UNIVERSITY OF BERGEN

Department of Information Science

MASTER'S THESIS

Exploring User Experience and Flow Indications in Mixed Reality

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Abstract

This thesis investigates a user-centered approach to developing a Virtual Reality (VR) application and exploring Mixed Reality (MR). The intention of the VR application is to encourage cooperation and effective work, as well as an enjoyable experience. This is achieved by facilitating for progress during a problem-solving session and offering users the possibility to switch to another room for recreation. A theoretical background presents VR and presence, followed by introducing *flow* and relating these through a review of previous research.

Research through design lays the foundation for this research as the exploration and knowledge is gained through the implementation of design and development of an artefact through a user centered approach. Agile is utilized as the methodology for the development of the VR application. Agile methodology consists of sequential sprints each resulting in a usable product to potential users, leading to continuous feedback. This process is described, and the result, a VR application, is presented together with findings investigating the relationship between the user experience and flow, indicating that the user's experience of usability impacts flow indications.

The thesis lays the ground for further research on the use of VR as an effective facilitator for cooperation as well as for exploring how AI can be implemented to facilitate execution of tasks in a VR environment. Further research on how usability affects presence and the feeling of flow is also suggested.

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This thesis is dedicated to the memory of Gunvor Berentine Helland. Although she always encouraged my studies, she was unable to see me graduate. This is for her.

Contents

Chapter 1: Introduction

Most people have better focus and deliver more creatively in tasks when they find themselves in the state of flow (Reeve, 2018). Finding this flow state during a task execution can help exclude disruptions and improve focus on the task. A tool well designed to exclude disruptions is Virtual Reality (VR) technology. This technology is focused around the creation of experiences separated from the physical environment, disconnecting users from auditory and visual stimuli from their physical environment.

The rise of VR as a common tool in workplaces, as well as in peoples' homes, creates an opportunity to explore the possibilities of VR in everyday settings. VR technology makes it possible to create different virtual environments unconstrained by available physical space in order to realize unlimited possible layouts. One physical space can be used for multiple purposes through different virtual environments. This research aims to contribute to the exploration of this potential of VR technology and Mixed Reality (MR) by creating different virtual environments based on one physical environment and combining elements from this physical environment with the virtual. By utilizing a user-centered design process in the development, user needs and experiences are emphasized throughout the research. In addition to the user-centered development process, user experience (UX) design principles and flow indications in VR experiences are investigated.

Principles for good UX design will contribute to create flawless experiences by limiting interruptions in interaction with a product (Norman, 2013). *Flow* leads to higher engagement in a task, eliminating distractions, and result in better problem solving and enjoyment (Reeve, 2018). Thus, facilitating flow in a workplace, in a team, or among students would be beneficial, and this research aims to contribute to insight on how to utilize VR technology for this purpose, and investigate the relationship between a user's experience of a VR application and the ability to experience flow.

1.1 Motivation

According to statistics communicated by Lin (2020), the barrier in adoption of VR technologies is proving hard to overcome; consumers that do not use VR are not interested in trying or discovering it. This could be due to prejudices towards how and for which purpose VR can be used, or that they might find it difficult to imagine the possible areas of use. If VR could serve as a tool to improve productivity and task completion, as well as contributing to peoples' ability to experience satisfaction while solving tasks, this could be beneficial both from a business perspective as well as from a personal perspective.

Focusing in a home office situation can be difficult. Elements of distractions are more frequent and present than before—phones with multiple apps, the browser with endless entertainment—and in the home office householding tasks and other errands are available constantly while one is trying to focus on a piece of work or study. Procrastinating can seem like a good idea at the moment, and the brain would like to do anything else than what you are supposed to, because it seeks enjoyment. But what if doing what you actually need to do could give that same enjoyment? Being in flow when performing tasks can bring positive emotions and enjoyment. Investigating how to reach flow and how to facilitate this state would be useful as it can allow the brain to be challenged as well as engaged, all while limiting distractions.

Currently, a well-equipped and functional VR headset can be bought at an electronic retailer for the relatively affordable price of NOK 3849,-. This price point makes VR headsets accessible for many people, including researchers who want to investigate the benefits of the technology. VR is a relatively new technology, it develops fast, and people involved in creating and exploring new features often have a heavy technical background and may not always be user-oriented in their application development. Personally, I believe that developing new artefacts and improving existing technology are important for the progression of society, however, the importance of creating value for the individuals the technology is intended for, is just as important. Thus, this research is highly user-oriented in its process.

1.2 Research Problem

This research explores the relationship between usability and user experience in VR and the ability for a user to experience the psychological state of flow. The result of the research comprises a practical component and a theoretical component. The practical component is a VR application developed in collaboration with my research partner, Jonathan Lindø Meling, and the theoretical component is presented as this thesis.

The intention of the VR application is to encourage cooperation and problem solving for an effective work session as well as offer an enjoyable experience. This is achieved by facilitating a task solving process in one virtual environment in the VR application, and providing the possibility to switch to another virtual environment for recreation.

Research through design is the methodology guiding this research as the exploration and knowledge of the subject is gained through the implementation of design and development of an artefact, in this case a VR application. Agile was used as a method for constructing the development of the VR application. Agile methodology consists of sequential sprints each resulting in a version of a product that can be tested and reviewed with potential users, leading to continuous feedback throughout the process.

The development in this research seeks to explore mixed reality for VR headsets, and how a user-centered design process can influence the development. The research aims to contribute to a better understanding of flow in VR, in particular flow in a VR environment developed to facilitate effective task execution in addition to recreation possibilities. Further, the relationship between usability and flow are investigated and discussed. The development and evaluation of the VR application lays the foundation for exploring the following research questions:

RQ1: How can User-Centered Design facilitate the development of a Mixed Reality application for a VR headset?

RQ2: What is the relationship between usability and flow in a Virtual Reality environment?

1.3 Collaboration

The practical component (VR application) of this research was developed in cooperation with co-student Jonathan Lindø Meling. Our supervisors from the Centre for the Science of Learning and Technology (SLATE) guided the research. Chapter 5, which describes the development, is common to both theses and was written in collaboration because it concerns the development process which was executed in partnership.

1.4 Thesis Structure

This thesis is structured into seven chapters. This chapter presented an introduction to the research, including motivation and the research problem introducing the research questions. Chapter 2 presents related literature and discusses its relevance to this thesis. In Chapter 3 the different technology and development tools are described. Further, in Chapter 4, the methodology for research and development is established. Chapter 5 supplements the methods chapter by providing an extended description of the collaborative development process. Then follows Chapter 6, presenting and describing the application, discussing interesting findings, and acknowledging challenges and limitations of the research. Finally, Chapter 7 presents a summary and conclusion, as well as the research contributions and suggestions to further work.

Chapter 2: Background

The aim of this chapter is to situate the research. The background and theory supporting this research is presented to show its relevance to the research. Different understandings of the concepts of reality and virtuality are introduced, with a focus on virtual reality and relevant literature. Further, the chapter discusses the psychological concept of flow as it relates to the presence experienced in VR, followed by previous research on flow in VR and AR. As this research involves the design, development, and evaluation of a VR environment, it is situated in the field of Human-Computer Interaction (HCI). HCI is presented with a particular focus on User Experience (UX) and UX design. Lastly, principles and guidelines to consider when designing user experiences in general, and in VR in particular are presented.

2.1 Forms of Virtuality and Mixed Reality

According to Jerald (2015), reality can be considered to range on a virtuality continuum. Milgram et al. (1994) presents *the virtuality continuum* (see figure 2.1) where forms of reality are ranged from real environments to virtual environments, the real being the one in which we live, and the virtual being an artificially created environment. The environments between these two poles are broadly defined as Mixed Reality (MR). This includes Augmented Reality (AR) and Augmented Virtuality (AV). AR is when the real environment is extended with virtual elements, and AV is when real-world content is captured and brought to a virtual environment. A true virtual environment is, according to Jerald (2015), artificially created and does not contain content from the real world, it is a virtual reality (VR). Such environments should strive to capture the user's entire attention, leave a feeling of being completely present in another world, and being disconnected from the real world. Although VR aims disconnect the users from the real world, understanding the real world and how humans perceive and interact with it, is of great importance when creating functionality in VR experiences (Jerald, 2015).

Figure 2.1. The virtuality continuum illustrated by Kaufmann (2009), inspired by Milgram et al. (1994).

The umbrella term used for all combinations of real and virtual environments is Extended Reality (XR), which includes AR, AV, VR, and MR. The research's development of a VR application aims to explore a combination of physical and virtual elements, and will be referred to as mixed reality, although the application is developed with the intention of functioning on a VR headset. A VR headset is more affordable and accessible than AR glasses which otherwise could have been a viable approach for exploring the combination of physical and virtual elements. The "reality" in the research's development consists of a physical room with exact measurements recreated, and calibrated to, in a virtual environment. Other "real" elements consist of chairs, tables, and sofas, which can be interacted with simultaneously in both the virtual and the real world.

2.1.1 Virtual Reality

As the research in this thesis is concerned with VR technology and MR interaction these terms will be described in this section, followed by an introduction to presence and immersion. For a technical introduction to VR, see Chapter 3.

Definitions of Virtual Reality

Traditionally VR has been a broad term relating to any environment simulating a real or artificial environment. It is, therefore, useful to distinguish between desktop VR and immersive VR. In immersive VR, the environment surrounds the user, while desktop VR can be on a screen, not creating a total immersion to the user. In this thesis VR is used to refer to immersive environments created for a VR headset.

This research adheres to the definition of VR as "a computer-generated digital environment that can be experienced and interacted with as if that environment was real" (Jerald 2015, p. 9). Jerald's description of VR stresses that the ideal VR system enables the user to interact and walk around as if the environment was physically real (2015). Urke (2018), on the other hand, defines VR as different technologies that give the feeling of being in a different place through digital sensory impressions. Further description of the technology can be found in Chapter 3.

Mixed Reality

While the application is intended for use through a VR headset, physical elements and objects were incorporated to explore how this influenced the VR experience, thus an introduction to

MR follows. MR is described by Urke (2018) as virtual elements that interact with the physical world, and that the MR technology should digitally map out the current room using, e.g., depth sensors. However, several researchers in the field (Urke, 2018, Jerald, 2015, Skarbes, Smith, and Whitton, 2021), expresses that there is no agreement to the definitions of the different terms, or in which situations it is appropriate to use each term. This research explores MR as a mix of virtual and physical objects, where the virtual environment is based on a physical space, and where virtual objects have a calibrated physical counterpart.

Presence and Immersion

Presence is the subjective feeling of “being there” in an environment (Slater, 1999). Urke (2018) explains that people can forget their own physical surroundings, as they feel present in the virtual reality, which is a goal for many VR experiences. Jerald (2015) describes presence as an internal psychological and physiological state in which the person is aware of the virtual immersion and forgets about the technical medium as well as the real world.

Whereas presence is a subjective feeling, immersion is a characteristic of the technology which facilitates the feeling of presence (Slater, 1999). Hence, advanced HMDs have a greater immersion than a computer screen with a three-dimensional video (Urke, 2018). This research solely concerns technology described as immersive VR, which has the potential to facilitate a high degree of presence.

2.2 Psychological State of Flow

VR technology strives to capture the user’s attention by making them present in another world, disconnected from the real world. The capability of immersion is similar to the feeling of being in *flow*; “the state in which people are so involved in an activity that nothing else seems to matter” (Csikszentmihalyi (1990, p. 4). During a state of flow people experience being completely engaged in whatever task is being done, and no attention is paid to occurrences or feelings. According to Nakamura and Csikszentmihalyi (2014), flow can be experienced when a person is doing tasks that are just manageable enough, where they are tackling a series of goals with continuous feedback on the progress.

Flow is a state that a person can experience when doing an activity that has a level of difficulty that matches his/her skill level, meaning that the task is not too easy (leading to boredom), nor too difficult (leading to helplessness) (Reeve, 2018). According to Reeve (2018), *any* activity can be enjoyed if given the optimal challenge, exemplified by Csikszentmihalyi's study which found that students enjoyed homework more than viewing undemanding television programs, and that people more often experience enjoyment during challenging work than they do during leisure.

Rise of concentration, involvement, and enjoyment are positive experiences that can result from being in flow (Reeve, 2018). This happens at the optimal balance between challenge and skill, as seen on figure 2.2. However, other conditions can lead to worry and anxiety, if the challenge is too high, or relaxation and boredom, when too low. Apathy rises when both skill and challenge levels are low.

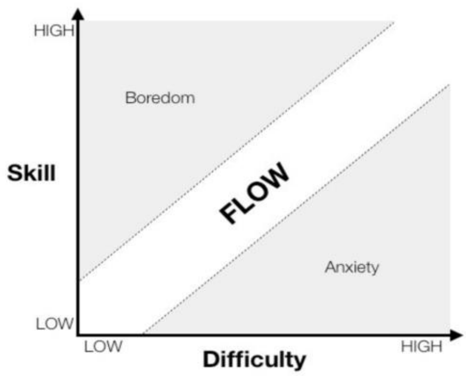


Figure 2.2. The flow model. Emotional consequences from different pairings of challenge and skill (Ishitani, 2012).

Nakamura and Csikszentmihalyi (2014) describe the subjective feelings of flow as "the intense and focused concentration on what one is doing in the present moment", "merging of action and awareness", "loss of reflective self-consciousness", "a sense of control of one's actions", "distortion of temporal experience", and "experience of the activity as intrinsically rewarding, such that often the end goal is just an excuse for the process" (p. 240). These six statements are utilized to find flow indications in section 6.3.

2.2.1 Flow, Presence, and Immersion

As described in the previous section, flow contributes to the elimination of occurrences other than the task at hand. Immersion, also, offer a similar contribution, as it gives the person experiencing it a deep absorption and engagement (Jerald, 2018). However, according to Jerald (2015), immersion concerns the technology and its characteristics rather than any subjective feeling, such as presence or flow that may result from the immersion. Flow in VR is thus connected to the feeling of presence and a sense of engagement with the virtual environment. VR is a technology that offers a high degree of immersion, excluding all visual cues, and, by using an audio headset, auditory cues are eliminated as well. In this section, a selection of studies that concerns flow, VR and AR technology, as well as the importance of UX, will be described.

Flow and VR

A study performed by Hassan et al. (2020) examines the correlation between the experience of flow and continued use of VR. Hassan et al. (2020) states that the lack of frequent VR use could be a possible sign of consumer dissatisfaction with VR experiences. Further, they argue that the essence of VR is telepresence, meaning "the feeling of being immersed in realities outside immediate ones" (Hassan et al. 2020, p. 1). Their research gives an account of previous investigations that has connected flow experiences and immersion. Positive outcomes from this previous research could, according to Hassan et. al. (2020), imply that experiencing flow in VR can prolong the use per session, and positively impact consumer adoption and time spending in VR.

The study by Hassan et. al. (2020) aims to investigate preconditions for experiencing flow by investigating which preconditions lead to flow in VR, and further if this flow experience has an impact on the use of VR. The study analyses survey data where 681 participants replied to their questionnaire. An interesting finding from the study is that an autotelic experience of flow appears to be mainly linked to the *challenge-skill balance* and *sense of control*. Consequently, Hassan et. al. (2020) suggests that the two factors should be given great importance when facilitating for autotelic experiences in VR.

The research by Hassan et. al. (2020) concluded that if the use of VR feels natural and seamless, people are more likely to continuously use it. From a UX perspective this can be understood in relation to Norman's (2013) design principles for good and natural design, as this supports a seamless experience for objects and experiences. Hassan et. al. (2020) acknowledge that it is important to notice that the feeling of autotelicy and flow are subjective and may not be the easiest experiences to induce intentionally through design. However, the relationship between continuous use and a seamless experience may imply that intuitive design could have an impact on the possibility to experience flow.

Another consideration to have in mind is that the use of VR depends on several factors such as physical inconvenience, discomfort, a space for setup, fatigue, and dizziness. In addition, the feeling of artificiality may occur as the visual sharpness in VR content is not yet comparable to reality; users can perceive individual pixels in the display, and the field of view is limited. Hassan et. al. (2020) expresses that such factors can complicate a user's experience in VR, reminding them of the artificiality of VR as well as their immediate physical experience.

As the study by Hassan et. al. (2020) is based on a survey, it is dependent on participants' self-reports which can be subject to miscommunication. Both the survey questions and the participants' answers could be misinterpreted leading to wrong or false information. Flow is an experience which makes self-report methods appropriate, however, surveys may exclude that possibility for participants to question statements or requests they do not understand.

Flow in AR

Because of AR's relevance to MR in that it also combines physical environments with virtual, this section presents a study of the relationship between flow and AR. A paper by Neal (2012) explores the flow state in AR and why this state of full engagement is the optimal user experience to aim for in design. Neal (2012) claims that while most of the research regarding applications and flow state are gaming-related, other applications might also benefit from considering flow in their design process in addition to usability. The research claims that the optimal user experience is dependent on the ability of the application to facilitate flow (Neal, 2020). In this research flow is described as a consequence of being engaged with an application, making the user lose track of time and exclude activities not related to the particular experience (Neal, 2012). This is described as the maximum engagement, which can be facilitated by user control and by controlling the key aspects of an experience in AR. Neal (2020) cites several studies of flow in the field of game design, where it was shown that flow could improve the user's mood, as well as decrease stress. He argues that application designers who desire an optimal user experience should consider designing for flow states as a part of the design process (Neal, 2012).

Flow studies in e-learning shows results such as increased learning, in addition to exploratory and positive behaviour, as well as positive user experience. Further, uneven flow and poor interface design can lead users to pause and reflect. According to Neal (2012), this shows that ease of use, proper usability, and good design decisions can contribute to the flow state attainment. For UX designers, the research claims that a *key consideration* is to keep the user engaged in their application. Neal (2012) states that since not all applications attempt to, or require to, evoke a flow state, the ones who do will be ahead when it comes to reaching an optimal user experience. Further, Neal (2012) also mentions the importance of upholding the balance between challenge and skill, as well as keeping the user focused on the task at hand. Neal (2012) states that attention is affected by emotion, and attention combined with emotion strongly influences whether a person can enter a flow state. He points out that flow is not a singular status, and that a user can be considered in a flow state when the flow channel is entered. This flow channel is a temporal area timeline similar to the one introduced in section 2.2. *Flow exit points* are introduced as elements or distractions that can eliminate a person from flow (Neal, 2012).

Similarly, to Hassan et. al (2020), Neal (2012) stresses the importance of a well-designed interface capable of providing seamless interaction. This will contribute to less distractions for the user, making it easier to focus on the current task or challenge (Neal, 2012). Interruptions and interface confusion are described as the main source of flow exit, thus a seamless interaction is the first thing to consider when aiming for a user flow state in AR. Research on flow in VR suggests that the interaction should be natural to avoid distractions when facilitating flow (Hassan et. al., 2020, Neal, 2012). To further investigate interaction and usability, HCI and UX design will be described in the following sections.

2.3 Human-Computer Interaction

HCI is, according to the Interaction Design Foundation (n.d.), a field of study in which the main focus is humans and their interaction with technology. HCI as a formal field of research is relatively new, as it was founded in 1982 (Lazar, Feng, and Hochheiser, 2017). However, HCI related work in fields such as management, psychology, software engineering, and human factors, can be found earlier than this. The interaction between the human and the computer became important when the computer entered homes and offices, consequently serving a different purpose than in laboratories. Highly qualified engineers were no longer the only users of computers, thus computer interfaces needed to be easier to use by less computer proficient groups, creating the need for the field of HCI. HCI draws on many different disciplines, such as computer science, sociology, and psychology. The majority of HCI research will, according to Lazar, Feng, and Hochheiser (2017), fall within artefact contributions or empirical research. This research includes artefact development and a written thesis, thus contributing to both. Artefact contribution as the practical component is a design and development of a new artefact, while empirical contribution as both qualitative and quantitative data are gathered using surveys, focus groups, diary studies, and more (Lazar, Feng, and Hochheiser, 2017).

Given that HCI is a broad field that has derived from several different disciplines, it overlaps with domains such as user-centered design (UCD), user interface design, and user experience (UX) design. The Interaction Design Foundation (n.d) claims that UX design has evolved from HCI. HCI, however, has an academic approach, focusing on scientific research and the development of an empirical understanding of users, while UX design relates more to industry, designing and building products or services (Interaction Design Foundation, n.d.). Thus, moving into UX design and Norman’s guide to good design and interactions will be beneficial in a design perspective.

2.4 User Experience Design

To design for how humans will experience an artefact through interaction it is crucial to focus on the humans and their cognition, emotions, and interactions with the world (Norman, 2013). Norman and Nielsen (Nielsen Norman Group, 2021) describe UX as “all aspects of the end-user's interaction with the company, its services, and its products”. The experience is crucial, as it impacts peoples’ overall impression of interacting with something. Cognition and understanding are tightly connected with emotion, thus a good understanding of a product can lead to positive emotions as the user feels capable of managing the artefact. On the other hand, negative emotions such as confusion and frustration can arise if there is a lack of understanding (Norman, 2013).

Norman stresses that every new technology or technique of interaction will need to be experimented with and studied thoroughly to fully implement principles of good design. The following section presents Norman's principles of design in light of VR interaction.

2.4.1 General Design Principles and Guidelines for VR Design

As VR is a constantly developing technology and best practice is in continual improvement, there is no determined, agreed upon principles or heuristics to follow when designing experiences in VR. Still, there exists sufficient, well developed principles to follow for generally designing good user experiences, including Norman's principles for design. In the book "The Design of Everyday Things" Norman (2013) presents several different principles to secure good design. These can be used as the foundation for how to proceed when designing, developing, and reviewing a VR application. Norman explains that when humans are to interact with a product, three things need to be discovered; what it is, how it works, and which actions are possible. This is discoverability, and results when five elementary psychological concepts are appropriately applied to a product. The psychological concepts consist of affordances, signifiers, constraints, mappings, and feedback. In addition to these, Norman presents conceptual models as a last, but nonetheless important, principle, which creates a true understanding of a product. These six principles will here be presented and explained in the relevance of user experience in VR.

Affordance, according to Norman (2013), refers to the perceived and actual attributes of a thing, which provides an indication of what it can be used for. It denotes the relationship between the physical object and a person, or an operating agent. The relationship between the object's properties and the operating agents' capabilities is what determines the possible usage of an object. In virtual environments, objects and things will also stand in a relationship to the user and needs to be designed in a manner where the possible actions are seen as available for the user. Norman (2013) explains that the existence of an affordance depends both on the object and the user. To create this relationship of affordance, a designer should create a cue of the possible actions on an object, which leads to the next principle of design, signifiers.

Signifiers are a way to communicate to the user where an action should take place. It signals where to interact with an object or how a product can be used. Signifiers should give the user information about the purpose, structure, and possible operations of the object they belong to. Norman (2013) claims that signifiers are more important than affordances because they communicate how to use the design, elucidating the affordance to the user. When signifiers are utilized appropriately, the designer succeeds in making the user interact with the interface or object as intended, and the user avoids feeling insecure of how to act (Norman, 2013). Signifiers in VR could signal which actions that are possible or which directions the user can move toward. Buttons signify that something will happen when it is pressed. By including a text label on or besides the button, this will indicate which action pressing the button leads to. According to Jerald (2015), VR designers should establish well communicated signifiers that are easily discovered by the users to ensure effective interaction. When designing VR applications, and interactive artefacts in general, it is important to be aware of the effect of a misleading signifier. If there are objects that signalize pressing, or some kind of interaction, then it should lead to some action. If a user tries to press a button only to realize that it does not lead to an action, the user has been misled, which could cause the user to feel confused and unsure of how to interact in the VR application (Jerald, 2015).

If the communication from the designer to the user is successful, an interaction leads to a result and the user gets *feedback* to the applied action (Norman, 2013). This principle of design concerns letting the user know that the system is working on your request or action. Norman (2013) states that this feedback needs to be immediate and informative. Immediate to ensure that the user does not have to wonder if the executed action was interpreted, and informative to communicate the outcome of the action. If the feedback is not precise, it could, according to Norman (2013), be distracting and lead to frustration on part of the user. The feedback needs to be planned to secure appropriate information at the right time and place (Norman, 2013). Especially important in VR is the timing of the feedback. The movement of the user's head or hands need to create an immediate visual change, confirming the user's ability to naturally interact with the VR system. The lack of immediate feedback to the movement of the head can in the worst cases lead to users feeling ill and experiencing motion sickness. Another important feedback in VR concerns the controllers and their ability to give feedback to the users position and motions of limbs and body. According to Jerald (2015), strong haptic cues when touching or colliding are difficult to pursue in VR. Substitutions to these kinds of sensory feedback will be elaborated in the Chapter 3.

In addition to feedback on which actions have been completed, knowing which action is possible, or not possible, in regard to an object or interface is crucial. This refers to the principle of *constraints*, defined by Norman (2013) as powerful clues to limit the set of potential actions. According to Norman (2013), the use of constraints in design can lead people in novel situations to determine the appropriate action. Further, Norman (2013) defines four kinds of constraints: physical, cultural, semantic, and logical. Physical constraints refer to physical limitations of the object properties, while cultural constraints regard behaviour in social settings. Semantic constraints rely on the user's knowledge of the situation and the world, and the meaning of this. Logical constraints refer to the relationship between the spatial or functional layout of the object and the things that it affects or is affected by (Norman 2013). This logical and natural relationship refers to the mapping of two sets of things, which is the next principles of design.

Mapping is a term that Norman (2013) has borrowed from mathematics, and this refers to the relationship between elements. Norman (2013) explains that the relationship between a control and the result is easily perceived when there is a natural or understandable relation between these. Further, by taking advantage of spatial analogies when designing can lead to an immediate understanding, a natural mapping (Norman, 2013). Jerald (2015) states that in VR, mappings from hardware to interaction techniques defined by software are crucial. In VR, the mapping can be referred to as the compliance, which is the matching of sensory feedback with input devices. The maintenance of compliance should, according to Jerald (2015), improve the user's performance and satisfaction by giving the feeling of interacting with a single coherent object. Further, he explains that a direct spatial mapping causes an immediate understanding of the user's circumstances. If the user can figure out how to pick one object up, then the same manoeuvre will comply with other objects (Jerald, 2015).

A *conceptual model* is an explanation of how something works (Norman, 2013). This explanation is often simple and does not have to be either complete or accurate, just useful. Norman (2013) stresses that a product or object often has multiple conceptual models depending on the user. These models can also be referred to as *mental models*, which is an individual's understanding of how something works. The major clues of how things work, Norman (2013) explains, comes from the perceived structure, from the mentioned signifiers, affordances, constraints, and mappings. Jerald (2015) also stresses that VR creators should use principles such as signifiers, feedback, and constraints in their design to help the users form mental models. As the created virtual environment is based on how humans interact in the real world, some interaction in VR will seem natural for many people, as they can interact as they normally would.

2.5 Summary and Relevance

This chapter described different forms of virtuality including VR, AR, and MR to explore the terms that are important for this research. Further, *flow* is introduced by describing how it feels to be in this psychological state and how one is able to reach it. Then research investigating flow, presence and immersion in different XR technologies was presented to elaborate how and why reaching flow can be beneficial for the experience of interacting with an artefact. The field of HCI was introduced, followed by a presentation of UX design to further investigate design principles light of VR interaction, and to explore the importance of good design in VR technology.

Chapter 3: Technology

Different technologies require different considerations in design, and the choice of which technology to use to solve a problem will impact the user experience. This chapter presents the technology used in developing and testing the VR application and describes the attributes and functionalities of the VR headset used in this research. The platforms and software used to prototype and develop are also described.

3.1 Virtual Reality Headset

According to Jerald (2015), VR is a technology that facilitate real-world-like interaction, while Urke (2018) describes VR as a system that gives the feeling of being in a different place. The immersive VR headset utilized for this research provides both features, which will be described in this section.

Jerald (2015) classifies the physical tools or hardware that is used to communicate information to the application, and which are used for interacting with the virtual environment, as input devices. These devices may vary a lot from each other and should be examined when choosing hardware and designing for interactions. One of the characteristics to consider when designing for VR includes the size and shape of the input device, and how it feels and reacts (Jerald, 2015). Another characteristic to consider is how many degrees of freedom (DoF) of user movement that the VR device supports, defined as "the number of independent dimensions available for the motion of that entity" (Jerald, 2015, p. 280). The DoF ranges from a single motion (analog trigger) to 6DoF which is a full 3D translation (up/down, left/right, forward/backward) and rotation (roll, pitch, and yaw).

As Jerald (2015) points out, VR interaction does not only concern an interface for reaching user goals but concerns the users' ability to work in an intuitive manner and avoid frustration. Designers of a VR application should make the VR application communicate to the users how the application or virtual world works, as well as how the tools work (Jerald, 2015).

3.1.1 Oculus Quest

The VR environment in this research was developed for the Oculus Quest headset. The Quest is an "all in one" stand alone headset with controllers, which means that it does not require wires and a separate computer to function. The Oculus Quest headset consists of a head-mounted display (HMD) and two controllers (figure 3.1), which can all be regarded as both input and output devices. The controllers are tracked by the system to be in the correct relation to the HMD.

Figure 3.1. Illustrations of the Oculus Quest's HMD and controllers (Oculus, 2021).

3.1.2 Head Mounted Display

An HMD is a visual display that can be attached to a person's head. The HMDs tracking of position and orientation is essential for VR because the display and headphones move with the head (Jerald, 2015). HMDs can be categorised into three types based on how or whether one can see through them. Non-see-through HMDs visually block out the real world and its elements, providing full immersion. This is the type of HMD utilized in this research. Other types are optical-see-through HMDs, facilitating augmented reality experiences by extending the real environment with virtual elements, and video-see-through HMDs supporting augmented virtuality (Jerald, 2015).

If virtual objects are to appear stable and rendered appropriately, the display needs to react to the head's movements momentarily. This will provide the greatest amount of immersion, but it depends on challenges such as accurate tracking, low latency, and careful calibration (Jerald, 2015). Since this research is concerned with MR environments, these challenges were particularly important to address, as inaccurate tracking and latency could result in users colliding with the physical objects placed in the room. Thus, a careful calibration was essential to ensure that the physical and virtual elements corresponded.

3.1.3 Controllers

According to Jerald (2015), for the majority of VR experiences one or more controllers is appropriate and they should offer interaction in 6DoF. Buttons are also a part of the input device, often used when changing modes, selecting something, or starting an action. Jerald (2015) states that buttons can be very practical in VR applications, however, it is worth being aware that too many buttons can lead to confusion and error. Jerald (2015) also mentions that there is an ongoing debate regarding whether the use of hand-held controllers and bare-hands input devices is the best approach.

The Oculus Quest was equipped solely with tracked hand-held controllers as input devices when we started to develop for our application. Later in the development process, Oculus launched an update for the Quest offering hand tracking functionality on the device. At the time, however, documentation on how to implement this was scarce and it was therefore challenging to implement the features from the hand-held controllers. For this reason, the use of hand-held controllers for the application, were continued.

The debate on hand-held versus bare-hand systems has one side whose opinion is that buttons are primitive and unnatural forms of input, whereas the other side argues that buttons are an essential part of game play (Jerald, 2015). Jerald points out that this, as with every other debate, depends on the use and situation. Further, he elaborates that buttons are great when the action is binary (two states), reliability is required, if the action needs to occur often, and if physical feedback is essential. He also stresses that gestures can be slower than buttons and lead to more fatigue, but that for creating a sense of realism the natural bare-hand input provides a greater sense of presence (Jerald, 2015).

Reliability is another input device characteristic, which is concerned with whether the device is able to consistently work within the users' personal space. Unreliability in an input device can cause frustration, fatigue, increased cognitive load, breaks-in-presence, and reduced performance. Thus, reliability should be considered when choosing a device (Jerald, 2015).

Tracked hand-held controllers are 6DoF devices that are tracked by the system and can therefore be visually co-located with the real hand position. In addition, the controller can give haptic feedback and touch cues (Jerald, 2015). According to Jerald, one of the advantages with such controllers is that they act as a physical prop enhancing the user's presence through physical touch. Jerald (2015) also points out that such controls can contribute to better communication with the virtual world as well as helping the user concretize the spatial relationship. He explains that such props prevent a user from the direct feel of passive objects in the world, such as seats, handlebars, and cockpit controls, without dropping the controller (Jerald, 2015).

3.1.4 Passive and Active Haptics

Haptics are “artificial forces between virtual objects and the user’s body” (Jerald, 2015, p. 304). According to Jerald (2015), haptics can be categorized as either passive or active. To create a sense of touch in VR, one can create a physical object which matches with a virtual object, described as passive haptics (Jerald, 2015). Further, he explains that the use of passive haptics increases presence, improves cognitive mapping of the environment, as well as training performance (Jerald, 2015). This kind of haptics can contribute to the environment feeling more real. However, the most common form of haptics are active haptics that mostly serve as computer-generated vibrations. By using active haptics such as tactile haptics, one has the advantage of providing an artificial feeling of touch on multiple virtual objects, though it feels less real than passive haptics (Jerald, 2015).

In the VR application developed during this research, both passive and active haptics was utilized. As the virtual room corresponds precisely with the physical room, the walls and objects in the room serve as passive haptics, giving the users a feeling of being present in the same room as before entering the VR experience. Objects such as tables and chairs were present both in the virtual and the physical room, meaning that touching a table the user sees virtually can be felt with physical touch. The application also provides tactile haptics when users interact with virtual objects such as buttons, in which the controllers will provide small vibrations when it is pressed.

3.1.5 Audio

Audio plays a crucial role in adding awareness to the surroundings, both in the real world and in VR environments. Fictum (2018) stresses that sounds should be as real as possible to have the most impact. This can be ambient sound effects, such as tree rustling and running water, that according to Jerald (2015) can create a sense of realism and presence, as it can facilitate situational awareness in a virtual environment. In addition to creating realism, sounds can be informative and useful by creating awareness of properties or objects Jerald (2015). This can impact a user's attention and, therefore, be utilized as a signifier towards a desired task or object.

Basic audio output is available through the Oculus Quest's HMD, but for the audio to contribute to an immersive experience, the audio is preferably presented through headphones. To create realistic audio cues, Jerald (2015) suggests auralization, which is sound rendering which simulates reflection and binaural differences between the ears. This results in spatialized audio, perceived as if in a real environment (Jerald 2015). For this research's VR application, a headset that supports spatialized sounds was utilized to ensure that the sounds that were added in the virtual environment were as realistic as possible.

3.2 Mixed Reality

To give a representation of how VR could expand and increase possibilities of a *real* room, the virtual room should preferably look as close to the real room as possible. While this research utilizes a VR headset designed to support complete virtual experiences, it was desirable to explore how implementing physical objects influenced peoples' feelings of being present in the environment. By including elements from the physical world, the research moved from being solely focused on VR, to also experiment with mixed reality.

The expansion of the physical environment would perhaps be more realistic by exploring this in AR. However, AR glasses are not consumer products yet, making it less accessible for researchers as well as for potential users or customers. Although making an MR environment by mixing physical elements with the virtual was preferable due to accessibility, the VR application was dependent on precise measurements and scaling of the physical room, the objects, and the exact position of these. The VR application is based on a 56 m^2 large room with the possibility of utilizing the whole space for interaction, only constrained by the walls of the room (both virtual and physical). Thus, users could walk around in the environment in every part of the room, in the same manner as they would be able to do outside of VR, preventing unnatural interaction such as teleportation.

3.3 Prototype Without Code

At the very beginning of the research, investigations were made to discover possibilities to demonstrate and test a planned virtual environment without implementing ideas into programmed applications. Limited possibilities were found, however, a plugin for an already familiar web prototyping tool, Adobe XD, was explored. This plugin, called Draft XR, provided the possibility to transform two-dimensional (2D) surfaces in a three-dimensional (3D) environment (Reiners, 2020). When investigating this environment through a VR headset, it felt like experiencing 2D objects in a 3D environment. The plugin proved to be of lower quality than expected, limiting the design of a credible environment. Thus, prototyping in this research was performed using pen and paper, and by developing a VR application. A further description of the design and development process can be found in Chapter 5.

3.4 Unity

To develop the VR application, a software for creating 3D multi-platform experience, Unity (2021) was chosen. Documentation and resources were available through Unity's website community, and tutorials on how to create environments using this software existed due to its popularity in creating VR experiences. Using Unity, the VR application was developed by building objects and adding elements. These could be given multiple features by adding attributes such as programmed scripts, audio sources, colliders, etc.

Unity Collaborate

Unity has integrated tools that makes it easier for online collaboration. In developing the VR application, an extension called Unity Collaborate was utilized. This extension enables working on the same file from separate computers, with changes uploaded continuously to the shared file. For each upload, a new version was automatically created to keep track of changes and ensure that no progress was lost. The collaborative features in Unity made it easy to share code, changes on different devices, and to synchronize the project to ensure both developers were working on the same version.

3.5 Summary and Relevance

This chapter presented different technology that was utilized in the research. VR headsets and its components were investigated, and tools for development were presented. Attributes of the VR headset have been presented to give an overview of the components a user will encounter when interacting with a VR experience.

Chapter 4: Methods

In this chapter the methods used to conduct the research, as well as methods employed for the development of the practical component, will be presented, and discussed. First a preliminary study performed in advance of this research is presented. Then Research Through Design (RtD) as an overarching approach to the research, providing the foundation for the development as it is connected to the research. Further, the specific method used to develop the prototype is presented, followed by a presentation of the methods employed for user research, desk research, and analysis.

4.1 Research Questions

The methods presented in this chapter are employed to answer the following research question:

RQ1: How can User-Centered Design facilitate the making of a Mixed Reality application for a VR headset?

RQ2: How can UX design principles for VR design influence the ability to explore flow in VR?

4.2 Preliminary Study

A preliminary study (Helland and Meling, 2020) was performed in advance of this research. This study investigated participants' abilities to relax and/or recreate and distance themself from their daily duties, by exploring different VR experiences. The research was executed as a diary study, which is a method suitable when participants are not reachable, or when participants are to report events regularly over a period of time (Preece, Rogers and Sharp, 2015). In this study, two participants (limited number of users because people who were in possession of a VR headset had to be chosen) entered one of three pre-selected VR applications for about 10 minutes during their daily routine of work or studies. Color Space, Cosmic Flow, and 360 Virtual Nature were selected due to their potential to facilitate relaxation and recreating. After testing the application, the participants filled out an online questionnaire with a selection of questions where they would range statements, as well as some open questions where they could elaborate if necessary. The questions considered their experience of the application, the ability to relax in the environment, and their perceived stress level before, during, and after trying the VR applications.

4.3 Research through Design

Research through design (RtD) is an approach utilized to generate new knowledge based on scholarly research that employs design methods, practices, and processes. This approach allows an exploratory procedure, as it acknowledges the development of an artefact as a source of knowledge and a contribution to research. As the aim of the project as a whole is to conduct research and gain insight through developing an artefact, the RtD approach was considered highly appropriate as it combines traditional research and design (Zimmerman, Forlizzi, and Evenson, 2007), as well as providing a foundation for the development of the VR application.

Zimmerman and Forlizzi (2014) suggests five steps to be followed when carrying out a RtD project. The steps are (1) Select, (2) Design, (3) Evaluate, (4) Reflect and Disseminate, and (5) Repeat. The first step is to choose an area of research or a problem with investigation potential. Further, one of the RtD practices to follow (lab, field, or showroom) needs to be chosen. According to Zimmerman and Forlizzi "field practice will most likely place a working prototype into the field and assess if it produces the intended behaviours and outcomes" (2014, p. 184), which supports the choice of this approach in this research. As part of selecting a field of research, desk research was carried out, described in the following section. The four next steps are are presented first as an iterative cycle consisting of four activities, and further as short time boxed iterations known as *sprints*.

4.4 Desk Research

To *select* an area of research a search of literature was carried out to get an overview of the existing research in the relevant fields. Fields of interests include technological research on VR and MR, UX in VR, the relationship between usability, presence, immersion, and flow. Chapter

2 provided an overview of the information retrieved in this desk research. Websites utilized to retrieve relevant research were ResearchGate, Google Scholar, Springer, and ScienceDirect. The title and a brief skim of the abstract were used to determine the potential relevance of the papers towards this thesis. Further, the potential papers' abstract and conclusion or summary were studied to choose papers with relevance for more thorough reading. In addition to search queries in the relevant fields, related papers were also found through the reference list of the discovered papers.

4.5 Design Process

The components of design i.e., finding the right problem and meeting human needs and capabilities, are the basic construct of the design process (Norman, 2013). The British Design Council introduced the double diverge-converge pattern in 2005, called the double diamond design process model. This model is based on the basic construct of the design process. Finding the right problem consists of the divergence to examine the underlying issues, and then the convergence to a single problem. The space of possible solutions is then expanded—the divergence—before the designer finally converges to a proposed solution. Norman (2013) modified the 2005 British design council model as seen in figure 4.1. He explains the model as follows: It starts with an idea, which expands through the initial research exploring the fundamental issues. This is when the designers converge to the real, underlying issue, i.e., finding the right problem. Design research tools are used to explore the possible solution, and converging to one suitable solution (Norman, 2013)

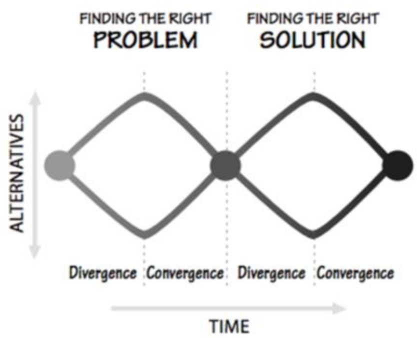


Figure 4.1. The Double-Diamond Model of Design. Norman's modified version of the 2005 original model (Liu, 2016).

As previously mentioned, there are two phases of design, finding the right problem and fulfilling human needs. The process of these phases has their foundation in the iterative cycle in Human-Centered Design. This iterative cycle consists of four activities, observation, ideation, prototyping, and testing (see figure 4.2). The step of observation involves researching customers or potential users of a product, where the aim is to understand the users and their interests and activities. It is here of crucial importance that the observation is done on people who match the intended user group (Norman, 2013). The next step is ideation, which focuses on generating as many ideas as possible without constraints. The third step is prototyping, where the designers create mock-ups of the final product in order to explore how the ideas are experienced by the users. The final step is to test the prototype with the potential target group. This process can be iterated as long as needed, depending on the amount of time available. To incorporate this design process and user focus to a development method, agile development, presented in the next section, is utilized.

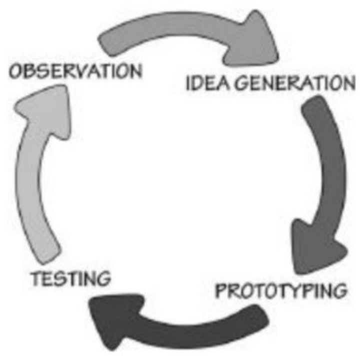


Figure 4.2. The iterative cycle of Human Centered Design (Krishnan, 2018).

4.6 Agile Development

Due to the prototype's impact and close relation to the user, it is appropriate to develop in a way where the user is in focus in all steps and to perform user tests frequently. Thus, agile development is chosen as the development method. This approach urges continuous "launches" of the product, with the possibility to get feedback from potential users after each launch. Agile development is a methodology based on iterative development, where the ultimate value is that it makes it possible for teams to deliver products faster, with higher quality and predictability, as well as the team's ability to react to requirements and changes throughout the process

(Cprime, n.d.). According to Beck et al. (2013), satisfying customers is one of the main priorities, preferably through early and continuous launches following a short time span. In addition, the importance of implementing changes, even late in the development phase, is beneficial for customers and can give the product an advantage over competitors.

Using Scrum boards is a common strategy to keep track of the team's progress during the development. This kind of board usually contains three or more sections, "to do", "in progress", and "done". This kind of board can be utilized during the development to provide an overview of tasks and the progress.

The Agile process consists of short, time-boxed iterations known as sprints. Each sprint results in a working product to be tested with potential users for feedback. As in the iterative cycle, described in the previous section, these cycles consist of steps facilitating the development of an artefact.

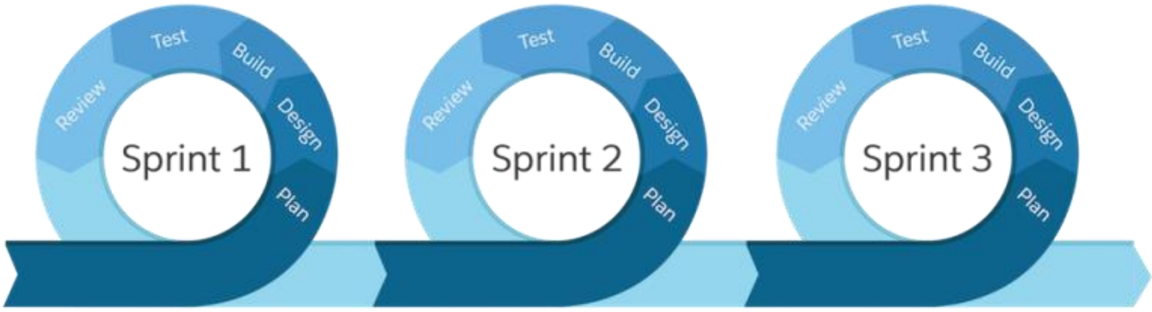


Figure 4.3. Agile methodology with continuous sprints. Illustration from Kishan (2020).

A brief description of the five steps, their purpose and how they were implemented in the research will be described in the following section. A more thorough description of what each step consists of in this specific research, and how they are implemented in the development process is elaborated in Chapter 5.

4.6.1 Sprints

Before starting the sprints, preliminary research on how to conduct agile sprints and how to prepare were conducted. Based on the DAD inception phase and "sprint zero" (Disciplined Agile, 2020) a setup for how to conduct the sprints was created. The elements creating the foundation for the sprints were *common vision*, *scope*, *test strategy* and *possible challenges*. The common vision is important to keep track and make sure that the development is going in the right direction. The scope is more concrete actions or goals that are to be completed during the ongoing sprint. Test strategy is set to be prepared on how to conduct the user tests and what is going to be tested. Finally, a selection of possible challenges is written down in order to be able to discuss potential solutions.

As mentioned, the agile sprints consist of five steps: Plan, Design, Build, Test, and Review. The planning step involves determining goals, scope, test strategy, and possible challenges during the sprint. These are written down on a large paper and attached to a board which would then be visible throughout the sprint. In the design phase of the sprint, ideas are sketched out based on the goal and scope of the sprint. Pen and paper were utilized for sketching as the tools for sketching or prototyping for VR were limited, deficient and cumbersome to use. In the build stage we implemented the design from the sketching to the VR development tools and developed a functional application that could be tested with potential users. For the test step, the test strategy is implemented in user tests, to discover whether the outcome of the development reached, or was in line with, the goals and scope set previously in the sprint. As part of the review step, both the user tests and the sprint completion itself was analysed, resulting in a user test report providing an overview of the insights and feedback, as well as sprint retrospective to explore what needed to be changed in further development. The methods utilized for user research and evaluation during the sprints are presented in the following section.

4.7 Methods for User Research and Evaluation

To form a better understanding of the application's potential users, several research methods are implemented during the sprints in the agile development. In order to secure data from at least two different perspectives (triangulation) the user research utilizes focus groups, prototyping, user tests, post-test interviews, as well as data analysis.

Focus Groups

A focus group is an arranged environment or situation where participants are recruited to give insight about a certain subject (Preece, Rogers and Sharp, 2015). In this research, focus groups were executed to gather information about experiences and expectations about VR environments. Focus groups were chosen because of the ability to create a supporting environment for people to express their opinions (Preece, Rogers and Sharp, 2015). A significant advantage of using focus groups is that different and insightful issues and aspects can come up in discussion that could have been missed otherwise (Preece, Rogers and Sharp, 2015). The purpose of gathering the focus groups is to understand peoples' opinions on VR, what they have used or use it for, how they imagine a relaxing room in VR, and what potential it could have or what use it could serve.

Prototyping

To be able to visualize ideas and gather feedback from potential users, *prototypes* can be developed. A prototype can be described as "one manifestation of a design that allows stakeholders to interact with it and to explore its suitability" (Preece, Rogers and Sharp, 2015, p. 286). As prototyping is an effective way to explore design ideas, this is a crucial aspect of the sprints' design phases as it is used to visualize ideas and concepts for the VR application. In this research, the idea visualization was performed by pen and paper as alternatives to create digital prototypes in VR without programming are limited. Further considerations in regard to prototyping with VR can be found in section 3.3. These kinds of sketches by pen and paper can be described as *low-fidelity prototypes* which are useful because they tend to be quick and simple to produce (Preece, Rogers and Sharp, 2015). The goal of such a prototype is to visualize design alternatives rather than creating a fully interactive prototype. A *high-fidelity prototype* provides more functionality than a sketched one and aims to look more like the final product. With this type of prototype one can test ideas and technical issues with interacting participants (Preece, Rogers and Sharp, 2015).

User tests

To evaluate users' behaviour, experience, and opinions, user tests are performed during the development period. The user tests consist of three sections, pre-test questions, testing the application, and a post-test semi-structured interview. Questions asked before testing the application can concern different personalia and other warm up questions about the users and their experience on different subjects. User tests can be conducted in a *controlled environment* to evaluate the application's usability and engagement among users. Controlled settings have the ability to prevent external influence and distractions (Preece, Rogers and Sharp, 2015). The research's application is developed based on a specific physical room (the Forskningslab), thus, using this room as the testing environment was the logical and obvious choice. During the user tests, data gathering through observation and note taking, in addition to recordings (audio, video, and video recordings through the VR HMD), secure documentation from the application user test. User observation can, according to Preece, Rogers and Sharp (2015), help locate usability problems that would not have been discovered through reports. In addition, user observation can provide insight into how users behave when trying the system, which is of great significance in user-centered design (Preece, Rogers and Sharp, 2015).

What is important to acknowledge is that when performing tests or observations in a controlled environment, it is inevitable that the user will experience the situation as formal, and that they might feel anxious. People being observed in controlled environments, such as the Forskningslab, could lead to behavioural changes, also known as the Hawthorne effect (Preece, Rogers and Sharp, 2015). Trying to lighten the mood by informing participants about the testing, as well as asking informal questions, leading them to talk about themselves, can be beneficial to prevent this (Preece, Rogers and Sharp, 2015).

Interviews

In addition to testing the application on users and observing their reactions, in-depth interviews can bring valuable insight. Interviews collect qualitative data about the user's experience and opinions. The in-depth interviews were performed as semi-structured interviews with a prepared set of questions that ensures that all participants are asked the same questions, facilitating comparison across users when evaluating the test and interviews. It is, however, also possible to be flexible in asking follow-up questions to participants' answers. Allowing comments or questions based on observations made during testing, as well as follow up questions, secure information and elaborations that otherwise could be missed (Preece, Rogers and Sharp, 2015).

Analysing Data

Note-taking, recording (audio and video), and observation contributes to data gathering during a user-centered process. This results in qualitative data, focusing on the *nature* of interactions or themes, patterns, and stories, that should be analysed to gain insight of the users and their encounter with an artefact (Preece, Rogers and Sharp, 2015). A combination of (1) identifying recurring patterns, (2) categorizing data, and (3) analysing critical incidents can be used to analyse qualitative data. According to Preece, Rogers and Sharp (2015) such analysis can start by looking for patterns while gaining an overall impression of the data. A technique to identify themes in the data includes the *affinity diagram,* aiming to organize individual insight to show common structures and themes. Notes on insight are grouped according to their relation to each other, gradually forming themes. The patterns in these themes can relate to behaviour, situations, or events, and form several themes (Preece, Rogers and Sharp, 2015). The second data analysis includes categorization of data, where transcripts from interviews are analysed in detail by searching for words, phrases, utterances, or identifying stories or themes. The main principle of this method is to divide the data into elements which again are categorized (Preece, Rogers and Sharp, 2015). The third data analysis technique involves looking for critical incidents. Specific incidents of significance can be discovered through observing, watching video material or during the interview, where obstacles or confusion appears (Preece, Rogers and Sharp, 2015).

4.8 Chapter Summary

This chapter began by shortly describing a preliminary study executed as a diary study previous to this research. Further, RtD was described as an overarching approach in this research and connected to the desk research and design process. Agile development was introduced and described as the design process of this research, followed by a description of the methods utilized for user research and evaluation during the process.

Chapter 5: Development

[1]This chapter describes the details of the agile development method, introduced in Chapter 4 in a more comprehensive matter. The 3 sprints are presented in the order of execution, with the sprint components, *plan*, *design*, *build*, *test*, and *review* described. The sprints 1, 2, and 3, are presented in a chronological order according to their execution.

5.1 Sprint 1

The aim of the first sprint was to create mixed reality (MR) rooms where the virtually created room would be a 1:1 scaled version of a real room, the Forskningslab. During this sprint different technological solutions to create these rooms were explored, and we gained insight into how people felt navigating in a MR environment. For the user test a total of four participants were recruited which had varying experience engaging with VR.

5.1.1 Plan

The start of sprint 1 was used to prepare the sprints progress and tasks. A planning stage involves determining goals, scope, test strategy, and possible challenges that could be encountered during the sprint. These were written down on a large paper and attached to a board which would then be visible throughout the sprint, see figure 5.1.

[1] This chapter is written as a common chapter for the thesis of both Jonathan Lindø Meling and Stine Olsen Helland. The development described has been done collaboratively.

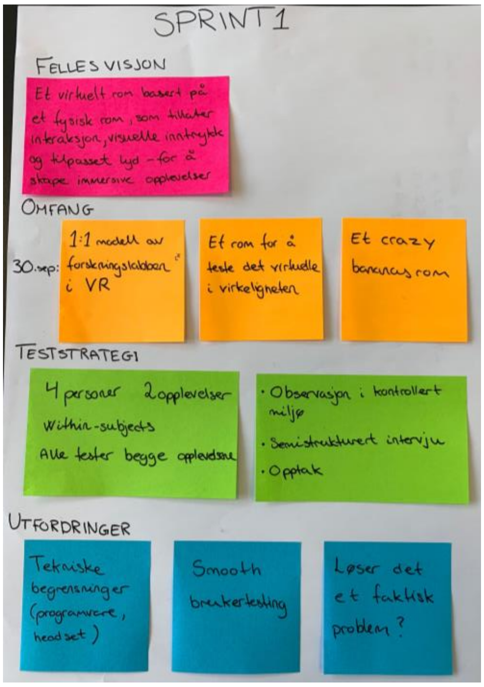


Figure 5.1. Common grounds set for sprint 1 development.

The vision for the research as a whole is to create a virtual room, based on a physical room, which allows interaction, visual impressions, and adjusted sound—to create immersive experiences. This is the overall goal of the project, and thus not very specific, but not too vague either. Next, specific tasks or completions to be accomplished within the sprint were defined. The three focused accomplishments for sprint 1 were:

- 1:1 model of the Forskningslab in VR,
- A room to test the virtual environment in the physical space,
- The second environment which we named *Crazy bananas room.*

For the test strategy we defined which components and structure would be used and which participants we would prefer for the user tests. Finally, to be prepared for possible challenges, potential problems or difficulties that might occur during the sprint were written down.

In the planning phase a scrum board using Trello (2020) was created to maintain an overview of tasks to be done during the sprint. Three sections were included: remaining tasks; tasks in progress; and finished tasks. This created a valuable illustration of the progress and makes it easier to keep track of which tasks should be prioritized. The tasks were divided into categories such as "planning", "technical", "user testing", and "evaluation", according to their characteristics. The scrum board during sprint 1 can be seen in figure 5.2.

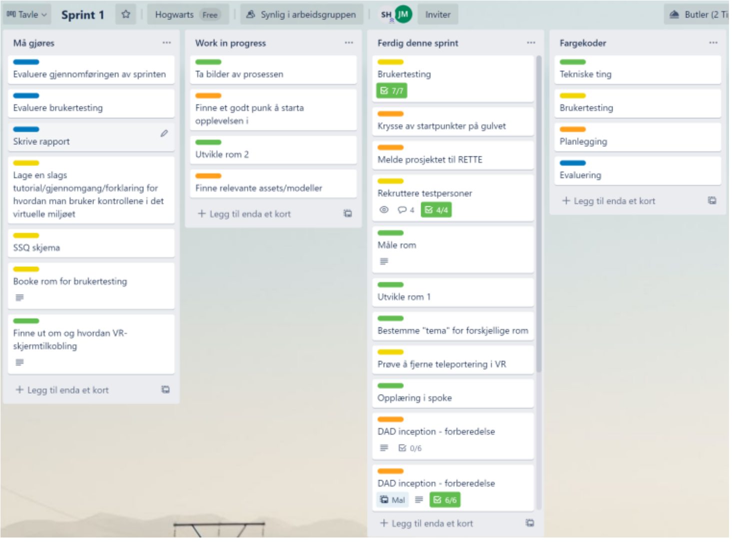


Figure 5.2. Screenshot of the scrum board during sprint 1.

5.1.2 Design

As the prototype relies on the physical space and objects in the Forskningslab we started with measurements of length and width of walls, as well as objects in the room and their positions. The room was then visualised on a floor plan with the associated measures and fixed objects, see figure 5.3.

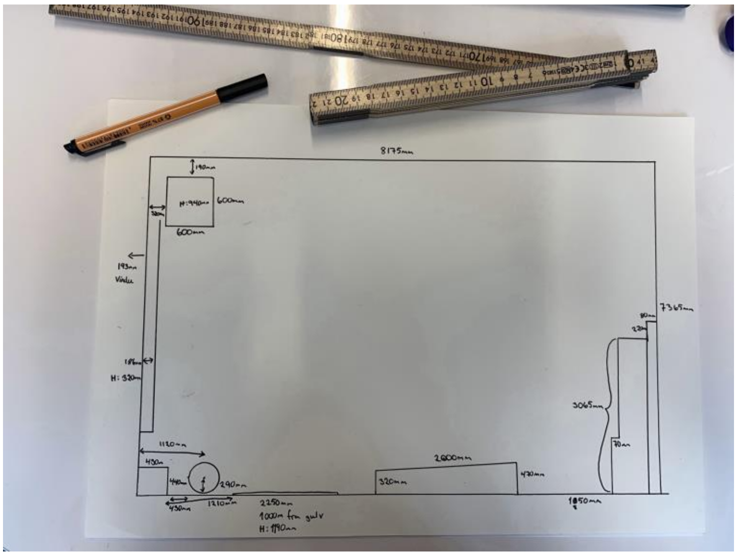


Figure 5.3. Carefully measured walls and objects on a floor plan sketch.

To design and prototype for VR we used pen and paper to visualise how we imagined the room would look in VR. Since the experience is in 360° it can be difficult to design for every aspect of the experience. Thus, to create sketches that covered the entire environment we approached it by drawing the rooms from a Birds eye view, which means "*viewing something from a high angle*" (Merriam-Webster, n.d). This allowed us to efficiently illustrate and plan every object and angle that was to be placed in the environment. Designing from a Bird's-eye-view made the transition of implementing the designs into the building stage rather straightforward. An example of two of the designs is shown in figure 5.4. In the section of the sprint where we sketched and designed, we did not pay consideration to the ability or possibility to implement the exact figures or visions, but to get a more overall expectation or guidance on where to start.

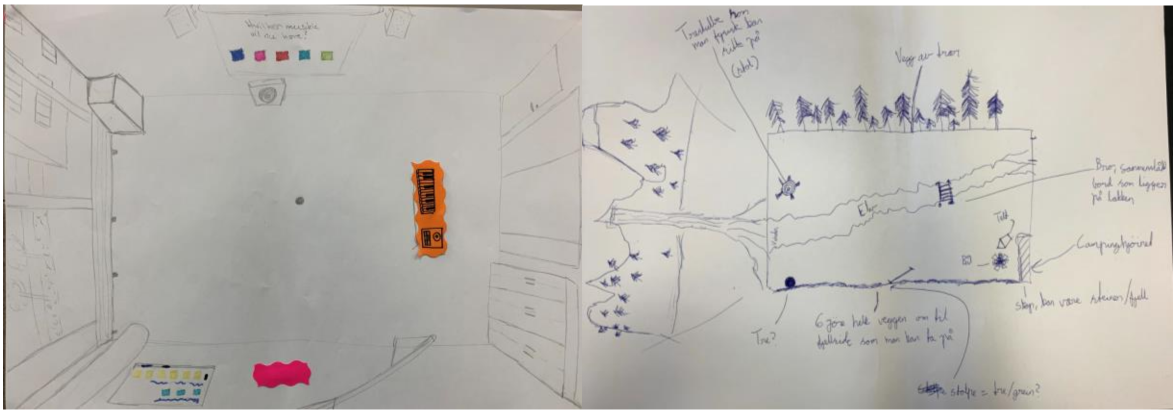


Figure 5.4. Two of the prototype drawings. To the left: close to reality drawing with some extra elements. To the right: drawing of the potential "crazy" room with text explanation.

Considering the floor plan drawing with measurements and the different sketches of how we visualised the two different rooms, the sketches were then used as blueprints for building the environments in Unity.

5.1.3 Build

During the building stage implementations from the design phase were turned into functional virtual environments that were to be tested with future users. In the first sprint prototypes were developed using both Mozilla Hubs and Unity. The original intention was to solely use Unity for the development, but after being acquainted with the potential for simple multiplayer applications using Mozilla Hubs, it was decided to test this as well. Hubs is a platform that lets users share, create, and join virtual rooms. Hubs offers a multiplayer environment without having to write any code of your own (Hubs, n.d.) This offered an opportunity to build an environment faster than developing in Unity, which is a great tool for rapid prototyping.

In the first step of the building stage a 1:1 scaled; virtual representation of the physical room was developed based on the drawings from the design phase. The measurement units used in

Unity are equal to centimetres and meters, making the measurements transferable to virtual representation of the room. The objects in Unity were positioned using meters on the x, y, and z axes. The environmental objects, such as walls and tables, were built using primitive geometrical objects that were scaled 1:1 with meters. To scale the objects to fit with the measurements made in the planning section, height, width, and depth were added to the objects as attributes, using Unity inspector as seen in figure 5.5.

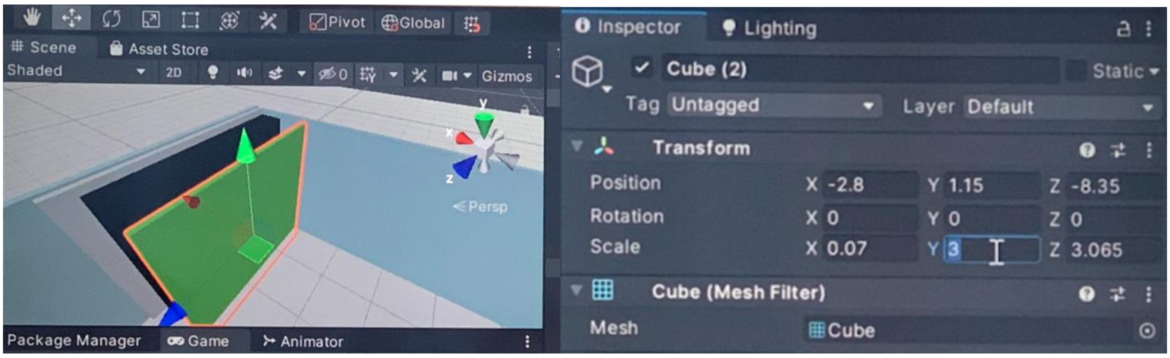


Figure 5.5. Screenshot of an object in Unity and how it is scaled and positioned.

As the environment in Hubs mainly used pre-built 3D models, scaling objects to fit with the measurements of the Forskningslab were more intricate. The objects could not be scaled to fit with our measurements, thus we had to create the “ground” room by using a floor that could be scaled to some degree to fit with the Forskningslab. Other objects were scaled using the 1x1 grid laid out on the floor.

To test whether our implementation of the virtual room was equivalent to the physical room, the starting points had to be at identical locations both in the physical and virtual environment. This was solved by using *calibration spots*, predefined locations that matched in virtual and physical space, helping us keep a reference where the user and objects should be located. The accuracy of the calibration spots was crucial. If a calibration spot was only a few centimetres off it would create a false illusion of the appearance of the environment, causing the user to walk into objects or walls that were perceived to be closer or further away.

A calibration point was marked on the floor with a piece of tape. The physical room we utilized for the prototype was frequently used by teachers and other students, thus we had to measure and mark this point for each session as we could not rely on the mark being at the same position as last time. An example of a calibration spot is illustrated in figure 5.6.

Figure 5.6: The calibration point for the user's spawn position; making sure the user is located in the same position in both the physical and virtual environment.

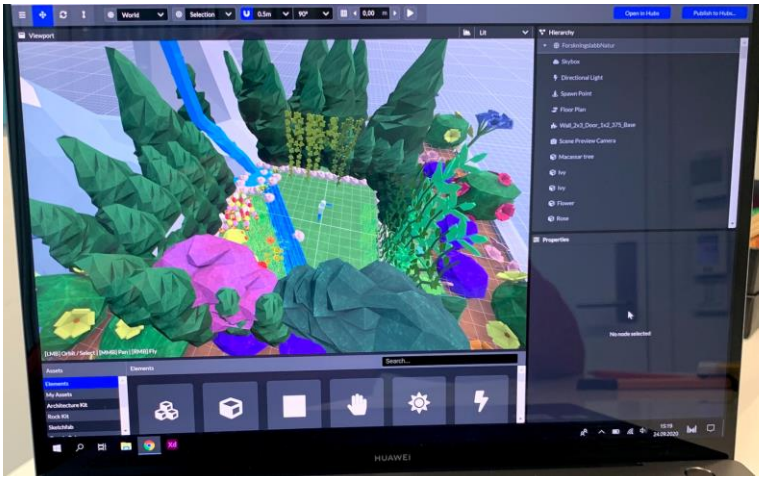


Figure 5.7. Screenshot of one of the environments developed using Mozilla Hubs.

The environment created in Hubs (see figure 5.7) was supposed to represent an idyllic place for the users to reconnect and explore the different visuals. Here we placed a lot of different nature elements to see what happens to the participants' attention, and how they reacted in different areas of the environment.

The recreation of the Forskningslab in Unity had a similar appearance as the physical room as well as some elements that only existed in the VE. These consisted of a mirror where the users could see a reflection of the room, including themselves as an avatar. Some interactable elements were also added to be able to see how the participants felt interacting with virtual elements. The elements, one gun and two different music notes, could be picked up by the user. The notes also played two different songs based on which note was picked up.

5.1.4 Test

During the first sprint the primary focus was to develop two significantly different environments to see participants' reactions to these. Both environments were based on a 1:1 scaled virtual representation of the Forskningslab at MCB. The first environment (environment 1) aimed to look and feel as similar to the physical room as possible, and MR was achieved by having a chair and a table at the same place in the virtual and physical space. The second environment (environment 2) portrayed a nature space with several different items and visuals, making it completely different compared to the physical room.

All participants were recruited through our own network. Due to Covid-19 restrictions we chose participants from the same location at the university as a precaution to minimize the chance of infection spreading across groups outside of the university. A description of the participants can be found in table 5.1.

Table 5.1. Information about the participants gender, age, and previous VR experience.

Subject	Gender	Age	VR experience
1	Female	23	Novice
2	Male	24	Experienced
3	Female	24	Experienced
4	Female	25	No experience

Originally there were supposed to be 2 male and 2 females, but one of the male subjects gave notification at the last minute that he was experiencing Covid-19 symptoms just ahead of testing. This participant had been chosen based on his experience with VR, and a successor had to be found in a limited time space with preferably no previous VR experience. Participant 1 was chosen as a substitute because of her limited experience, leading to an uneven balance between gender, but we believe that this would not be a significant issue as the VR experience level was emphasized. Figure 5.8 shows two different participants testing environment 1, a MR experience, while being observed.

Figure 5.8. Participants testing the environment where the chair and table were a part of the experience.

After the participants had tested both the environments, they were asked to fill out a Simulator Sickness Questionnaire (see figure 5.9 for example filled out by participant 1). The results of the survey were used to determine how comfortable or uncomfortable the VR experience felt for the participants.

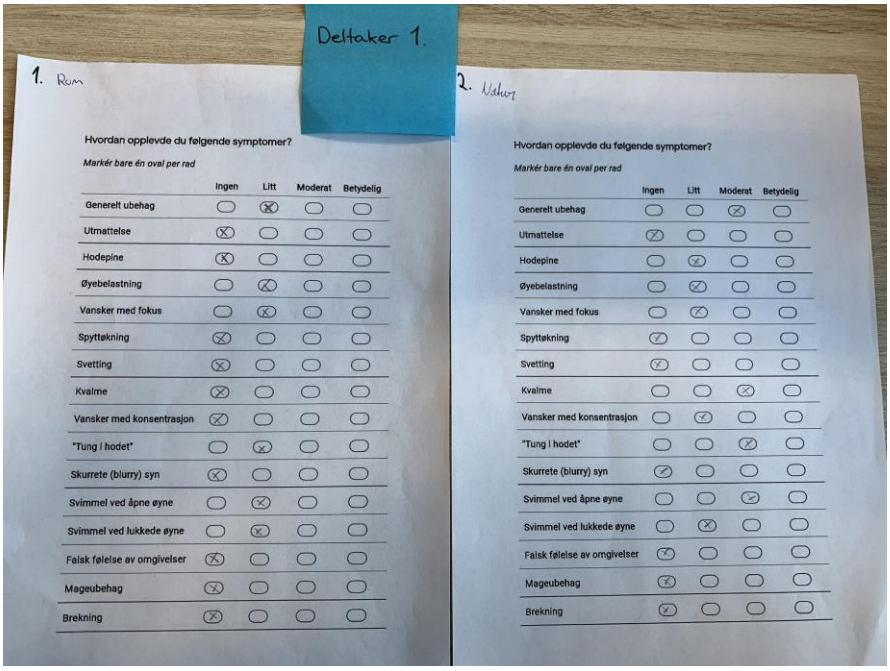


Figure 5.9. SSQ filled out by participant 1 after testing each of the environments.

After the participants had tested both environments and filled out a questionnaire after each, we went through the symptoms with the participant and compared the two questionnaires with each other to see if the participants had any input or feedback concerning this. The interview then continued with the interview questions given in table 5.2.

Table 5.2. Interview guide.

How did you feel about your height?
How would you describe the overall experience?
What did you like about experience 1 & 2?
What did you not like about experience 1 & 2?
What made you decide to start walking in the direction you did?
Did you think about other things while in VR? Did you feel immersed?
Did you feel like you were in a real room while navigating in the VR-experience?
How do you feel about the combination of VR and physical rooms to create a more realistic experience?

Each of the interviews were then transcribed. An analysis of the transcribed answers to the questions and other input gathered from the tests and interviews will be described in the next section.

5.1.5 Review

To analyse the data from the user test and the post-test interview a board with feedback notes from each of the environments was created. The feedback was categorised into positive and negative comments or discoveries, as well as neutral findings. The board was also lined with categories to which field the feedback belonged. To fill in the board the transcribed texts were analysed, and any interesting findings were noted on post-its and placed on the board in the appropriate place.

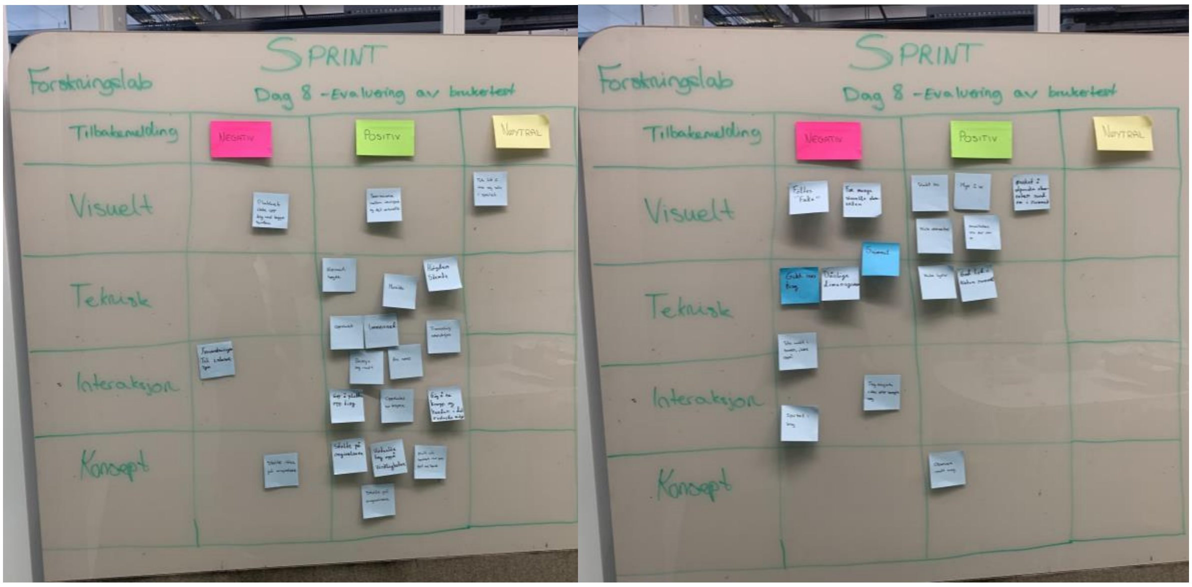


Figure 5.10. Board to visualize findings from sprint 1. Virtual representation of the Forskningslab to the left. Nature environment to the right.

The post-its on the board were then discussed and the suggestions placed on a list for improvement to the next sprint. The findings were written up in a *user test report* which discussed various and key aspects of the user test. The *key findings* from the user test were:

- Participants very much enjoyed interacting with virtual items (picking up and down and throwing) in the virtual world.
- Participants were not afraid of crashing when walking around in the fake-real-world.
- The environment made in Mozilla Hubs lagged more than the Unity environment leading to a general higher physical discomfort among the participants.

Based on the results from all the SSQs the conclusion in the user test report was "*Nature" generally resulted in higher scores on discomfort*. This is most likely due to "lots of elements" and more lagging in the Hubs implementation than in the Unity implementation". The high level of discomfort the participants experienced in the environment developed using Mozilla Hubs, was not desirable and it was decided that all future development would use Unity.

To review the execution of the sprint, a brief sprint retrospective (Scrum.org, 2020) was performed and discussed. This is to discover *what worked well*, *what could be improved, commitments to the next sprint*. The aspects that worked well during this sprint were 1) the design and sketching of our ideas of the virtual environments, 2) the technical implementation, which had fewer technical problems than expected, and, 3) measuring the Forskningslab to create a 1:1 scaled virtual room in Unity. What needs to be improved includes: running the user tests should be more efficient, including 1) being more prepared for our role in relation to the participants while in the VR environment. 2) include more diversity in which test participants are recruited; however, the strict Covid-19 social interaction regulations restricted our ability to recruit people outside our personal network. Thus, the commitment for e next sprint is to create a carefully planned and detailed procedure for the user tests.

Finally, in sprint 1 we completed the scope and were in line with the vision for the development result, however, as the goal appeared to be a bit vague and not easy to measure the degree to which it was reached, the main goal was re-written (see planning section in Sprint 2).

5.2 Sprint 2

To continue the development of the VR application, a second sprint was performed. For sprint 2 it was desirable to continue with the Unity environment from sprint 1 and add features such as interaction between people and a second environment based on the same room. During the sprint, it was investigated how physical space can be the foundation for multiple virtual environments. The different environments, scaled 1:1 with the physical room, were to be accessed from the same application.

5.2.1 Plan

To plan the second sprint e steps from sprint 1 were repeated, setting the common grounds for the sprint execution. The vision meant to apply for the entire development period was revised due to discoveries in sprint 1. The new set of common grounds for sprint 2 is shown in Figure 5.11.

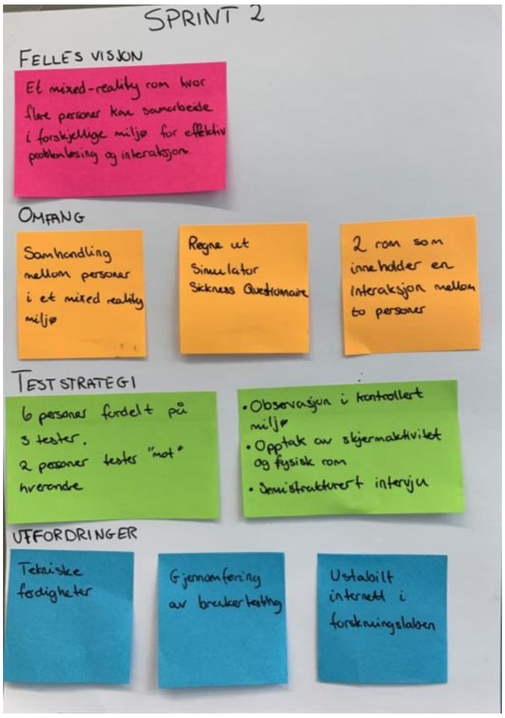


Figure 5.11. Common grounds for sprint 2.

The revised vision from sprint one was written on the board for common ground, "*a mixed reality room where multiple persons can cooperate in different environments for efficient problem solving and interaction*". Next, the three most important tasks to complete were listed as the scope (omfang), 1) interaction between persons in a mixed reality environment", 2) calculate SSQ, and 3) two rooms that contain interactions between two persons. Initially, the test strategy was to test six people in three separate user tests, where each would include testing with two participants. As the Covid-19 pandemic was on a resurgence at the time of testing, a change in plans, described in the test section, was necessary. Possible challenges for sprint 2 were identified as "technical skills", "conducting user tests (in a time with limited physical interaction)", and "unstable internet connection in the Forskningslab".

As in the first sprint a Trello board was used as an overviewing platform. The scrum board used to keep track of sprint 2's tasks can be seen in figure 5.12.

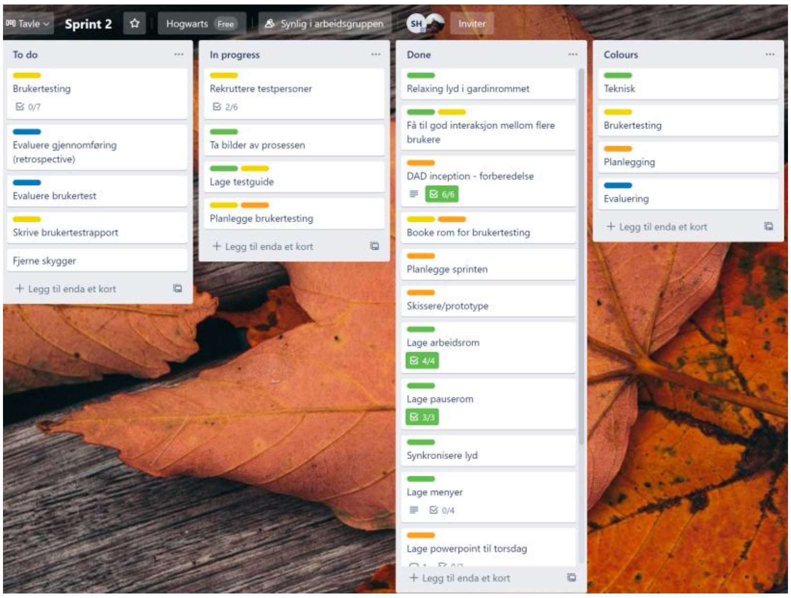


Figure 5.12. The Trello board for the second sprint.

5.2.2 Design

Sketching illustrations by pen and paper from a bird's-eye view proved to be an efficient way of quickly mapping out the features and looks we wanted, so this was continued. This overview of the rooms and features were also of great benefit when placing objects and defining sections in the rooms. One of the drawings of the recreational room, which can be seen in figure 5.13, shows how we envisioned the recreational room to look at the end of the sprint. This ended up being quite similar to the final version of the room.

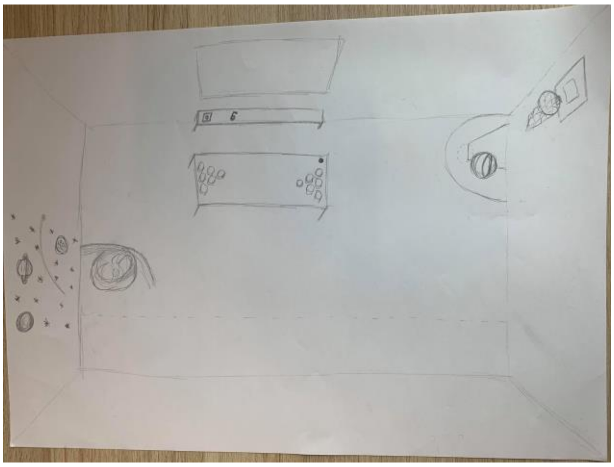


Figure 5.13. The sketch for the recreational room.

5.2.3 Build

Based on the decision not to use the Hubs platform, all development was done exclusively in Unity. Unity is a cross-platform game engine that allowed us to more freely create the prototype we envisioned; on the other hand, this meant we had to spend a lot more time on learning C#, a programming language neither of us had previous experience with before this research. Unity itself is a rather large and complex engine and a large amount of time was spent understanding the workflow and how to create and develop environments. As VR is a rather new area within Unity, there was somewhat limited documentation and resources available for learning.

Multiplayer environment

One of the priorities in this sprint was to create an environment where multiple people could be present and interact with each other. After researching potential engines for multiplayer VR, the *Photon Network* was utilized. This engine lets multiple users engage with each other simultaneously in the same virtual environment (Photon, n.d). After successfully setting up the engine we started to plan and code the functionality of different objects that were to be synchronized over the network.

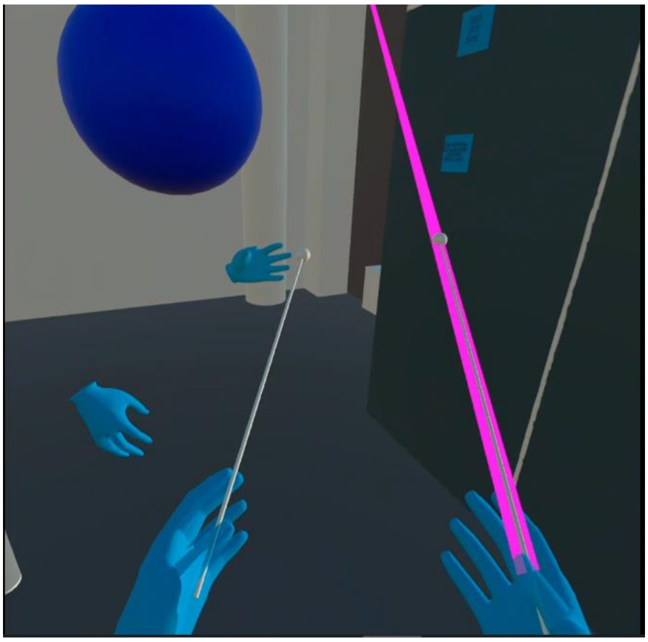


Figure 5.14. The two participants working together to solve a task from the whiteboard.

Functionable rooms

The original plan was to have two different rooms/environments: One where people could work and cooperate on tasks, and one to relax and play games. The workload was divided and each of us focused on one room and helped each other when needed. For the work room it was desirable to create a space that functioned as an improved version of a workspace with which people felt familiar. Thus, the intractable objects that were added to the workspace comprised virtual screens, buttons, post its, a virtual keyboard, and several other functionable objects. In figure 5.15, the work room, virtual and real, can be seen from the same angle.

Figure 5.15. Sprint 2 virtual and physical environment.

Tasks

As part of this user test participants were to solve a selection of tasks that encouraged interaction with the objects in the room. The tasks were listed on a virtual scrum board as “to do” and were:

(1) Place out the different screens.
(2) Stick post it notes to the storyboard screen.
(3) How many used debit cards according to the statistics? Write on a post-it.

Participants were also asked to continuously update the scrum board, by placing the note on “to do”, “in progress” and “done”.

Switching environments

For the users to switch between the environments in the room, a door was placed at the same location as the door in the physical room. As a door is a logical object to change location in the real world, we transferred this to the virtual environment. To change rooms in the virtual experience the user just presses the button with the name of the room at the door. When changing rooms, users will be located in the same position in the new environment as in the previous environment. The recreational room contains two games, basketball and beer pong, and a relaxation area. The beer pong game was placed on a virtual table, which is positioned where there is a table in the real environment, see figure 5.16.

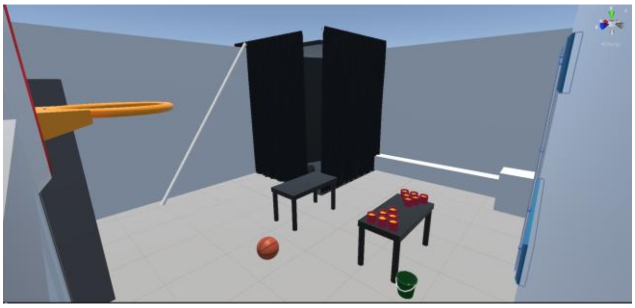


Figure 5.16. An overview of the recreational room with a relaxing area at the back, a basketball game, and a beer pong setup.

In the corner there is an area for relaxation with comfortable chairs, in the virtual and real world, as well as positioned audio which distances this area from the rest of the room. Both of the environments make use of physical objects such as tables and chairs that were represented in both virtual and physical reality.

5.2.4 Test

As the focus for this sprint was to create two rooms with different visuals based on the same physical layout that enabled multiplayer use, two participants were required for each test. The initial plan, described in the plan section, was to have six participants in total, divided in three tests. However, restrictions regarding the Covid-19 pandemic were changing frequently at the time, limiting student access to the university campus. Consequently, we decided that an expert evaluation of the application would be beneficial, as well as minimize social interaction. A request was made to run user tests with two chosen experts to the administration responsible for access to the Forskningslab, which were granted.

For the test one expert in interaction design and one in VR were recruited, details in table 5.3. The experts tested the VR application at the same time, and were asked to solve tasks together in the same virtual and physical environment.

Table 5.3. Details of the experts recruited to user tests in sprint 2.

Subject	Gender	Age	VR experience	Area of expertise
1	Female	35	None	Interaction design
2	Male	27	Expert	VR

Before the participants entered the environment the research aims and the concept they would be testing and evaluating were explained. Different functionality with the HMDs and controllers were also explained, as well as what they could expect from the application's workroom and recreational room. Questions asked before and after the VR experience are listed in table 5.4. Data collected during this user test includes video recordings of the participants VR exploration and an audio recording of the interviews.

Table 5.4. Questions asked before and after the expert user test.

Before
What background do you have?
What experience do you have with VR?
Have you been in a VR-environment together with another person?
Have you been physically *and* virtually in the same room as someone before?
After
What do you think about being two people in the same virtual and physical room?
What is your experience in executing the tasks?
How was it to interact with another person in VR?

How did you feel about the usability in VR and in the tasks that were performed?
Did you experience any limitation?
What could a concept like this be used for?
Did you expect other things in the break room? What makes you relax?
What is your relationship to work and breaks? Are you able to separate between them?

5.2.5 Review

As in sprint 1, this step consisted of reviewing the user tests, as well as reflecting on the sprint execution as a whole. To review the data gathered from the user test the audio recordings were transcribed and interesting aspects were identified. The video recordings made it easier to recall details which otherwise might have been missed. An analysis of video showed that the interaction between the users in the virtual and physical world worked well. An analysis of the interviews showed that both experts commented on how they felt aware of the other participant. Observations made during the user test showed that while cooperating on the tasks the participants used both verbal and non-verbal communication. Non-verbal communication included hand gestures such as pointing in a direction or handing over an object to the other participant. Even though the interaction went well, several usability problems arose during the test. A recurring challenge was the affordance of the button located on the table; it was not quite clear that the buttons could be pushed. This led to the participants struggling with the first task, which included using buttons to activate the virtual screens.

In the interview, both participants expressed that it was hard to see which direction the other person was looking because their heads were represented as a blue sphere and not something with humanoid features. This caused confusion as they were not sure if they were looking in the same direction, and this impacted their task solving efficiency. It is likely that this affects how immersive the environment is perceived. Both participants also commented that the Virtual keyboard was cumbersome to use when both wanted to access it at the same time, as it was placed at the same spot for both users and took up a lot of space. When going through the SSQ with the participants, they reported a low degree of nausea and generally did not feel much discomfort during the test. This is most likely because of the coherence between the physical and the virtual room, and the limited number of items and animations.

Findings from the user test conducted in sprint 2 were sorted as positive or negative, and divided in three different categories: concept, technical, and interaction. The notes are based on exact citations from the participants while in the VR environment, and feedback during the post-test interview. An overview of the board with user test notes can be seen in figure 5.17.

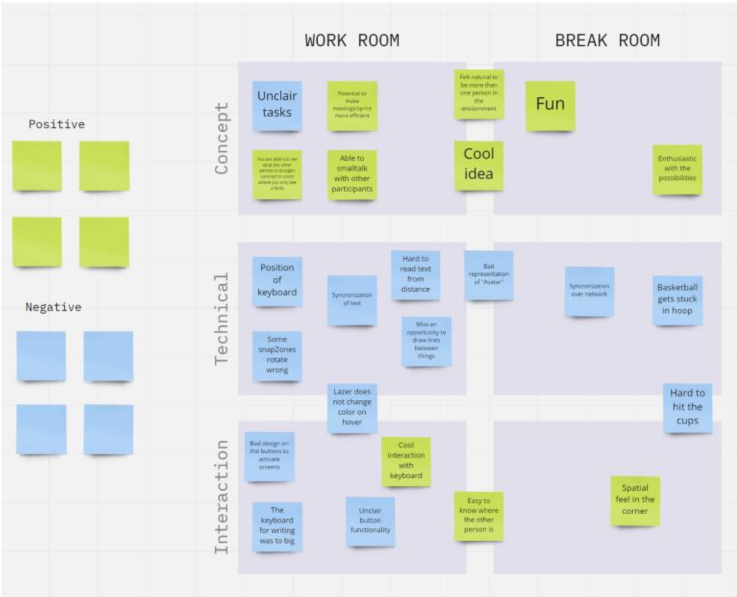


Figure 5.17. Miro board with findings from the user test in sprint 2.

To review the second sprint a sprint retrospective was performed to identify what worked well, as well as identify potential improvements for the next sprint. We found that the technical implementations done in this sprint worked well. The scope of creating a multiplayer environment was successful, as well as the creation of two rooms that each consist of an interaction between at least two people. Several new functionalities, writable post-its, sticky zones on the virtual screens and the option to switch between rooms without having to exit the application, were successfully added. In addition, binaural sound as well as the mix of physical and virtual objects were implemented successfully. As explained in the test section, the test strategy concerning participant numbers could not be implemented due to social restrictions, however, the strategy of observing in a controlled environment, making recordings, and interviewing using semi structured interviews was conducted as planned. Thus, at the end of sprint 2 the vision for the research is still valid, and not changed for Sprint 3.

5.3 Sprint 3

Starting sprint 3, Norway was in social lockdown and the university campus was closed. This led to a digital execution of the sprint, where each of us worked from each of our living rooms. This influenced the workflow with the application as we could not test it in the appropriate environment, the Forskningslab, located on the university campus. Therefore, the majority of the additions made in this sprint had to involve features that were not dependent on the physical location. This included: a new concept of an auditory facilitator guiding users; the ability to communicate over a network; and several technical improvements and features.

5.3.1 Plan

In the third sprint we repeated the first starting steps from the previous sprints, creating a new set of common grounds. The vision for the development remained the same, "*A mixed reality room where multiple persons can cooperate in different environments for efficient problem solving and interaction*". The new common grounds for sprint 3, in addition to the remaining vision, is shown in figure 5.18. The scope for sprint 2 consisted of: illustrating how an automatic facilitator can be implemented; developing functionality for the possibility to draw lines; and technical improvements.

Figure 5.18. Common grounds set for sprint 3 development.

During the planning stage of sprint 3 the tasks that needed to be done to complete the scope were defined. These were listed on the scrum board together with findings from the second user test, see figure 5.19. This was done to keep track of which tasks were in focus during the sprint, as well as an overview of which tasks are in progress and completed.

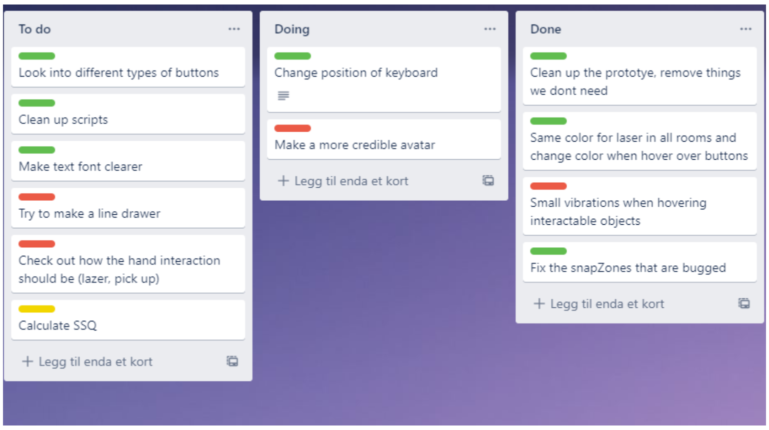


Figure 5.19. Sprint 2 improvement tasks.

5.3.2 Design

In previous sprints we sketched our mental visions of the different rooms with pen and paper. This sprint does not introduce new rooms or environments, therefore the design step focused on design decisions for the existing rooms and objects, including buttons, laser pointer, and avatar.

Buttons

An important finding from the second sprint was the lack of affordance in the interactable buttons, which one of the participants described as *"floating screens"*. Initially the participant did not understand that they were buttons that could cause action. In the beginning the buttons appeared similar to a pushable button from a website, the idea of which was that this would feel familiar to participants. However, it turned out that they expected buttons that felt and looked familiar as physical buttons rather than digital; thus the buttons were updated. Figure 5.20 shows the advancement of the button design during the sprint.

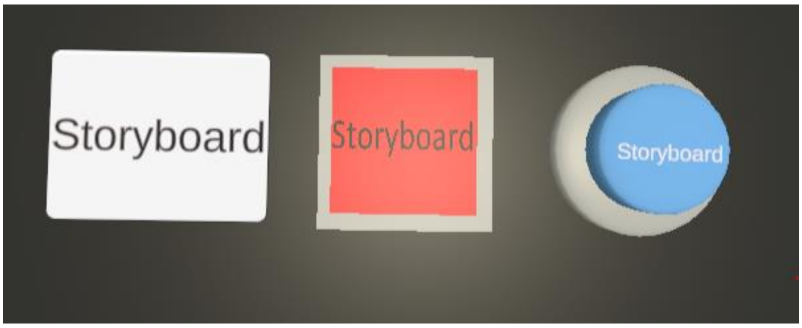


Figure 5.20. Evolution of button design.

The button to the left in figure 5.20 was the one causing difficulties in sprint 2. During sprint 3 this was improved to the one on the right, which resembles a real-world button. The new button also gives feedback in the form of a soft vibration when pushed.

Laser pointer

In addition to picking up and interacting with objects by hand, each person is able to pick up and interact with objects using a laser. The laser functions as an extension of the hand, allowing interactions with objects further away. When the laser is not active it is coloured white, when a user points at an interactable object it changes colour to red signalling that the user has aimed the laser at an interactable object.

Avatar

The initial avatar did not have any facial attributes. This caused challenges relating to non-verbal communication, but it also impacted the presence as the participants were never aware of what direction the other person was looking. To solve this, we incorporated an avatar with facial features, such as hair and eyes, in addition to the body, head, and hands.

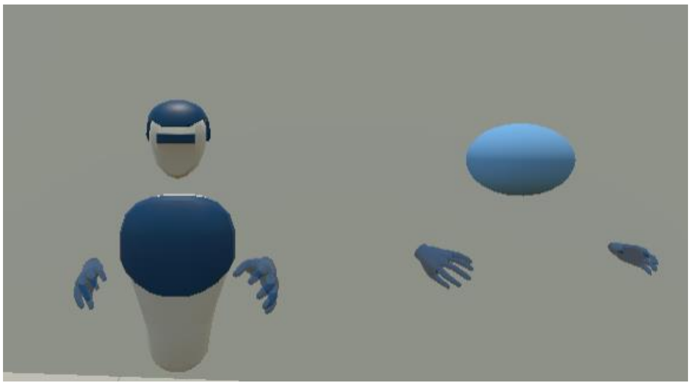


Figure 5.21. The original avatar on the right. The newest implemented avatar to the left.

5.3.3 Build

In the build section of sprint 3 we continued the development in Unity as the previous sprints had proved this software sufficient. The build section was divided into three main sections: drawing, automated facilitator, and proximity chat.

Drawing

The ability to draw lines between objects, especially in the work room, was a feature considered desirable in the application. However, previous attempts to implement this during the development were unsuccessful due to the lack of documentation and available tutorials. As this feature again was brought to attention by the expert testers during the user test in sprint 2, further investigations towards a possible solution were conducted. This solution was to combine a functionality of recognizing objects drawn by moving hands and the creation of objects when something was triggered. This resulted in a line appearing when triggering the selected button, and moves along with the controller when it is held in. Limitations with the solution are that the lines that are drawn are only visible to the person drawing the line. We also struggled to implement an eraser function where the user can erase part of the line, however, it is possible to delete the previous drawn line in its entirety.

Automated Facilitator

To better understand the full potential of efficient collaboration and task performance in virtual environments, an automated facilitator that would take the participants through a set of tasks was implemented. This idea arose after one of the experts in the previous user test gave feedback on how he often felt meetings over Zoom felt inefficient and time consuming. Thus, the facilitator's role is to efficiently guide participants through each step of a work process. The facilitator's quotes and task explanations were implemented using a text-to-speech generator. The facilitator is activated when a user in the environment presses the facilitator button.

Proximity Chat

For the users to be able to communicate from different physical locations we needed to implement a voice chat. Proximity chat is a way to imitate how sound travels in a way similar to real-life. In short, the closer two people are to each other, the louder their voice will be. This is different from how most digital communication/collaboration is done today over platforms such as Zoom, Teams etc. This feature creates a setting closer to the physical world enabling people to talk in groups rather than always addressing everyone in the same room or video conference. As Photon was being used to set-up the multiplayer environment, the voice chat was also implemented using *Photon Voice*. This allowed for a fluent integration of the voice chat, since the multiplayer environment was already hosted using Photon Network.

5.3.4 Test

As mentioned earlier, the strict social lockdown and closed campus limited a full implementation of sprint 3, where the test stage was highest influenced. As the university campus was completely closed, with no possibility to access for user testing, we planned for a future user test to be executed when possible. The user test was carried out three months later than planned, instead of coherent with the other steps in this sprint.

The purpose of conducting these user tests is to evaluate the usability of the application, gain knowledge of how the facilitator was understood, and identify the extent to which participants experienced simulator sickness. In addition, an observation of how participants felt interacting with users in the same virtual space that were not in a shared physical space was to be conducted. In addition, each of the individual research subjects were observed and investigated.

The initial plan was to have five sets of user tests, with at least two participants in each. However, the restriction against social contact limited the amount of user tests to a singular set with two participants.

Before the participants were to enter the VR environment the questions listed in table 5.5 were asked to gain some fundamental knowledge of the participants and their experience with VR.

Table 5.5. Interview questions for before and after the user test.

Before
Age, profession/education, tech-interest
What is your experience with VR?
Have you cooperated with someone using VR? How?
What are your thoughts around communication through Zoom/Teams or other video platforms?
(If previous experience with VR: Do you have any thoughts regarding usability with VR? any aspects that are difficult to understand?)

Further, an introduction and short explanation of the concept and the application was given. After the user test, the questions in the interview guide, shown in table 5.6, were asked. This was carried out as a semi structured interview. This method was utilized to secure topics that were of interest were not missed while interviewing participants.

Table 5.6. Interview guide for after the user test.

After
What was your general impression regarding usability in VR and the tasks you were to solve? Was anything unclear?
Were you able to focus on the tasks rather than the controllers you had to use to solve them?

Did the interaction with the environment feel natural?
How did you experience following the auditory facilitator?
How did it go completing the given tasks?
How was it to communicate/interact with another person in VR?
Did you experience any limitations?
Did you think about other things while in VR?
Did you become aware of objects or your physical surroundings while executing the tasks?
Presence
Did you feel that you interacted with a *real* person in the virtual environment?
Did you ever forget that you were in a virtual environment?
What do you think about seeing the body language of the person you are working with?
Did you feel more present in the cooperation than over Zoom or Teams?
Did you feel present in the virtual environment?
Did you feel so immersed in the environment that you forgot the time?

5.3.5 Review

For reviewing the sprint, the common grounds, set and visualized during the planning stage, to discover to which extent this had been executed would have been considered. To review the user tests, transcriptions of the audio material were made, as well as reviewing the video material by noting interesting comments or topics to compare across participants. A brief user test report was written to get a clear overview of the preparations, execution, and results.

Finishing this sprint, we fulfilled the vision of "*A mixed reality room where multiple persons can cooperate in different environments for efficient problem solving and interaction*" to the best of our ability, given the Covid-19 restrictions. The scope of the sprint was also implemented successfully.

Executing the sprint digitally worked well because of Unity's collaboration tool, communication through Zoom, and task overview using a Trello board. As we were not able to access the location the application was dependent on to function fully, user tests were not performed coherently with the other steps in this sprint, causing a few months of delay. Further analysis of the data gathered from this user test are presented separately in each of the theses.

5.4 Chapter Summary

This chapter described the agile development that was utilized in this research as a method to explore and create VR experiences in an application. The development was iterated in three steps, called sprints, each with different areas of focus. Each of the sprints are described in detail with their purpose and accomplishments. The result of this development will be presented in the following chapter.

Chapter 6: Results and Discussion

This chapter presents the application resulting from the development research and answers to the research questions. A questionnaire exploring flow and usability, developed through investigating previous research and findings from user research, is presented, and the questionnaire results from the final user test is presented.

6.1 Description of the Application

This section presents the final result of the application. The features of the application are introduced and explained along with illustrations from the application. The application serves as a proof-of-concept prototype, where users can interact with the application to experience the core functionality of the intended final product. This functionality includes movement, interactable components, a facilitator guiding users through tasks, as well as two different rooms, each dedicated to a different purpose, respectively work and recreation.

The Concept

The final prototype, a VR application, is designed to facilitate cooperation in an environment for executing tasks, called the *work room*, and an environment facilitating breaks and recreation, called the *break room*. Both rooms are developed based on the physical room *Forskningslab* at the university campus. A detailed description of the development process is found in Chapter 5. The aim of the work room is for the users to step-wise execute a set of predefined tasks. The users are guided by an auditory facilitator introducing one task at a time. The facilitated tasks include simple assignments such as “place different boards around the environment” and “write a fact on a post-it note”, however, it is envisioned that more complex exercises and workshops could be facilitated using this concept in future work. The main focus during development was to make an environment that could work as a proof-of-concept, and that could be tested with potential users during the development to receive feedback on both the concept and the usability of the application. As VR offers an environment with minimal interruptions from the physical world, investigating users’ reactions to assignments similar to work or study situations, as well as if the break room encourages relaxation or recreational activities, was of interest. The break room was therefore developed to distinguish between work and breaks. In the break room there are three main activities: a beer pong table, a basketball game, and a cubicle with sofas, lower light conditions, and relaxing sounds.

Work room

Both environments in the VR application contain several interactable objects. In the work room users are guided through a selection of interactions through an auditory facilitator explaining the tasks that should be completed. The tasks utilize the benefits of having a virtual workspace, with several screens of information that can be moved around to preferred locations (see figure 6.1: Left), post-its that can be written on (see figure 6.1: Right) and placed on several surfaces, as well as the ability to draw lines between objects or drawing to visualize a thought.

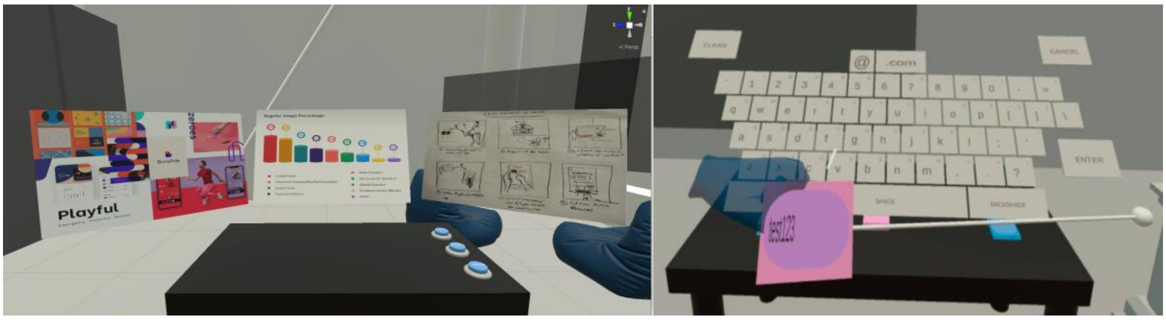


Figure 6.1. Left: Virtual screens activated by the buttons. Right: Virtual keyboard for writing on post-its.

The virtual facilitator was developed to create an efficient execution of tasks among users, by guiding them through a desired set of tasks. The facilitator is activated by pressing a designated button, causing a presentation of the facilitator and its purpose. Further, the facilitator continues with presenting the first task. It should be noted that the tasks are rather short and simple, as the purpose is to investigate the potential of an automated facilitator. However, the intention is that tasks can be modified or advanced in further development of such a facilitator.

Break room

The study performed preliminary to this research (Helland and Meling, 2020) showed that people struggled to separate between work and breaks, arguing the difficulty of engaging in recreational activities whilst situated in an environment associated with work. Thus, this research aims to explore how a physical space can be utilized for multiple purposes using VR technology. Results from the preliminary study also implies that people prefer different activity levels when taking breaks during work or studies, thus this room includes three different “break activities”. These activities consist of a game of beer pong, a basket with a basketball, and a sofa area in a relaxing cubicle. The intention of the first two activities is to engage the user in a competitive action where they are physically active. The third, relaxing cubicle, intends to have a relaxing impact, targeting users that may find a calm environment more appealing when taking a break.

Figure 6.2. The three main activities in the break room; beer pong, basketball, and the relaxing cubicle.

6.2 User Centered Design

RQ1: *How can User-Centered Design facilitate the development of a Mixed Reality application for a VR headset?*

In order to answer RQ1, reflections over the development process are presented in this section. As part of a user-centered design method, agile development was utilized to secure progress throughout the development, while simultaneously including users. Agile development, as introduced in Chapter 4 and elaborated in Chapter 5, consists of sprints; short, time-boxed iterations—each leading to a test with potential users—which secures the incorporation of user feedback. By including users during the design process, valuable feedback on ideas and concepts were gathered to improve the application regularly. Using this development method resulted in several usability issues being uncovered and improved during the process. Usability issues included the affordance of several buttons in the environment, which lacked signifiers indicating that the button was interactable. A description and illustration of how the buttons evolved during the development can be found in section 5.3.2. This section also includes other redesigns based on the feedback from user test participants.

Section 2.4.1 described UX design principles in light of VR design and development which formed a foundation for the development process. Having such considerations in mind throughout the process contributes to keeping the focus on potential end users of the VR application. This way, one can avoid poor design choices and poor interactions. That being said, it is unlikely that this focus alone causes flawless designs and seamless interaction. By utilizing agile and its continuous sprints, the process itself encouraged testing the artefact frequently, contributing to feedback and improvements in the interaction design. To summarize user-centered design was beneficial for securing progress, keeping the users in mind, and discovering usability faults throughout the development.

6.3 Findings from User Research

RQ2 *What is the relationship between usability and flow in a VR environment?*

In order to answer RQ2, the findings on usability made during the development (see Chapter 5 and summary in section 6.2), together with the preliminary diary study and user tests carried out as part of the development process, will be presented and discussed. The findings are organised in the categories: *Presence and Immersion*, *Flow*, *Investigating Usability and Flow*, and *Degree of Comfort*.

Presence and Immersion

This section presents findings relating to being immersed by VR and feeling present in an environment, based on the preliminary study and user tests.

Preliminary study

From the preliminary pilot study, performed as a diary study with two participants exploring different VR applications, data were gathered through self-reports over a two-week period, and a semi-structured interview at the end. Interesting findings include feedback from an application facilitating relaxation (Cosmic Flow), where the two participants had conflicting experiences of feeling present in the environment. Participant 1 expressed feeling bored because of the lack of interaction, causing stress about other tasks that had to be done.

Participant 2 expressed that exploring this VR application eliminated background noise from the physical environment, leading to fewer interruptions. Participant 2 also mentioned that meditation was somewhat of an interest to him. This could be a factor that contributed to him feeling more present in the application than participant 1. Participant 1 expressed that the day this application was explored was an abnormally stressful day with multiple tasks to complete, which could have contributed to focusing on that instead of the VR experience.

User tests

Findings from interviews after the first set of user tests performed during sprint 1 showed that the participants felt engulfed by the two different VR applications. One of the questions from the user test guide was “did you think about anything else than being in the VR environment?”. This question helped investigating how engulfed the participant felt using the technology, and their presence in the virtual environment.

“I felt very engulfed” - Participant 1

“No, I did not think of anything else, just that I am here (in the virtual experience)”
- Participant 2

The general feedback was that the participants did not experience thinking of other things during the VR experiences and expressed being engulfed or immersed. One of the participants expressed that the environment with several elements (nature) got her more engulfed because there was more to explore. In the other environment, imitating the physical room of the Forskningslab, she expressed being more conscious in the environment, being aware that the virtual room was the “same” as the physical room and that the different elements were an extension of the room. Observations made during the user test showed that this participant was very engaged by the environments, expressing motions of excitement while moving around.

Flow

This section will present findings indicating flow. The findings originate from a preliminary diary study (explained in section 4.2), and user tests run during the development of the VR application. The findings are derived through investigating data for cues or indications that can imply that the user has experienced flow, based on the knowledge of flow presented in section 2.2.

Preliminary study

One of the VR applications the participants were to discover during the diary study was an environment situated in a 3D colouring book (Color Space). After testing this environment, participant 1 drew parallels to meditating, stating that it was easy to forget the world around her, helping to decrease stress. These statements could imply that the participant experienced flow because of the ability to forget the world and outer stress. When this participant tested the other VR applications (Cosmic Flow and 360 Nature) she reported that it did not get her thoughts away from the fact that she had a lot to do, which indicates that these experiences did not facilitate flow for her. Participant 1 reported that interaction caused exclusion of other thoughts, implying that for her, interaction or task execution helped facilitate flow (recall section 2.2). The other participant, however, expressed that using Cosmic Flow for meditation helped remove disturbance and that he could spend a lot of time in it without noticing time passing by, which indicates a feeling of flow. Both participants expressed that Color Space, which allowed interaction, was the one that caused them to think the least of their physical surroundings.

User tests

During the user tests executed as part of the agile development, several findings indicating flow came to light. Findings from user tests executed while developing the research's VR application are presented here.

User test sprint 1

Participants expressed that the VR application contributed to immersion and the elimination of distractions. These expressions can imply that they were able to "shut out the world" and that they experienced flow in exploring the VR applications.

"I did not think of anything else, I was very focused" - Participant 3

During the first set of user tests, it was not made clear what our role as observers were (recall that the intention was that we were in the physical environment to observe), and some participants ended up asking questions about what they "should do" or made general comments. It was desirable to observe natural comments based on experiences, but a few of the participants asked questions during the session that we felt the need to answer, as we had not clearly specified our role to the participants. Having this interaction with the participant probably caused participants to be more aware of the surroundings outside the VR headset, disturbing their flow. In addition, participants were told that they could leave the experience when they wanted, leaving them with a choice of when to exit the environment. This could also disturb the flow, as they would have to think of this and decide for themselves.

"I felt more engulfed when I could see my body and hands in a mirror" - Participant 4

One of the indications of experiencing flow is feeling less aware of the self (Nakamura and Csikszentmihalyi, 2014), and this expression is interesting because the participant expresses that the appearance of her body increases how engulfed she felt in the environment. Research shows that this statement could be an indication that the participant experienced a virtual embodiment and identified herself with the virtual body (Kilteni, Groten, and Slater, 2012). The participant's awareness of her avatar through the mirror does not necessarily imply that she is aware of the virtual body as an object which could prevent the performance of any activities or preventing the ability to experience flow. Rather, these are indications that the participant identifies with the virtual body as she does with her physical body in real life (Kilteni, Groten, and Slater, 2012). In this way, except when staring into a mirror, the body is not an object of focus but rather embodied, and so something that can be acted through *towards* objects (Ihde, 1990).

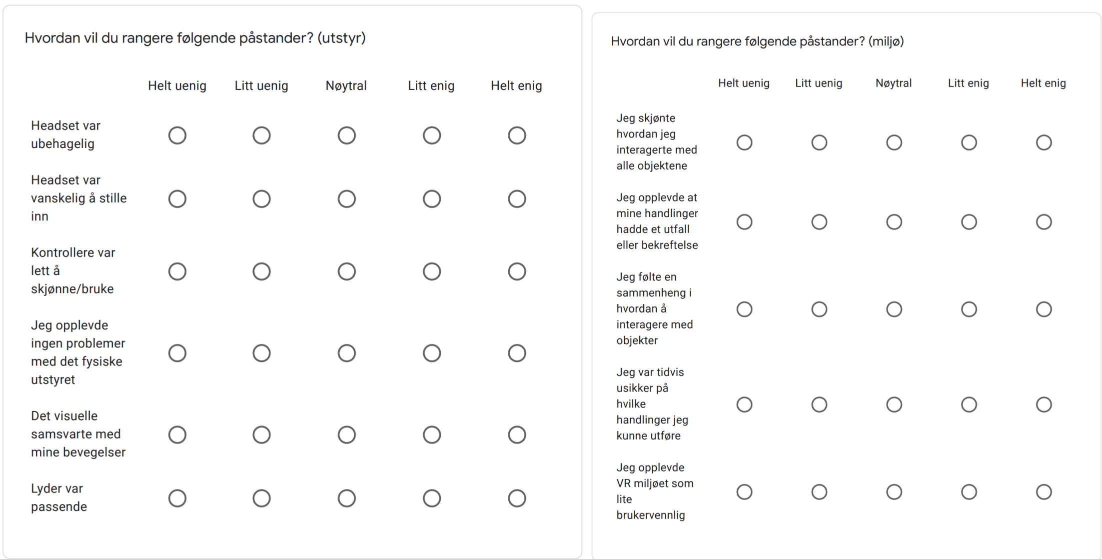
User test sprint 2

The second set of user tests were performed as an expert evaluation by an interaction design expert and a VR expert. The user test investigated the concept of the application, as well as the interaction design and usability. Searching for flow indications on video recordings showed that the participants were highly engaged in performing the tasks in the workroom and cooperated well. The games in the break room also engaged the participants, according to their body language as well as their verbal communication with each other. The relaxing section of the break room, separated by virtual curtains, initially engaged according to the participants' verbal communication, where they expressed that it felt like they were in a different room. Subsequently the participants appeared calm and present after sitting down on the sofas, however, this section is the part where the participants had been told to spend time at the end of the experience, possibly causing them to be aware and think that this is the *exit*. This was also the least interactive part of the VR application, which had no goal other than to facilitate relaxation. This can, according to Reeve (2018), lead to boredom, and thus the exit of flow (Neal, 2012).

At the beginning, the tasks to be performed in the work room were not clearly enough communicated by the researchers, causing confusion among the participants while executing the tasks. This could have impacted the participants’ ability to enter flow, as it interrupted the task execution. As this was discovered during the second sprint, the approach to how the tasks should be introduced were changed during the third sprint. Here, an auditory facilitator was implemented to explain more carefully how to execute the tasks in the work room.

Investigating Usability and Flow

A questionnaire was developed to investigate the relation between the user’s experience of flow. The statements in the questionnaires are based on the theory of flow and principles of design, introduced in Chapter 2. The questionnaires were filled out by participants during the delayed user test in sprint 3 (recall section 5.3), after experiencing a VR application. In the questionnaire they were asked to rate whether they agreed or disagreed with a set of statements about flow and usability, on both the equipment and the experience itself. The questionnaire, seen in figures 6.3 and 6.4, utilized a 5-point Likert scale where the participants rated their level of agreement from *strongly disagree* to *strongly agree*. The questionnaires can also be found in Appendix A.


Hvordan vil du rangere følgende påstander? (utstyr)

	Helt uenig	Litt uenig	Nøytral	Litt enig	Helt enig
Headset var ubehagelig	○	○	○	○	○
Headset var vanskelig å stille inn	○	○	○	○	○
Kontrollere var lett å skjønne/bruke	○	○	○	○	○
Jeg opplevde ingen problemer med det fysiske utstyret	○	○	○	○	○
Det visuelle samsvarte med mine bevegelser	○	○	○	○	○
Lyder var passende	○	○	○	○	○

Hvordan vil du rangere følgende påstander? (miljø)

	Helt uenig	Litt uenig	Nøytral	Litt enig	Helt enig
Jeg skjønte hvordan jeg interagerte med alle objektene	○	○	○	○	○
Jeg opplevde at mine handlinger hadde et utfall eller bekreftelse	○	○	○	○	○
Jeg følte en sammenheng i hvordan å interagere med objekter	○	○	○	○	○
Jeg var tidvis usikker på hvilke handlinger jeg kunne utføre	○	○	○	○	○
Jeg opplevde VR miljøet som lite brukervennlig	○	○	○	○	○

Figure 6.3. Usability statements on the VR equipment and the VR environment.

Hvordan vil du rangere følgende påstander?

	Helt uenig	Litt uenig	Nøytral	Litt enig	Helt enig
Jeg følte meg fokusert og konsentrert på oppgavene jeg løste	○	○	○	○	○
Jeg tenkte ikke på meg selv eller var spesielt selvbevisst	○	○	○	○	○
Jeg følte kontroll over handlingene jeg utførte	○	○	○	○	○
Jeg tenkte ikke på tid eller tidsbruk	○	○	○	○	○
Jeg synes aktiviteten i seg selv var givende	○	○	○	○	○
Jeg fokuserte mer på å "bli ferdig" enn å utforske miljøet	○	○	○	○	○

Figure 6.4. Statements to investigate flow after experiencing VR.

This questionnaire was filled out by two participants who tried the VR application. The results are discussed around the 6 flow statements (recall section 2.2).

(1) *I felt focused and concentrated on the tasks I solved*

Participant 1 slightly agreed to feeling *focused* and *concentrated* on the tasks being solved, while participant 2 answered neutral. Further, participant 1 highly agreed that the acts caused a result or action which could indicate that right feedback at the right time can facilitate focus and concentration, indicating flow. Participant 2 slightly agreed that the act caused a result or action, implying that its feedback possibly did not always occur appropriately, preventing full focus.

(2) *I did not think of myself or felt particularly self-conscious*

Participant 2 slightly disagreed to not thinking of the self and feeling self-conscious, while Participant 1 slightly agreed. This implies that participant 2 felt more self-conscious than participant 1. Further, participant 1 slightly agreed to understanding how to interact with objects, while participant 2 answered neutral. This indicates that users become more aware of the self when they do not know which action is possible, or not possible, explainable through Norman's (2013) principle of constraints. This self-consciousness possibly occurs when possible actions are not clear, causing users to think that it is their "fault" that they cannot figure out how to interact or proceed.

(3) *I felt in control of my actions*

Neither of the participants felt that they were in *control* of their actions, one answering neutral and the other one slightly disagreed. This is confirmed by participant 1 by slightly disagreeing to the controllers being easy to understand, and by both slightly agreeing to being insecure of the possible actions.

(4) *I did not think of time or time spent* & **(6)** *I focussed more on getting the tasks done, than exploring the environment*

Participant 1 highly agreed to not thinking about *time* passing, while also slightly disagreeing to focus on getting the task done, rather than exploring the environment. Participant 2 slightly disagreed to not thinking about time passing, while slightly agreeing to focus more on getting the tasks done, rather than exploring the environment. These differences indicate that exploring the environment causes a user to be less aware of time, and that focusing on finishing the tasks makes a user more aware of the time passing.

(5) *I think the activity in itself was rewarding*

Participant 1 slightly agreed to the activity in itself being *rewarding*, possibly confirmed by highly agreeing to the feeling that acts lead to a result or action. Participant 2, on the other hand, answered neutral to the activity in itself being rewarding, and that he slightly agreed that the acts lead to a result or action. Further, Participant 2 answered neutral to both the understanding of how to interact with objects and the experienced consistency, indicating that if an act does not lead to some result or action, the activity does not feel rewarding.

Degree of comfort

Comfort has been a focus point throughout the research and development of the VR application. As entering VR requires the user to wear a HMD that eliminates visual cues of the real world, this can potentially lead to a mismatch between a person's visual and physical cues. Furthermore, graphics and elements can cause difficulties in focusing and be tiring for the eyes and the head. In the user tests performed during the development, participants were asked to fill out a Simulator Sickness Questionnaire (SSQ), after experiencing the environments. Interesting findings from these questionnaires, interviews, and observations will be presented here.

User test 1

As mentioned in section 5.1, two different environments were tested during sprint 1. The results from the sets of user tests showed a generally higher degree of discomfort in the environment that had a lot of different graphical elements than the environment imitating the physical room with fewer graphical elements. This is probably because the many visual impressions in the first caused fatigue in eyes and the head, whereas the second environment was gentler in that it was neutral and similar to the physical room.

Some of the participants had negative impressions regarding the VR headset (impact on eyes and headache) being uncomfortable, where one was particularly sensitive towards wearing VR headsets, and expressed discomfort immediately after putting it on.

User test 2

Based on observations, one of the participants regularly adjusted the HMD, indicating that it was not suitably adjusted. Thus, the participant became aware of the physical equipment facilitating the VR experience and not the experience itself. The other participant expressed that the HMD felt heavy, making the distinction between the physical world and the virtual world noticeable.

User test 3

Both of the participants reported a generally low occurrence of discomfort on the SSQ during their time in the VR application. However, both of the participants reported a little "difficulty with focus", which could indicate that the HMD were not adjusted correctly or that the artificiality causes more difficulty in focus than in the real world. In the future it could be interesting to investigate participants' answers to this particular statement after executing a task in the physical world, as *focus* also can concern the subjective feeling of concentrating.

6.4 Challenges and Limitations

Throughout the process of developing the prototype several challenges led to limitations in this research. Both technical restrictions as well as social restrictions due to Covid-19 limited the development of the VR application as it is dependent on a physical space, and the inclusion of users during the process.

A great technical challenge was synchronizing interactions and elements over a network for multiple users to see. Especially complex interactions such as writing and drawing did not synchronize as other interactions over the network. If investigating the collaboration in VR further, these synchronizations should be investigated more carefully to implement a higher degree of functionality. In addition, some behaviour in VR and Unity seemed to happen randomly and did not appear with an error message in Unity which made the behaviour difficult to discover and repair. This impacts the overall impression of the VR application as it does not appear as seamless as desired and intended.

Further, the ongoing pandemic influenced the developing process as the prototype is dependent on a specific physical space at the university campus. Closing of the university campus for a significant time-period several times during the development phase made it challenging to try out and test the prototype regularly during our sprint. Most of the development was carried out working from home, with limited physical space to move around and therefore to fully test the prototype's potential.

Further, limitations of this research include that user tests have not been performed in an adequate way to secure optimal feedback from a user's perspective. Again, the ongoing pandemic influenced the ability to run user tests on the prototypes and VR application, as it depended on a physical space on campus which were frequently closed off. In addition, the restriction against social contact limited the amount of participants testing the VR application when the campus first was available. From a user centered perspective, the lack of participants available for testing and feedback will impact the artefacts final result, both regarding the concept as a whole, but also the usability and the experience of a seamless VR application. In addition, because the participants recruited for user tests were people in close relation to the researchers, the selection of participants does not represent the society's variety.

Lastly, the interest towards flow and the relationship to presence in VR, and how it can be affected by the user's experience of usability, came late in the development process making the data collection about flow limited.

6.5 Chapter Summary

This chapter described the VR application, developed through this research, and its functionalities, followed by reflections over the development process with a user-centered approach. Further, findings from the user research were presented in the categories *Presence and Immersion*, *Flow*, *Investigating Usability and Flow,* and *Degree of Comfort*. Lastly, the chapter acknowledges the challenges and limitations of the conducted research.

Chapter 7: Conclusion

The research described in this thesis presents how user centered design can be implemented to make a mixed reality application for VR headsets. A background of previous research on relevant topics such as forms of virtuality, HCI, UX design with design principles, and the psychological state of flow were introduced. The different technologies utilized in developing the VR application were described, followed by presenting RtD as a methodology for the research and the methods employed for the artefact development and evaluation. This included an introduction to the agile development method, and the concepts of sprints. A separate chapter, written in collaboration with the co-researcher, elaborated how this agile method was utilized in this concrete research, describing details of the three sprint executions. This development led to an application for the VR headset Oculus Quest, with mixed reality features. This application was described together with reflections on the development process to answer RQ1. Further, interesting findings from the preliminary study and the user tests were presented to discuss RQ2. Based on these findings a questionnaire to investigate how participants experienced usability and flow were presented, followed by acknowledging the research's challenges and limitations. Last, the contributions and suggestions for further work are presented in this chapter.

7.1 Research Contributions

First, this research contributes to the exploration of mixed reality by developing a VR application based on a specific physical environment, with physical objects as an extension of the virtual environment. Chapter 4 argued that through RtD, the development process of the VR application, and the VR application itself, is a contribution of knowledge, thus the exploration carried out through agile development contributes to knowledge of the artefact itself and potential users.

Second, the research investigates UX—highly influenced by the usability—and the ability to experience flow in a VR application. By reviewing previous literature on flow and flow indications, as well as the importance of usability when creating seamless experiences, findings were discussed in light of that insight. The results of this indicated that there is a relationship between the perceived experience of flow and the experienced usability of a VR application.

Third, a questionnaire with a set of statements about usability and flow was developed, that can be utilized to investigate usability, both on VR equipment and the interactions in the environment, and flow indications. The research suggests that such a questionnaire where users can answer to which degree they identify with statements regarding flow, usability, and user experience can be useful, and the answers can contribute to discovering the user's presence in a VR application.

7.2 Future Work

The research contributions enable several possibilities for further work and investigation, while the limitations indicate several factors that could be improved and executed more comprehensively.

As mentioned, a significant limitation includes the ability to carry out user tests in a desired amount during the development period. A more comprehensive implementation of user tests to secure more qualitative data to establish further insight to how design principles impact the flow of the users are suggested. In addition, physiological data would be beneficial to support or oppose the participants statements during interviews or happenings during the use of the application.

To further investigate the relationship between usability and experiencing flow, A/B testing could be utilized by testing one application experienced to be seamless, and followed by a test with some usability weaknesses. Comparing the flow indications from these tests could explore if these usability weaknesses have direct influence on the user's ability to experience flow.

It would be interesting to develop the facilitator in the VR application to guide more intricate tasks, and to give appropriate feedback and suggestions during a session of problem solving, by incorporating artificial intelligence. It would also be beneficial for the participant to be able to communicate with the facilitator to clear up potential misunderstandings during the task execution.

The suggestions for further work could contribute to investigate the findings made in this research further. New findings can confirm assumptions made in this research or draw new lines in the discussed topics.

7.3 Final Words

This research contributed to explore innovation with a user perspective, resulting in promising indications that focusing on usability can contribute in facilitating flow. Considering flow as an aspect when developing or designing artefacts would be interesting to explore further as it is proven to contribute to higher engagement and enjoyment when performing an activity, indicating a better user experience.

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Appendix A

Questionnaires regarding flow and usability

Hvordan vil du rangere følgende påstander? (utstyr)

	Helt uenig	Litt uenig	Nøytral	Litt enig	Helt enig
Headset var ubehagelig	○	○	○	○	○
Headset var vanskelig å stille inn	○	○	○	○	○
Kontrollere var lett å skjønne/bruke	○	○	○	○	○
Jeg opplevde ingen problemer med det fysiske utstyret	○	○	○	○	○
Det visuelle samsvarte med mine bevegelser	○	○	○	○	○
Lyder var passende	○	○	○	○	○

Hvordan vil du rangere følgende påstander? (miljø)

	Helt uenig	Litt uenig	Nøytral	Litt enig	Helt enig
Jeg skjønte hvordan jeg interagerte med alle objektene	○	○	○	○	○
Jeg opplevde at mine handlinger hadde et utfall eller bekreftelse	○	○	○	○	○
Jeg følte en sammenheng i hvordan å interagere med objekter	○	○	○	○	○
Jeg var tidvis usikker på hvilke handlinger jeg kunne utføre	○	○	○	○	○
Jeg opplevde VR miljøet som lite brukervennlig	○	○	○	○	○

Hvordan vil du rangere følgende påstander?

	Helt uenig	Litt uenig	Nøytral	Litt enig	Helt enig
Jeg følte meg fokusert og konsentrert på oppgavene jeg løste	○	○	○	○	○
Jeg tenkte ikke på meg selv eller var spesielt selvbevisst	○	○	○	○	○
Jeg følte kontroll over handlingene jeg utførte	○	○	○	○	○
Jeg tenkte ikke på tid eller tidsbruk	○	○	○	○	○
Jeg synes aktiviteten i seg selv var givende	○	○	○	○	○
Jeg fokuserte mer på å "bli ferdig" enn å utforske miljøet	○	○	○	○	○

Appendix B

Simulator sickness questionnaire

Hvordan opplevde du følgende symptomer?

Markér bare én oval per rad

	Ingen	Litt	Moderat	Betydelig
Generelt ubehag				
Utmattelse				
Hodepine				
Øyebelastning				
Vansker med fokus				
Spyttøkning				
Svetting				
Kvalme				
Vansker med konsentrasjon				
"Tung i hodet"				
Skurrete (blurry) syn				
Svimmel ved åpne øyne				
Svimmel ved lukkede øyne				
Falsk følelse av omgivelser				
Mageubehag				
Brekning				