Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Civil and Environmental Engineering

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Investigating intuitive map use and the effects of landmarks in VR

Master's thesis in Engineering and ICT
Supervisor: Terje Midtbø
February 2023

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Abstract

VR equipment is rapidly developing and evolving, and is considered a medium with a lot of potential for maps. Preliminary research is needed to establish good standards and practices.

This thesis aims to contribute to understanding interactions between maps and VR. It presents theory regarding VR and maps and current research into combining the two. A suitable test environment was developed to test intuitive map usage and the effects of landmarks in VR. The experiment that was conducted found no significance in the use of landmarks and indicated that most participants kept the map in their field of view while mostly using a north-up orientation. However, the use of assistance when participants got lost did seem to indicate some positive aspects of landmark use.

Sammendrag

VR-utstyr blir stadig mer avansert og utvikler seg raskt, og er sagt å være et medium med stort potensiale for kart. Grunnleggende forskning er nødvendig for å etablere gode vaner og standarder.

Denne oppgaven ønsker å bidra til forståelsen mellom kart VR. Teori om VR, kart og kombinasjonen av disse, blir presentert i oppgaven. Et egnet testmiljø ble utviklet for å teste intuitiv kartbruk og effekten av landemerker i VR. Eksperimentet som ble gjennomført fant ingen signifikans i bruken av landemerker og indikerte at de fleste deltakerne beholdt kartet innenfor deres synsvinkel for det meste orientert mot nord. Derimot indikerte bruken av assistanse når deltaker gikk seg vill noen positive aspekter ved bruk av landemerker.

Preface

This is a master's thesis in geomatics written during the fall semester of 2022 at the Norwegian University of Science and Technology (NTNU). It is the final subject, TBA4925 - Geomatics, Master's Thesis, of the master's program Engineering and ICT. Terje Midtbø has supervised this work, and I would like to thank him for his assistance and insight during the last year.

Kristian Flock
28th of Febuary, 2023

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Acronyms

DoF = Degrees of Freedom. 5

GIS = Geographic Information System. 10

HMD = Head-Mounted Display. 4

UI = User Interface. 5

VR = Virtual Reality. 3

XR = Virtual Reality + Augmented reality. 11

Chapter 1

Introduction

Virtual reality has kept up the momentum generated by the new VR revolution that started almost a decade ago. With equipment continuously improving and big companies investing heavily in the space, the rapid development seems to continue. To most people, virtual reality systems are becoming more affordable, increasing their availability. When entering into a new medium like virtual reality, it can be beneficial to understand why and how certain practices work better than others.

Maps have long been said to be a good fit for virtual reality; maps represent information about our world, and virtual reality brings the digital world even closer to the real one and presents itself as a medium ideal for sharing information in new ways. The potential for new ways of learning and communicating additionally presents virtual reality as an exciting new frontier for cartography and geomatics. However, despite the potential, understanding and research of virtual reality and maps remain sparse. It is necessary to build foundations of research so that more complex ones can take place. Given that virtual reality can have many familiar elements to both the digital and psychical realities, it is also important to find out what research from either is applicable.

This thesis aims to sufficiently give background theory to the current standing of virtual reality technology, maps, and geomatics, and their combination to answer the following questions:

- How do people intuitively use maps in virtual reality?
- Does landmarks affect navigation in virtual reality?

To answer these questions, an experiment was conducted with a virtual test environment developed in the Unity game engine. The environment was presented as a game to participants, with programmed observers automatically collecting and writing data.

The structure of the thesis is as follows: In Chapter 2, theory relevant to virtual reality and maps are presented. This is subjects such as interaction with and application of virtual reality, map navigation, and the use of landmarks. In Chapter 3, the creation of the experimental environment and the experiment's setup is detailed. Chapter 4 contains the results analysed from the experiments, followed by a discussion of those results. Finally, the work is summarised in Chapter 5, and final conclusions are presented.

Chapter 2

Theory

This chapter introduces the relevant theory and necessary background information used to understand concepts and reasoning behind decisions made when developing the test environment described in Section 3.2. Virtual reality, how it works and is used, is presented along with theory on maps, its usage, and the importance of landmarks. Finally, the interaction between these two fields is presented through relevant studies.

2.1 Virtual Reality

Virtual Reality, or simply VR as it is most commonly referred to as, has gained significant attention over the last years. Many slight differentiations in its definition exist [1–3]. Still, common among them is the emphasis on stimulating one or more of the user's senses, generated by a computer and conducted through connected technology, which creates an immersion in a simulation. Exactly how this immersion is achieved varies today and has differed through time.

Many might think of VR as a new technology; however, its early iterations go as far back as the 1950s. In its early development, although first being a concept for immersive cinema [4], the development of VR technology was being done mainly on a research level. In the early 90s, the entertainment industry again picked up the technology, this time driven by video game companies [5], releasing the first systems for the general public. However, the technology did not see immense success, and development halted when public interest disappeared. Though some steps were still being made, the next big driver in development was the Oculus Rift DK1, released in 2013. This crowdfunded VR system reignited the public interest in VR technology and started the modern VR revolution that has led us to where the technology stands today.

2.1.1 Interaction

The simulations that are generated for VR are commonly referred to as virtual environments. These virtual environments can be as simple as a recorded 360-

Figure 2.1: Meta Quest 2, the headset used in the experiment [6].

degree view of a roller coaster ride, in which the user is essentially just along for the ride, or much more complex, including freedom of movement, interaction with objects in the environment, and even interaction with other people in the same environments. R. Schroeder defines these complex environments that include interaction with other people when they are persistent over time and are experienced together as a world for social interaction, as virtual worlds [7]. These spaces should be distinguished from online multiplayer games, as in these games, the gameplay structure is the main focus, and social interaction often comes second. A similarity to games, however, is that most virtual environments are created using game engines. These development platforms, which are powerful tools for creating three-dimensional worlds for games, can be adapted to create virtual environments. These days, this process is often as simple as implementing a custom camera and controls designed for VR systems, and a world created in a game engine, loaded onto a VR system, becomes a virtual environment.

Although highly specialized VR gear exists and might give more highly immersive experiences, most commercially available VR systems today use simpler equipment that works for most available virtual environments. This equipment consists of a head-mounted display, HMD, and a set of controllers, one for each hand. Some systems rely on external processing power when used, while others have the necessary resources in the HMD. An example of the latter is the Meta Quest 2, the system used in the experiment described later in Section 3.5, and it can be seen in Figure 2.1. The HMDs main function is to sit on the user's head and show a wide display to each eye that simulates regular vision. Some might include speakers or headphones for sound as well. In addition to this, the HMDs have sensors, which might also be external, depending on the system, that track the user's head. Old or cheaper VR systems might typically offer three degrees of

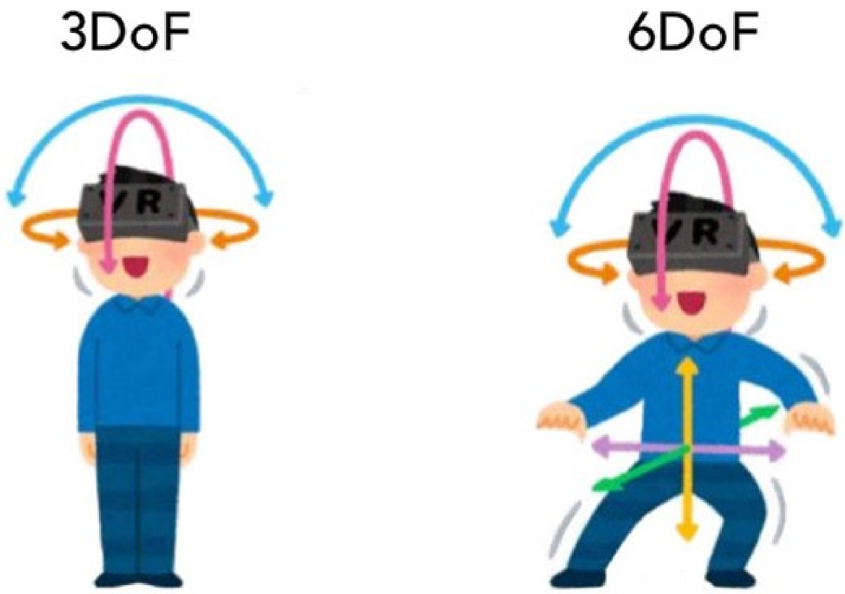

Figure 2.2: Diffreces between three DoF and six [8].

freedom, DoF. This entails tracing all rotation around the user's head as a central point, detection of looking left or right, up or down, or tilting the head to either side. Modern systems now commonly offer six DoF. In addition to the three previously mentioned, the three additional DoFs track the head's physical location, i.e., movement forward or backward, left or right, or vertical movement. A visualization of the two different sets of DoFs is shown in Figure 2.2. Some HMDs also offer tracking of the user's hands, which can then be used as controllers, although each hand gesture still needs to be implemented individually in each application. If the user is using only their hands or more traditional controllers, closely resembling game controllers, the same sensors detecting the HMD's movement, might also detect the same positional data for the controllers.

How the user interacts with the virtual environment when using the equipment is also important. The user interface, UI, is an essential part of this. Human-machine interaction is an important part of modern-day living. The science behind it has matured to have multiple standards defined, and many books written on applying these standards. However, UI implemented in VR environments will differ slightly from these standards or at least require customization. As stated by Gu, Y., many people will lose immersion in a virtual environment if the UI is lacking [9]. He also outlines difficulties, increased complexity and lacking research, and suggests strategies for designing three-dimensional UI. He suggests focusing on the human aspect, how they think, and what they are familiar with, throughout the process to ensure a good design. Another important factor is how to interact with the UI. A user study by H. Kharoub, et al., comparing point-and-click, controller-based, and hand gesture methods, suggested that the former was the most effective and preferred on a general level [10]. Although best on a general level, the authors also suggested that some users preferred other methods for specific tasks.

Another important factor is VR-sickness. VR-sickness is a form of motion sickness, similar to what is experienced by some people when travelling in fast-moving vehicles. The usual symptoms include nausea and discomfort and can last for a prolonged period of time, even after removing the HMD. There are three theories as to why VR-sickness occurs, described by A. Kemeny et al., in Getting Rid of Cybersickness [11]: The poison, the ecological, and the sensory conflict theories. Firstly, there is the controversial theory that the symptoms occur as the body is experiencing visual hallucinations and thinks it has been poisoned and is trying to reject toxins. This theory seems unlikely, as regurgitation would be an ineffective response. Then there is the ecological theory that states that the user may lose postural stability during prolonged time spent in a simulation. Finally, the sensory conflict theory. This theory states that the sensory mismatch between what a person sees in the simulation and what is experienced by the body in real life. This theory seems to be the prevalent and most commonly accepted theory. No matter what causes VR-sickness, it is important to consider how to minimise its impact on the user's experience when using VR systems.

2.1.2 Application

Modern applications of VR vary greatly. Perhaps its biggest commercial use comes from games. The concept of existing inside a video game world is enticing for many and can often enhance the immersion experience if done well. An example of this can be found in the horror game Outlast. Throughout the game, the player is being chased by monsters, and with VR, the level of horror is said to be heightened [12]. Many early games available on VR systems were direct ports of existing games from their respective PC or console versions, like Outlast. However, more games are being made specifically and exclusively for VR systems. Similar to games, because of the frequent use of cartoon-ish characters or player models from games or other popular media, virtual worlds also exist for VR systems. These worlds have social interactions as their main focus, though minigames or other activities for the users to enjoy also exist. One of the most popular of these worlds is VR Chat. A still frame of how a social interaction here might look is displayed in Figure 2.3. Working much like virtual worlds, but on a more professional level, are systems aimed at remote work collaboration. A major investor in this field is Meta, who changed its parent company name from Facebook, to emphasise the new focus on the VR space and what they call the Metaverse. This term is used for building a complex virtual world with many possible applications. What Meta has launched so far in their endeavour is Horizon Workrooms, a meeting platform, allowing people to arrange remote meetings in VR [13]. The public has reacted with

Figure 2.3: A screenshot of an interaction in VRChat [15]

mixed feelings to the platform thus far, but Meta is still committed to developing and expanding their Metaverse [14].

Another commercial use of that VR exists, is using VR for previews before finishing sales. An architect can show a house model to a customer, which in turn, they will experience their house before it is built and can comment with informed inputs about what they like or dislike. Or, if simply buying a house, a digital tour can be arranged in VR if the buyers cannot attend a physical viewing of the property. Other examples include showing cars before they are produced or preview of other simpler items. What these examples would entail is the use of digital twins. Digital twins are digital copies of real objects or locations that are as realistic as possible. When combined with sensors, you get digital twins that can monitor the real-time conditions and report to the digital twin if something is wrong [16]. When combined with VR, this could allow a remote expert to view, for example, a problem happening in a factory far away, figure out a solution, and then give it to an onsite technician who could implement it.

A big and rapidly developing field, when it comes to the application of VR, is simulation training. VR enables people to be able to train and gain experience in a safe practice environment, before applying their skills in real life. One of the early adaptors of VR simulation was NASA [5]. Their interest has always been to simulate flight and space experiences as realistically as possible to be able to train astronauts well without real experience, which is massively expensive to acquire due to the costs of launching a rocket. Similarly, pilots can also gain some initial experience with flying a plane, by using VR simulations [17]. This is applicable in other fields of work as well. In dangerous lines of work, such as mining, VR simulation can improve learning and training methods, and reduce costs of full-scale training environments, among other factors [18]. In the medical field, surgeons can be trained in VR with similar benefits as mentioned before [19]. Also, patients recovering from conditions such as a stroke or other debilitating conditions can be helped by VR and increase the speed of their recovery [20].

2.2 Maps

Humans have used maps for thousands of years to help us navigate and store information. For most of its use, geographical features such as rivers, coastlines, forests, or mountains were most important. Noted on maps were also important settlements and major roads when they were relevant. In modern society, we use maps more than ever, and their use has more potential than ever. The basic principles are largely the same, show a distinct geographical location, overlaid with what information you want to present. What has changed with the digital revolution over the last decades is how much information we have available to us. Especially with the introduction of the Internet, vast amounts of information are publicly available. No person could ever hope to know all that information. However, maps are a well-suited medium to present much of it.

2.2.1 Map navigation

When using a map today for wayfinding purposes, referred to as navigation, most people will use an app on their phone like Google Maps. These maps have simplified many aspects of traditional navigation and made it convenient. We no longer need to identify the start or end of a route by ourselves, and the map will automatically adapt to your preferred orientation, typically north-up or forwards-up. A north-up orientation indicates that a map is locked in orientation, with north always up on the map. Forwards-up map orientation is when the map's orientation is different, depending on and being the same as what direction the user is facing. These methods of orienting a map both have advantages. Experiments by A.J. Aretz and C.D. Wickens suggest that north-up oriented maps are better suited when planning a route ahead of time [21]. The same experiments also suggest forwards-up oriented maps perform better when actively navigating an environment. This has to do with north-up oriented maps requiring mental rotation of the map before making decisions related to the navigational task. These results were later confirmed in a study by N.J. Smets et al., which found that a forward-up oriented map significantly outperformed a north-up oriented map in a search and rescue task [22]. Similarly, F. Hermann et al., found that a forward-up oriented map completed their navigational tasks on mobile devices faster and with no navigational errors [23].

A navigation model, originally presented by S. Jul and G.W. Furnas and improved by R.P. Darken and B. Peterson, can be seen in Figure 2.4. The process starts by forming a target of what should be achieved. Then, figuring out how to do that is the next step. Next, an observation of the current situation is needed. This leads to a plan of action. Next up is acting on that plan and creating a cognitive map.

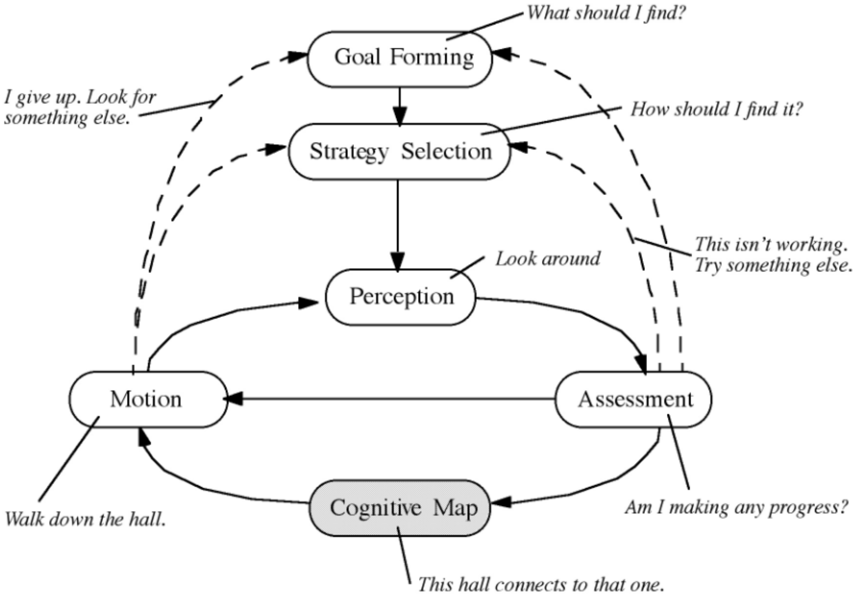

Figure 2.4: A diagram explaining the flow in a navigation process [25]

A cognitive map is a mental representation of surroundings and how objects perceived there are spatially related [24]. The process then repeats itself going back to various stages depending on the situation, until the target is reached.

2.2.2 Landmarks

An important element of effective wayfinding and navigation, is landmarks. Landmarks are prominent features in the environment that stands out, and have long been used for wayfinding and descriptions of routes [26]. When constructing a cognitive map and gaining spatial knowledge of a new environment, landmarks are the initial knowledge gained, before figuring out paths between and the network these paths create [27]. Landmarks are also shown in a study by C. Bauer et al., to contribute to one's ability to self-locate on a map [28]. Landmarks are also shown to create incidental spatial acquisition when applied with a mixed reality HMD in indoor navigation, according to a study by Bing L. et al. [29]. An experiment by I. Delikostidis et al., also showed better completion times of tasks by a prototype map including landmarks with an indication of their visibility, when compared to Google Maps [30]. The specified tasks were initial recognition of position, identification of destination and travel route, active navigation, and destination confirmation.

2.2.3 VR and maps

"GIS-VR will become a standard tool for geomorphological teaching and research in the future." [31] This was the statement and prediction presented by J.D. Vitek et al., in 1996. Now, over 25 years later, it still remains a prediction. This is closely connected to the stagnation in VR development that occurred after the 1990s. VR and geographical information systems, GIS, have yet to reach their full potential together. However, more and more research is now being conducted into the relationship between the two as VR technology once again is rapidly developing. An article by Zhihan, L. et al., from 2016, once again concluded that GIS is once again well suited for VR [32]. This time they highlighted its potential to present big quantities of geographical data in 3D and its potential value for educational purposes. A. Santos-Torres et al., sought to understand the better method of interaction with GIS in VR [33]. They found that controller-based interaction seemed better than body-based interaction when considering time selection, error rate, and usability.

S.P. Henriksen and T. Midtbø have done two different studies relating to VR and maps. The first study related to the viability of lower-cost VR systems when conducting research in VR [34]. This study found variations in participants' experience using the equipment. This was using equipment available in 2014. However, the problems raised in this study remain important to handle. VR-sickness and lack of immersion were two significant, highlighted problems. Some technological factors relating to these problems have improved with better equipment. Higher frame-rate, resolution, and an increased field of view in most systems are now part of modern VR systems and contribute to better immersion and less VR-sickness. Movement systems, which most notably relate to VR-sickness, are still very important to consider when designing a virtual environment. The second study investigated what kind of map orientations performed best when participants were to solve a maze [35]. The study was inconclusive, not showing a significant difference in performance between north-up orientation and forward-up oriented maps. This is not in line with the studies discussed in Section 2.2.1, where forward-up was the significantly better orientation for this task.

C.R. Bruns and B.C. Chamberlain have also conducted A study to test participants' special memory using VR [36]. They found a correlation between high-accuracy landmark recollection and recollection of the navigated route and specific scenes along that route. This study did not provide freedom of movement but focused on recollection elements along one predetermined path. A paper by N.G. Vinson has several guidelines created to assist in creating landmarks in virtual environments [37]. These guidelines highlight the need for landmarks to be visually distinct, a high contrast in colour and height compared to the rest of the environment is preferred. There should be multiple landmarks, and they should differ from each other in position and look. They should also be placed at focal points throughout the environment and not hidden away.

Chapter 3

Method

Central to this thesis is the conduction of the experiment used to collect data, which was then analysed to try and answer the questions presented at the beginning of this paper. This chapter describes the test environment in which the experiment was carried out, as well as its development process, and the final experimental setup.

3.1 Framework

The application containing the test environment was developed using the Unity game engine. By the company's own description, it is a "real-time development platform" [38] being used to create more than 50% of the world's video games and have applications within the architecture, automotive, film industry, and more. Given its widespread use, many tutorials, assets, and online forums exist. This, alongside integrated scripting support in C#, is why Unity is chosen as a framework. The OpenXR standard [39] and the XR Interaction Toolkit [40] were essential assets used during the development and deployment of the application. OpenXR made it so the application could be developed for a general XR, a term used for augmented reality and VR collectively, platform and then deployed to a specific HMD without considerable effort. The XR Interaction Toolkit supplements Unity proving assets and interaction systems for XR. In this project, it provided components for the main camera rig, movement systems, controller input, and the objects and UI the user interacts with, as well as all the interaction systems between these elements.

3.2 Test environment

The test environment was presented to the participants as a game where the user had to navigate out of two different labyrinths. Before starting, the participants were presented with an open environment and a simplified labyrinth to familiarise them with movement and UI elements.

The movement system gave the participants multiple alternatives when it came to movement. The first system was chosen on the background of familiarity. A joystick-based movement system was implemented because the test environment was presented as a game, and the controllers used had a similar layout to traditional game controllers. This means the participants could use one joystick to move and another to look around. An alternative to using the joystick to look around was simply rotating physically while wearing the HMD. This type of control is inherent to HMDs, as mentioned previously in Section 2.1.1, and in this case offered six DoF, although somewhat limited, see Section 3.5 Previous studies concerning navigation in small spaces by E. Langbehn et al. [41], concludes that joystick-based navigation performed worse than other methods of navigation, was not preferred among users, as well as causing more VR sickness, the effects of which are discussed in Section 2.1.1. This study suggests that redirected walking system performed best when it came to users acquiring spatial knowledge and was, together with teleportation, preferred subjectively among users and is recommended by the authors. Both systems were considered before, ultimately, teleportation was implemented as an alternative movement system. This was because the labyrinths are much larger than a single room, and there would not be room for a redirected waking system when conducting the experiment. In practice, the participants used a ray coming out of their left hand while holding the controller to point to where they wanted to travel, and while the ray was white, they then pushed a button to activate the teleportation. This ray also enables interaction with buttons, which can be activated while aiming the ray at them. As for looking around, teleportation can be combined with either rotating with the joystick or physical movement.

A depth-first maze generation algorithm was used to get the labyrinth's layout. This was done not to have an underlying human bias and patterns in the layout. The algorithm gave a labyrinth in text format, the code is supplemented in Appendix 1, which was adapted into the test environment. The visual design of the labyrinths was kept simplistic and repetitive so as not to distract or give other major ways of navigating other than using the map and landmarks made available to the participant. The general design can be seen in Figure 3.1.

Apart from the start menu, the game has two main UI elements: the panic button and the map. The elements exist in a fixed space relative to the participant, and always follow their movement. They are placed outside of the initial viewing space of the participant and exist down and to either side. This is another decision made so as not to distract and to use the elements intentionally and not accidentally. The map itself is the current labyrinth seen from above, as seen in Figure 3.2. The coloured shapes on the map are towers that also exist in the labyrinth and serve as landmarks. The towers were placed in positions where they are in one unique quadrant each so that one will be visible from everywhere within the labyrinth. They can also be turned on or off, the use of which will be discussed further in Section 3.5. The white dot indicates the starting point of the labyrinth and does not move with the participant. However, if the participant interacts with

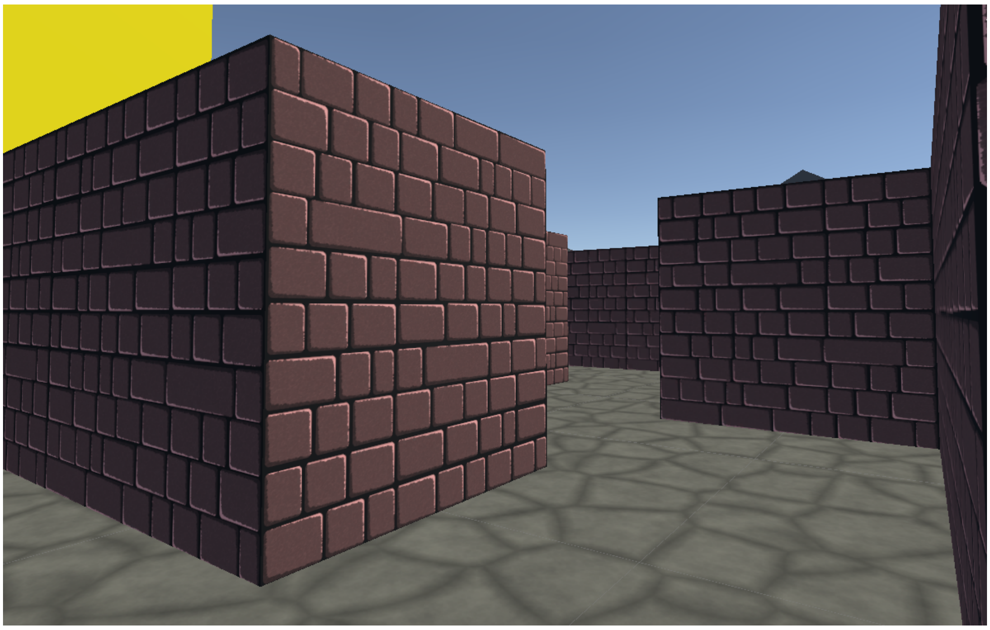

Figure 3.1: The general design of the mazes used in the experiment.

the panic button, shown in Figure 3.3, the white dot will move to the current location of the participant. The use of this functionality will also be discussed further, in Section 3.4. The button was labelled “panic button” to discourage the use of the button unless necessary. To interact with the map, the participant’s right hand needed to be moved over a white square, which is the map turned around to not reveal any information without interaction and then activated by pushing a button. While holding the button, the map will stay in the right hand. Physically rotating the controller will rotate the map in hand. Releasing the button while holding the map will return it to its original position. The map was designed this way to make every decision to interact with it intentional and possible to track.

3.3 Pilot study

A pilot study was held to fine-tune the test environment’s details. Here, potential problems and optimisations could be discovered, resulting in some test environment changes. Three volunteers, two with a background in geomatics, were asked and agreed to help with the pilot study. They were informed about the details of the project, its goals, and its methods. The initial run through the labyrinths was kept as an indicator of what an above-average participant might achieve in relation to completion speed. The two labyrinths were considered almost equal in complexity; the first was a bit more difficult when it came to diverging paths, while the second was slightly bigger and, therefore, longer. After the initial trial run, discussions were held as many things became clearer after having experienced the

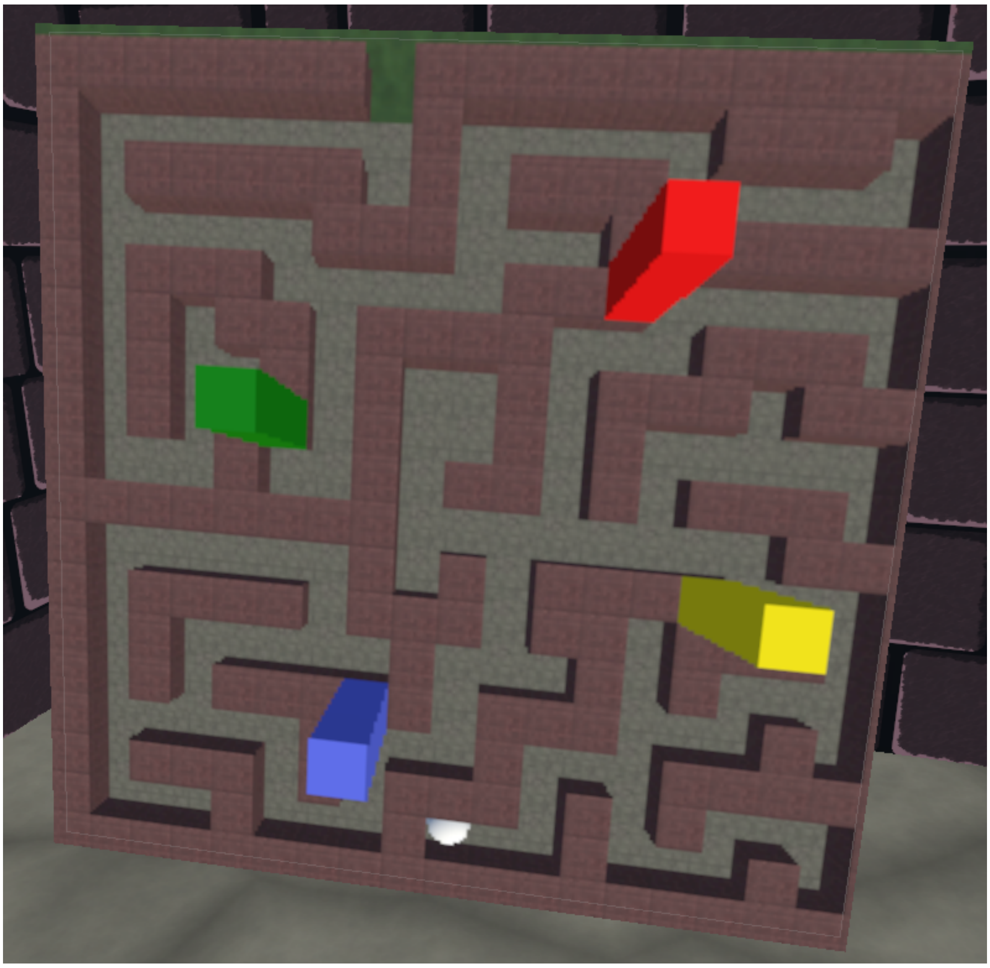

Figure 3.2: One of the maps supplied to participants in the test environment.

Figure 3.3: The design of the panic button participants could interact with if they got lost.

test environment. The volunteers then tried to break the test environment as best as possible to find potential problems future participants might encounter. After this, a final discussion about the test environment was held, and concluded the pilot study.

Together with the supervisor of the project, a few decisions were made concerning the test environment. It was decided that every participant should always have the white dot available as a starting point, however, it should not indicate any direction, giving the participants additional knowledge. This would keep the map and the shape of the labyrinth as the focus and necessitate the use of the map combined with spatial recognition and navigation. Also, to emphasise this, the name of the panic button was changed from “assist button”, giving it a more dire name to encourage its use only if strictly necessary. The use of the button was also logged to see which participants would use the button, and comparisons could be made in relation to other results and contributing factors. Aside from small visual design changes, the final change to the test environment was reducing the movement and rotation speed while using the joystick-based movement systems. As mentioned in Section 2.1.1, it is important to consider VR sickness when developing an application for the platform. So, the speed was reduced to lessen the dysphoria between movement in reality and what was observed in the application. This phenomenon did not apply to teleportation, as it was instantaneous, and physical rotation was one-to-one with rotation in the test environment.

3.4 Measurements

To answer the research questions of this thesis, it was necessary to gather data from the test environment. Therefore, observers were programmed into the application containing the test environment. Firstly, several factors were considered to observe how the participants intuitively used the map. The number of times the participants picked up the map and kept it within their viewing space was tracked. If the participant kept the map in their hand but lowered it so that it was not being used, this was tracked as a separate use. Each use was also timed. While the map was being held and looked at, the angle of the map was recorded several times per second. This was able to indicate if the participants were using the map north-up, which was defined as the initial orientation of the map, or if they oriented the map after themselves and where they were going, using a forwards-up orientation.

As mentioned earlier, the use of the panic button was logged and would, of course, indicate that the participant had used this form of assistance. The other results generated by this participant needed to be interpreted with this in mind.

To observe the effect of the previously discussed towers, which functioned as landmarks in the labyrinths, mainly timing, and comparisons were used. Each labyrinth recorded the time used to complete it, as well as if the towers were enabled or not. Before entering the test environment, a setting deciding which of the two labyrinths should have towers were available, and so could be activated.

Additionally, there was a system to record the amount of time the participant used to look at the towers. The system was, however, flawed and was not included in the final version of the test environment. This was due to the difficulty of tracking the participant's eyes' exact position and focus, not just the entire viewing space or parts of it. If assumptions had been made about typical eye positions or something similar, it was possible to get an estimate of the time spent looking at the towers, however, this was not deemed accurate enough.

3.5 Experimental setup

The application containing the test environment was uploaded to a Meta Quest 2 HMD, and the Meta Quest 2 Touch controllers were also used. This VR system uses onboard computational power from the HMD, and the controllers are similar to traditional gaming controllers. However, one is held in each hand and has a different button layout because of this. The system can be seen in Figure 2.1. The display is an LCD display, with up to 120hz refresh rate, a resolution of 1832x1920p per eye, and 97 degrees horizontal, and 93 degrees vertical field of view [42].

The participants in the experiment were recruited on a volunteer basis, mainly from the first or second year of civil engineering studies, however, others did also participate. The experiment took place in a quiet room to reduce distractions. A stationary boundary, virtually provided by the HMD, contained the participants and made sure they never collided with objects while participating. The boundary was rather small, limiting the full use of the six DoF, especially the freedom of movement along the different axis. The participants were given the HMD and controllers and asked to open the game. Before starting half the participants were asked to interact with the setting concerned with the towers so that half would have them activated in the first labyrinth and half in the second. This was random when possible, however, it was at no point certain exactly how many people would participate in the experiment, as immediately after agreeing to volunteer, they participated. They were then talked through how the movement systems, what their strong sides and drawbacks are, and UI elements worked while navigating the starting area and first simple labyrinth previously mentioned. The participants were not informed about the measurements that would be taken, to ensure that the data collected, stayed free from biases that could appear if they knew. They were then informed that the experiment would start.

After completing the experiment, the participants were given a short survey to complete. This asked them their age, gender, experience level with maps, and experience level with VR in general. This gave the data context and a clear picture of the composition of the group of participants that participated in this experiment.

Chapter 4

Results

This chapter describes the results of the experiment and how they were analysed. The results are discussed only after the relevant numbers are presented and how they were acquired. The data collected, the application file, assets used in the development, and the file containing all statistical work are attached to the thesis in a .zip file.

4.1 Survey results

The survey results gave information about who participated in this experiment as a group, without being directly linked to specific people. Of the 24 participants, 19 were between the age of 18 and 23. The remaining five were between 24 and 29. 17 of the participants were male, while seven were female. Regarding map experience, 15 claimed no significant experience outside of normal use. In contrast, seven claimed to be experienced map users, orally citing orienteering, extensive navigation while in the compulsory military service of Norway, or being experienced hikers. Two participants were also geomatics students, which means their degree pertains to the study of maps. Lastly, experience with VR. Here, 11 participants had never tried VR before, nine had tried before, and four claimed to be experienced in using VR systems. The individual answers can be seen in Table 5.1 in Appendix 2.

4.2 Data analysis

To analyse the data recorded during the experiment, the Minitab Statistical Software [43] was used. It offered a wide range of tools, from simple statistics to tests for significance. The statistical methods mentioned in this section were all carried out using these tools.

One of the things recorded from the test environment was the frequency of map use. After mapping out the data directly from the files, the results of which can be seen in Table 5.3 in Appendix 2, it was possible to get simple statistics

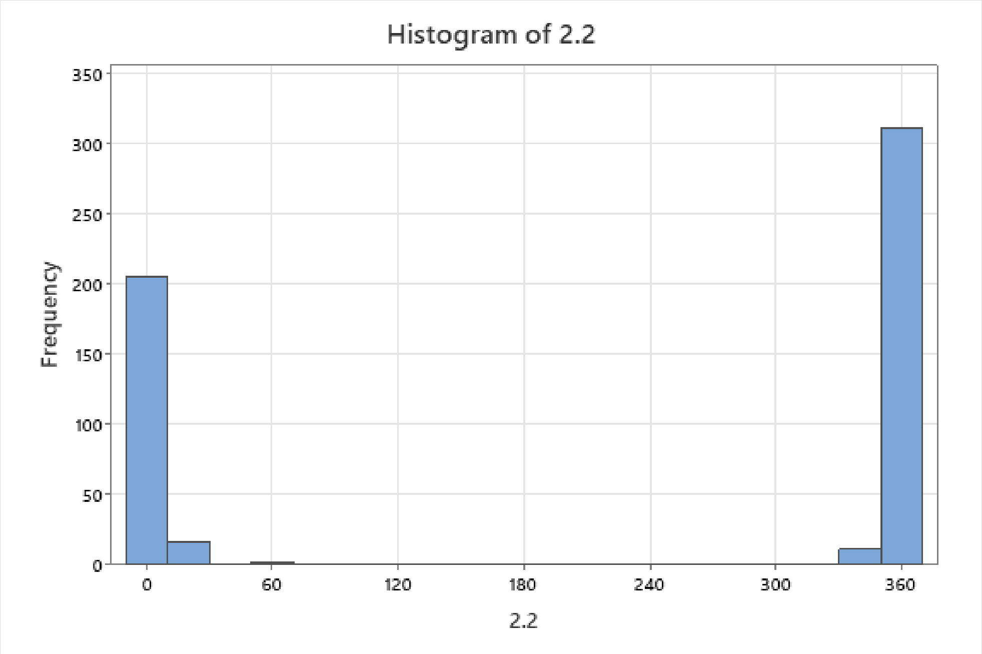

Figure 4.1: A histogram showing use of a map defined as a north-up orientation.

describing the data. The average number of times a participant looked at the map while solving one labyrinth was 2.125 times. The minimum, first quartile, and median were all one, the third quartile was two, and the maximum was 12. When considering each labyrinth separately, the first had an average of 1.625, the second of 2.625 times the map was used. The first labyrinth had a different maximum of five, while all the rest of the statistics remained the same as when considering the total. The second labyrinth, however, had an increased median of two and a third quartile of three, while the rest stayed equal to the total.

To determine the participants' map orientation, the recorded angles were put into histograms. Here, a concentration of map angles just above 0 or under 360 degrees would indicate that the participant had used the map in a manner similar to a north-up orientation, as this was similar to the original angle of the map, 0. An example of a histogram determined to be representing a north-up orientation can be seen in Figure 4.1. If a participant had used a forwards-up orientation relative to themselves, the spread of the recorded angles was greater. An example of this can be seen in Figure 4.2. Angles around the initial angle were still prevalent in this type of use. However, significant portions of the recorded angles also contained a wider variety. After all the data was analysed this way, the results presented Table 5.2, again in Appendix 2, was how the participants distributed among the two different orientation styles. Note that some participants used both styles, and are stated to have used north-up first and forwards-up orientation secondly, as was the case with everyone who used both.

The final factor that this experiment aimed to determine was whether the

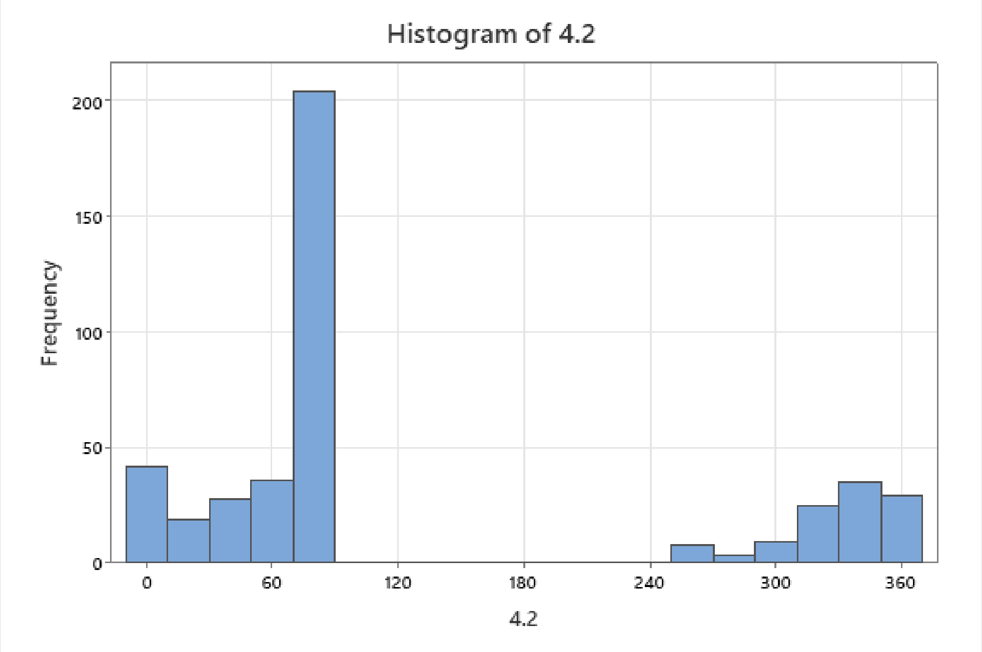

Figure 4.2: A histogram showing use of a map defined as a forwards-up orientation.

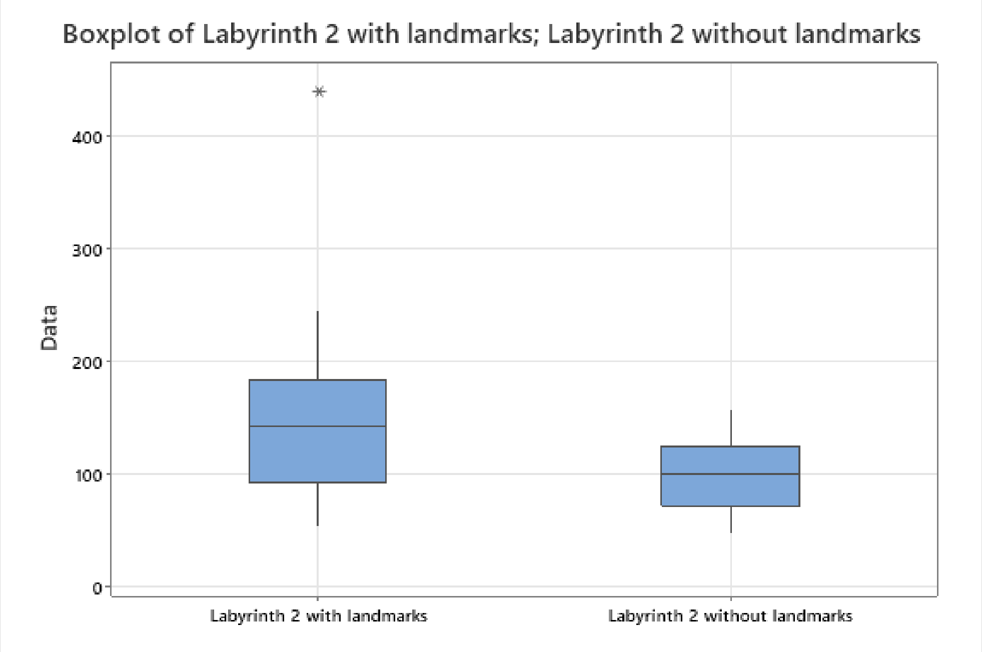

Figure 4.3: A Box plot showing completion times divided into four quartiles, and with an outlier positioned above.

landmarks impacted the participants' ability to navigate the labyrinths. To do this, an unrelated t-test was conducted on the recorded times the participants had used to complete each labyrinth, the method for which was outlined by R. Kitchin and N.J. Tate in Conducting research into human geography; theory, methodology and practice [44]. The individual times can be seen in Table 5.2. Before doing the test, however, a few steps were needed. First, the results were graphed into box plots. These plots, of which an example is displayed in Figure 4.3, visualise the minimum, at the bottom of the thin line below the box, the first quartile, indicated at the start of the box, the median, the line inside the box, the third quartile, the upper line of the box, the maximum, the end of the thin line above the box, as well as the outliers, indicated by the asterisks in either extremity above or below the rest of the plot. These plots give an idea of the results, but do not yet say whether these results are significant. An important assumption when conducting a t-test is that the data used have a normal distribution. By removing the outliers indicated by the box plot, the data conforms much closer to a normal distribution, an example of which can be seen in Figure 4.4 and Figure 4.5. These modified data sets were used going forward. Then, to get a more accurate t-test, it is important that the variances of each set can be considered equal when calculating. To do this, an F-test was conducted. After obtaining the variance of each data set, a value for F was calculated by using the formula:

$$F = \textit{grater variance}/\textit{lesser variance}$$

Then, this F-value was compared to a critical F-value unique to each data sets $\textit{degrees of freedom} = n - 1$ and a significance level of $alpha = 0.05$. If the calculated F-value was smaller than the critical one, which was the case with every data set from the experiment, the t-test could then take place. In the t-test, our null hypothesis is there is no significant difference between the results of participants completing the labyrinths with and without landmarks. The research hypothesis, to contrast, is that there is a significant difference between the two. The confidence level, as before, is set to 95% or significance level $alpha = 0.05$. Minitab produces a p-value which was compared directly to the significance level of alpha. The results of all these calculations are displayed in Table 4.1. The results of the t-test regarding landmarks concluded that there was no significant difference with a 95% confidence level. To see if any other recorded factor showed a significant difference, the process was repeated for those with and without any VR experience, and for those without and those who had significant experience using maps or were geomatics students. These results are also displayed in Table 4.1. The t-tests concluded that, similarly to before, there were no significant differences at a 95% confidence level.

Scenario	Variance with	Variance without	Calculated F-value	Critical F-value	P-value
Labyrinth 1, landmarks	418.02	853.39	2.05586	3.02038	0.517
Labyrinth 2, landmarks	2992.8	1117.33	2.67853	2.75339	0.064
Labyrinth 1, map experience	932.6	684.06	1.36333	2.84857	0.720
Labyrinth 2, map experience	1878.9	2633.0	1.40135	2.76691	0.597
Labyrinth 1, VR experience	879.17	470.24	1.86950	3.10249	0.117
Labyrinth 2, VR experience	1944.3	2236.4	1.15023	2.84857	0.091

Table 4.1: This table shows the calculated statistics for each scenario tested for significance

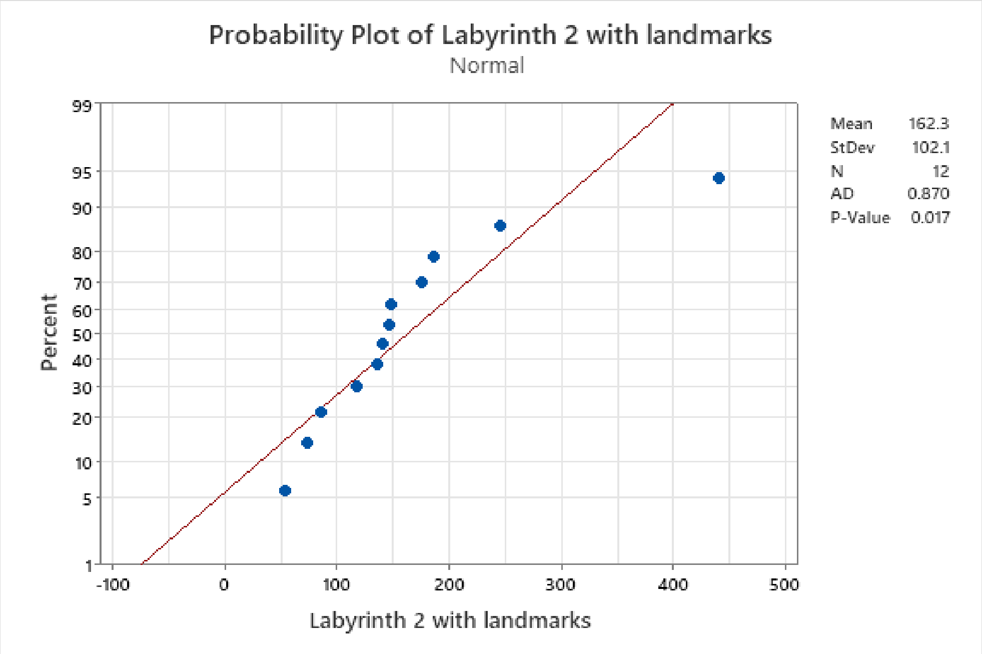

Figure 4.4: A graph showing normality among a dataset, here with an outlier present.

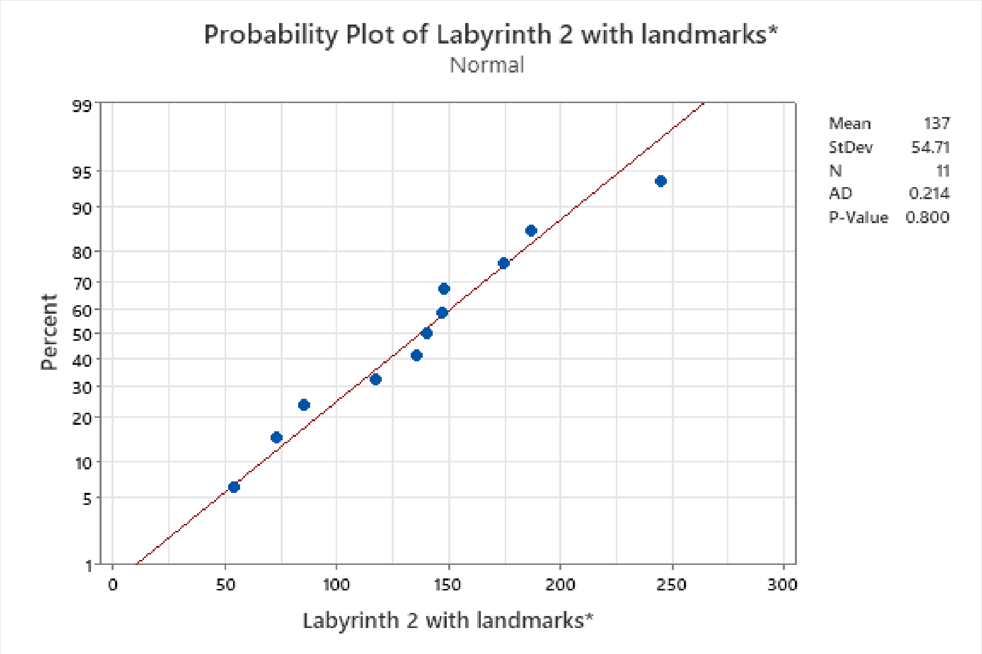

Figure 4.5: A graph showing normality among a dataset, here without an outlier present.

As Table 5.2 shows, some participants used the panic button. Table 4.2 displays the attributes that can be linked to either the participant or the specific labyrinth of the recorded time. Six out of seven times the panic button was used, there were no landmarks in the labyrinth. Again, six out of seven times, the participants reported no significant experience with maps. Four out of seven participants were experienced with VR. Two of the seven were male, and aged between 18 and 23. And finally, three out of seven times the panic button was used, the time was later identified as an outlier in the data. This was every outlier except one, which was the time of participant number six in labyrinth one, 141 seconds, which was much less significant than the outliers that were produced when the panic button was pressed.

4.3 Discussion

The first question presented in this thesis asked how maps are intuitively used in VR. The numbers show that most people picked up the map and kept it close to their field of view while navigating. This could suggest that a small map within the field of view of the user, a mini-map, could be used by most to navigate semi-complex tasks. When comparing when the high numbers of frequencies occurred, the three highest frequencies occurred when the panic button was used. This can be explained by the fact that the participants actively had to locate and press the button, bringing the focus away from the map. However, it can also be argued

Participant nr	Landmarks?	Age	Gender	Map experience	VR experience	Outlier?	Frequency
6	No	18-23	Male	Experienced	Some experience	No	3
8	No	18-23	Male	Ordinary	Some experience	No	7
17	No	18-23	Female	Ordinary	Some experience	Yes	2
19	No	18-23	Female	Ordinary	Some experience	No	7
22	Yes	18-23	Female	Ordinary	Never used	Yes	12
23	No	18-23	Female	Ordinary	Never Used	Yes	2
24	No	18-23	Female	Ordinary	Never Used	No	1

Table 4.2: This table shows the characteristics associated with use of the panic button

that these participants felt more lost and needed to perceive their surroundings to assess their location on the map. This highlights the need to see the map in detail to locate oneself, so a small map should not be the only way to navigate. When it came to what orientation of the map, most people used a north-up orientation. Although the fastest time in labyrinth two was achieved by a participant using a forwards-up orientation, it did not seem significantly faster overall. A reason why so many people perhaps kept the initial north-up orientation of the map throughout, could be because they all managed to perform the required mental rotation of the map in their head. The second labyrinth had a longer average completion time. So the three people who changed their orientation style between the two labyrinths perhaps did not manage the mental rotation of the map sufficiently anymore, and changed their style.

The second question of the thesis, regarding the effects of landmarks in navigation in VR, did not achieve the answer that could be expected from the available theory. The many positive findings related to the use of landmarks in navigation and wayfinding, would lead to expectations of better times with the landmarks present in the labyrinths. The conclusion of the t-tests did not find any significant difference when landmarks were made available to the participants. In fact, the smallest p-value achieved by any of the scenarios would have suggested that landmarks negatively impacted performance. The participants can be partitioned into two groups when considering who had the landmarks available first and second. One of the groups outperformed the other in both labyrinths, suggesting that other factors were more significant than the landmarks. This was why more scenarios than needed to answer the thesis' questions were calculated, to see if any of the available and comparable factors could be found to be significant. None did at a 95% confidence level, however, the most consistently low factor when looking at the p-values in Table 4.1, was VR experience. This highlights the need to distribute participants equally in a similar experiment regarding their VR experience.

One measurement that could indicate the importance of landmarks is the analysing of the use of the panic button. The fact that all except one use of the button occurred when landmarks were not present could show their positive qualities.

Most participants did not report being experienced with maps, and this lack of experience seemingly could be compensated for by introducing landmarks. Studies have also shown that modern navigational aids could have a negative effect on people's spatial cognitive skills [45]. Given their young age and inexperience with maps, these participants could be part of those impacted by this phenomenon. Highlighting the importance of landmarks could contribute to smarter maps, designed to reverse the trend.

4.3.1 Evaluation

When looking back at the experiment that was conducted, several potential improvements could have been made. The fact that one group performed better than another, suggests that more people would have been beneficial in rooting out random factors affecting the experiment. The complexity of the labyrinths was originally considered to be pushing the upper limit, however, perhaps a more complex labyrinth would have highlighted the positive qualities of using landmarks when navigating. The landmarks themselves could perhaps also have been designed better. If each side of the landmarks had been more distinct, they could have provided the participants with even more information when orienting themselves after them. A positive element of the experiment, which was not reflected in the numbers, but rather observed while the experiment took place, was that very few participants reported to have experienced VR-sickness. Though short completion times might also contribute, the steps taken to avoid discomfort seem effective. Many people were using the teleportation system and turning physically, suggesting that intuitive systems designed well may be preferable to more familiar joy-stick-based movement systems under the right circumstances.

Chapter 5

Conclusion

This thesis aimed to investigate intuitive map use and the effect of landmarks in navigation in VR. This involved observing how people used maps given to them to complete navigational tasks and how landmarks affected their abilities.

To achieve this, an experiment was set up where a test environment would automatically collect relevant data. The test environment was developed as a game in the Unity game engine, to not indicate to participants what they were being tested in. Considerations were taken to reduce VR-sickness, so it would be comfortable to navigate the test environment. 24 participants were recruited on a volunteer basis and completed two labyrinths. Each participant had landmarks available in one of the two labyrinths, half in the first and half in the last labyrinth. A pilot study was conducted to improve the design before the final experiment.

After analysing the result, the effects of landmarks on completion times were not shown to be significant. A higher number of participants and a better distribution of participants with VR experience, which was the factor seemingly most likely to affect completion times in the test environment, could improve a similar experiment. Longer labyrinths and well-designed landmarks might also highlight the effects of landmarks in VR better than this experiment could. The results did indicate that most people picked up the map a few times and kept it within their field of view. Those who used the map many times were also those who needed assistance and felt lost. This could suggest that a mini-map available, though also with a full-scale map available, within a VR navigation setting, could be sufficient for semi-complex active navigation. The analysis of the use of an assistance tool, a panic button that revealed the participants' position, highlighted some positive aspects of using landmarks. All participants, aged between 18 and 23 and generally not experienced with maps, did not have landmarks active in their labyrinth, except for one. This suggests that the landmarks are helpful to those who have little experience with maps when navigating in VR.

Future work might repeat a similar experiment, made better by learning from the successes and faults of this one, to try and isolate the factor of effects of landmarks even better. It would also be interesting to see other types of maps that take advantage of the possibilities inherent to VR. Another potential is to explore navigation in other urban or more open settings, perhaps in combination with a mini-map.

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Appendix 1

Code taken from article by Rosetta Code [46].

```
F make_maze(w = 16, h = 8)
   V vis = [[0] * w [+] [1]] * h [+] [[1] * (w + 1)]
   V ver = [[’|  ’] * w [+] [String(’|’)]] * h [+] [[String]()]
   V hor = [[’+--’] * w [+] [String(’+’)]] * (h + 1)

   F walk(Int x, Int y) -> N
      @vis[y][x] = 1
      V d = [(x - 1, y), (x, y + 1), (x + 1, y), (x, y - 1)]
      random:shuffle(&d)
      L(=xx, =yy) d
         I yy == -1
            yy = @vis.len - 1
         I xx == -1
            xx = @vis[0].len - 1
         I @vis[yy][xx]
            L.continue
         I xx == x
            @hor[max(y, yy)][x] = ’+  ’
         I yy == y
            @ver[y][max(x, xx)] = ’   ’
         @walk(xx, yy)

   walk(random:(w), random:(h))

   V s = ’’
   L(a, b) zip(hor, ver)
      s ’’= (a [+] [String("\n")] + b [+] [String("\n")]).join(’’)
   R s

print(make_maze())
```

Appendix 2

Participant number	Age	Gender	Map experience	VR experience
1	24-29	Male	Geomatics student	Experienced
2	18-23	Male	Experienced	Never used
3	18-23	Male	Experienced	Some experience
4	18-23	Female	Experienced	Never used
5	18-23	Male	Ordinary	Never used
6	18-23	Male	Experienced	Some experience
7	18-23	Male	Ordinary	Some experience
8	18-23	Male	Ordinary	Some experience
9	18-23	Male	Ordinary	Never used
10	18-23	Male	Ordinary	Some experience
11	24-29	Male	Experienced	Some experience
12	24-29	Male	Geomatics student	Experienced
13	18-23	Male	Ordinary	Experienced
14	18-23	Male	Ordinary	Never used
15	18-23	Female	Ordinary	Never used
16	18-23	Male	Ordinary	Never used
17	18-23	Female	Ordinary	Some experience
18	24-29	Male	Ordinary	Experienced
19	18-23	Female	Ordinary	Some experience
20	18-23	Male	Experienced	Some experience
21	24-29	Male	Experienced	Never used
22	18-23	Female	Ordinary	Never used
23	18-23	Female	Ordinary	Never used
24	18-23	Female	Ordinary	Never used

Table 5.1: This table shows the survey results per each participant.

Participant number	Towers	Time 1	Time 2	Orientation
1	1st	46	51	North-up
2	2nd	74	175	North-up
3	1st	60	131	North-up
4	2nd	120	148	Forwards-up
5	2nd	100	117	North-up
6	1st	141	125*	North-up
7	2nd	39	54	North-up
8	1st	116	125*	North-up
9	2nd	72	140	North-up
10	1st	51	69	North-up
11	2nd	71	85	North-up
12	1st	75	48	Forwards-up
13	2nd	52	73	North-up
14	1st	82	119	North-up 1st, forwards-up 2nd
15	2nd	129	245	North-up
16	1st	92	80	North-up
17	2nd	608*	187	North-up
18	1st	84	100	North-up
19	1st	83	157*	North-up
20	2nd	71	136	North-up
21	1st	61	101	North-up 1st, forwards-up 2nd
22	2nd	107	441*	North-up
23	2nd	370*	147	North-up 1st, forwards-up 2nd
24	1st	89	98*	North-up

Table 5.2: This table shows the the measured variables per each participant in each labyrinth. The times are given in seconds used to complete the associated labyrinth. *Panic button used

Participant number	Frequency of use 1	Frequency of use 2
1	1	2
2	1	3
3	2	2
4	2	2
5	1	1
6	1	3
7	1	1
8	5	7
9	1	1
10	4	2
11	2	2
12	1	1
13	1	1
14	1	1
15	1	3
16	1	1
17	2	1
18	2	1
19	1	7
20	1	2
21	3	4
22	1	12
23	2	2
24	1	1

Table 5.3: This table shows the frequency of map-use per each participant in each labyrinth.

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