be too small to determine the actual answer to this question. A conclusion can be deduced that it is definitely worth putting more effort into combining VR technology with the elicitation process The second Research Question (RQ2) stated, "Does using VR as a tool for eliciting certain requirements provide significant benefits over eliciting the same information with traditional methods (eg. interviews, questionnaires)?"; This question can be partially answered, however, more statistical analysis is needed to make strong conclusions. As an exploratory study, the findings have proven that it is beneficial to develop further applications of VR in elicitation and other Requirements Engineering processes.

Requirements Engineering is one of the most important phases of software development, and it is always improving. With upcoming technology in VR, it is time for us to embrace this technology and use it to it's full potential to see significant results.

5.1 Threats to Validity

Use of Virtual Reality is proven to help with selecting landmarks on a street; however, it does not prove that it works for most other cases. To generalize the results found in this thesis, a significant study is needed where multiple experiments in other domains are required. There are also different levels of immersion that can be acquired in VR - using sound and haptic feedback - which may result in different results for different projects. After completing the pilot experiment, there are still some developments needed in the research started, explained in more details in Section 5.2.

From the questionnaire given to Group 3, one of the questions asked whether or not the participants needed to have the immersion to successfully complete their task; more than 50% of the people responded that it was not needed. Although an improvement was seen in the numbers after using VR, there may not be a need for immersion and expensive equipment for certain projects. Which brings the next point, the equipment itself is very expensive currently for small businesses and individuals (other than hobbyists) to acquire for the purpose of requirements elicitation. There are many other techniques that can be used for a much lower price, and the benefits provided by the VR may not be justifiable. The prices are definitely moving in the correct direction though; the HTC Vive used in this experiment recently dropped their MSRP by $200.00.

Virtual Reality hardware and software still also seems to be a little complicated and hard to set up. The room needs to be completely clear of all obstructions and a powerful PC with top of the line Video Card is necessary to successfully run any software. Another sector that comes into play with these technologies may be Augmented Reality (AR), where a brand new environment is not needed; you simply augment the current environment that the user sees. For example, if the user is in a room with a chair and a table - using the camera from the device, a real-time projection can be seen on the screen with certain augmentations; the user could see an object that does not exist on the table - placed by the AR software that only the user can see. This can be useful in certain scenarios such as furniture placement - you can actually see the room that you want to place furniture, and experience exactly what it would feel like in the room. The application of AR is completely different from VR, though it deserves a mention as it may be useful in certain scenarios rather than VR.

5.2 Future Work

Previously, the experiment was designed and formulated and executed in this thesis. To continue the study further and find more validation for using VR as a tool in elicitation sessions, it would be beneficial to at least record more data with different domains. The whole study will be completed in phases over a period of 3 years at a minimum; of which, the thesis is the first step.

In the near future, there may be further experimentation needed in order to statistically prove that VR is better for some requirement types than traditional elicitation techniques. There is a great desire to use a within-subject design for these future experiments so that a more normalized group of participants can be acquired in each group. Currently, a within-group design has the capability of placing, at random, participants that are proficient at VR technologies in a single group. However, this bias can be reduced if every participant goes through every elicitation technique. In order to avoid the carryover effect where the performance of one elicitation technique informs the other, several sets of smaller experiments will be performed with each participants. For example, with our current experiment, for each route that a participant selects landmarks for, a random elicitation technique can be chosen for a participant for each route; route 1 may use the VR technique, route 2 may use Street View, route 3 may use VR, and so on. Randomizing at the route level for each participant rather than placing participants in random groups ensures that each subject contributes evenly to all elicitation techniques.

Below are the phases of the entire study, of which this thesis was Phase I. There are two more years worth of work remaining after the writing of this thesis.

Phase I, Observational Experiment: For the first phase, an observational experiment is designed in order to observe and determine whether or not using VR is feasible in a requirements elicitation setting. This thesis will go through completing this phase, and show the results found. In summary, this phase will include preliminary research: a literature review including VR and requirements elicitation, documenting preparation steps for conducting a VR study, determining the types of requirements that may be elicited successfully using VR, and documenting any threats to validity and hardships that the research may face.

Phase II, Elicitation Technique: The second phase includes documenting the elicitation technique, in detail, for a generic set of requirements that work well eliciting using VR. The requirement types and examples researched in the previous phase contribute towards further research in this phase. Documenting the elicitation technique involves not only theorizing the process of using Virtual Reality, but also proving via stronger experiments that it is worth further development in the next phase. In addition to the preparation phase documented in the previous phase, the elicitation technique needs best practices and general protocols for elicitation sessions.

Further experimentation is necessary with stronger statistical analysis to prove the fact that VR is or is not better than using traditional elicitation techniques, for certain requirement types. This statistical analysis will help researchers and readers determine whether or not it is worth using this technique in their elicitation sessions. The reason this fact is left to the second phase is due to the unknown territory which is VR for the RE field.

Phase III, Developing Environments: After documenting best practices and significantly proving that VR can work for eliciting requirements for projects, it may be beneficial to create some generic environments that can be used for several different types of requirements. For example, a world map could be a generic environment that can be used for several different settings: the world we live in plays a big role in the software we use. However, customization of such environments would greatly help the affordability of using VR in future projects. In which case, the analyst would only need to change the existing environment to suit the requirements elicitation project in question, rather than create an environment. Creating several customizable environments will be the last and final step of the elicitation technique.

5.3 Conclusion

This thesis evaluates Virtual Reality as a tool for requirements elicitation and seems to be better in a single case scenario. The method describes the preparation steps for using VR, guidelines for software engineers and developers for incorporating VR in their software requirements phases. Using VR, participants are able to fully immerse themselves in the environment and feel as if they are really 'there'. This is a giant step for the presence in human-computer interaction and provides details that are otherwise not attainable.

According to the research done in this thesis and the data collected, there is definitely room for improvement for VR as it relates to requirements elicitation. However, it is necessary for us to combine these two research areas together to find a better result for requirements elicitation. As new technologies are introduced, the requirements society should embrace and take advantage of the inventions in other fields such as gaming and virtual technology. Therefore, after determining the usability of VR for elicitation purposes, the next 2 years will be worked on Phase II and Phase III.

Virtual Reality does have some flaws and there is some room for improvement. Training is necessary for participants so the features can be used to it's full potential, and it can be disorienting. However, for a select chosen candidates, the benefits can outweigh the flaws. Using VR can provide requirements to the analyst that are otherwise unattainable. In the end, VR is another tool in the elicitation techniques for the analyst to use to gain as much information about the software as possible. There are other ways to receive the same information; however, VR may be the most unambiguous in certain given scenarios.

References

[1] U. Erra and G. Scanniello. Assessing communication media richness in requirements negotiation. *IET Software*, 4(2), 2010.

[2] Joel Harman, Ross Brown, Daniel Johnson, Stefanie Rinderle-Ma, and Udo Kannengiesser. Virtual business role-play: Leveraging familiar environments to prime stakeholder memory during process elicitation. In *CAiSE*, 2015.

[3] C. Cruz-Neira and R. R. Lutz. Using immersive virtual environments for certification. *IEEE Software*, 16(4):26–30, Jul 1999.

[4] V. Winter, D. Desovski, and B. Cukic. Virtual environment modeling for requirements validation of high consequence systems. In *Proc. of IEEE RE'01*, pages 23–30, 2001.

[5] S. Sharma and S.K. Pandey. Requirements elicitation: Issues and challenges. In *Proc. of INDIACom 2014*, pages 151–155, 2014.

[6] P. Rajagopal, R. Lee, T. Ahlswede, C.-C. Chiang, and D. Karolak. A new approach for software requirements elicitation. In *Proc. of SNPD/SAWN 2005*, pages 32–42, 2005.

[7] Suzanne Robertson and James Robertson. *Mastering the requirements process: Getting requirements right.* Addison-wesley, 2012.

[8] Vincenzo Gervasi, Ricardo Gacitua, Mark Rouncefield, Peter Sawyer, Leonid Kof, L Ma, P Piwek, A De Roeck, Alistair Willis, H Yang, et al. Unpacking tacit knowledge for requirements engineering. In *Managing requirements knowledge*, pages 23–47. Springer, 2013.

[9] Peter Marshall and Damian Gordon. Eliciting tacit knowledge from a domain of physical skill. *Proceedings of the European Conference on Intellectual Capital*, pages 222 – 230, 2011.

[10] Didar Zowghi and Chad Coulin. Requirements elicitation: A survey of techniques, approaches, and tools. In *Engineering and managing software requirements*, pages 19–46. Springer, 2005.

[11] Glenn J. Browne and Michael B. Rogich. An empirical investigation of user requirements elicitation: Comparing the effectiveness of prompting techniques. *J. Manage. Inf. Syst.*, 17(4):223–249, Mar 2001.

[12] Unnati S. Shah and Devesh C. Jinwala. Resolving ambiguities in natural language software requirements: A comprehensive survey. *SIGSOFT Softw. Eng. Notes*, 40(5):1–7, September 2015.

[13] Irit Hadar, Pnina Soffer, and Keren Kenzi. The role of domain knowledge in requirements elicitation via interviews: an exploratory study. *Requirements Engineering*, 19(2):143–159, 2014.

[14] Ritu Agarwal and Mohan R Tanniru. Knowledge acquisition using structured interviewing: an empirical investigation. *JMIS*, 7(1), 1990.

[15] Glenn J Browne and Michael B Rogich. An empirical investigation of user requirements elicitation: Comparing the effectiveness of prompting techniques. *Journal of Management Information Systems*, 17(4):223–249, 2001.

[16] Wernher R Friedrich and John A Van Der Poll. Towards a methodology to elicit tacit domain knowledge from users. *IJIKM*, 2(1), 2007.

[17] Ideo. *IDEO Method Cards: 51 Ways to Inspire Design*. 2003.

[18] Alistair Sutcliffe, Brian Gault, and Neil Maiden. Isre: Immersive scenario-based requirements engineering with virtual prototypes. *Requir. Eng.*, 10(2):95–111, May 2005.

[19] D. A. Bowman, A. Sowndararajan, E. D. Ragan, and R. Kopper. Higher levels of immersion improve procedure memorization performance. In *Proc. of JVRC'09*, pages 121–128. Eurographics Association, 2009.

[20] Joshua R. Ehrlich, Lauro V. Ojeda, Donna Wicker, Sherry Day, Ashley Howson, Vasudevan Lakshminarayanan, and Sayoko E. Moroi. Head-mounted display

technology for low-vision rehabilitation and vision enhancement. *American Journal of Ophthalmology*, 176:26 – 32, 2017.

[21] Steve1 Downey. History of the (virtual) worlds. *Journal of Technology Studies*, 40(2):54 – 66, 2014.

[22] Mel Slater and Sylvia Wilbur. A framework for immersive virtual environments (five): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and virtual environments*, 6(6):603–616, 1997.

[23] Richard Holloway and Anselmo Lastra. Virtual environments. Technical Report 93-033, 1993.

[24] Joshua R Ehrlich, Lauro V Ojeda, Donna Wicker, Sherry Day, Ashley Howson, Vasudevan Lakshminarayanan, and Sayoko E Moroi. Head-mounted display technology for low-vision rehabilitation and vision enhancement. *American journal of ophthalmology*, 176:26–32, 2017.

[25] Konstantina Kilteni, Raphaela Groten, and Mel Slater. The sense of embodiment in virtual reality. *Presence: Teleoperators and Virtual Environments*, 21(4):373–387, 2012.

[26] Søren Lauesen and Houman Younessi. Six styles for usability requirements. In *REFSQ*, volume 98, pages 155–166, 1998.

[27] Hadi Ghanbari, Jouni Similä, and Jouni Markkula. Utilizing online serious games to facilitate distributed requirements elicitation. *Journal of Systems and Software*, 109:32–49, 2015.

[28] João Fernandes, Diogo Duarte, Claudia Ribeiro, Carla Farinha, João Madeiras Pereira, and Miguel Mira da Silva. ithink: A game-based approach towards improving collaboration and participation in requirement elicitation. *Procedia Computer Science*, 15:66–77, 2012.

[29] Maria V Sanchez-Vives and Mel Slater. From presence towards consciousness. In *8th Annual Conference for the Scientific Study of Consciousness*, 2004.

[30] Alistair Sutcliffe. Scenario-based requirements engineering. In *Requirements engineering conference, 2003. Proceedings. 11th IEEE international*, pages 320–329. IEEE, 2003.

[31] Doug A Bowman, Joseph L Gabbard, and Deborah Hix. A survey of usability evaluation in virtual environments: classification and comparison of methods. *Presence: Teleoperators and Virtual Environments*, 11(4):404–424, 2002.

[32] Roy S Kalawsky. Vruse—a computerised diagnostic tool: for usability evaluation of virtual/synthetic environment systems. *Applied ergonomics*, 30(1):11–25, 1999.

[33] AG Sutcliffe and K Deol Kaur. A usability evaluation method for virtual reality user interfaces, 2008.

[34] Alistair Sutcliffe, Brian Gault, Terence Fernando, and Kevin Tan. Investigating interaction in cave virtual environments. *ACM Transactions on Computer-Human Interaction (TOCHI)*, 13(2):235–267, 2006.

[35] Ann M Hickey and Alan M Davis. Requirements elicitation and elicitation technique selection: model for two knowledge-intensive software development processes. In *System Sciences, 2003. Proceedings of the 36th Annual Hawaii International Conference on*, pages 10–pp. IEEE, 2003.

[36] Cristina Leovaridis and Monica BAHNĂ. Aspects regarding virtual reality as innovation in creative industries. *Revista Romana de Sociologie*, 28(3/4):157 – 172, 2017.

[37] William R Sherman and Alan B Craig. *Understanding virtual reality: Interface, application, and design*. Elsevier, 2002.

[38] Helen Sharp, Anthony Finkelstein, and Galal Galal. Stakeholder identification in the requirements engineering process. In *Database and Expert Systems Applications, 1999. Proceedings. Tenth International Workshop on*, pages 387–391. Ieee, 1999.

[39] Fares Anwar and Rozilawati Razali. A practical guideline of selecting stakeholders for requirements elicitation-an empirical study. *International Journal of Software Engineering and Its Applications*, 9(2):95–106, 2015.

[40] Kay Stanney. Realizing the full potential of virtual reality: human factors issues that could stand in the way. In *Virtual Reality Annual International Symposium, 1995. Proceedings.*, pages 28–34. IEEE, 1995.

[41] Sari Kujala, Marjo Kauppinen, Laura Lehtola, and Tero Kojo. The role of user involvement in requirements quality and project success. In *Requirements Engineering, 2005. Proceedings. 13th IEEE International Conference on*, pages 75–84. IEEE, 2005.

[42] Akitoshi Yoshida, Jannick P Rolland, and John H Reif. Design and applications of a high-resolution insert head-mounted-display. In *Virtual Reality Annual International Symposium, 1995. Proceedings.*, pages 84–93. IEEE, 1995.

[43] Alan J Wecker, Joel Lanir, Tsvi Kuflik, and Oliviero Stock. Where to go and how to get there: Guidelines for indoor landmark-based navigation in a museum context. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services Adjunct*, pages 789–796. ACM, 2015.

[44] Reinhard Sefelin, Michael Bechinie, Regine Müller, Verena Seibert-Giller, Peter Messner, and Manfred Tscheligi. Landmarks: yes; but which?: five methods to select optimal landmarks for a landmark-and speech-based guiding system. In *Proceedings of the 7th international conference on Human computer interaction with mobile devices & services*, pages 287–290. ACM, 2005.

[45] Pepijn Viaene, Pieter Vansteenkiste, Matthieu Lenoir, Alain De Wulf, and Philippe De Maeyer. Examining the validity of the total dwell time of eye fixations to identify landmarks in a building. *Journal of Eye Movement Research*, 9(3), 2016.

[46] Robert Tscharn, Tom Außenhofer, Dimitri Reisler, and Jörn Hurtienne. Turn left after the heater: Landmark navigation for visually impaired users. In *Proceedings of the 18th International ACM SIGACCESS Conference on Computers and Accessibility*, pages 295–296. ACM, 2016.

[47] Mary M DaRif and Barbara A Merriman. Paint color card and methods of using the same, February 7 2006. US Patent 6,994,553.

[48] Michelle E Portman, Asya Natapov, and Dafna Fisher-Gewirtzman. To go where no man has gone before: Virtual reality in architecture, landscape architecture and environmental planning. *Computers, Environment and Urban Systems*, 54:376–384, 2015.

[49] Ekaterina Aleksandrova Petrova, Mai Rasmussen, Rasmus Lund Jensen, and Kjeld Svidt. Integrating virtual reality and bim for end-user involvement in building design: a case study. In *The Joint Conference on Computing in Construction (JC3) 2017*, pages 699–709. The Joint Conference on Computing in Construction (JC3) 2017, 2017.

6 Appendix

6.1 Color Likability Experiment

Purpose of Experiment This experiment involves eliciting requirements from the stakeholder (client, user, etc) to accurately determine the most likable color needed for a particular purpose. The premise is that color perception changes when it is exaggerated to larger scales; colors on small cards look different when they are put on giant walls. However, it is too time consuming, and cost ineffective to paint a big room or wall to test color likability. This is when VEs come into play. Colors in a large room or wall may be perceived correctly by the stakeholder and therefore assist in making a decision.

Groups and Description

1. Group (VR): Virtual Environment
2. Group (GQ): Graphical Questionnaire
3. Group (F2F): Interview

Group VR: This group will be subjected to a virtual room which looks like an ordinary room with regular items such as a chair, table, bookshelves, and paintings. The colors of the walls can be changed by the user using buttons. The interface of these buttons can either be hardware: using controllers held by the participant; or software: using buttons inside the room itself. The texture of the walls will replicate a real-life wall as much as possible.

There will be three controls consisting of six total buttons. One way of determining color in digital format is to use the Hue, Saturation, and Luminosity (HSL) model. Hue represents the actual color; saturation represents the amount of grey mixed into the color: 0 represents grey for all hues, and 255 is the most saturated version of the hue. Luminosity represents the amount of white in a hue, usually perceived as brightness. Luminosity of 0 represents black, and luminosity of 100% represents white. The buttons are as follows:

Increase Hue	Decrease Hue
Increase Saturation	Decrease Saturation
Increase Luminosity	Decrease Luminosity

By convention, all values are represented ranging from 0 to 255 but can also take form as a percentage. The users can determine the color of the walls using these three values, and confirm once they reach the determined color. This experiment will only include *Pantone* colors; the reason for this is explained in the Section Validation of Requirements.

Group GQ: The second elicitation technique will be as a graphical questionnaire. The questionnaire will ask questions related to the user's preferences about colors, rooms, and mood. Depending on the answers, it will suggest some colors for the user to pick from. Alternatively, the user also has the ability to pick their own colors using the same three controls described previously: hue, saturation, and luminosity.

The main difference between these two groups will be the fact that the first group gets to experience the color in a real room, first-hand. The graphical interview will only be subjected to the color on a small box on a computer screen or a mobile phone.

Group F2F: This group will be subjected to a traditional elicitation technique of interview from a developer or analyst. The interviewee and the analyst will have a conversation about mood, tone of colors, warm/cold color likability, general colors (red, green, blue, orange, yellow, etc.). After the interview and receiving ideas from the client, the analyst would prepare three different colors based on the client's responses and descriptions.

Below are the attributes that the client would be using for describing color:

1. Brightness
2. Saturation
3. Glossy/Matte
4. General Color (violet, indigo, blue, green, yellow, orange, red)
5. Mixing two general colors

Validation of Requirements: After receiving the above requirements from your stakeholders, there is a need to validate them to see if they are correct. Correct requirements will not need any changes later down the road – hence, they save money and time after your creation is finished. Since there are three different populations subjected to different experiments and elicitation techniques, it requires three validation techniques for each group.

During validation, the client who choose the color (or the description of color in Group F2F), will have a chance to change the color to their liking, if their needs have not been met. Below is a description of how validation will work for each group.

In general, each group is faced with the colors they chose in a higher order of immersion and has a chance to decide whether they would like to keep their original color. If not, the exercise to select the color was obviously not effective for this kind of requirement.

Group VR: Virtual environments are the closest form of environment to real-life. Therefore, it only makes sense to develop a validation technique that creates the color chosen in the real-world. This is the reason I decided to restrict the colors in this group to pantone colors. Pantone colors are replicable in a tangible format from a digital version. Therefore, it is possible to convert the colors chosen digitally into tangible format that the stakeholder can hold. At this point, the stakeholder has a choice of changing the color into another color of his or her liking.

If the stakeholder changes the color to another: the exercise has failed since the color chosen in the VE was not what the stakeholder expected. If the stakeholder approves the color: the exercise has passed since the color chosen in the VE was exactly what the stakeholder wanted. The success rate of this experiment depends on how many stakeholders accept or reject the final printed color.

Group GQ: Since the graphical questionnaire includes small cards of colors that the stakeholder can change and also choose form the suggested colors, the colors chosen by the stakeholders are then presented in the same virtual environment used by Group VR. In this exercise, Group GQ is able to view the colors they chose in a giant room and experience it virtually.

Similar to Group VR validation of colors, Group GQ is given the chance to change the color based on their perception of the color in a large scale. If the stakeholder changes the color to another: the exercise has failed since the color chosen in the VE was not what the stakeholder expected. If the stakeholder approves the color: the exercise has passed since the color chosen in the VE was exactly what the stakeholder wanted. Again, similar to the previous group, the success of this elicitation technique depends on how many stakeholders that go through the process accept or reject the color finally chosen.

Group F2F: After the conversation to describe the color in the interview, the stakeholder is presented with the color chosen by the analyst depending on the interview questions and the pre-exercise survey. The color is displayed on screen with sliders for hue, saturation, and luminosity; described in Group VR procedure.

The stakeholder has a chance to change the sliders and therefore change the color if it does not meet their needs. It is possible to determine the effectiveness of this elicitation technique based on how many people from this population change their final color.

Data Collection: There are a few types of data that needs to be collected for this experiment to be successful. Below are the sections that describe some data collected before the exercise, during the exercise, and after the exercise. Before the exercise, each candidate, irrespective of the group will be given a survey that has the following questions to determine the mood of the candidate.

During elicitation, the color determined by the analyst will be recorded. During the validation phase, an overall number of how many people have corrected their colors for each elicitation technique will be recorded, and the final color chosen (if different from elicitation phase). Below is a sample of the data to be collected for each group.

The post validation data collection will include a survey taken by all participants.

Analyzing Data Each participant's answers and actions will be analyzed to create an explanation of the results. For each elicitation technique, the determination of which one is superior in this scenario will be made based on the number of participants that change their color during validation phase. Since the validation phase is consists of a technique that is objectively superior to the elicitation, it can be deduced that the color chosen in the validation phase is the correct one. For example, describing colors with words and actions is quite difficult. Therefore, Group F2F will be able to accurately determine their chosen colors during validation, which gives them the option to visually choose the hue they desire.

The pre-experiment survey will mainly be used by the Group F2F so that the analyst can suggest colors based on the participant's mood. Group GQ and Group VR will participate in this survey to validate whether mood affects the color choice of people; since each of these groups will have full control over the colors they choose in their elicitation phase.

The post-validation survey is for the research team to gain insights from the participants, whether they thought the experiment was successful or not. The participants will also give insight on their elicitation technique and how effective it was for this purpose.

Inferring Conclusions: There is one main conclusion that can be inferred through our research: whether VR is a superior choice for eliciting color choices and likability, when compared to traditional techniques such as questionnaires and interviews. It is also possible to determine whether mood affects color likability of a person. The pre-elicitation survey will categorize participants in several mood categories and then a pattern will be determined, if any.

6.2 Questionnaires

Group 1

Question	Mean	Std. Dev.	Median	Mode
The level of functionality was appropriate for the task on hand	4.25	0.622	4	4
I found it easy to access all the functionality of the system	4.17	0.937	4	5
It was hard to move backwards to fix a small mistake I made	2.92	1.240	3	3
Displayed information was too complicated to understand the task	1.58	1.165	1	1
I felt comfortable using the system	4.17	0.835	4	5
There were many small issues while using the system	2.50	1.314	2	2
The controls of the system were easy to understand	4.25	0.965	5	5
The system behaved in the manner I expected	4.17	0.835	4	5
The system appeared to freeze or pause at intervals	1.92	1.311	1	1

Rate the overall system you have used in this experiment here today.	4.17	0.835	4	5
It was easy to communicate with the analyst	4.58	0.515	5	5
I was able to express the landmarks exactly how I wanted	4.00	0.953	4	4
I would prefer not to talk after I understood my task (select landmarks quietly)	2.00	0.853	2	2
The analyst understood exactly what I meant	4.50	0.674	5	5
I had to repeat myself sometimes about what I was saying	1.25	0.452	1	1
It was hard to concentrate while interviewing	1.33	0.492	1	1
Rate the overall communication experience during the experiment	4.50	0.522	5	5
The dispaly device was appropriate for the task on hand	4.50	0.674	5	5

The input devices were appropriate for the task on hand	4.50	0.674	5	5
There were no glitches in the display	3.92	1.084	4	5
Rate the overall hardware used for this experiment	4.33	0.778	5	5
I felt like I was really	3.50	1.446	4	4
Higher levels of immersion would help in determining the correct landmarks	3.50	1.087	4	4
Driving or walking outside would feel exactly like picking landmarks on a screen	3.50	1.382	4	4
The amount of lag (deplay) in the system affected my performance	1.67	0.778	2	1
The image quality on screen affected my performance for the task	3.17	1.403	4	4
I lacked a sense of depth while using the system	2.25	1.055	3	3
I had a good sense of scale (size) while looking at the environment	4.00	1.044	4	5

Rate the overall immersion of the system you worked with.	3.83	0.937	4	4

Table 10: Questionnaire statistics for Group 1

Group 2

Question	Mean	Std. Dev.	Median	Mode
The level of functionality was appropriate for the task on hand	4.25	0.622	4	4
I found it easy to access all the functionality of the system	4.17	0.937	4	5
It was hard to move backwards to fix a small mistake I made	2.92	1.240	3	3
Displayed information was too complicated to understand the task	1.58	1.165	1	1
I felt comfortable using the system	4.17	0.835	4	5
There were many small issues while using the system	2.50	1.314	2	2
The controls of the system were easy to understand	4.25	0.965	5	5

The system behaved in the manner I expected	4.17	0.835	4	5
The system appeared to freeze or pause at intervals	1.92	1.311	1	1
Rate the overall system you have used in this experiment here today.	4.17	0.835	4	5
It was easy to communicate with the analyst	4.58	0.515	5	5
I was able to express the landmarks exactly how I wanted	4.00	0.953	4	4
I would prefer not to talk after I understood my task (select landmarks quietly)	2.00	0.853	2	2
The analyst understood exactly what I meant	4.50	0.674	5	5
I had to repeat myself sometimes about what I was saying	1.25	0.452	1	1
It was hard to concentrate while interviewing	1.33	0.492	1	1

Rate the overall communication experience during the experiment	4.50	0.522	5	5
The dispaly device was appropriate for the task on hand	4.50	0.674	5	5
The input devices were appropriate for the task on hand	4.50	0.674	5	5
There were no glitches in the display	3.92	1.084	4	5
Rate the overall hardware used for this experiment	4.33	0.778	5	5
I felt like I was really	3.50	1.446	4	4
Higher levels of immersion would help in determining the correct landmarks	3.50	1.087	4	4
Driving or walking outside would feel exactly like picking landmarks on a screen	3.50	1.382	4	4
The amount of lag (deplay) in the system affected my performance	1.67	0.778	2	1
The image quality on screen affected my performance for the task	3.17	1.403	4	4

I lacked a sense of depth while using the system	2.25	1.055	3	3
I had a good sense of scale (size) while looking at the environment	4.00	1.044	4	5
Rate the overall immersion of the system you worked with.	3.83	0.937	4	4

Table 11: Questionnaire statistics for Group 2

Group 3

Question	Mean	Std. Dev.	Median	Mode
Funtionality				
The level of functionality (control) provided by the system was appropriate for the task	4.38	0.650	4	5
The functionality provided by the VR system was ambiguous	2.92	1.441	3	2
I found it easy to access all the functionality (control) of the system	4.31	0.947	5	5

It was difficult to remember all the functions available	1.62	0.650	2	1
I understood the meaning of the control interface	4.62	0.506	5	5
I did not need to use all the functions provided	3.38	1.193	3	2
Overall I would rate the VR system in terms of functionality as:	4.23	0.832	4	4
User Input				
I found the input device to be easy to use	4.38	0.768	5	5
I would have preferred an alternative input device	1.77	0.927	2	1
The system response to user input was acceptable	4.23	0.927	4	5
I found the input device too sensitive to use	1.77	0.599	2	2
The input device was ideal for interacting with a virtual environment	4.15	0.899	4	4
I kept making mistakes while interacting with the system	1.92	0.954	2	1

I had the right level of control over what I wanted to do	4.00	1.080	4	5
It was easy to select and move objects in the virtual environment	3.85	0.987	4	4
The input device was too complicated to use effectively	1.54	0.877	1	1
I found it easy to move or reposition myself in the virtual environment	4.23	0.927	4	5
Visual feedback relating to the interface was inadequate	1.77	0.725	2	2
Overall, I would rate the user input as	4.46	0.660	5	5
System Output (Display)				
I found the display device appropriate for the task	4.38	0.650	4	5
The amount of lag (delays) in the image affected my performance (negatively)	2.00	0.913	2	2
The display resolution was adequate for the task	3.54	0.967	4	4
I was aware of distortions in the image	3.62	0.961	3	3

The display field of view was appropriate for the task	4.08	0.760	4	4
The quality of the image affected my performance (negatively)	2.08	0.862	2	2
The information was presented in a meaningful way	3.54	0.776	4	4
There were no glitches in the display	2.92	1.188	3	2
Display feedback was adequate for the task	4.23	0.725	4	4
My eyes felt uncomfortable after using the system	2.15	1.214	2	2
Objects in the virtual environment were very realistic	3.31	1.109	3	3
I had difficulty getting used to the display	1.62	0.650	2	1
When I moved my head the image update was acceptable	4.15	1.214	5	5
Displayed information was too complicated	1.54	0.519	2	2
I felt nauseous when using the system	1.85	1.214	1	1

When menus were displayed I fully understood their meaning	4.31	0.630	4	4
I lacked a sense of depth in the image	2.08	0.862	2	2
Audio feedback (when used) helped my performance	3.58	0.900	3	3
The lack of tactile/force feedback reduced my performance	1.85	0.689	2	2
Overall, I would rate the display system as	4.23	1.013	5	5
Consistency				
The VR system behaved in a manner that I expected	4.31	0.630	4	4
It was difficult to understand the operation of the interface	1.38	0.506	1	1
The information presented by the system was consistent	4.15	0.555	4	4
I was confused by the operation of the system	1.23	0.439	1	1

The sequence of inputs to perform a specific action matched my understanding of the task	3.92	1.038	4	4
The use of icons, menus, and toolbars was inconsistent	1.62	0.650	2	1
The actions of controls with icons and symbols were obvious	4.31	0.630	4	4
Overall, I would rate the consistency of the system as	4.46	0.660	5	5
Flexibility				
I found it easy to perform tasks in the order I chose	4.38	0.650	4	5
The user interface interfered with the way I wanted to interact with the system	2.62	1.387	2	2
The user can tailor the system to suit their needs	3.54	0.776	3	3
I could not achieve what I wanted in the VR system	1.77	0.725	2	2
I was able to take shortcuts in using the system	3.31	1.377	4	4

Overall, I would rate the flexibility of the system as	4.00	0.707	4	4
Simulation Fidelity				
The underlying simulation was accurate	3.69	1.032	4	4
The simulation was too simplistic to be of use	2.15	0.689	2	2
I was impressed with the way I could interact with the simulation	4.00	0.816	4	4
The simulation behaved in a very unusual manner	1.69	0.630	2	2
Objects in the virtual environment moved in a natural manner	2.92	1.498	3	3
I felt disoriented in the virtual environment	1.69	1.032	1	1
I had the right level of control over the simulation	4.08	0.641	4	4
The virtual environment was too complicated	1.62	0.870	1	1
I thought the quality of the simulation enhanced my performance	3.62	1.044	4	4

The simulation appeared to freeze or pause at intervals	2.46	1.050	2	2
Overall, I would rate the fidelity of the simulation as	3.62	0.961	4	4
Error Correction/Handling and Robustness				
I found it easy to undo mistakes and return to a previous state	3.15	1.345	3	2
I was unaware of making mistakes	2.23	0.927	2	2
The system provided protection against trivial errors	3.23	1.013	3	4
There was no means of 'undoing' an operation	2.31	1.182	2	1
It was not possible to make silly mistakes	2.38	0.768	2	2
The VR system was very robust and reliable	3.62	0.961	4	4
Overall, I would rate the reliability of the system as	3.92	0.760	4	4
Sense of Immersion/Presence				

I did not need to feel immersed in the virtual environment to complete my task	2.92	1.256	3	4
I got a sense of presence (i.e. being there)	3.85	0.801	4	4
The quality of the image reduced my feeling of presence	3.08	1.320	4	4
I thought that the field of view enhanced my sense of presence	3.85	0.987	4	4
The display resolution reduced my sense of immersion	2.62	1.261	2	2
I felt isolated and not part of the virtual environment	2.08	1.038	2	2
I had a good sense of scale in the virtual environment	4.33	0.651	4	4
I often did not know where I was in the virtual environment	2.00	1.044	2	1
Overall, I would rate the sense of presence of the simulation as	3.92	0.954	4	4
System Usability				
I thought that the system worked against me	1.85	0.987	2	1

I would be comfortable using this system for long periods	3.85	1.281	4	5
I did not have a clear idea of how to perform a particular function	1.46	0.519	1	1
The overall system response time did NOT affect my performance (negatively)	4.15	0.899	4	4
I found it difficult to learn how to use the system	1.31	0.630	1	1
I felt in control of the system	3.92	1.382	4	5
The system did not work as expected	1.54	0.519	2	2
I can see a real benefit in this style of interaction with computers	4.38	0.870	5	5
I found it difficult to work in 3D	1.69	1.182	1	1
I enjoyed working with the system	4.62	1.121	5	5
Overall, I would rate the usability as	4.31	1.182	5	5

Table 12: VRUSE Usability Questionnaire Results

6.3 Requirements Data: Landmarks

The following is a full set of data recorded during the elicitation sessions. ‘N’ represents that the participant could not find any landmarks for that particular turn.

Group 1 has 12 participants, which selected landmarks using only the map view. Group 2 has 13 participants, which selected landmarks using Street View in Google Maps. Group 3 has 13 participants, which selected landmarks using VR-Elicitation method described in thie thesis.

Table 13: Group 1, participants 1 - 4

ID	101	102	103	104
R1-T1	N	N	N	Apartment complexes
R1-T2	N	Parking Lot	Hookah Lounge	Parking Lot
R1-T3	Skybridge	Bridge	N	Overpass bridge
R1-T4	WellsFargo	Melting Pot (Unseen)	Melting pot (Unseen)	Church
R1-T5	CVS	QuickTrip/CVS	CVS	Parking Lot
R1-T6	Biltmore	Pint & Plate (Unseen)	Apartmetn after CVS	Yellow complex
R2-T1	HM	Dillards	Restaurant	Red/White Building
R2-T2	Rosa Mexicano	Rosa Mexicano	HM	Rosa Mexicano
R2-T3	Regal Cinema	Regal Theater	Movie Theater	Regal Cinema
R2-T4	Yard House	Pig and Pearl	Pig and Pearl	N
R2-T5	Gap	Gap	Jos A Banks/Gap	Brick/Red+White
R2-T6	Rosa Mexicano	Banana Republic	N	Rosa Mexicano
R2-T7	BB&T	BB&T	BB&T	BB&T
R3-T1	N		Belvings & Hons (Unseen)	Park (Unseen)
R3-T2	Probate Court	Park (Unseen)	Parkign Garage	City Hall
R3-T3	State Court	Parking Garage	N	Large Red building
R3-T4	Church	Church	Church	Church
R3-T5	SweetTreats Marietta	N	The Local	N
R3-T6	First baptist church	BoA	Parking Deck	Church
R3-T7	BoA	N	N	Parking Deck
R3-T8	Zion Baptist	Zion Baptist	Church	Zion Church
R4-T1	N	Antiques center	N	S white building
R4-T2	Church	Church	Church	Church
R4-T3	N	N	N	Glass Sculpture
R4-T4	King Falafel	N	Casa Lever (Unseen)	N
R4-T5	N	Ferrari	N	N
R4-T6	N	N	St. Regis Hotel	Pointed spire building
R4-T7	Cartier	N	Zara	N
R4-T8	N	N	N	N
R5-T1	USPS	Auto Service	Auto Service	Postal Service
R5-T2	N	N	N	Railroad
R5-T3	BB&T	BB&T	N	BB&T
R5-T4	Shoe Repair	Shoe Repair	Shoe Repair	Shoe Repair
R5-T5	Firehouse Subs	Pharmacy	Cole Pharmacy	Four-lane highway
R5-T6	N	Gas Station	Gas Station	Griffin Auditorium
R5-T7	N	American Deli	American Deli	Court

Table 14: Group 1, participants 5 - 8

ID	105	106	107	108
R1-T1	N	N	N	N
R1-T2	Parking lot	Parking lot	N	Public parking
R1-T3	Brown Building	Overpass	Hospital	Pedestrian Bridge
R1-T4	Wells Fargo	N	Wells Fargo	Church
R1-T5	CVS	CVS	CVS	Hotel
R1-T6	Orange Building	Pint & Plate	Pint & plate	N
R2-T1	Red White building	Dillards	Dillards	N
R2-T2	Red White Building	Rosa Mexicano	Rosa Mexicano	Restaurant
R2-T3	Regal Cinema	Regal Cinema	Regal Cinema	Theater
R2-T4	Red Tent	AT&T	AT&T	ATT
R2-T5	Gap	JoS A Banks	JoS A Banks	Jos A Banks
R2-T6	Curved Building	Banana Republic	Rosa Mexicano	Restaurant
R2-T7	Glass Building	N	Glass Building	Office building
R3-T1	Parking lot	Gazebo	Gazebo	Pavilion
R3-T2	City Hall	Overpass	2 Parking Lots	Clock Tower
R3-T3	Red Building	N	Parking lot	Parking lots
R3-T4	Church	Red parking deck	Court House	N
R3-T5	Park	The Local	Square Park	Square park
R3-T6	BoA	BoA	BoA	Bank
R3-T7	BoA	BoA	BoA	Bank
R3-T8	Red Building	Red Building	Zion Church	Church
R4-T1	N	Red Roof	N	N
R4-T2	Palace	Church	Synegogue	Church
R4-T3	Usability Error - CVS	Glass Statue	CVS	Glass Statue
R4-T4	N	Red Roof	Citibank	N
R4-T5	Glass building	N	Ferrari Store	N
R4-T6	Pointed Spire	Church spire	N	N
R4-T7	Cartier	Zara	Cartier	N
R4-T8	Stacked building	N	T-Mobile	N
R5-T1	Postal service	Slices pizza	USPS	Post office
R5-T2	Railroad	UPS	Railroad	Railroad
R5-T3	BB&T	BB&T	BB&T	BB&T
R5-T4	Auto service	Shoe Repair	BB&T	BB&T
R5-T5	Firehouse subs	Firehouse	BurgerKing	N
R5-T6	Jessies Armasted	Shell Gas	Valero	Shell Gas
R5-T7	Grass Field	American Deli	Court	N

Table 15: Group 1, participants 9 - 12

ID	109	110	111	112
R1-T1	N	N	N	N
R1-T2	Parking lot	N	Sivas	N
R1-T3	Taller building	Walkway Bridge	Bridge	N
R1-T4	N	Wells Fargo	Church	N
R1-T5	Parking lot	Parking lot	Quicktrip	CVS
R1-T6	Red curtains	N	N	N
R2-T1	Bar - vague	Dillards	Dillards	Dillards
R2-T2	N	N	HM	N
R2-T3	Regal Cinema	Regal Cinemas	Theater	Cinemas
R2-T4	Regal Cinema	Yard House	IT'S Sugar	Pig and Peark
R2-T5	Ann Taylor	Jos A Bank	Gap	Jos A Bank
R2-T6	Median	Sub station	Banana Republic	N
R2-T7	BB&T	N	BB&T	Parking Deck
R3-T1	N	Parking lot	Park	Park
R3-T2	Bridge	City Hall	Statue	N
R3-T3	N	N	N	Parking garage
R3-T4	N	Church	Church	Parking garage
R3-T5	Park	Park	Park	Park
R3-T6	N	White Church	Church	Parking garage
R3-T7	Red White Stripes	Parking lot (vague)	Parking lot	Parking lot
R3-T8	Red building	Zion Church	Zion Church	Church
R4-T1	N	N	Frozen Yogurt	N
R4-T2	Church	Cathedral	Church	Church
R4-T3	Glass sculpture	N	Glass Statue	N
R4-T4	N	N	Citibank	N
R4-T5	N	N	Stone sculpture	Tall Spire
R4-T6	Church spire	Church (spires)	Church	N
R4-T7	Cartier	Carlier	Bank	N
R4-T8	N	N	N	N
R5-T1	N	USPS	Post office	N
R5-T2	N	State Farm Insurance	International (not seen)	N
R5-T3	N	BB&T	BB&T	N
R5-T4	N	Shoe Repair	Shoe Repair	Building
R5-T5	Burger King	Pharmacy	Pharmacy	N
R5-T6	Gas station	Valero	Valero	Gas station
R5-T7	N	Courthouse	Courthouse	Building

Table 16: Group 2, participants 1 - 4

ID	201	202	203	204
R1-T1	Mistake - Yes	N	Park At 5th	N
R1-T2	Parking lot	Parking lot	Parking lot	Sivas
R1-T3	Bridge	Bridge	Luthean Tower	Skybridge
R1-T4	No	ATT Building	Church	Statue 16:27
R1-T5	CVS	CVS	CVS	CVS
R1-T6	No	Building C	Building C	Building C
R2-T1	Y	ERR	9 Entry	Express
R2-T2	Y	ERR	HM	HM
R2-T3	Y	ERR	Regal Cinemas	Regal Cinemas
R2-T4	Y		1 Entry	The pig and the pearl
R2-T5	Y		8 Entry	Jos a Bank
R2-T6	Y		12 Entry	Rose Mexicana
R2-T7	0		14 Entry	N
R3-T1	N	Bridge/ClockTower	Gazebo/Benches	N
R3-T2	Courthouse	CourtHouse	Parking Garage	Court Building
R3-T3	Y	Parking/Juvenile Ct	N	Court Building
R3-T4	N	Building D	Parking Lot	Superior Court
R3-T5	N	The Local	The Local	The Local
R3-T6	BoA	BoA	BoA	BoA
R3-T7	BoA	BoA	BoA	BoA
R3-T8	Confused - N	Hill Park	Hill Park	Hill Park
R4-T1	Confused	Good Nature Foods	Good Nature FLower	Good Nature Flower
R4-T2	Y	Ashley Jewels	Cathedral	Ashley Jewelry
R4-T3	CVS	CVS/3Flags	3 Flags	CVS
R4-T4	Church	Citibank	Skywalk+Park	Citibank
R4-T5	N	Church	Confused or Chase	Steiger
R4-T6	Polo	N	POLO	Church
R4-T7	Salvatore	Godiva	Salvatore Store	Salvatore
R4-T8	N	LLADRO	Porche design	Porche Design
R5-T1	Gas Station	Post Office+Gas Station	Gas station	Auto shop
R5-T2	Railroad	Railroad tracks+Griffin Package	Griffin Package	Griffin Package
R5-T3	N	N	N	N
R5-T4	Y	Bank building	Shoe Repair	BB&T
R5-T5	Y	Burger King	ColePharmacy	ColePharmacy
R5-T6	Shell Gas	Shell Gas	Gas Station	Valero gas station
R5-T7	Mistake - Yes	Court house	Wings Store	Clock Tower

Table 17: Group 2, participants 5 - 8

ID	205	206	207	208
R1-T1	N	N	N	N
R1-T2	Sivas	Glass building	Parking Lot	Public parking
R1-T3	Skybridge	Catwalk	Walkway	Hospital
R1-T4	Church	ATT	N - Can't see	Park
R1-T5	CVS/QT	CVS	CVS	CVS
R1-T6	N	N	N	N
R2-T1	Dillards	Dillards	HM	Dillards
R2-T2	HM	HM	HM	HM
R2-T3	Regal Cinamas	Kinncuns	Regal Cinema	Cinema
R2-T4	Yard House	Pig and the Pearl	Buildings	Yard House
R2-T5	Ann Taylor	Ann Taylor	Gap	Ann Taylor
R2-T6	American Apparel	Rosa Mexinca	Banana Republic	Bush medium
R2-T7	BB&T	Glass Building	BB&T	Glass building
R3-T1	Clock Tower	Gazebo	Clock Tower	Clock Tower
R3-T2	Bridge - right after	Courthouse	Bridge	Parking Deck
R3-T3	Parkign Garage	Parking	N	N
R3-T4	N	N	N	Uphill
R3-T5	Antique Store	The Local	Park	Green Park
R3-T6	White Church	BoA	BoA	BoA
R3-T7	BoA	BoA	BoA	Parking lot
R3-T8	Zion Church	Hill Park	Hill Park	N
R4-T1	N	Good Nature	Good Nature	Good Nature
R4-T2	Religious Building	Ashley Jewelry	Church	Sand colored church
R4-T3	Columned Building	CVS	CVS	CVS
R4-T4	Black Glass	Citibank	Citibank	N
R4-T5	N	Steiger	Ferrari	Ferrari Store
R4-T6	POLO	The Peninsula	The Peninsula	Historical building
R4-T7	Godiva	Salvatore	Salvatore	Red Curtains
R4-T8	Bonobos	Bonobos	Omni Hotel	Porsche Design
R5-T1	Slices	Post office (unclear)	Auto Shop	Courthouse
R5-T2	Griffin Package	Griffin Package	Griffin Package	Single Brick
R5-T3	N	N	N	N
R5-T4	BB&T	BB&T	BB&T	BB&T
R5-T5	Burger King	Claxton Cole Pharmacy	Pharmacy	N
R5-T6	Shell Gas	Shell Gas	Valero	Valero
R5-T7	Clock tower	Courthouse	Wings Shop	Church

Table 18: Group 2, participants 9 - 13

ID	209	210	211	212	213
R1-T1	Townhouses	Square building	The park @ 5th	Mistake - N	Blue House
R1-T2	Public parking	N	Public parking	Mistake - Sivas	Glass house
R1-T3	Skywalk	Bridge	Bridge	Mistake - Bridge	Bridge
R1-T4	ATT Building	Church	ATT Building	Church	Church
R1-T5	CVS	Quicktrip CVS	Qucikrip CVS	Mistake - CVS	Quick trip
R1-T6	N	Mustard building	Pint Shop	Parking Deck	Cafe
R2-T1	Dillards	Dillards	Express	HM	HM
R2-T2	HM	HM	HM	Regal Cinema	Cinema
R2-T3	Regal Cinema	Regal Cinema	Regal Cinema	Theater	Cinema
R2-T4	pig and the pearl	N	It's Sugar	Yard House	IT's Sugar
R2-T5	Ann Taylor	Ann Taylor	Jos A Banks	Ann Taylor	Ann Taylor
R2-T6	American Apparel	Banan Republic	American Apparel	American Apparel	American Apparel
R2-T7	Big building	N	BB&T	BB&T Tower	Glass building
R3-T1	Clock Tower	Clock Tower	Clock Tower	Clock Tower	Clock Tower
R3-T2	Parking garage	Bridge	Parking Garage	Parking Sign	Parking Deck
R3-T3	N	Parking	N	N	Justice Center
R3-T4	Brick with Glass Window	N	N	Parking lot on left	N
R3-T5	Square park	Park	Park	Record shop	Park
R3-T6	BoA	BoA	BoA	BoA	BoA
R3-T7	BoA + Parking	BoA	BoA	N	BoA
R3-T8	Church Steeple	Hill Park	Church	Church	Zion Church
R4-T1	Good Nature	Good Nature	Good Nature	N	Good nature
R4-T2	Mosque	Church	Church	Mosque	Starbucks
R4-T3	CVS	CVS	CVS	Glass platform	CVS
R4-T4	Citibank	Water fountain	Citibank	N	Citibank
R4-T5	N	N	N	Ferrari	N
R4-T6	Rolex shop	POLO	POLO	Wempe	POLO
R4-T7	Salvatore	Glitch Error	Godiva	Zara	Salvatore
R4-T8	Porche Design	Glitch Error	Porche Design	Omni hotel	Bonobos
R5-T1	Auto Store	USPS	Post Office	Courthouse	USPS
R5-T2	Griffin Package	Griffin Package	Railroad	Griffin Package	Griffin Package
R5-T3	N	N	N	N	N
R5-T4	Shoe Repair	BB&T	Shoe Repaid	Shoe repair	BB&T
R5-T5	Pharmacy	Pharmacy	Burger King	Burger King	Burger King
R5-T6	Valero	Shell	Valero	Shell Gas	Shell Gas
R5-T7	Clock Tower	Wings shop	Clock Tower	Wings Deli	Courthouse

Table 19: Group 3, participants 1 - 5

ID	301	302	303	304	305
R1-T1	N	Red Building	The park 5th	Tower	The Park
R1-T2	N	Towards pointy tower	Glass Contraption	Parking Lot	Sivas
R1-T3	Y	Building	Skywalk	Skywalk	Tall Building/Skywalk
R1-T4	Y	White and Glass building	N	Church	ATT
R1-T5	Y	Quick Trip	Quick trip	Quick Trip	CVS
R1-T6	N	Confused	Chapel and red doors	N	Building C
R2-T1	Y	Dillards	Dillards	Dillards	Kate's
R2-T2	N	Blue roofs	HM	American Apparel	HM
R2-T3	Y	Regal Cinemas	Regal Cinama	Regal Cinema	Regal Cinema
R2-T4	Y	Yard House	Pig and the Pearl	Yard House	Pig and Pearl
R2-T5	Mistake	Glass Building	Atlantic building	Atlantic building	PSA Bank
R2-T6	Mistake	Mistake	Mistake	Mistake	11 Entrance
R2-T7	BB&T	BB&T	BB&T	BB&T	BB&T
R3-T1	ClockTower	Clock Tower	No time	Clock Tower	ClockTower
R3-T2	Parking	Parking Entrance	No time	City of Marietta Building	Parking Garage
R3-T3	Parking	Parking Entrance	No time	Parking Entrance	N
R3-T4	N	Confused - Building?	No time	N	Blue roof building
R3-T5	The Local	N	No time	Antiques	Towards Green building
R3-T6	BoA	White Building	No time	BoA	BoA
R3-T7	N	BoA	No time	BoA	BoA
R3-T8	N	Towards Red church	No time	N	
R4-T1	Y	Good Nature Store	Lens Crafters	Good Nature	Good Nature
R4-T2	Y	Error	Green Dowms	Church/Religious building	Mosque Church
R4-T3	Y	Error	CVS	Lifted up building	CVS
R4-T4	Confused, N	Error	Water Fountain	Statue	Citi bank
R4-T5	Ferrari	Error	Ferrari Store	Rustic Looking	Ferrari
R4-T6	The Peninsula	Error	The Peninsula	N	The Peninsula
R4-T7	N	Error	Mistake	Red Roof building	Versache
R4-T8	Bonobos	Error	Mistake	N	Porche Design
R5-T1	N	No time	Saki Sushi Place	Saki Sushi place	No time
R5-T2	Griffin Package	No time	Griffin package	N	No time
R5-T3	N	No time	N	N	No time
R5-T4	Shoe repair	No time	Shoe repair	BB&T	No time
R5-T5	Burger King	No time	Burger King	Burger King	No time
R5-T6	GLITCHED	No time	Left at Valero	Shell Gas	No time
R5-T7	Glitched	No time	Courthouse	Courthouse	No time

Table 20: Group 3, participants 6 - 9

ID	306	307	308	309
R1-T1	N	Castle House	The Park	N
R1-T2	Public Parking	Sivas	N	Red brick building
R1-T3	Skywalk	20 Story Building	Skybridge	Skybridge
R1-T4	Stone Church	Church	N	Church
R1-T5	Quick Trip	Quick Trip	CVS	CVS
R1-T6	Yellow building	Small Park	Building C	Yellow building
R2-T1	Dillards	Dillards	9 Entrance	Express
R2-T2	Regal Cinema	Rosa Mexicano	HM	Regal Cinema
R2-T3	Regal Cinema	Regal Cinema	Regal Cinema	Regal Cinema
R2-T4	Yard House	Pig and Pearl	1 Entrance	Patio
R2-T5	Ann Taylor	Publix	8 Entrance	8 Entrance
R2-T6	American Apparel	Banan Republic	Banana Republic	Banana Republic
R2-T7	BB&T	Police Department	BB&T	14 Entrance
R3-T1	Clock Tower	Clock Tower	Clock Tower	Clock Tower
R3-T2	Parking Garage	Parking Deck	Parkign Entrance	Parking Garage
R3-T3	Parking	Court House	Parking	Parking Garage
R3-T4	N	N	N	N
R3-T5	The Local	Park	The Local	White Building
R3-T6	BoA	Before church	BoA	Red brick wall
R3-T7	BoA	N	BoA	White Stripe Red Brick
R3-T8	Church	Memorial Park	N	Glass Brick
R4-T1	Good Nature	Glass Pane	Good Nature	Glass building
R4-T2	Mosque	Mosque, Church	Starbucks	Religious
R4-T3	CVS	CVS	CVS	N
R4-T4	Citi bank	Citi bank	Sculpture	Fountain
R4-T5	Steiger	Ferrari Store	N	White building
R4-T6	The Peninsula	The Peninsula	The Peninsula	The Peninsula
R4-T7	Zara	REd umbrella building	Lost	Stone with Red
R4-T8	Bonobos	Usability - Confused	Lost	Bonobos
R5-T1	No time	Before Railroad	N	Railroad
R5-T2	No time	Griffin package	Griffin package	Brick building
R5-T3	No time	N	N	N
R5-T4	No time	Shoe repair	Shoe repair	BB&T
R5-T5	No time	Burger King	Pharmacy	N
R5-T6	No time	Shell Gas	Shell Gas	Gas stations
R5-T7	No time	Courthouse	Wings Deli	Clock tower

Table 21: Group 3, participants 10 - 13

ID	310-Parapalegic	311	312	313
R1-T1	Brick Townhouses	N	N	N
R1-T2	restaurant	Sivas	Yellow booth	Sivas
R1-T3	Walkway over road	Walkway	Bridge	Bridge
R1-T4	Church	ATT Building	Church	Church
R1-T5	CVS	Quicktrip CVS	CVS	CVS
R1-T6	N	Yellow Mustard Bldg	Cafe / Restaurant	N
R2-T1	Dillards	Express	Express	HM
R2-T2	Cinema	Blue Shading	Cinema	HM
R2-T3	Cinema	Cinema 18	Cinema	Cinema
R2-T4	Pavilion	Pig and Pearl	Pig and Pearl	Pig and Pearl
R2-T5	N	Ann Taylor / Gap	8 Entrance	JoS A Bank
R2-T6	BB&T	American Apparel, Round Building	American Apparel	American Apparel
R2-T7	BB&T	BB&T	BB&T	GlassBuilding
R3-T1	Overpass	Clock Tower	N	Clock Tower
R3-T2	Parking Deck	Red Brick Parking	Parking Sign	Parking
R3-T3	N	Square Red Brick	Parking buildings	Parking
R3-T4	Tan building	Up the hill	White store	N
R3-T5	Square	Park	Park	Park
R3-T6	Church (block before)	BoA	BoA	White church
R3-T7	Paid parking lot	N	BoA	BoA
R3-T8	Steeple	Church	Church	Church
R4-T1	Good nature	Good nature	Angelas Pizza	Good nature
R4-T2	Mosque	Camera Express	Church	Church
R4-T3	Glass landmark	CVS	Flagpoles	CVS
R4-T4	Historical Low rise	Citi bank	N	Citi bank
R4-T5	N	Ferrari	Ferrari	N
R4-T6	The Peninsula	The Peninsula	POLO	St Reigis
R4-T7	Historical building	Feragamo	Salvatore	Feeling Sick - Cartier
R4-T8	N	Porsche Design	Jewelry store	Tmobile
R5-T1	Railroad	Repair Shop	Court house	Before railroad
R5-T2	Brick building	Griffin Package	Griffin Package	Griffin Package
R5-T3	N	N	N	N
R5-T4	Shoe repair	Spalding Shoes	Spalding shoe repair	BB&T
R5-T5	Steepl	Pharmacy	Pharmacy	Burger King
R5-T6	Gas station	Valero	Shell	Shell Gas
R5-T7	Clock tower	Clock tower	Direction Academy	Church