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MELBOURNE

# Evaluating the User experience of Mobile VR

by

Gonzalo Enrique García Martínez

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# *Abstract*

For decades, Virtual Reality (VR) systems have provided unique user experiences, inspiring researchers to develop methods for assessing the user experience (UX) in VR. Until recently, VR was restricted to tethered configurations; now, portable systems such as Oculus Quest combine excellent immersion with mobility, allowing VR to move into public spaces and unpredictable contexts. Just as the emergence of mobile screen-based computing required the development of new methods of design and evaluation, so the emergence of mobile VR prompts us to consider whether existing UX evaluation methods need to be augmented.

UX in VR is commonly measured through questionnaires; however this approach is criticized for the reliability of its results. There have been several alternatives using other subjective and objective methods, but it is still unclear which could be the most suitable. This provided me with the opportunity to test the suitability of existing methods and to devise new ones that take advantage of the novel features of these mobile devices. For this research project, I investigated and used a combination of techniques to evaluate UX in mobile VR devices. The proposed method included questionnaires, a semi-structured interview, and observation techniques such as note-taking and a novel idea of interaction logging in VR.

I validated this approach via an empirical study. I measured UX in a VR prototype that replicates flooding in the city of Melbourne, Australia. Our method could identify UX problems involving relevant UX components such as presence, immersion, usability, engagement, emotion, simulator sickness, flow, skill, technology adoption and judgement. My findings also highlighted the importance of using qualitative and quantitative data together to measure UX in VR. I encourage the use of observation methods such as interaction logging and note-taking since they provided useful behavioural information to measure the UX of mobile VR.

# Declaration

I certify that:

- This thesis does not incorporate without acknowledgement any material previously submitted for degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person where due reference is not made in the text.
- Where necessary I have received clearance for this research from the University's Ethics Committee (Approval Number 1954364.1) and have submitted all required data to the School.
- This thesis is 19113 words in length (excluding text in images, tables, bibliographies and appendices).

Signed: Gonzalo Enrique García Martínez

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Date: November 1st, 2020

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# Preface

We submitted a paper to the 32nd Australian Conference on Human-Computer Interaction (OzCHI) on August 21st, 2020 named: "Evaluating the user experience of mobile VR: existing and novel methods". I am the primary author in this paper and I also volunteered to anonymously review papers submitted to this conference under the supervision of Dr Greg Wadley.

This thesis includes information from the paper in all chapters, from Chapter 1 to Chapter 10. It presents the content and contribution of the paper without constraints of page limit, figures and tables.

This research project and the development of my VR prototype allowed me to be part of another research project that was also submitted to this conference. The paper is named: "Melbourne 2100: Dystopian Virtual Reality to provoke engagement with climate change", and I am the second author. It should be noted that the content from this second paper is not included in my thesis since it is part of another different research.

## *Acknowledgements*

I would like to thank my supervisor Dr Greg Wadley, and a PhD candidate Kate Ferris, for their guidance, motivation, feedback and research knowledge they shared with me through this entire process. Furthermore, Academics and PhD students from the Interaction Design Lab who tested my VR application and provide me with insightful comments to improve it, especially Gabriele Marini and Romina Carrasco with the design and technical recommendations.

I would also like to show my gratitude to my parents, who despite the distance were always there to support me and advise me when I needed it most. My brother, my sister and my nephew for their ongoing support and continuous encouragement in these two years of study in Australia.

To my friends who are studying and living here in Melbourne. We shared pleasant moments all this time inside and outside the university. Discussions and conversations before the deadlines, as well as moments of fun and relaxation. Also, to my friends with whom I am still in touch in Peru, especially with those that I could visit on my last holiday trip to my hometown.

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# Chapter 1

## Introduction

For many years, UX became a buzzword that has been widely adopted by the Human-Computer Interaction (HCI) community ([Law, Roto, Hassenzahl, Vermeeren, & Kort, 2009](#)). As technology advances, the creation of novel and interactive products increase, and therefore their UX evaluation become more important and relevant. In the literature, there is not clear agreement about the nature and scope of UX ([Law et al., 2009](#)), and also there are several definitions for this term. One of the most cited papers is presented by [Hassenzahl and Tractinsky 2006](#). They defined UX as "a consequence of a user's internal state, the characteristics of the designed system and the context within which the interaction occurs".

In the years after 2000, HCI researchers asked how we should evaluate the UX of mobile devices ([Duh, Tan, & Chen, 2006](#); [Goodman, Brewster, & Gray, 2004](#); [Kjeldskov & Graham, 2003](#); [Kjeldskov et al., 2005](#)). New methods were developed, including recreating outdoor contexts in the laboratory, and doing field studies (e.g. [Kjeldskov, Howard, Murphy, and Carroll 2003](#); [Kjeldskov, Skov, Als, and Høegh 2004](#); [Kjeldskov and Stage 2004](#)). Now virtual reality, too, is going mobile in the form of systems such as Oculus Go and Quest. These provide a greater sense of embodiment ([Flavián, Ibáñez-Sánchez, & Orús, 2019](#); [Tussyadiah, 2013](#)), more immersive experiences, higher sensory stimulation, more engagement and more behavioural actions than the common tethered VR platforms ([Flavián et al., 2019](#)). Furthermore, they are becoming more affordable and accessible and they may be used in different contexts in the near future ([Eghbali, Väänänen, & Jokela, 2019](#)). Recent research is exploring how users and also spectators engage in the use of these devices in outdoor locations and proposed design recommendations (e.g. [Eghbali et al. 2019](#); [Harley et al. 2019](#)). This suggests that, as with mobile phones, HCI researchers should investigate how best to evaluate the UX of mobile VR and design for it.

Unfortunately, there are only a few UX models in the literature (e.g. UXIVE Model by [Tcha-Tokey, Christmann, Loup-Escande, Loup, and Richir 2018](#), Model based on Flow by [Cheng, Chieng, and Chieng 2014](#), Model based on Acceptance and Continuance by [Shin, Biocca, and Choo 2013](#), Model influenced by Virtual Environment Features by [Lin and Parker 2007](#), Model based on Interaction by [Mahlke 2008](#)) that are used to evaluate virtual environments ([Tcha-Tokey et al., 2018](#)). It is difficult to create successful virtual experiences for users because there are several complex UX components now being researched (see UXIVE Model in [Table 1.1](#)) ([Greenfeld, Lugmayr, & Lamont, 2019](#); [Rebelo, Noriega, Duarte, & Soares, 2012](#); [Sutcliffe & Kaur, 2000](#); [Wienrich, Döllinger, Kock, Schindler, & Traupe, 2018](#)). These components can provide an effective experience for users. However, evaluating them in VR is difficult ([Allam, Razak, & Hussin, 2009](#); [Gandhi & Patel, 2018](#)). There have been several proposals, but there is yet to be an established leading method ([Jerald, 2015](#); [S.-u. Kim, Lee, & Koo, 2017](#); [Wienrich et al., 2018](#)).

Presence is widely considered a key component in VR ([Slater, Steed, McCarthy, & Maringelli, 1998](#)), and also helps to understand and evaluate the effectiveness of virtual environments ([MacIntyre, Bolter, & Gandy, 2004](#)). This term has been the subject of extensive research ([Bouchard, St-Jacques, Robillard, & Renaud, 2008](#); [Ghani et al., 2016](#); [IJsselsteijn, De Kort, Midden, Eggen, & Van Den Hoven, 2006](#); [Schuemie, Van der Straaten, Krijn, & Van der Mast, 2001](#)) highlighting that the term itself is ambiguous and hard to define ([Meehan, Insko, Whitton, & Brooks, 2002](#)). Unfortunately, there is not a reliable method to measure presence in these virtual environments and it is still one of the key debates in presence community ([Darken, Bernatovich, Lawson, & Peterson, 1999](#); [Ghani et al., 2016](#)).

Although presence can be measured through quantitative and qualitative methods ([Spagnolli, Bracken, & Padova, 2011](#)), the vast majority published methods in presence measurement use questionnaires based on subjective ratings on participants after the virtual experience (e.g. [Insko 2003](#); [Lessiter et al. 2001](#); [Lombard and Ditton 2006](#); [Schuemie et al. 2001](#); [Schwind, Knierim, Haas, and Henze 2019](#); [Silva, Donat, Rigoli, de Oliveira, and Kristensen 2016](#); [Slater 2004](#); [Spagnolli et al. 2011](#); [Witmer and Singer 1998](#)) and just a few use qualitative methods (e.g. [Garau et al. 2008](#); [McCall, O'Neil, and Carroll 2004](#)). In the same way, the use of questionnaires is predominant to measure the remaining UX components presented in [Table 1.1](#) (e.g. [Rebelo et al. 2012](#); [Tcha-Tokey et al. 2016](#); [Wienrich et al. 2018](#)). Furthermore, these questionnaires are usually created for specific virtual environments which causes differences between them ([Thornson, Goldiez, & Le, 2009](#)). Recent research suggests that qualitative methods would provide a wider perspective about different aspects of UX in virtual environments and complement quantitative methods ([Ghani et al., 2016](#)).

UX Component	Description
Presence	Commonly defined as the sensation of “being there” in the virtual environment (Ghani, Rafi, & Woods, 2016; Held & Durlach, 1992; Lessiter, Freeman, Keogh, & Davidoff, 2001; Slater & Wilbur, 1997).
Immersion	An objective description of aspects of the system such as field of view and display resolution (Slater & Wilbur, 1997).
Usability	Ease of learning and using the virtual environment (Tcha-Tokey, Loup-Escande, Christmann, & Richir, 2016).
Emotion	Feelings of the user such as pleasure, satisfaction, frustration, disappointment, etc. (Tcha-Tokey et al., 2016).
Engagement	Connection between a person and an activity consisting of behavioural, emotional and cognitive components (Tcha-Tokey et al., 2016).
Simulator Sickness	Feelings such as nausea, disorientation, stress, headache, dizziness that sometimes occur while using VR (Tcha-Tokey et al., 2016).
Technology Adoption	Actions and decisions taken by the user for a future use or intention to use the virtual environment (Tcha-Tokey et al., 2016).
Flow	Pleasant psychological state of sense of control, fun and joy that the user feels when interacting with the virtual environment. (Tcha-Tokey et al., 2016).
Skill	knowledge the user gain in mastering his activity in the virtual environment. (Tcha-Tokey et al., 2016).
Judgement	Overall opinion (e.g. positive, indifferent or negative) of the experience in the virtual environment. (Tcha-Tokey et al., 2016)

TABLE 1.1: UX Components in VR (UXIVE Model)

## 1.1 Terminology: Mobile VR

Several terms are used to describe mobile VR systems, including “standalone”, “untethered” and “wireless”. For this thesis, I used the term “mobile”, and in Table 1.2, list contemporary mobile devices in the category. I decided to take this term because the majority of papers in the literature used it; and also, because of the relation I stated of mobile VR and the emergence of mobile phones that occurred many years ago.

These mobile devices provide positional tracking that afford greater ease of movement, a better sense of embodiment and immersion (Flavián et al., 2019; Tussyadiah, 2013). They do not need to be tethered to an external device (e.g. PC or smartphone). For this research project, I used the Oculus Quest platform.

VR Device	Positional Tracking	Degrees of Freedom (DoF)
HTC VIVE Focus	Inside-out	3
Lenovo Mirage Solo	Inside-out	3
Oculus Go	No	3
Oculus Quest	Inside-out	6
Oculus Quest 2	Inside-out	6
Pico VR Neo	Yes	6

TABLE 1.2: Contemporary Mobile VR Devices

To better understand the second and third column of the table above, I used the definitions from [GoogleVR 2018](#). Positional tracking is the use of visual and inertial sensors to model the user’s position relative to the virtual world. Inside-out means that these sensors are located on the device being tracked. 3DoF means that the device can track rotational motion but not translational (e.g. users turned their head left or right, tilted it up or down, or pivoted left and right.). 6DoF means that the device can track both (e.g. users moved forward, backward, laterally, or vertically.) (see Figure 1.1).

With these novel features, the portability, the longest battery life (from 2 to 3 hours), and strong computing power can take these devices to outdoor contexts in the same way it happened with mobile computer systems. It would not be a surprise that in the near future people would start using these on the bus or the tram, or even in a plane. Moreover, their novel features increase user responses which led me to the creation of the novel method presented in this thesis to evaluate UX on these devices in the field.

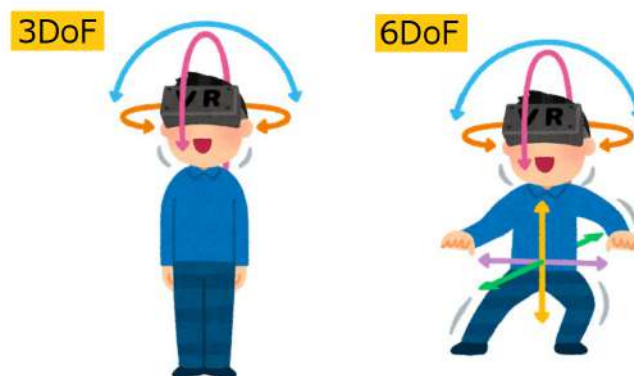


FIGURE 1.1: Degrees of Freedom in Mobile VR

## 1.2 Iterative Design Development

To develop a stable and robust VR application to test the proposed method, I used an iterative design (Jerald, 2015) to overcome some of the common usability problems in VR. It involves the active participation of the user in the initial phases of the design process. This iterative design consists of 3 stages (Table 1.3), I iteratively received feedback from HCI experts after they tested the VR prototype (Jerald, 2015) (Figure 1.2). I could improve the virtual experience and found bugs as well until I obtained a stable version to conduct a lab study with real users.

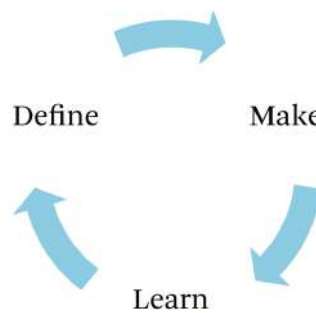


FIGURE 1.2: Iterative Design for VR

Stage	Description
Define	In this stage developers understand the requirements and attempt to answer the question: "what do we make?" It also included the identification of the people who will be using the VR application. Moreover, the creation of storyboards and estimation of time and costs. This stage served me to identify my future sample and plan the research project over 3 semesters.
Make	In the second stage, developers attempt to answer the question: "how do we make it?" Therefore, design and implementation occurred in this stage. At the beginning it is helpful to use free hand sketches in order to build a functional prototype ready for users. This stage was useful to choose the software tools and hardware devices I used for the VR prototype implementation.
Learn	In this third stage, developers received feedback from users and attempt to answer the question of what worked well and what does not. Communication between users and developers is important in order to improve the VR prototype. This stage helped me to obtain a stable version of the prototype for the lab study.

TABLE 1.3: Stages in the Iterative Design for VR

### 1.3 Approach

This thesis proposes a method that combines quantitative and qualitative UX techniques, a combination that can provide more valid results (Tcha-Tokey et al., 2016). The techniques used are questionnaires, a semi-structured interview and observation including note-taking and screen recordings. I measured UX using a mobile VR device with a VR prototype that replicates part of the CBD of Melbourne, Australia.

To test my method, I adopted the UXIVE model which includes the following UX components: presence, immersion, usability, simulator sickness, engagement, emotion, technology adoption, flow, skill and judgement since these are considered relevant in designing VR applications. With this research I did not want to propose a UX model for VR, I aimed to propose a new method to measure the user experience of applications using mobile VR devices in outdoor settings. To achieve this, I needed to know which UX components are the most active in the literature. Therefore, I took into account the UX components presented in the UXIVE Model (Table 1.1) in order to categorise my findings.

I planned to do this study in an outdoor location in the same way that several studies were done for mobile computer systems. However, due to COVID19, we had to conduct it in a controlled environment at The University of Melbourne.

### 1.4 Contribution

The main contribution of this thesis is methodological (Wobbrock & Kientz, 2016). I proposed a combination of observation techniques that are rarely used in VR (Flotynski & Sobocinski, 2019), such as direct observation, interaction logging, real-time monitoring of the interaction, with note-taking. These techniques complemented usability and presence questionnaires I used, and interviews I conducted to gather information about the UX of my prototype. I developed a stable VR application and I could use my method to assess it. This thesis presents this method in detail along with evidence of its utility. I encourage HCI researchers to use this combination of quantitative and qualitative methods in measuring UX of mobile VR.

Furthermore, I proposed a plan to take this method to an online context. Based on the experience of this research project, I provided changes and adjustments to make the proposed method suitable for remote studies. I decided to create this plan because of the restrictions imposed due to COVID19 and the limitations of conducting face-to-face



studies in the HCI community. This plan would help researchers who are thinking or planning to conduct online recruitment and data collection.

Finally, the development of this artifact (Wobbrock & Kientz, 2016) can be used for Virtual Heritage Environments, Virtual Urban Environments or it can even be useful in modelling impacts and solutions of Climate Change.

## 1.5 Research Goal

The introduction of the previous sections about UX in mobile VR devices and the gaps found in the literature have led me to answer the following research questions:

- **RQ1:** How can we measure UX of mobile VR devices in outdoor settings?
- **RQ2:** How can we apply the proposed method in people's home during pandemic?

To answer these questions, I first built a VR prototype with the mentioned iterative design. Then, I conducted a lab study with volunteers to test the VR prototype and collect quantitative and qualitative data using the proposed method. After that, I analyzed this data and finally shared my findings. These final results are divided in two sections in this thesis: results of the VR test and results of the evaluation method.

## 1.6 Thesis Outline

The structure of this thesis is as follows:

- Chapter 1: in this chapter, I present an introduction about mobile HCI with VR and how it is related to mobile computer systems many years ago. Also, and an overview about UX, the terminology of Mobile VR, the iterative design I used to build the VR prototype, the contribution of this thesis and the research questions.
- Chapter 2: in this chapter, I describe the emergence of Mobile VR and its relation to earlier Mobile HCI. Also, techniques to evaluate experiences in VR and the relation between UX components, how they are being measured and the problems authors found.
- Chapter 3: in this chapter, I present the proposed method to measure UX of Mobile VR, and how I came up with this novel idea. Also, requirements I needed to conduct the study efficiently.

- 
- Chapter 4: in this chapter, I describe the VR prototype I used for test and how I implemented it.
  - Chapter 5: in this chapter, I described how I test the method on the VR prototype. This method includes the objective and subjective techniques I found in the literature and others I proposed.
  - Chapter 6: in this chapter, I summarize the results of the test with the VR prototype. I describe the findings for demographics, all UX components, and limitations.
  - Chapter 7: in this chapter, I describe the results of the proposed method, how effective it was measuring UX and how the proposed techniques measured each UX component.
  - Chapter 8: in this chapter, I discuss the limitations and drawbacks of the proposed method. I also present some recommendations based on the problems I faced.
  - Chapter 9: in this chapter, I describe the future work. I proposed a plan to conduct online studies with the proposed method.
  - Chapter 10: in this chapter, I make a final conclusion about this research project.

## Chapter 2

# Literature Review

### 2.1 Mobile HCI

#### 2.1.1 Earlier studies of Mobile Computer Systems

Decades ago, researchers examined and reviewed research methods in the field of mobile HCI. They found that there was a greater trend towards mobile computer systems testing within labs but few in the field ([Kjeldskov & Graham, 2003](#)). This revealed a concern since the use of smartphones were being used in outdoor places with unpredictable contexts thanks to their portability and their novel features. There were experiments to understand and improve the user experience with these devices in outdoor settings, as well as studies that replicated an outdoor setting within a controlled environment.

[Kjeldskov et al. 2003](#) designed a mobile prototype named TramMate to reduce the complexity and inflexibility of public transport; and also the use of cars that can be time-consuming and unreliable. They provided a route-planning tool for the tram-based public transport system of Melbourne, Australia. This fieldwork consisted of three steps: interview with users, observation of their current practice, which is driving a car, and acting-out future practice (using the prototype). With this information, they could collect the key requirements and relevant information to produce their preliminary sketches for the design of TramMate in a PDA.

[Kjeldskov and Stage 2004](#) developed new techniques to evaluate the usability of a mobile computer system. They conducted two experiments and compared them. Users had to perform tasks of sending and receiving messages (SMS). The first experiment involved 6 techniques in a lab: using the mobile system while sitting on a chair, walking on a treadmill at a constant and varying speed, walking at constant and varying speed on

a course that is constantly changing, and walking in a pedestrian street. The second experiment was conducted in the field with only two techniques: performing tasks while playing a computer game and walking in a pedestrian street. To evaluate these studies, they collected three types of data: usability problems with video recordings of users, their performance with video and audio recordings, and finally a workload test. They found no significant differences between the two experiments in these three categories which demonstrated that studies conducted in the lab can provide similar results than studies conducted in the field.

[Kjeldskov et al. 2004](#) conducted a usability evaluation of a context-aware mobile system named MobileWard. This prototype was designed to manage tasks during morning procedure at a hospital. Authors conducted two usability evaluations, one in a laboratory and another one in the field. They used questionnaires and an interview to gather data from users after testing the prototype. They recreated the healthcare context in a usability laboratory; and identified the same usability problems in the lab as in the field except only for one. This demonstrated that we can produce successful mobile system usability results recreating the use of context in a usability laboratory.

### 2.1.2 Recent studies of Mobile VR

In the same way, today, VR researchers have been studying the use of VR in outdoor settings with different contexts. [Harley et al. 2019](#) designed two storytelling VR experiences of real-world locations: "The Greenhouse" and "The Labyrinth". They used a Samsung Note 5 and a Gear VR headset; and they enriched the experience including smartphone features such as: GPS, camera, audio narratives, text messages and augmented reality. They conducted a user study outdoors with at least two researchers nearby to observe and answer questions. After the experience, their participants answered a customized questionnaire and a semi-structured interview. They concluded that one of the biggest concerns of mobile VR is the safety of the participants in public spaces.

[Eghbali et al. 2019](#) investigated and identified factors that influence the experience of users and spectators in public contexts. Their study consisted of three phases and it was conducted in a university restaurant using a Samsung Gear VR with a Galaxy S7 Edge. In the first phase, participants received an introduction of the use of the device, tested the application, and answered questions of an interview and a questionnaire. The second phase was focused on the spectators. Researchers approached to people who were passing by and asked them to complete a questionnaire if they were interested. Finally, the third phase was a session with UX experts to create design recommendations for socially acceptable VR based on the data they collected in the field studies.

Williamson, McGill, and Outram 2019 explored the social acceptability and usability of VR for in-flight entertainment. First, researchers provided a questionnaire to passengers in order to identify user attitudes about the VR usage in-flight and understand what type of problems can arise. Then, based on this information, they developed a VR cinema application that took into account three key concepts: awareness of the events of the plane, reduce movement required to interact in VR to avoid unintentional contact with other passengers, and enable interruption of the VR app without requiring any physical contact. They tested this application using a Samsung Gear VR and a Samsung S7 phone with real passengers. Participants completed a questionnaire and took part in a semi-structured interview. With this data and the corresponding analysis, the authors provided design recommendations for the development of mobile VR entertainment applications that can be socially accepted when travelling by air.

## 2.2 Emergence of Mobile VR

With the previous literature, we can see how the emergence of mobile VR is indeed analogous to the emergence of earlier mobile devices. I identified key aspects of both and presented this comparison in Table 2.1 to support my argument. Moreover, Figure 2.1 and Figure 2.2 illustrates the change that occurred to these two technologies from decades ago until today. They support and illustrate the analogy presented in this thesis; and the need to investigate mobile VR further.



FIGURE 2.1: Desktop Computers (1980s) leaving labs in form of Smartphones (2020)

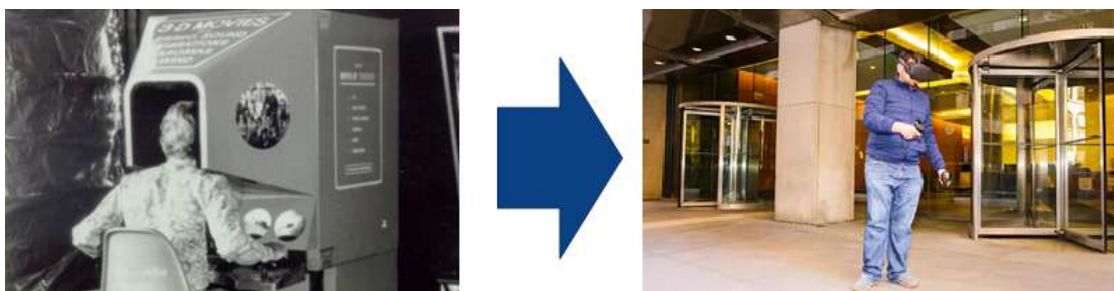


FIGURE 2.2: Stationary VR machines (1950s) leaving labs in form of Mobile VR headsets (2020)

Category	Smartphones	Mobile VR
<b>Outdoor-Context</b>	Computers stopped being just stationary and left indoor settings in the form of small mobile devices. Thus, people started to use them in different places and contexts	In the same way, VR left labs too and is starting to be used not only in indoor settings, but also in public spaces with unpredictable contexts.
<b>Mobility</b>	From room-size computers to small and portable devices. Today, they are easily carried in a pocket and people use it everywhere.	Mobile VR devices are portable too. Also, wireless since they do not need to be connected to an external device to work. Therefore, they can be used anywhere.
<b>Design</b>	Researchers focused on creating and improving the design of mobile devices and applications to provide richer experiences to users.	Similarly, recent research is exploring how to create pleasing and more usable virtual experiences to users considering the context and mobility.
<b>Computing Power</b>	One of the reasons why computers did not leave labs was because they needed powerful processing power at that time. This changed over time, and now small phones can have it.	VR required a strong computing power too. Today, VR has it without oversized hardware and its processing power is enough for users.
<b>Affordability</b>	Long time ago, smartphones were not easy to obtain due to their high cost. Over time, they became more accessible and today it is difficult to find people without one.	Mobile VR devices are becoming more accessible. Prices are dropping and people are trying this technology. In September of this year, the Oculus Quest 2 was announced at only 299USD.

TABLE 2.1: Analogy of Smartphones and Mobile VR

Apart from the similarities, I also found some small differences that are now present:

- The size of the devices. Even though both are portable, smartphones can be kept in a pocket easily whereas mobile VR devices need a bigger space (e.g. bags, backpacks). Probably in the future we will have much smaller versions of VR devices.
- VR takes away users' vision of the real world completely and immerse them in a 3D environment, which can be a potential threat to their safety. Smartphones, on the other hand, requires attention to a specific 2D screen and users can see

the real world with ease. However, accidents have also been reported due to its inappropriate use (e.g. texting while walking or driving).

- Finally, users who use VR mobile devices are more prone to simulator sickness than using standard smartphones. Recent research is trying to tackle and decrease this problem in VR (e.g. [Fernandes and Feiner 2016](#); [Kostrova and Yuri-Andersson 2020](#); [Norouzi, Bruder, and Welch 2018](#))

### 2.2.1 Evaluation of Mobile VR applications

Earlier mobile HCI research and the lack of methods for mobile VR devices, motivated me to investigate existing methods in the literature and elaborate new ones. Most of the methods used to evaluate the experience of users in VR are questionnaires and interviews; and they are mostly conducted in controlled environments (i.e. laboratories). However, the use of questionnaires has been criticized for the reliability of their results, and conducting interviews in outdoor settings can be affected by external factors. For example, the time of availability of the participant, or an appropriate place to ask and answer questions without interruptions.

On the other hand, few VR studies used observation techniques. They can provide richer information about problems in the virtual experience. Due to the novel features of mobile VR devices (e.g. DoF, positional tracking), the experience of users improved providing them more interaction. These user behavioural patterns can be captured through observation while the user is testing the app. Thus, users would not spend more time in a study, which can be beneficial and suitable for field studies.

To elaborate the proposed method in this thesis, I made a comparison about the current evaluation techniques in the literature and analyzed how they can be affected in indoor and outdoor settings (Table 2.2). Besides from observation techniques which are more convenient for field studies according to this table, I considered to use questionnaires and interviews but taking into consideration their problems.

These techniques in conjunction can identify in a better way problems in a VR application that is tested in the field. Their execution requires a mobile VR device. It cannot be used with tethered VR platforms for two reasons. First, tethered VR devices are not portable (wireless). They need to be connected to a PC. Therefore, it would not be possible to take them to outdoor contexts. Second, tethered VR devices do not have the novel features mobile VR devices have (e.g. positional tracking, DoF). Hence, users do not have that freedom of movement in the virtual environment with which the proposed method takes advantage with the observation techniques.

Technique	Indoor	Outdoor
<b>Questionnaires</b>	<p>They required time to complete and can be exhausting if there is a large number of questions, which is fine since participants and researchers scheduled an exact day/time in advance.</p> <p>Researchers have an adequate space and participants can complete them without interruptions.</p>	<p>Time-consuming and exhausting if it has many questions as well, which can be a problem in the field if the participant does not have availability.</p> <p>Participants need an adequate space to complete them and they can be interrupted by external circumstances.</p>
<b>Interviews</b>	<p>Can be time-consuming, but participants accepted it with anticipation.</p> <p>In a lab, researchers can conduct it without interruptions as having a proper space and resources.</p>	<p>Time-consuming as well, researchers need participants who have enough time to be part of the study.</p> <p>Interviews can be interrupted by external factors, which can affect data collection.</p>
<b>Observation</b>	<p>They can be performed while the user is using the VR app. Thus, there is no interruption.</p> <p>Participants need a large space to test the app and for their safety.</p>	<p>In the same way, they can be performed while the user is testing the app.</p> <p>Participants also need the necessary space for their safety while testing the virtual experience</p>

TABLE 2.2: UX Evaluation Techniques Comparison in Outdoor/Indoor Settings

## 2.3 UX in VR

Nowadays, technology is playing a fundamental role in our society. The continuous growth in software and hardware is quite promising. This is why several emerging technologies are appearing and focusing on different areas of study such as: healthcare, engineering, retail, military, real state and education (Onyesolu & Eze, 2011). One of these technologies is Virtual Reality (VR), which has great features to offer a surprising user experience (UX). VR has changed the way we interact with computing systems using a graphical user interface (GUI) (Kharoub, Lataifeh, & Ahmed, 2019). Virtual experiences provide realistic visualisations and allow users to interact using gestures (e.g. head, hand, or body movements) which increase and improve the user experience (Re & Bordegoni, 2014). As a consequence of these interactions and the context at hand, users can have different experiences with the same VR application since these responses



and reactions are affected by their own expectations, beliefs, preferences, perceptions, emotions, and accomplishments (Rebelo et al., 2012).

UX is defined by the ISO 9241-210:2019 as the "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service". Some authors proposed UX models that considered these perceptions and responses in form of UX components in order to investigate and measure them in VR. For this research, I considered the UXIVE Model (Figure 2.3) presented by Tcha-Tokey et al. 2018. I used this model to organize my findings for each UX component after testing my method. I chose this model for one main reason. It is simple, and the UX components in that model are adaptable for several virtual environments since it was created based on four UX models (Cheng et al., 2014; Lin & Parker, 2007; Mahlke, 2008; Shin et al., 2013). For example, previous models described Telepresence (e.g. Cheng et al. 2014) as a component when Presence includes it. Also, Satisfaction (e.g. Shin et al. 2013) or Enjoyment (e.g. Lin and Parker 2007) which are included in Engagement. The UXIVE model considered Experience Consequence as negative symptoms during or after testing the virtual environment. However, for this thesis, I considered a more used term: Simulator Sickness. Generally, VR studies in the literature only focused on a single or couple of these components, primarily presence and immersion (Tcha-Tokey et al., 2018).

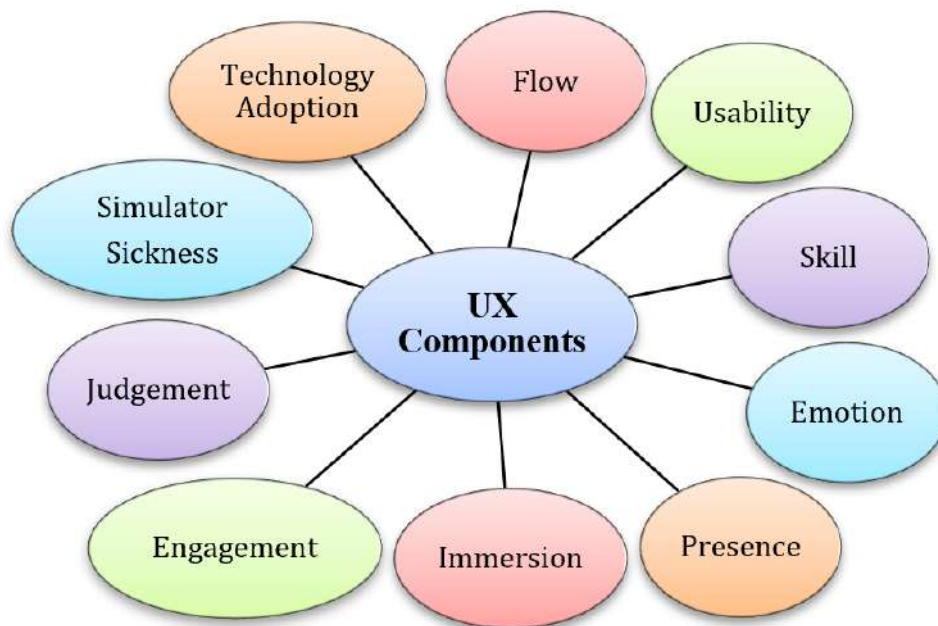


FIGURE 2.3: UX Components in VR (UXIVE Model)

## 2.4 Measuring UX in VR

Prior work has discovered multiple components of user experience in VR and used a range of techniques to study them. These components were listed previously in Table 1.1 and discussed here.

### 2.4.1 Presence

There have been arguments against the use of questionnaires to measure presence. Slater 2004 argues that the use of questionnaires cannot measure presence in a virtual environment. His argument is simple, we cannot rule out the possibility of presence in a virtual application with the simple fact of asking the user about it after the experience. This argument is supported by another from Schwind et al. 2019; they stated that questionnaire results are incomplete and inconsistent since they rely on the participant memory. Slater 2004 even stated that “presence researchers must move away from heavy reliance on questionnaires in order to make any progress in this area”. He proposed that presence should be studied based on virtual sensory data and the current context of the virtual environment.

Another drawback in VR studies with HMD and post-questionnaires is break-in-presence (BIP) (Jerald, 2015). This problem occurs when the researcher removes the HMD from the participant, at this moment the participant needs to re-orientate in the real world which might affect the level of presence when the participant fills the questionnaire (Sanchez-Vives & Slater, 2005). There were some approaches to deal with this problem. Schwind et al. (2019) proposed evaluating presence within the HMD. However, they found no significant difference between filling a questionnaire inside or outside the VR. Also, Garau et al. 2008 proposed a qualitative analysis to investigate BIPs in virtual environments. They asked their participants to draw their level of presence during the experience detecting four whiteout anomalies (Garau et al., 2008). Even though it was useful to learn more about BIPs, they could not compare their graphs because they did not match a general timeline. Moreover, participants were not accurate on this task, and some of them forgot how many of these whiteouts occurred.

Aside from subjective measures such the post-questionnaires, objective measures such as behavioural and physiological are reliable to measure presence (Insko, 2003). However, they are expensive in hardware and they required more time for analysis (Insko, 2003; Von Der Pütten et al., 2012; Weibel et al., 2018). Furthermore, behavioural measures can provide biased results since it is possible that the researcher acts consciously or

unconsciously in favour of a desired outcome (Insko, 2003). On the other hand, physiological measures such as a change in heart rate, in skin conductance, or skin temperature can be caused by several different stimuli (Insko, 2003), and therefore, affect the measurement of presence. Insko (2003) stated that the answer of choosing an appropriate measure is “to use as many as is feasible”. In using two or more methods, researchers are less likely to encounter errors in measuring presence.

### 2.4.2 Immersion

It should be noted the importance of relevant UX components that influence presence in the literature. According to Dalgarno and Lee 2010, several authors supported and encouraged the importance of measuring immersion in VR. This component is capable of influence presence (McMahan, 2013; Mestre & Vercher, 2011) and it is recommended to measure them together (Schwind et al., 2019). It is being largely measured subjectively through questionnaires, but also objectively (task completion time, eye movements) (Jennett et al., 2008). To this day, immersion is a currently active research area and quite discussed in presence research (Ghani, Rafi, & Woods, 2019).

### 2.4.3 Engagement

Engagement can be created in a virtual environment with imagination through tasks or challenges, which at the same time ensures presence (Rebelo et al., 2012). Several studies agreed on the relationship of these two UX components (Lin & Parker, 2007; McMahan, 2013; Schwind et al., 2019; Tcha-Tokey et al., 2018) and other studies the relationship between immersion and engagement, describing this latter as the first state of Immersion (Brockmyer et al., 2009; Tcha-Tokey et al., 2018). Some of the recommendations from authors to provide engagement in a virtual environment are: embodiment (Childs, 2010), virtual interaction and an orientation space to guide and familiarize participants with the use of the virtual environment (Christopoulos, Conrad, & Shukla, 2018). Several VR studies used questionnaires to measure engagement (e.g. Tcha-Tokey et al. 2018; Witmer and Singer 1998) as well as qualitative data from interviews (Ivancic, Schofield, & Dethridge, 2016).

### 2.4.4 Emotion

Emotion became relevant since VR increases emotional responses from users (Diemer, Alpers, Peperkorn, Youssef, & Mühlberger, 2015; Estupiñán, Rebelo, Noriega, Ferreira, & Duarte, 2014). Some studies confirmed the correlation between presence and emotion,

(Bouchard et al., 2008; Riva et al., 2007; Tcha-Tokey et al., 2018) and some others stated more emotional responses from users in more immersive environments (Diemer et al., 2015; A. Kim, Chang, Choi, Jeon, & Lee, 2018). As other UX components, emotion has been measured through questionnaires (e.g. Lichtenfeld, Pekrun, Stupnisky, Reiss, and Murayama 2012; Tcha-Tokey et al. 2016) but also, through interviews and physiological measures such as heart-rate, skin conductivity, breathing patterns, among others (e.g. Greenfeld et al. 2019; Lugmayr and Bender 2016).

#### 2.4.5 Usability and Simulator Sickness

Usability and Simulator Sickness are considered relevant components in the UX for VR studies too (Jerald, 2015; Tcha-Tokey et al., 2018), and they are actively mentioned in the literature. On the one hand, there is an important need to support the process of evaluation of usability in VR (Sutcliffe & Kaur, 2000). On the other hand, Simulator Sickness is vital in VR because it can negatively affect the experience and reduce the level of emotion on users (Tcha-Tokey et al., 2018) and therefore, affect the entire virtual experience. Simulator Sickness includes negative symptoms produced by the VR experience. In the literature there are a variety of ways to refer to this problem (e.g. VR Sickness, Cybersickness, Motion Sickness, etc.). For this thesis I used "Simulator Sickness" in order to encompass these terms. It includes all negative symptoms such as nausea, dizziness, headache, eyestrain, etc. (Lavallo, 2017). The majority of the studies measured these two UX components with questionnaires and a few with qualitative data (e.g. S.-u. Kim et al. 2017; Lecon 2018; Paes and Irizarry 2018; Sutcliffe and Kaur 2000; Takada, Fujikake, and Miyao 2009; Tcha-Tokey et al. 2016).

#### 2.4.6 Flow and Skill

Although there is little research on Flow in VR (Hassan, Jylhä, Sjöblom, & Hamari, 2020), I considered it because it can benefit or affect other UX components presented in my prototype. Flow is strongly related to engagement since it has been demonstrated that the more users experience flow, they tend to be more engaged. (Csikszentmihalyi, 2014; Egbert, 2003). Furthermore, it can influence presence (Cheng et al., 2014; Shin et al., 2013; Tcha-Tokey et al., 2018), and it can be affected by simulator sickness (Hassan et al., 2020; Tcha-Tokey et al., 2016). This component has been measured through questionnaires (e.g. Heutte 2011; Jackson and Eklund 2002), but it also can be captured through qualitative techniques (Hassan et al., 2020).

I also considered Skill since it can affect Usability, Simulator Sickness and Flow (Tcha-Tokey et al., 2018). Furthermore, it is important in virtual environments because there

needs to be an optimal balance between the user's skill and the task or activities he/she performed with the VR prototype (Csikszentmihalyi, 2014). Skill has been measured through questionnaires (e.g. Aggarwal, Balasundaram, and Darzi 2008; C. Murphy, Coover, and Owen 1989), but much more by tasks performance or tasks completion (e.g. Piccione, Collett, and Foe 2019; Tcha-Tokey et al. 2018; Tichon 2007)

#### 2.4.7 Technology Adoption and Judgement

Finally, Technology Adoption and Judgement. This first can be positively influenced if users enter to a flow state in the virtual environment (Hassan et al., 2020; Tcha-Tokey et al., 2018), and also by creating engaging and usable virtual experiences (Shin et al., 2013; Tcha-Tokey et al., 2018). Judgement, on the other hand, is influenced by presence and simulator sickness (Tcha-Tokey et al., 2018); and is markedly related to technology adoption (Mahlke, 2008). This relationship can be explained more clearly with an example. If a user is not affected by negative symptoms fatigue or dizziness (simulator sickness), they would have a positive opinion regarding VR (judgement), and therefore, there may be the possibility that he/she may use it in the future (technology adoption). Both UX components can be measured through questionnaires (e.g. Baños et al. 2000; Poeschl-Guenther and Döring 2013; Venkatesh, Morris, Davis, and Davis 2003) and qualitative data techniques as well (D. Murphy, 2017).

#### 2.4.8 Relation between UX Components

In summary, the relations between each UX component presented from the UXIVE Model (Tcha-Tokey et al., 2018), and other relevant relations found in the literature that were mentioned previously are illustrated in Figure 2.4. This demonstrates how difficult is to evaluate UX in VR since each of these components influences other components. In this figure, each color represents an UX component and the arrows mean "influence". For example, immersion, engagement and flow influence presence; and this latter influences emotion and judgement.

Furthermore, there are several techniques to measure each UX component and some of them have been criticized by different authors. As I can see in the literature, the majority focused on using questionnaires and interviews. The proposed method from this thesis would not only rely on them, but also on observation techniques that detect behavioural patterns from participants inside the virtual environment and outside, in the real world.

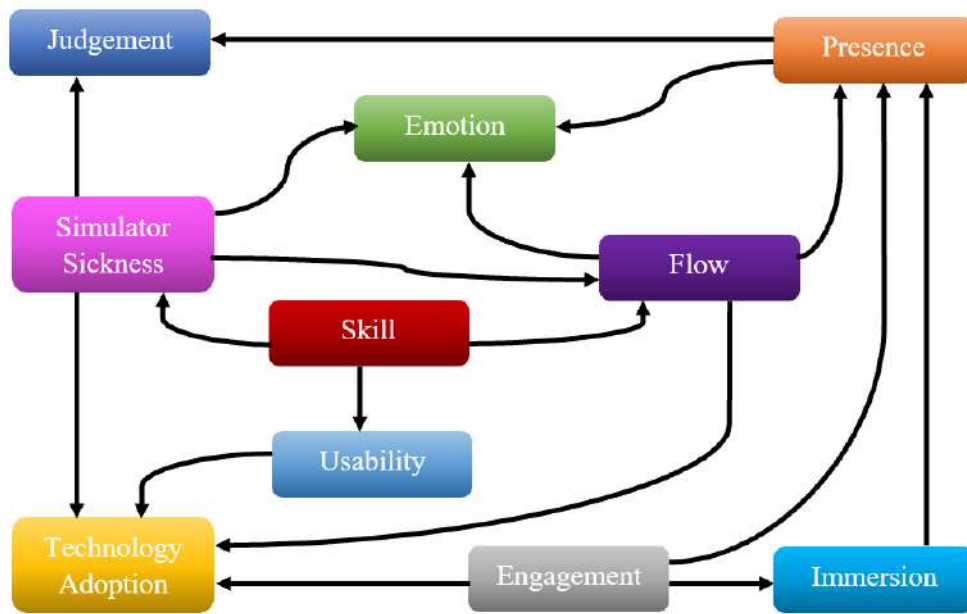


FIGURE 2.4: Relations between UX Components

## Chapter 3

# Proposed method for studying UX in Mobile VR

To address **RQ1**, I proposed a method to evaluate UX of mobile VR which is suitable and convenient for studies in outdoor locations. Some prior work from the literature has focused on post-experience measures using questionnaires and interviews, and not expressions and actions performed by the user during the experience. A Mobile VR device allows such behavioural patterns thanks to its positional tracking system, the degrees of freedom and its wireless connection; and all of them can be captured through observation techniques. I developed and tested this method to answer specifically my **RQ1** (see Table 3.1). It addresses a user's entire experience, with video recordings and observation notes complementing questionnaires and interviews.

Techniques	Description
1. Semi-structured Interview	Conducted before and after the user tested the virtual experience.
2. Questionnaires	A set of UX scales that measured presence, immersion and usability.
3. Direct observations of participants and note-taking	I directly observed participants during their VR experience and took notes of their use of the VR prototype.
4. Interaction Logging using a 3rd party software	Video Recordings that captured user's screen output wirelessly for later analysis. Monitoring user's view of virtual space in real-time through an external screen.

TABLE 3.1: Proposed Method

In Figure 3.1, I described the proposed method graphically, The number 1 illustrates the semi-structured interview. We audio recorded the conversations for later transcription and analysis. Number 2, represents the questionnaires. Participants filled them with the help of an online tool (Qualtrics). They could answer questions in a tablet and they were saved in the cloud. Number 3 shows the researcher performing the direct observation and note-taking while the user is testing the prototype. We took into account gestures and verbal expressions. Finally, number 4, describes how the virtual experience of the HMD broadcasts to the laptop wirelessly. We could observe real-time actions from participants in the virtual environment and video-recorded them in a laptop for later analysis.

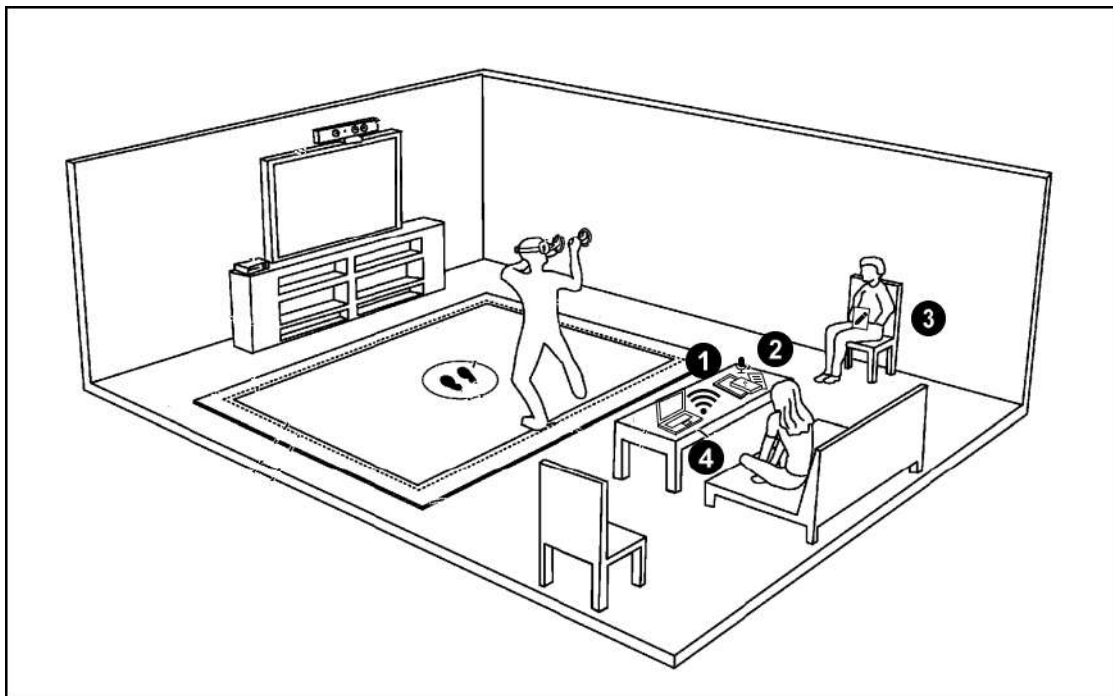


FIGURE 3.1: Proposed Method. Image modified from (Derek Strickland, 2019)

We used a private network to properly connect the VR device and the laptop to broadcast the content of the virtual experience. The hardware devices and software applications we used for the lab study were:

#### Hardware devices:

- Mobile VR Oculus Quest and controllers.
- One tablet.
- Two laptops.
- One audio recorder device.
- Headphones



**Software applications:**

- Third-party program Oculus Link used to broadcast the content from Oculus Quest to the laptop.
- Camtasia as a screen recorder to video-record the laptop screen.
- Qualtrics for data analysis and storage.

It was necessary to have a large environment in order to prevent the participant from colliding with objects in the physical world. We conducted the lab study in a large usability laboratory at The University of Melbourne. We set the Guardian Boundary System from Oculus Quest. This system allowed us to set an area (e.g. circular or square) where the participant could have their virtual experience (Figure 3.1). It displayed wall and floor markers when users were close to being outside the predefined area (Figure 3.2). If a participant was a bit close to leave the area, the system showed blue markers. If he/she was too close, it showed red markers instead, and if the participant was completely out of the predefined area, the headset showed the real world with the help of the external cameras of the device. With this feature, participants were free to move and act spontaneously without harming incidents, which benefited the study. Lastly, we had an extra chair, which we could use if the participant felt bad and could not continue the virtual experience. Fortunately, this problem did not happen.

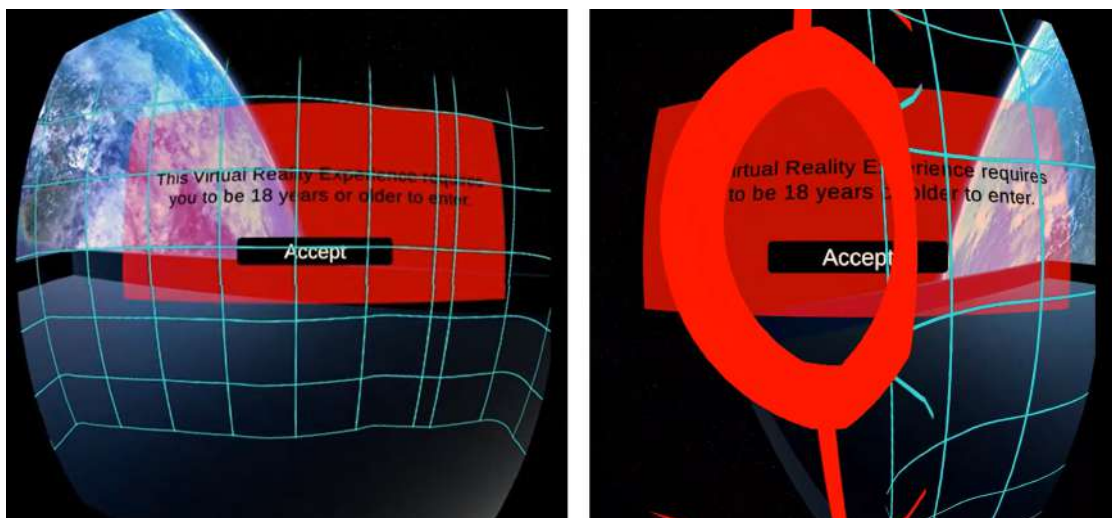


FIGURE 3.2: Example of the Guardian Boundary System outside the predefined area

## Chapter 4

# VR Prototype Development

### 4.1 Development Tools

To create this virtual experience and test the method I needed development tools and a mobile VR headset.

- Unity: popular and highly recommend in VR development ([Jerald, 2015](#)). Unity is a cross-platform engine I used to develop the 3D scenarios and 3D models. For this research project, I used the version 2019.2.12f1. Furthermore, there are free assets on Unity Store I took into account to improve the VR prototype; and software documentation and online support that guided me in the development process
- Visual Studio 2019: an integrated development environment (IDE) that works pretty well with Unity to develop 2D or 3D games. With the help of this IDE, I created C# scripts and linked them with the Unity models. In this way, I could create user interactions and effects for the 3D environments (e.g. underwater effect, flood-level, avatars, etc.).
- Oculus Quest: one of latest virtual reality headsets created by Oculus VR ([Figure 4.1](#)). I chose this device because it improved some drawbacks and problems of previous versions such as Oculus Go and Oculus Rift. Furthermore, compared to other devices from other companies it is considered by several developers one of the best for its new features. For instance, 6DoF movement and position tracking. Also, is wireless, thus, it does not need to be connected to a computer which is important for field studies.



FIGURE 4.1: Oculus Quest

## 4.2 VR Experience: Melbourne 2100

I collected feedback and I performed informal tests to improve the application with the help of HCI experts at The University of Melbourne. They provided me with usability recommendations, improvements and I could detect errors beforehand. In this way, I obtained a robust stable version for the lab study.

The app contains a main menu scene (Figure 4.2 left) where users could familiarize with the virtual environment. They can look at some information about the application and a “Start” button which after pressing it, places the user into the main scene of the application. The core idea of this scene was to embody the user in the city of Melbourne with an interactive task to provide engagement in the application. Participants needed to use a slider to adjust the flood-level of the Yarra river which represented the probable flood-level in Melbourne from the year 2019 to 2100 (Figure 4.3). The VR prototype included a voice-over that talks about the future of Melbourne with a melancholic music in the background (St. George, Crawford, Reubold, & Giorgi, 2017), whilst the water level of the Yarra river increases over time and is reflected in haptic feedback via the controllers. I also added water sound effects when the user gets into the river or when he leaves it. Lastly, users have three ways to move in the virtual environment:

	Description
<b>Joysticks</b>	Users could translate and rotate using joysticks on the controllers.
<b>Teleportation</b>	Users were able to teleport with the left controller by pressing the left trigger and pointing to the place to which they wanted to move (Figure 4.2 right).
<b>Tracked movement</b>	Using positional tracking and 6DoF, the mobile VR device could track and translate a user’s real-world movements to the virtual world.

TABLE 4.1: Ways to move in Melbourne 2100

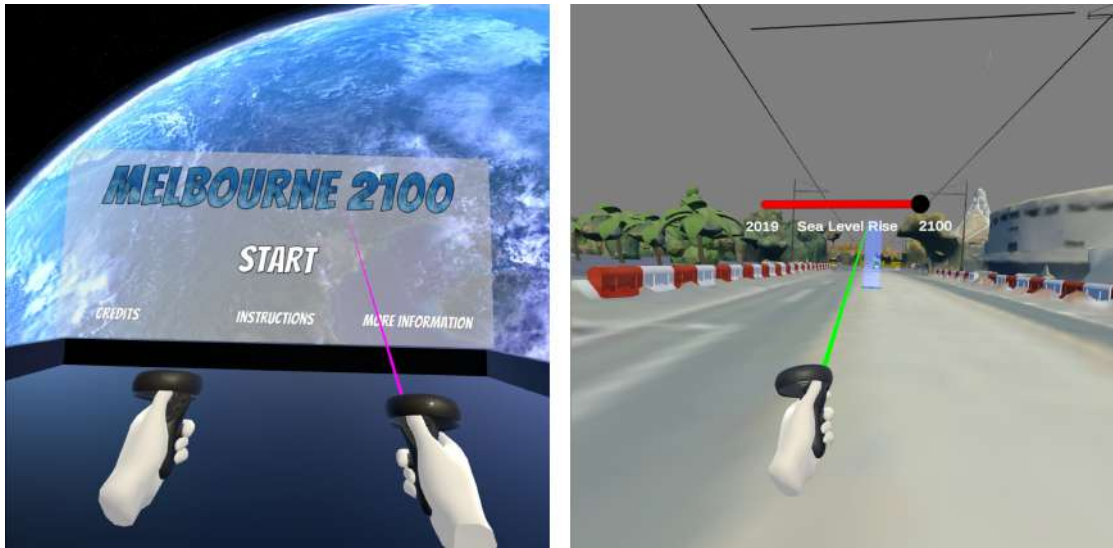


FIGURE 4.2: Main Menu Scene (left) and Teleportation (right)

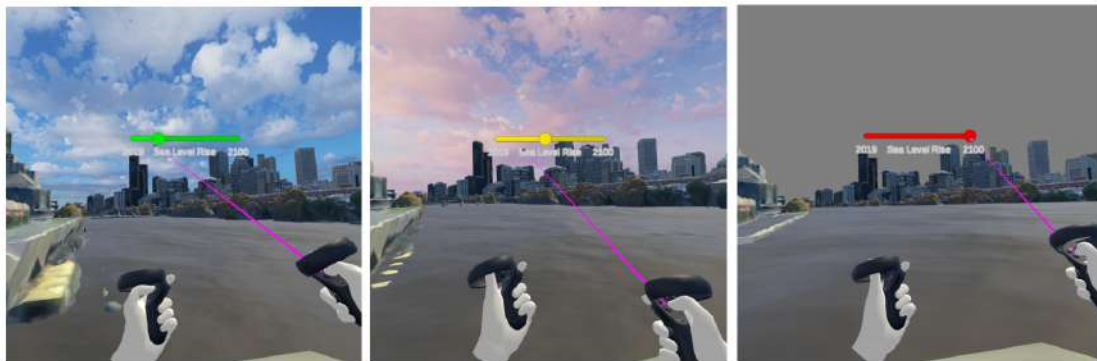


FIGURE 4.3: Sea Level Rise and slider in Melbourne 2100

The 3D model was provided by the City of Melbourne’s Open Data Platform ([City of Melbourne, 2018](#)). This 3D model represents Melbourne in its entirety, however, for this project, I focused on Flinders Street Station, Art Centre, Federation Square, Princes Bridge-Birrarung Marr, Queens Bridge (Figure 4.4) and Southbank areas of Melbourne since they are highly iconic and recognizable places for people who live and work in Melbourne.

The VR prototype was intended to provoke feelings of concern and anguish in the participants to enrich the virtual experience for its evaluation. By creating an application that replicated the city where participants live or work, and also giving them the ability to change the sea-level helped to accomplish this purpose.

I decided to place the participant to a specific initial position in the 3D Melbourne City model. This specific place was the edge of the bridge next to the Arts Centre which provided a well-known view in Melbourne towards Southbank and the CBD (Figure

4.5). This was useful since most of the participants recognized Melbourne as soon as they began the virtual experience in that scene.



FIGURE 4.4: From left to right, Flinders Street Station, Art Centre, and Princes Bridge-Birrarung Marr

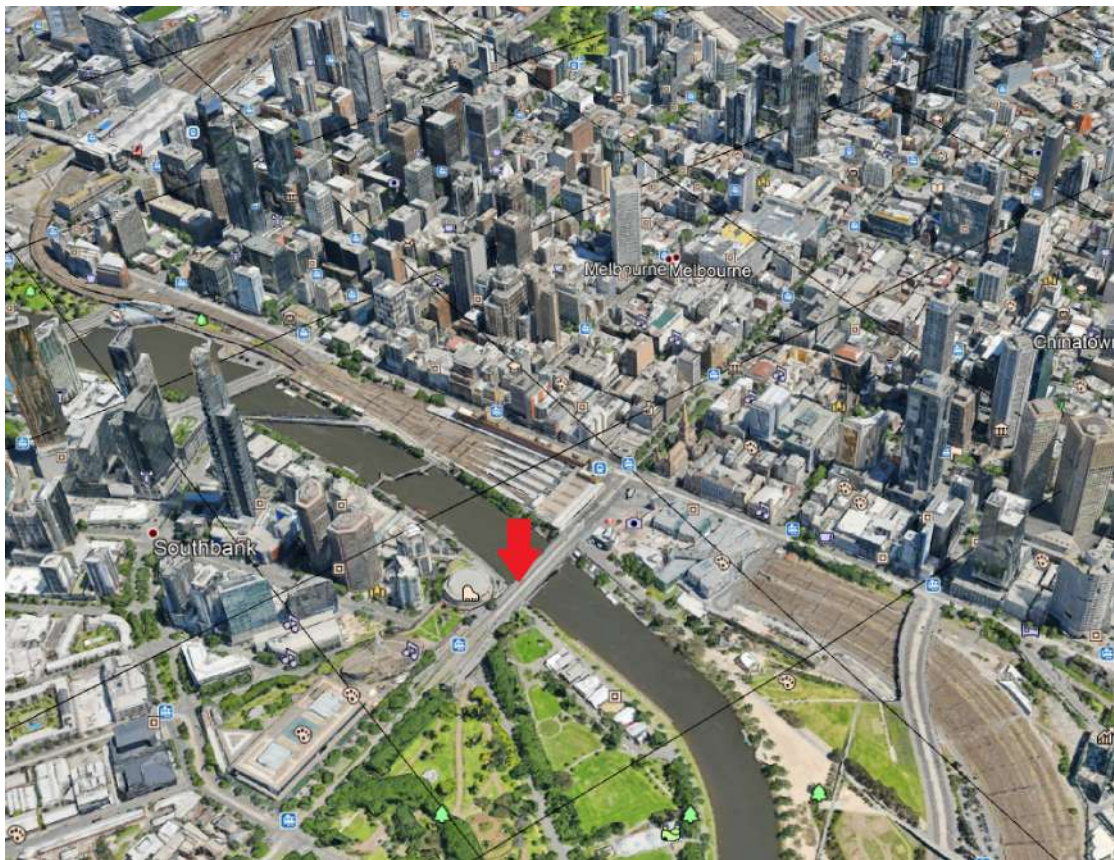


FIGURE 4.5: 3D Melbourne Map showing the initial position of the user (Red Arrow)

## Chapter 5

# Using the proposed method

### 5.1 Participants

To choose a sample size, I conducted a feasibility analysis (Caine, 2016) based on time and resources available, and also considered typical sample sizes used in VR studies. The time that each participant would need to complete the procedure was estimated to be 45 to 60 minutes. Resource constraints limited me to study one participant at a time. Usability experts recommend 6 to 12 participants (Preece, Sharp, & Rogers, 2015). In the end, I was able to test the VR prototype with a total of 11 participants across a few days of testing (Figure 5.1 and 5.2). Participants were selected by convenience sampling. The inclusion criteria for this study were adults (18+), fluent in English, who could give written consent. Participants were recruited via emails, social media, snowball sampling, face-to-face, and advertisements via local libraries and buildings at The University of Melbourne. Participants were reimbursed with a 20AUD gift card.



FIGURE 5.1: User engaged in UX study



FIGURE 5.2: User testing tracking movement

## 5.2 Data Collection Procedure

The entire procedure lasted around 45 minutes for each participant (Figure 5.3). First, participants completed a Plain Language Statement, a Consent procedure, and answered some questions from the first part of a semi-structured interview. I then explained the use of the HMD and controllers. After that, the participant tested the VR application while I performed interaction logging, which recorded their activity via third-party software on a laptop. I observed the user's physical movements, along with their view of the virtual environment, and took notes on how the user was responding to the app. As soon the participants finished the experience, they answered the second part of a semi-structured interview about the experience and completed questionnaires about presence, immersion and usability.

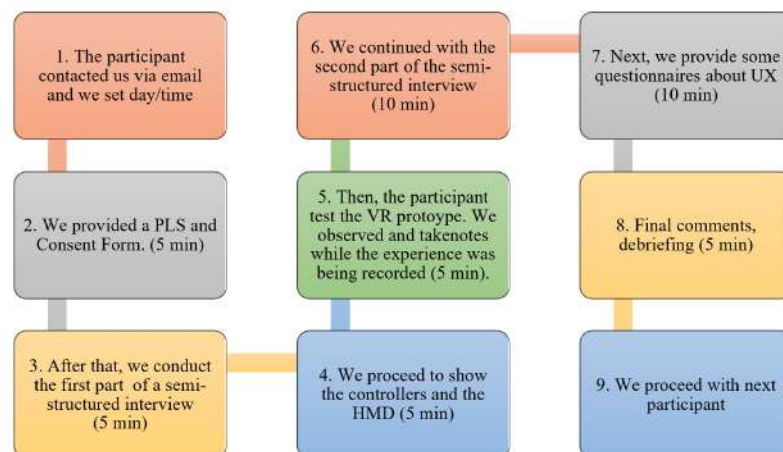


FIGURE 5.3: Procedure of the Lab Study (Approximately 45 minutes)

### 5.3 Interview

Each participant underwent an audio-recorded semi-structured interview with open and closed questions (Preece et al., 2015), in two parts. The first part was conducted before the user tried the prototype: this contained demographic questions such as age, whether they lived or worked in Melbourne and gender, and questions about previous experience with VR and Simulator sickness susceptibility. The second part was conducted immediately after the user finished the VR experience. These questions related to Simulator Sickness experienced, how the participant felt about the experience, what was good and bad, and whether they had recommendations for improving the prototype.

### 5.4 Observation

We performed two types of observation while the participants were using the HMD.

#### 5.4.1 Direct observation of behaviour

We observed the participants' behaviour directly as they moved about the physical room with the device. I took notes of the participant's vocal and behavioural expressions. I compared this with each participant's interaction logging to examine what the participants were doing at the time of the expressions and movements. This complemented interaction logging and provided significant insights into UX.

Participants did not feel the presence of the researchers (observers) in the room. I provided headsets to the participants and evidently they could not see us because they were using the HMD. When the participants asked questions or expressed something while using the VR, we did not answer them because we did not want to interrupt the experience.

#### 5.4.2 Interaction Logging

I conducted interaction logging to monitor what participants did in the virtual environment. By broadcasting the VR video into my laptop in real-time, I was able to observe and record the whole experience of each participant. I could analyze which buttons participants pressed (Figure 5.4), and analyze user behaviour and usability issues accurately.





FIGURE 5.4: VR Hand Controllers

## 5.5 Questionnaires

I used two scales to evaluate the usability, presence and immersion of my VR prototype. SUS (Brooke, 1996) and VRUSE (Kalawsky, Bee, & Nee, 1999). They both were provided to the participants after the post-trial interview.

### 5.5.1 SUS

SUS is a Likert Scale questionnaire with ten questions that have been used in several projects to measure usability in VR (e.g. Deb, Carruth, Sween, Strawderman, and Garrison 2017; Dorta, Kinayoglu, and Hoffmann 2016; Ni, Fehlings, and Biddiss 2014; Rand, Kizony, and Weiss 2008). Authors found it simple and effective since the participant just need to select on a point scale from 0 (Strongly disagree) to 5 (Strongly agree) after testing the experience. Participants, who were not sure, marked the centre point of the scale (3).

To score SUS, I needed to perform a simple math operation with reverse scoring (Suárez-Alvarez et al., 2018). The scores of the odd questions (1,3,5,7,9) are subtracted by one (-1) whilst even questions by five (-5). For example, if question 1 is rated with 3, the result would be 2. If question 2 is rated with 4, the result would be 1. These results are added and multiplied by 2.5 having a number between 0 to 100, which is the final result.

### 5.5.2 VRUSE

VRUSE is a Likert Scale questionnaire that was used in several projects as well (e.g. Karaseitanidis et al. 2006; Patel, Campion, and Fernando 2002; Westerdahl et al. 2006). It contains 100 questions that are split into 10 factors (i.e. groups of questions): Functionality, User input, System output, User guidance and help, Consistency, Flexibility,

Simulation fidelity, Error connection/handling and robustness, Sense of immersion/presence and Usability.

For this research, I only considered two: usability and sense of immersion/presence because completing the entire questionnaire for each section is long and expensive (Kalawsky et al., 1999). To score VRUSE, I performed the same procedure as I mentioned with SUS. Overall, the use of these questionnaires for these three UX components helped me to compare and complement findings from qualitative data.

## 5.6 Data Analysis Procedure

First, I computed the results of the questionnaires with Excel, and I highlighted the questions that were rated low. Then, after I received the transcribed audio-recordings from the semi-structured interview, I selected relevant comments from users and categorised each of them into a UX component from the UXIVE model.

For the observation techniques, I had 6 pages of notes taken by direct observation and about 85 minutes of video-recordings from the interaction logging. I selected observation notes related to UX and categorise them as I did with the interview data. After that, I watched all the video-recordings, some of them more than one time; and wrote down UX problems for the components I found.

In Excel, I gathered problems that occurred only in one technique but I also matched UX problems that were repetitive in two or more techniques. For example, questions from the presence questionnaire that were rated below because of the low quality of the 3D graphics and comments about the same issue in the semi-structured interview. Finally, I classified each UX problem for severity: cosmetic, serious and critical.

Aside from problems, I collected information about features that worked well in the virtual environment. Moreover, recommendations and feedback by the users to improve the VR prototype for future studies.

## 5.7 Ethics

We obtained ethics approval by The University of Melbourne Human Ethics Subcommittee (no. 1954364.1). We did not collect or store any sensitive personal data from participants since it was not necessary for my research purposes. To make sure that participants understand the study, we provide them a consent form. This document

contains a summary of the study and the right to quit the data collection process whenever the participant wants.

Furthermore, I found three possible negative effects of using the VR application on the participants. First, there has always been a risk that participants can experience simulator sickness. Second, whilst moving in the virtual world, participants can bump into objects in the physical world. Finally, presenting flooding in Melbourne to people who live or work in this same city can be emotive and cause unexpected reactions. Fortunately, there were not serious problems regarding these aspects, only mild dizziness in three participants.

## Chapter 6

# Result of the UX Study

### 6.1 Demographics

In total, 11 participants participated in this empirical study, 6 were male and 5 were female, with mean age 24. The majority were recruited from the student and staff population of The University of Melbourne, and 91% lived or worked in Melbourne. 73% had used VR before, for gaming or research participation. However, the majority only used it once a year or less because of lack of opportunity or access to these devices.

It is important to highlight that all participants did not remember the type of VR they used previously. Indeed, they are non-gamer participants. Because of the global COVID19 pandemic and the associated restrictions imposed on face-to-face research, I might start to conduct online studies which would improve the sampling diversity with participants that already own an Oculus Quest (e.g. more experienced VR users of all genders, ages).

### 6.2 Presence

Questionnaire	Results
VRUSE (Usability)	69.34/100
VRUSE (Presence/Immersion)	59.32/100
SUS (Usability)	67.91/100

TABLE 6.1: Questionnaire Results

VRUSE indicated that presence/immersion was acceptable as a first VR prototype (Table 6.1). However, it was impacted by the low resolution of the 3D model. This was confirmed through interview data such as:

- “I think the resolution was bad” (Participant 1)
- “I think things like image quality would improve”. (Participant 5)
- “The only thing I would criticize is the detail”. (Participant 10)

These comments aligned with low-scoring questions in the presence/immersion questionnaire: “The quality of the image reduced my feeling of presence” and “The display resolution reduced my sense of immersion”. Some participants recommended adding avatars, vehicles and city noises to improve the model, and pointed out inconsistencies:

- “It’s a bumpy floor” and “But, I don’t understand like there ... This pieces above the ground”. (Participant 1)
- “I understood that you were trying to get people to feel like they were in it, but because the road wasn’t actually a road, and then the floating islands, that was actually what really got me. I was like, “Why are there floating islands here?”. (Participant 6)

I found that using a model of a city in which the participants live provoked mixed feelings and emotions and therefore increase presence as was demonstrated in other VR studies (e.g. [Rebelo et al. 2012](#); [Tcha-Tokey et al. 2018](#); [Tullis and Albert 2008](#)). Furthermore, I detected presence through observation of head and hand movements when the sky changed colour, and glances towards iconic parts of the city. One participant pointed and said: “Whoa, that’s Southbank” (Participant 6). Interview data complemented these findings with the following comments:

- “Yeah, it’s fine. I can still recognize Melbourne” and “It’s very interesting to see, the place you know, seeing it being flooded”. (Participant 1)
- “So it made me feel that I am that person who’s standing there and actually having an experience of everything around” and “I somehow felt if that is the reality for a person who is going to live in 2100”. (Participant 2)
- “Is that our university? Or am I at the Yarra River. There’s Flinders street”. (Participant 4)

- “I recognized the SBS building because you actually got some of the details on there” and “Oh, I’m actually staring at the planet”. (Participant 6)
- “I feel I was in maybe 2000 or maybe... next century”. (Participant 7)
- “I really feel that I’m in that place and in that time. (Participant 8)
- “It was very cool to see Melbourne” and “I was between like Fed Square”. (Participant 9)
- “Swanston street straight and after passing the famous train station and on that bridge to cross the Yarra River. (Participant 11)

### 6.3 Immersion

I found that immersion helped the sense of presence, supporting the correlation between presence and immersion suggested by [Shin et al. 2013](#). There are user statements that reflect the high level of immersion that the VR prototype had in the study. For instance:

- “I think it’s good. It’s very immersing” (Participant 1)
- “It’s basically how you get immersed into that, the graphics around you and the reality of that VR was really amazing” and “It was like you literally immersed into that environment. So, it felt really interesting” (Participant 2).
- “What an immersive experience!”. (Participant 8)
- “What if I just decide to stay there? It’s immersive. (Participant 10)
- “It’s quite immersing. It feels me having this in a real environment and see how the surrounding environment just evolves over time” and “Sometimes I forget myself I was in the lab”. (Participant 11)

Additionally, I found that sound effects enhanced presence and immersion, echoing the results of [Azevedo, Campos, and Jorge 2014](#). For instance, a participant jumped out of the river (Figure 6.1), heard the water sound effect, and commented:

- “I think that helped with immersion a lot more than the visual stuff for me” and “And then when it rose, I could hear the water. That was so effective, and it was the ... yeah ... but that was because I accidentally ended up in the river.” (Participant 6).



FIGURE 6.1: User after jumping from Princes bridge into the Yarra river

## 6.4 Usability

The study demonstrated that the usability of the VR prototype was good but can be improved (Table 6.1). I found some interactions in the virtual environment were not working properly, such as the laser pointer. Through interaction logging and observation notes, I observed that three participants confused the button to move the slider (e.g. right trigger with button A), and could not move it correctly. Moreover, three participants tried to use the slider when it was locked since the water-level was rising. Despite these problems, these three participants were able to move it on the second or third attempt.

I observed that some of the participants wanted to walk using the tracked movement from the Oculus Quest, especially in the main menu scene, but chose to use the joystick instead: I believe they were afraid of colliding with objects in the real world (e.g. the wall). I did not expect the battery of the device and the controllers to drain so quickly. One of the participants got a low battery message from the device and one of the controllers stopped working.

The voice-over was effective, though some participants mentioned they could not concentrate on the voice and the 3D environment at the same time. The voice-over worked as a tutorial, explaining that participants could point at the slider with a laser to change the water-level with Button A. Almost all participants did this. The voice-over encouraged participants to explore the city with the use of joysticks (Rotation/Walking) and

teleportation. These two actions worked well in the lab study. However, I observed some strange movements with the left controller when two participants tried to teleport with the left trigger. They mentioned in the semi-structured interview that they wanted to teleport further away, but the teleport laser did not let them do it.

- "I thought I can jump actually really far, but so the only very really limited range that it can go". (Participant 4)
- "That's what I did. It's like, Why am I not teleporting?". (Participant 8)
- "The little teleporting thing did work very well" . (Participant 9)
- "I was trying to jump to the other bridge, but I wouldn't go as far as I always wanted". (Participant 10)

Few participants lost control over the application for a brief moment. For instance, one participant felt worried when the Yarra river started to rise and walked away from the edge of the bridge. Another similar problem happened when two participants fell into the river and could not get out for a short period of time. Fortunately, they could find they way out without problems and continued with the experience. I anticipated this problem and added stairs on both sides of the bridge to help users (Figure 6.2). Participants mentioned this problem in the semi-structured interview:

- "I think I've fallen into the water. (Participant 5, during experience)
- "I thought it wasn't going to happen, but it did. I ended up in the water and for a few seconds I thought there was no way out. I'm stuck. This was bugged, this is a software and you're stuck down. It turns out there was a way out ... But in one other corner there is some light, so I can see the stairs going up.". (Participant 10)

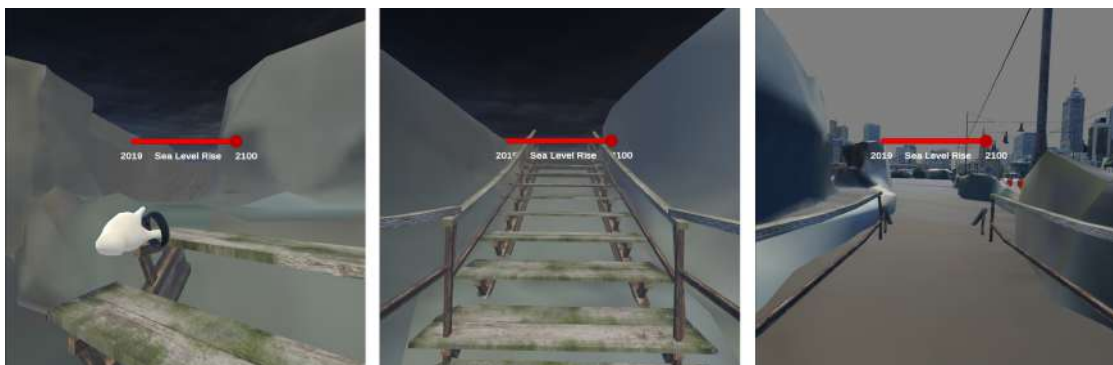


FIGURE 6.2: Stairs for user exit

Finally, four participants wished they could walk faster to explore more the city:



- "No. I wish if I could like move to more faster and go on more streets and see how it's going to be". (Participant 3)
- "I found I can just walk very slowly". (Participant 7)
- "Yeah, just something that makes it quicker than walking". (Participant 9)
- "I think there should be that extra option in terms of the exploration in the speed of the walking maybe, like a new function that's involved the control of the walking speed or you can run so I can move faster". (Participant 11)

## 6.5 Emotion

The virtual experience generated feelings among the participants. For almost all participants, it was sad, scary or sensitive, especially when the water level rose. One of the participants expressed dismay: "What do I do?" (Participant 4). I assumed that these feelings came out since the idea of recreating the city where most of the participants currently live or work being flooded is quite shocking. These observations were supported by statements from participants:

- "When the water started to rise, I feel a bit nervous, because I really feel that I'm in that place and in that time" and "I was anxious to go into the water because when it started I was like, Oh, there's this huge jump before I go into the water, and it feels like it's real" (Participant 8)
- "It was intrigued, and obviously disappointing when you get to Flinders St. station". (Participant 9)
- "It is kind of scary". (Participant 10)
- "It's a sad thing". (Participant 11)

After the water animation finished and participants started to explore, I observed in almost all the them faces of joy, entertainment, fun or concentration. I state that Emotion was a vital UX component along presence and immersion in the VR prototype since the experience of all participants was positively influenced by the feelings they had in the 3D Melbourne model. Furthermore, they could see the flooding of the city where they live, which was the key to provide an excellent experience and helped me to measure the UX in a more effective way.

## 6.6 Engagement

In general, participants found the virtual experience appealing, especially those who tried an HMD for the first time. The majority of the participants were attracted to this novel idea of replicating Melbourne City with the feature of changing the flood-level of the Yarra River. I received positive comments and could see how participants connected with the prototype during and after the experience enjoying it.

- “That was amazing. It was a fun experience”. (Participant 2)
- “So, it was fun to at least have a go for a few minutes”. (Participant 5)
- “As in that whole thing was very, very cool. And yeah, and especially because it’s very comfortable” and “I thought it was great”. (Participant 6)
- “It is an awesome experience”, “I consider it very awesome” and “It’s awesome. Yeah, it’s pretty cool”. (Participant 8)

Moreover, I received feedback in order to make the VR prototype more attractive. Some of the comments were about adding more interaction or messages that conveyed some kind of information about what was happening in the application.

- “More interaction during playing or something like, maybe go Flinders Station and click this and then there’s some explanation over there so they’re going to spend one minute reading through what is going on or explaining. Or maybe you put a video in there. So click on this button and then the video showing. I think that would be better”. (Participant 4)
- “Make it more interactive”. (Participant 8)
- “I was looking for hidden treasures in the sea by the way”. (Participant 10)

## 6.7 Simulator Sickness

Only one participant indicated susceptibility to motion sickness, though they experienced no symptoms in the test. However, I found that another participant tried to translate using the tracking system and joysticks at the same time which caused some dizziness. Moreover, three participants who did not state susceptibility reported feeling a little bit dizzy when they rotated their head, which is a factor in motion sickness (Turner & Turner, 2006):

- "I find a little bit dizzy after a while using that, so maybe using VR is not a good way to explore". (Participant 4)
- "When I started to walk or to move, then I started to feel dizzy. But all throughout, it's fine" and "But I just walk on the street, and then go, moving forward to following the street, but I feel a bit dizzy. So, I stopped. But I tried to look around me". (Participant 8)
- "When I'm finding just to rotate my view, like the angle of my view". (Participant 11)

These three cases were mild firstly because we did not observe any signs in disorientation in participants (e.g. stumbling or falling motions) and secondly because participants did not report it during the sessions or indicate that they needed to stop the experience at any time during the session. They reported mild symptoms after the experience and that it did not continue once the experience had finished. Overall, simulator sickness was not a problem in the study. Several participants denied having any symptoms when asked a Yes/No question about it and some of them stated they did not get sick:

- "I like the fact that I didn't get sick". (Participant 6)
- "I don't feel sick". (Participant 7)

## 6.8 Flow

Even though I did not expect many comments related to flow since it is more suitable for games and sports environments (Csikszentmihalyi, 2014); I could gather some insightful information about it. I could see through the video recordings that participants had the control in the virtual environment in terms of user movement. I agreed that the voice-over was helpful for the participants to enter into a state of flow. It guided them with the use of controllers and led them to explore the virtual environment. Five participants started to walk as soon as the experience started ignoring for a few seconds the voice-over; and the remaining participants stayed still listening to the entire voice-over. This latter was a problem since they expressed they would have liked to explore more, but the experience was over. Due to this problem, some participants stayed a few more minutes even when the virtual experience was over and the final credits and exit button appeared (Figure 6.3). This was a good sign since positive experiences of flow are associated with intentions to continue for longer VR sessions. (Hassan et al., 2020). Comments about the need of exploration are described below:

- "Oh, and so also the self explore is quite short, I think". (Participant 4)
- "So for me, if I were to suggest something, I feel like I would've explored more ...". (Participant 6)
- "I think one of the things that I felt was time. I thought it was going to go on a while and I was like, I was ready to walk into the city and then it turns out that it's time over". (Participant 10)
- "So the experiment just ends so I was not sure what will be the model inside the city, like how it will be like". (Participant 11)

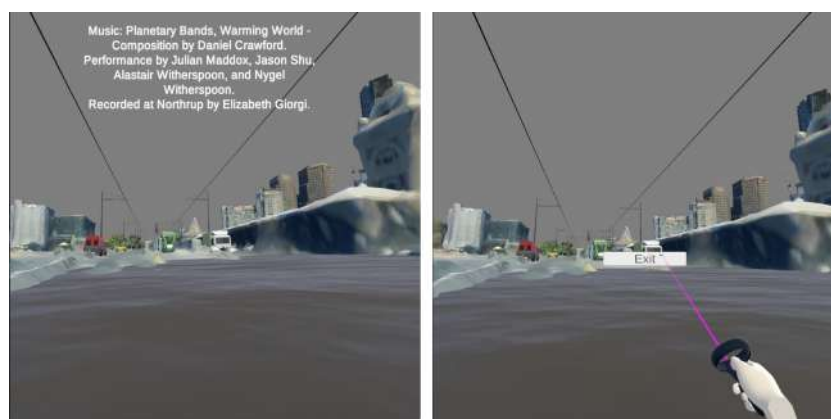


FIGURE 6.3: Final credits (left) and exit button (right)

One last interesting comment from a participant was about the existence of sense of agency and sense of control. I considered relevant because if users feel a sense of control, the more they tend to experience flow (Novak, Hoffman, & Yung, 2000). Furthermore, it is positively associated with any flow experience (Hassan et al., 2020), and could benefit the UX in the VR prototype, especially the engagement. This was demonstrated in previous studies by Csikszentmihalyi 2014; Egbert 2003.

- "Well, I think it gives people within the program a sense of agency, like they are in control of what happens versus it being something that they're viewing passively. And if you give people a kind of, even an artificial sense of control over their own environment, that might make them more proactive". (Participant 5)

## 6.9 Skill

I could see through the observation techniques that participants mastered the use of the controllers in the virtual environment. Almost all participants felt comfortable with the

slider after their first use. They started to play many times with it and checked the sea-level in different parts of the map. I could confirm this with the comments from the semi-structured interview.

- "So I liked the fact that there was a slider that you could actually play with the structure of the program itself rather than just being shown a movie. I think that it was making good use of the technology". (Participant 5)
- "I do think it was easy, I just don't think I'm very coordinated with the joysticks and stuff". (Participant 6)

Moreover, three participants teleported into places that I did not consider to be reachable such as the top of buildings or trees. This caused them to find some bugs on the map. Fortunately, none of these cases harmed the virtual experience in general because they happened almost at the end of the experience.

## 6.10 Technology Adoption

The use of this VR prototype motivated some participants to take actions in the real world and encourage to explore or investigate more about this emergent technology. Participants who tried the HMD for their first time were really impressed and even some of them did not know what could be achieved with this technology. Due to the positive state of flow presented by the participants and how some of them prolonged their experience, I believe it positively impacted their consumer adoption in VR. This is supported by [Hassan et al. 2020](#). Moreover, it increased their possibility of using of VR again in the future ([tom Dieck, Tom Dieck, Moorhouse, & Jung, 2018](#)). These are some of the comments I was able to collect along with those in the next section about Judgement:

- "I think there's actually a very good platform to foresee a future". (Participant 3)
- "There should be more things that I should be doing on VR" and "It kind of makes me think that I should be doing more of that in real life too". (Participant 10)

## 6.11 Judgement

Overall, I believe that the VR prototype was well accepted. Most of the participants expressed their appreciation when testing it. Some of these comments described how

innovative and powerful is this technology to show a future in a 3D environment of Melbourne.

- “The experience was really enriching”. (Participant 2)
- “It had the power to take me to the future”. (Participant 3)
- “I think it was good and it was novel, obviously I haven’t done anything like that before”. (Participant 5)
- ”Yeah. But the overall experience I think that’s very good.” (Participant 11)

Despite all these positive comments, I interviewed one participant who did not agree with the background music by describing it as manipulative. This happened since the background music was melancholic.

- ”I think that, I didn’t like the music that much” and ”I felt like the music was a bit sentimental and I felt like sometimes when people are trying to make a point and they’re trying to use music as part of making that point, it can end up being a bit, feeling manipulative because it wants to try and evoke a particular emotional state and the person who’s sort of listening to it. And I’m much more of a just the fact’s sort of person. I don’t like music in my information, kind of thing”. (Participant 5)

Lastly, it should be noted that one participant contacted me after the experience via email with some feedback and changes I could make to improve the prototype. This is a part of a message I received which demonstrated that the VR experience was not over for the participant when I removed the mobile VR device, but much later.

- “Your project gives realness and visualization to something we’ve never seen before and gives projection to the impact (which is quite scary!) and this will encourage people to take action and be more engaged” (Participant 8).

## 6.12 Limitations

The sample was homogenous: the majority were recruited from the student and staff population of The University of Melbourne since we published and conducted the research in one of its laboratories. This makes it difficult to generalize to other types of groups (Boletsis & Cedergren, 2019). In addition to that, the number of participants I

had in the study is similar to other studies such as: [Kauhanen et al. 2017](#), 13; [Trindade, Rebelo, and Noriega 2018](#), 13 or [Greenfeld et al. 2019](#), 15, but less than other studies (e.g. [Sutcliffe and Kaur 2000](#), 30; [Wang 2018](#), 80; [Madathil, Frady, Hartley, Bertrand, and Alfred 2017](#), 171 or [Leow, Ch'ng, Zhang, Cai, and See 2017](#), 200). I only had 11 participants in the study for these reasons. First, the COVID19 pandemic led to university shut down and restrictions placed on our city. Secondly, our group of researchers was small (and therefore capacity to collect and analyse data was limited) and the resources were limited to one mobile HMD unit and two laptops. Despite this limitation, the amount of information for each UX component I collected with the small sample size is quite surprising. It would not be unusual to find even more detailed information with a larger sample of participants. Also, the majority of participants tried a mobile VR device for the first time. Hence, they tended get the most out of it and explored this technology more.

Related to the above limitation, it would also have been very interesting to conduct this study in an outdoor location. Due to the restrictions imposed because of COVID19, this was not possible. However, there are favourable antecedents of conducting lab and field studies with mobile computer systems from many years ago. [Kjeldskov et al. 2004](#); [Kjeldskov and Stage 2004](#) found no significant differences in terms of evaluation when conducting and comparing their prototype results in a lab and in the field. This means that the results obtained in my lab study might not be considerably different from what I would have obtained in the field.

It was demonstrated that the quality of the 3D Model of Melbourne reduced the level of presence for the participants. Due to resource limitation, I could not build a model from scratch. To face this problem for future studies, I have implemented some improvements collected from user feedback. I believe they would improve the model by providing realism in the virtual environment. Additionally, I argue about the final presence/immersion result obtained with VRUSE (Table 6.1). I think if I had only considered these scales in isolation, I would have missed several insights about presence and immersion. Also, I consider it does not reflect the positive findings obtained through the semi-structured interview and observation methods (notes and interaction logging). This supports the idea of [Slater 2004](#), that using questionnaires alone is not enough to assess presence.

## Chapter 7

# Results: The Utility of the method assessing UX

With the use of objective and subjective methods in this study, I could have a better perspective about the UX in the VR prototype. I collected qualitative and quantitative data with the four techniques presented. They helped me to understand deeply UX problems and difficulties that the participants had in the study with the VR prototype. Table 7.1 shows how each technique contributed to the evaluation of each component of UX.

Participants reported the strengths and weaknesses of the VR experience through semi-structured interviews. Hence, I could obtain outstanding comments to all UX components. Qualitative data from the interview complemented data from questionnaires and observation techniques. I want to emphasize the emotion participants felt during the experience which improves the overall UX of the prototype and its measurement.

Observation provided me with insightful behavioural information. Participants were free to move and act naturally. Therefore, I could collect verbal expressions, facial expressions, and body movements which helped me to measure the UX in a more detailed way. I could identify issues and possible improvements related to the UX components in the prototype. However, I encountered one problem as well. It would have been interesting to perform observation in a natural environment with contextual interruptions.

Questionnaires provided a general overview of presence, immersion and usability. I found some correlation between the score of their questions and the qualitative data of the semi-structured interview and observation techniques. I was able to identify usability issues that led to enhancement of the VR prototype.



UX Component	Technique
Presence	Both observation techniques provided useful information related to this UX component and they were consolidated with the qualitative data from the semi-structured interview and the questionnaire.
Immersion	In the same way as presence, I could gather more information about this component with observation techniques and from the semi-structured interview based on comments from participants and the questionnaire.
Usability	As for presence and immersion, the questionnaire gave me a general overview, but the interaction logging and the observation notes were more helpful to find usability issues (teleportation, slider, hand controllers and preferences for mobility). Additionally, qualitative data from semi-structured interview complemented these findings.
Emotion	I measured this component with the qualitative data from the semi-structure interview. Also, I could collect some verbal and facial expressions of preoccupation (worry, fear and anxiety) with the note-taking approach.
Engagement	Data from the semi-structured interview. Moreover, I took observation notes about verbal expressions and states of happiness, concentration, fun and joy.
Simulator Sickness	I only relied on the semi-structured interview for this component. However, If there had been a serious incident, I would have observed it directly and confirmed how it happened with the video-recordings as I did with the mild cases of dizziness.
Flow	Interaction logging and comments from the semi-structured interview provided me with information about this component.
Skill	In the same way as Flow, I gathered information with the video-recordings and watched how users interacted. Also, I obtained some comments about this component from the semi-structured interview.
Technology Adoption	Mostly qualitative data, statements of the participants in the semi-structured interview.
Judgement	Qualitative data from the semi-structured interview. Participants expressed their opinion through comments.

TABLE 7.1: UX Components Evaluation

The combination of these four techniques provided me with relevant information about the UX of the VR app. I identified **19** UX problems in the prototype and categorised them by severity (see Table 7.2). This high number found is evidence for the effectiveness of the proposed method, adopting the argument used in the development of usability tests for mobile computer systems (Kjeldskov & Stage, 2004). Also, I could gather information in detail about all the UX components from the UXIVE Model with only these 4 techniques from my method. This is meaningful since generally VR studies only gather information for one or two UX components (Tcha-Tokey et al., 2018) using at most two techniques. Lastly, I also believe that this method can be used in any study of mobile VR in the field.

UX Components	Cosmetic	Serious	Critical	Sum
Presence and Immersion	1	3	2	6
Usability	1	2	3	6
Emotion and Engagement	0	2	0	2
Simulator Sickness	0	1	0	1
Flow and Skill	1	2	0	3
Technology Adoption and Judgement	0	1	0	1

TABLE 7.2: Distribution of total numbers of identified UX problems

## 7.1 Fixes and Improvements after UX evaluation

Participants stated issues and feedback I collected to enhance the VR prototype. I planned to implement all of them. However, due to time constraints, I have categorized each of them according to their priority (low, medium, high); and I selected those with medium and high importance. After I implemented these features and fix some bugs/errors, I ended up with a more stable and appealing version of the VR prototype (see Figure 7.1). Table 7.3 lists some features that were not working properly, and the corresponding fix I applied.

Issue	Fix
User walks slow	Increase movement speed to 1.5x
Difficulty teleporting	Increase range and hyperbolic to 2.0x
Slider visibility	Hide slider until animation finishes
3D Map boundary	Add some barriers to limit map access

TABLE 7.3: Melbourne 2100 Fixes

Furthermore, I implemented some improvements I considered they can provide a better look and feel to the VR prototype. According to the participants and my criteria, these new features should correct UX problems I found, and improve presence, immersion, emotion and engagement for futures studies.

- Add vehicles such as cars, trams in movement.
- Add trees and street signs to cover inconsistencies of the map.
- Add simulation of avatars (people) in the bridge.
- Add city noises from that specific place in Melbourne.



FIGURE 7.1: Initial Version (left) vs Current Version (right)

# Chapter 8

## Discussion

### 8.1 Issues related to data-gathering

Using objective and subjective methods gave me a better understanding of the UX in the VR prototype providing valid results (Tcha-Tokey et al., 2016). The novel idea of using interaction logging to measure presence and immersion was helpful to detect behaviour patterns according to head movements and hand controllers. It further provided me with usability problems with the VR prototype such as teleporting or adjusting the slider. Having a wireless connection to record the user was useful since I believe participants did not feel pressured or nervous. That would not have been the case if I had used the video capture that comes in the HMD because users would have realized they were being recorded during the experience.

The novel use of interaction logging and note-taking was helpful for collecting data on behaviour patterns and usability problems. The wireless connection allowed me to record the user's screen by a third-party software (interaction logging recording). Analyzing the interaction logging files was time-consuming as stated in Insko 2003; Von Der Pütten et al. 2012; Weibel et al. 2018. The recordings did not include audio, though this can be solved as new screencasting applications become available (e.g. SideQuest, AirReceiver). I encourage the use of interaction logging as long as the number of participants in the study is not very large relative to the number of researchers.

I used two sets of questions for usability in order to validate the results since there is no universally-accepted measure (Sutcliffe & Kaur, 2000). The two usability results are closely aligned. However, some participants reported difficulty understanding some items in the questionnaires:

- "What's a cumbersome to use?". (Participant 1)

- “When you say ”the system”, it’s not talking about the program it’s talking about the thing that you use?”. (Participant 6).

I assume that the use of different questionnaires for presence, immersion and usability from the literature would not change the final UX results since although the questions are different, they have the same purpose. However, that is something I will validate in the future. The use of notes helped me to gather relevant information that the video recordings could not record in sound. I chose this technique for two reasons. First, the missing sound in the video recordings; and secondly, because the VR experience contained a voice-over and almost all the participants did not utter a word. If that is not the case an applicable alternative would be a think-aloud approach, where participants verbalise their experience as they are going through the application (C. H. Lewis, 1982).

I decided to use questionnaires only of presence, immersion and usability, since they are the most relevant according to the literature. However, I believe that this can be chosen by the developers according to the context of the application. For example, in my case, I chose them because I replicated Melbourne in VR. I would not recommend using questionnaires for several each UX component because it would take more time to analyze the data and increase the time the user spends in the study.

Regarding the use of VRUSE, I believe if I had only considered these scales in isolation, I would have missed several insights about presence and immersion. The VRUSE result did not reflect the positive responses in the semi-structured interview and observation methods (notes and interaction logging). This supports the suggestion by Slater that questionnaires alone are not enough to assess presence (Slater, 2004)

Sometimes in interaction logging it was not possible to see participants pushing the buttons, but I could observe this trial and error by direct observation of the interaction logging instead. I did not observe any behavioural patterns in movement but in future I will be aware of the potential of this to occur because the Oculus Quest has room-scale capability. Because of the freedom of movement available to users, in future research I will consider using video recordings of the whole person in conjunction with VR output which should support a more reliable analysis.

## 8.2 Issues related to hardware

The Quest battery only lasted for 4 participants ( $4 * 45 \text{ min} = 3 \text{ hours}$ ) before it needed charging. Also, my laptop battery lasted only for 2 participants (1.5 hours) since it was broadcasting the video image of the Oculus Quest in real-time and a screen recorder

was capturing the video image for the interaction logging. Then, having a backup audio recorder is necessary if the principal audio recorder stops working unexpectedly. These considerations are important since it is very likely that researchers will not have access to sockets for charging in outdoor settings. I recommend using portable chargers or make extended pauses between participants.

Although the Oculus Quest is powerful, I had difficulties loading the map into it. I had to select chunks of the city and load them in background in the main menu scene (Figure 8.1). Even though I agreed it had adequate waiting timing, one participant felt it was long and recommended to implement some interactions or play some music. I agree it is a useful alternative, but I recommend to use that time to explain the hardware and software to the participants.

- "The loading time, this really takes time before it opens the application" and "Maybe while waiting, maybe there should be some explanation while having that loading time. So, you'll be entertained and you know what's going on, something like it" and "Or maybe some music. I can't remember. Is there any music while loading?". (Participant 8)

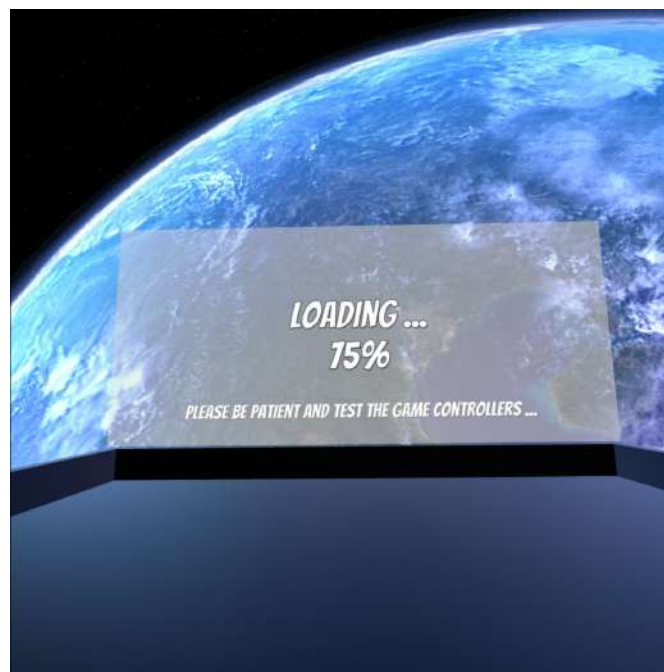


FIGURE 8.1: Loading panel in Melbourne 2100

When testing with novel equipment such as Oculus Quest, I recommend providing a detailed explanation of it to the participants. In the study, they were inexperienced with VR and needed to understand two aspects: how the mobile VR device works and also how to perform actions in the VR environment too (Figure 8.2). I spent time explaining

the device and controllers and users were able to perform better and more freely. This was also mentioned in the interviews by them. A tutorial would be especially useful for online deployments where the researcher is working remotely with the participants.

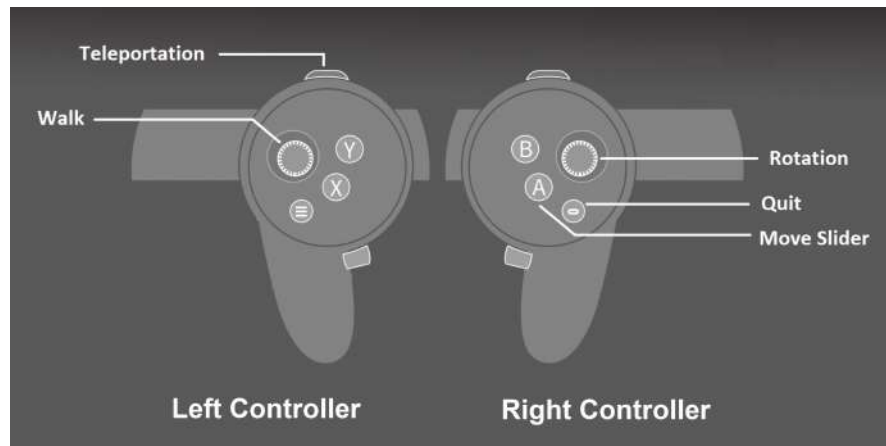


FIGURE 8.2: Hand Controllers and Actions

Finally, I could broadcast wirelessly the video-image from the mobile VR device to my laptop with a available private network. Both devices needed to be connected in the same network. This was not a problem in a lab study. However, this could change in a field study. I recommend to use smartphones to share a mobile Wi-Fi hotspot and take portable chargers since this feature consumes battery quickly.

## Chapter 9

# Future Work

We had planned to conduct a study in a natural environment with different contexts and interruptions. For example, in a restaurant, a mall or in a crowded place in the city such as Crowns Casino or FedSquare. However, due to COVID19 pandemic we cannot carry out face to face studies. Therefore, I focused this chapter on conducting online studies using the proposed method. Based on the experience I obtained in the first study and my findings, I could identify how I can get the most out of the method to make it suitable for remote studies with mobile VR devices.

We found a Facebook group with Oculus Quest users in Australia, and apparently there are more groups from other countries. This would ease recruitment for future studies. Also, it would provide a greater diversity in the sample with different contexts in various settings. Aside from that, I can recruit participants with Amazon Mechanical Turk, which is a crowd-sourcing marketplace that allows individuals and businesses to outsource their processes and jobs to a distributed workforce who can perform these tasks virtually ([Amazon, 2005](#)). Therefore, researchers can have access to a large population of willing participants for research studies.

I proposed a plan that includes some changes in the delivery of each of the techniques of my method (Table 9.1 and Figure 9.1). I might also use a cloud-based video conferencing tool for communication between the researchers and the participant (e.g. Zoom). I need participants to have a proper and adequate space to test the VR application. Moreover, a webcam, and microphone. Fortunately, most computers are already equipped with them.

I state that these changes to the method can be useful for HCI researchers who are struggling with the current impediments that were imposed because of COVID19 pandemic and cannot conduct face to face studies.



Technique	Description
<p><b>Semi-structured Interview</b></p> <p><b>Questionnaires</b></p> <p><b>Direct observations of participants and note-taking</b></p> <p><b>Interaction Logging using SideQuest</b></p>	<p>Conducted before and after the user tested the virtual experience through Zoom.</p> <p>A set of UX scales that measured 1 to 3 UX components using an online survey tool. They are provided after the experience.</p> <p>I can observe participants through the video call during their VR experience and took notes of their use of the VR application.</p> <p>Video Recordings that captured my screen. I plan to monitor and record in real-time their virtual experience through Zoom. Additionally I can record user interactions and actions using the mobile VR device in the real world.</p>

TABLE 9.1: Proposed Method for Online Studies

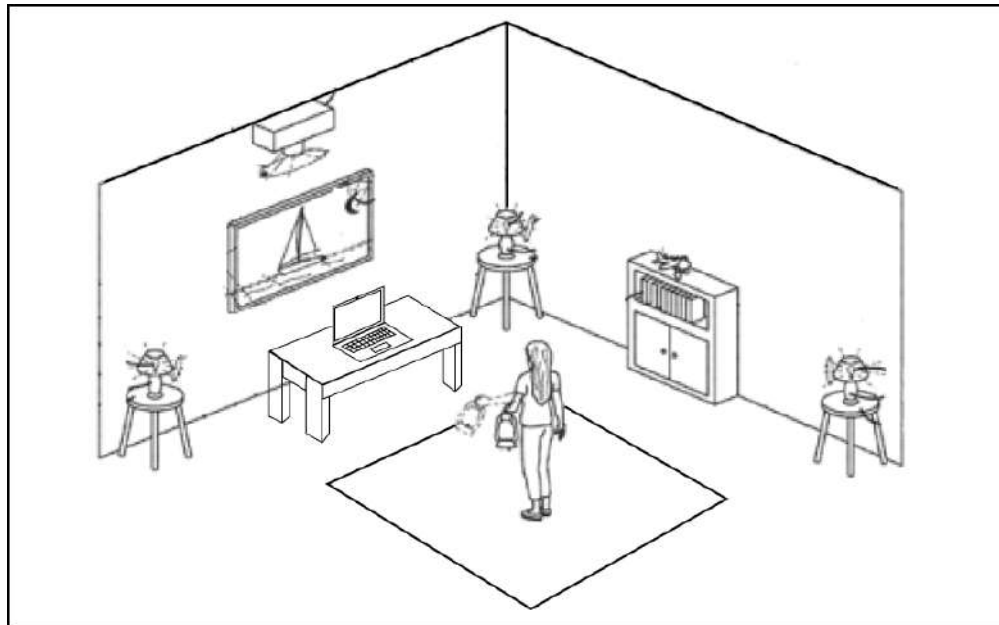


FIGURE 9.1: Proposed Method for Online Studies. Image modified from Finn 2018

I proposed the following plan for each technique in order to answer my **RQ2**. Aside from the changes to make it suitable to perform it remotely, I would like to change some aspects I encountered and learnt from the first study. I described them in detail below:

## 9.1 Interviews

There are not marked changes with the semi-structured interview. I plan to do it through Zoom with the camera on. Besides the questions about the virtual experience, I will change and increase the number of questions. I would like to include questions about the context and the device. For instance:

- Would you wear this device and the application in an outdoor setting? (e.g. restaurant, bus, train)
- Did you have any interruption (e.g. noise, people) while using the mobile VR device?
- Was it difficult to setup the VR application with the device? What about the software tools and the necessary space for the study?
- How long have you had your mobile VR device?
- How many times in a week you use your mobile VR device?

## 9.2 Questionnaires

In the same way as the semi-structured interview, there are not big changes for questionnaires. I only plan to use an online survey tool such as Qualtrics. I only need to send the link to the participant after testing the the VR application. Furthermore, I would change the questionnaires. There are several scales for each UX component in the literature. I plan to use others to validate that this would not affect the results of the method. For example, for presence, immersion and usability:

- PQ (Presence Questionnaire) and ITQ (Immersive tendencies questionnaire) from [Witmer and Singer 1998](#)
- PSSUQ (Post-Study System Usability Questionnaire) from [J. Lewis 1992](#)

## 9.3 Interaction Logging

To record the virtual experiences within the mobile VR device, I need participants to install SideQuest in their computers. This is a third-party application that provides useful features for Quest users. Developers can publish their applications in this platform

and users can download them. Therefore, I can upload my prototype to SideQuest or send a link of the APK file of Melbourne2100 to the participant. In this way, the participant can obtain my app using one of these two options. Lastly, the participant can use SideQuest to side-load the VR application onto his/her Oculus Quest at their home.

Furthermore, this application allows broadcasting from the device to a computer or laptop. Participants can share their screen in Zoom, and I will be able to see their virtual experience and themselves in the real world (Figure 9.2, number 3 and 4 respectively). Finally, I can record my screen of my laptop and analyse the videos later (Figure 9.2, number 1). I believe that the participants who have an Oculus Quest are experts or moderately experts and may already have previous experience with SideQuest.

## 9.4 Direct observation and note-taking

I plan to observe participants through Zoom, connecting my laptop to a bigger screen to appreciate in detail behavioural patterns from the participant and monitor the virtual experience in real-time in order to take notes (Figure 9.2, number 2). To achieve this, I might need another researcher. I can look at the participant and the other researcher can observe to the virtual experience. Lastly, I will require participants to think-aloud and audio record it.

Observation could also be done with researchers in different locations. This depends on the bandwidth and internet connection; and on the limitations the researchers have to conduct the study together.

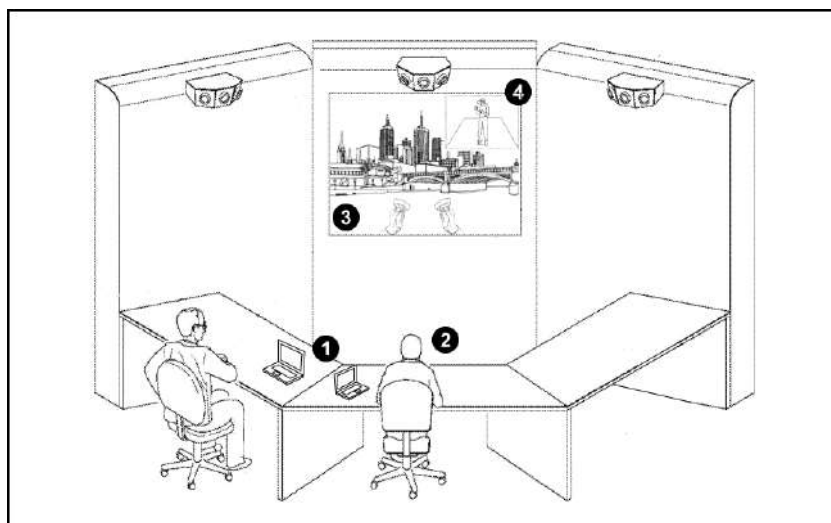


FIGURE 9.2: Observation techniques from Proposed Method in Online Studies. Image modified from [Swarm 2009](#)

## 9.5 Suitability of the method for online studies

I can confirm that the adjustments made to the method to make it suitable for remote studies works without problems since I tested it. Another researcher pretended to be the participant and I indicated the steps to setup the necessary software tools to verify if it works or not. I describe these steps in detail below:

- Step 1: Enable access to the VR application for potential participants:
  - Option 1, SideQuest allows to publish applications by developers. I could publish my VR prototype, and it can be available for participants.
  - Option 2, upload .APK file into cloud for participants to access.
- Step 2: After recruitment, the participant downloads APK file either through SideQuest or indirectly through access to the cloud space where I have uploaded the APK file.
- Step 3: Participants install the app on their Oculus Quest using SideQuest
- Step 4: Start the Zoom meeting.
- Step 5: Broadcast their quest to their PC/Laptop using SideQuest.
- Step 6: Share screen with interviewers/researchers.
- Step 7: I will be recording the audio and visual through Zoom.
- Step 8: Participant starts the VR app and goes all the way through.
- Step 9: Participant ceases the VR app and joins the interview through Zoom again.

We could successfully test these steps without critical problems remotely in two different environments. First, with a gaming computer in a room (Figure 9.3) and then with a non-gaming computer in a living room (Figure 9.4). This helped me to understand what difficulties I could face conducting remote studies using this method.

One of them to bear in mind is the low bandwidth. It can affect the quality of the video in Zoom. I need to ensure that the bandwidth is stable to record the screen. If this is not possible, I can ask the participant to self record instead. Then, participants can upload the video file into the cloud space I set up and I can download it from there.

Furthermore, the gaming computer performed better than the non-gaming computer. Broadcasting the video from Oculus Quest to the computer required a medium computing power to run smoothly. The gaming computer broadcast with better graphics than the non-gaming computer.

Finally, there might be some cases where the participant does not have an adequate space to test the app. However, I assume that participants who already have the device and use it at home already have the necessary space. Also, most likely these potential participants already have SideQuest installed on their computer because this application is popular among Quest users.



FIGURE 9.3: Test with a Gaming PC in a room



FIGURE 9.4: Test with a Non-Gaming Laptop in a living room

## Chapter 10

# Conclusion

This thesis presented a method for evaluating UX in mobile VR devices. Our work addresses a lack of evaluation methods for these emerging platforms. I was inspired by early mobile HCI research in which new usability methods were devised and tested that were attuned to mobile use. I validated my method through using it in an empirical study of a VR experience on Oculus Quest.

I aimed to explore and use existing and novel techniques and take advantage of features of the hardware platform. I conclude that the method worked well as it led me to identify multiple UX issues related to presence, immersion, usability emotion, engagement, simulator sickness, flow, skill, technology adoption and judgement. I advise against the use of questionnaires alone to evaluate UX in VR, and encourage instead the use of observation and interviews. My work will be of use to HCI researchers assessing VR experiences in emerging mobile platforms.

Finally, I presented a plan for future work describing changes for each technique of the proposed method to improve it; and especially to make it appropriate for online studies. This plan could be useful contribution for researchers who are restricted by social distancing rules imposed due to the COVID19 pandemic.

# Appendix A

## Interview Questions

- Do you live/work in Melbourne?
- What is your age?
- What is your gender?
- Have you used Virtual Reality Before?
- If yes, what type of Virtual Reality Device(s) have you used before?
- If yes, what do you use Virtual Reality for?
- How often do you use Virtual Reality?
- If you haven't used VR before why not?
- Are you susceptible to motion sickness or do you have any medical conditions that may make you more susceptible to motion sickness?

# Appendix B

## Questionnaires

5	4	3	2	1
Strongly Agree	Agree	Undecided	Disagree	Strongly disagree

FIGURE B.1: Rating Scale for Questionnaires

### B.1 SUS

#### B.1.1 Usability

- I think that I would like to use this system frequently.
- I found the system unnecessarily complex.
- I thought the system was easy to use
- I think that I would need the support of a technical person to be able to use the system.
- I found the various functions in this system were well integrated
- I thought there was too much inconsistency in this system.
- I would imagine that most people would learn to use this system very quickly.
- I found the system very cumbersome to use
- I felt very confident using the system.
- I needed to learn a lot of things before I could get going with this system.



## B.2 VRUSE

### B.2.1 Usability

- I thought that the system worked against me.
- I would be comfortable using this system for long periods.
- I did not have a clear idea of how to perform a particular function.
- The overall system response time did not affect my performance.
- I found it difficult to learn how to use the system.
- I felt in control of the system.
- The system did not work as expected.
- I can see a real benefit in this style of man—machine interface.
- I found it difficult to work in 3D.
- I enjoyed working with the system.

### B.2.2 Presence/Immersion

- I felt a sense of being immersed in the virtual environment
- I did not need to feel immersed in the virtual environment to complete my task
- I got a sense of presence (i.e. being there)
- The quality of the image reduced my feeling of presence
- I thought that the field of view enhanced my sense of presence
- The display resolution reduced my sense of immersion
- I felt isolated and not part of the virtual environment
- I had a good sense of scale in the virtual environment
- I often did not know where I was in the virtual environment
- I recognised the city (Melbourne)

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