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Virtual Reality as a Digital Collaboration Tool

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Abstract

The COVID-19 pandemic has changed the way people work; within a few weeks, working from home was enforced as the new normal. When the pandemic ends, however, it does not necessarily mean a return to the traditional office. Although working from home has its disadvantages, it also offers new opportunities for the future that can be explored. Going into a work era colored by the pandemic, we should ask ourselves what we want this future to look like. In light of this opportunity, this research investigates how Virtual Reality (VR) can be used to improve digital collaboration practices.

To investigate the potential of Immersive VR for digital collaboration, a prototype that allows people to engage in collaborative activities in a virtual environment was developed. The foundation of the research is based on the Research through design (RtD) model and the development of the prototype follows a user-centered design approach. The VR application was evaluated iteratively through 3 design sprints where two participants were physically and virtually co-located and collaborated on a task. The final evaluation explored collaboration where the participants were only virtually co-located, i.e., physically remote from each other.

The Virtual Environment (VE) was built based on a 1:1 scaled representation of a physical room in Media City Bergen (MCB). This allowed participants who were located physically at MCB to freely move around.

The evaluations of the user test showed that the participants used a lot of non-verbal communication when collaborating in the VEs. Participants also tended to experience a high level of presence in VE, leading to a collaborative process that felt somewhat more similar to traditional Face-to-face (F2F) interactions. It also showed the importance of good technological solutions for participants to be able to experience immersion in the VEs.

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Acronyms

VR	Virtual Reality
AV	Augmented Virtuality
AR	Augmented Reality
XR	Extended Reality
MR	Mixed Reality
RTD	Research Through Design
HMD	Head mounted display
VE	Virtual Environments
HCI	Human Computer Interaction
UX	User Experience
FOV	Field Of View
POV	Point Of View
F2F	Face to Face
DOF	Degrees Of Freedom
GPU	Graphical Processing Unit
NUI	Natural User Interfaces

1 Introduction

In early 2020, the world was introduced to a global pandemic that would influence all of us. Without any heads up, our ways of life had to change due to the social restrictions that were set in motion to reduce the spreading of the virus. For many, this meant working from home instead of going to the office. It is likely that the pandemic will change the way people work even after it is over. Multiple major companies such as Telenor and Twitter (Dwoskin, 2020; Stoltz & Tollersrud, 2020) announced that they would continue to offer their employees the possibility of working from home after the pandemic comes to an end. For many, working from home can offer increased freedom in terms of controlling one's own time and work, however after almost a year of working and studying from home, several negative aspects of the home office has come to light. A recent investigation carried out by the Norwegian government showed that almost half of all Norwegian students had challenges relating to mental health during the pandemic. 45% of the students who participated in the study stated they struggled with mental illness. (Regjeringen, 2021). A common challenge was that students felt isolated and lonely when they were not able to physically meet fellow students on campus. To address the social restrictions and lockdowns, video conference platforms such as Zoom and Teams have become the new normal. Digital platforms lack several aspects that we normally encounter when engaging in traditional face to face (F2F) interactions. Many experience fatigue from passively sitting in front of their computer listening to others speak. As we enter the post COVID-19 period, it is important to put some consideration into how working from home can be facilitated in a fluent and efficient way. In order to address the challenges of working and collaborating in a future where people might not be co-located physically, I look into how *Virtual Reality* (VR) can improve the current state of digital collaboration.

VR technologies allows people to become immersed in computer-synthesized worlds. As the world is comprised of software, it offers vast creative opportunities for the designers of VR environments. Cellan-Jones (2016) described 2016 as the year when VR became a reality. In 2016 immersive VR became commercially available for consumers; Oculus, HTC, and Playstation all became major stakeholders in the VR market. Since then, however, there have been several new releases of powerful and affordable VR Headsets making VR an even more viable option. Of these, the most notable is the recently released *Head-Mounted Display* (HMD), the Oculus Quest, and its successor the Oculus Quest 2. Both Quests are stand-alone headsets, which means the user can have a wireless experience without needing a powerful gaming computer to do all the heavy lifting in the background. The recent release of the Quest 2 is priced at only $299, making it highly affordable for both consumers and larger companies to incorporate it into their workflow (Robertson, 2020).

To address the issues regarding digital collaboration, this thesis describes the development of a prototype that aims to solve some of these challenges by using VR. The prototype was developed for an Oculus Quest headset, and comprised two different environments; one for working and one for recreational activities. The environments were created as a 1:1 scaled representation of a physical room located at Media City Bergen. This allows for some participants to be physically located together, while others can participate from remote locations; this way of working together seems likely to be more common after the pandemic ends.

The research carried out and reported in this thesis is motivated by a preliminary study carried out in 2020 by me and my research partner (Helland & Meling, 2020) where we developed a better understanding of how people struggle to differentiate between work and break while working from home.

1.1 Motivation

During my studies as a bachelor- and master's student in media and interaction design, I have grown used to working in groups to solve creative problems. Even while working on individual tasks there is a great benefit of being physically located with like-minded colleagues. My years as a student are soon coming to an end and hopefully, I will find myself working as a UX Designer in the near future. The changes in how we work due to the pandemic are likely to permanently change the way UX Designers work. Having worked from home this last year, I can definitely conclude that meeting with colleagues over Zoom is far from as stimulating as spending time with them in real life. So in a future colored by the pandemic, there must be better alternatives when it comes to engage in workshops online, having team meetings or just meeting friends for a chat. I use this research to examine how this future might look with VR to provide insight to both myself and others about how VR can support online collaboration in the future.

1.2 Research problem

This research aims to generate new knowledge that can be useful for understanding how VR can be used for digital collaboration in the future. Two research questions guide the work:

RQ1: Can virtual reality facilitate improved digital collaboration?

RQ2: How does embodied interaction impact digital collaboration?

1.3 Collaboration

The practical component of this research was made as a collaborative process together with co-student Stine Olsen Helland. Our supervisors from the Centre for the Science of Learning and Technology (SLATE) have supervised the research. As the development was executed in partnership, chapter 4, which describes the development process, is written as a common chapter for both theses.

1.4 Thesis Structure

The thesis comprises 6 Chapters.

Chapter 1: Introduction
The introduction presents the motivation behind the thesis, as well as the research question, and collaboration

Chapter 2: Background & Related work
This chapter presents review of literature relevant for this research and presents relevant definitions

Chapter 3: Research method
This chapter describes the methodology and methods that is used for the research

Chapter 4: Development
This chapter describes how the prototype was designed and developed.

Chapter 5: Results & Discussion
This chapter discusses the findings and results from the literature reviews and prototyping, and answers to the research questions.

Chapter 6: Conclusion
This chapter presents the conclusion on the project as a whole as well as future work.

2 Background & Related Work

In this Chapter, literature and previous work that form a foundation for this research is presented. Most of the literature describes research within the fields of Human-Computer Interaction (HCI) and VR. Concepts considered crucial for VR to become an efficient tool for digital collaboration are explained, and research on the advantages and disadvantages of video conferencing technologies is presented.

2.1 Virtual Reality

To form a solid basis on which to discuss and understand digital collaboration, an introduction to the medium of VR is needed. VR, as a term, is used to refer to anything from video games to fully immersive virtual worlds. VR is a part of a wider concept, *Extended Reality* (XR), which is an umbrella term that groups everything from a physical environment with virtual elements to a fully immersive virtual environment. Technologies included within the XR definition are *Augmented Reality (AR), Augmented Virtuality (AV),* and *Virtual Reality (VR).* Milgram & Kishinol (1994) talks about a *Reality Virtuality Continuum*. The model (see figure 2.1). consists of two poles; on the far left you have a real environment, while on the far right the environments are completely virtual. In Figure 2.2 you see an updated version of Milgram's model that specifies where Extended reality lies on Milgram's continuum.

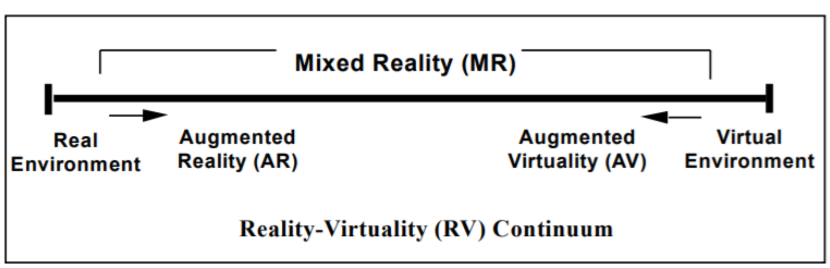

Figure 2.1 Milgram Reality Virtuality Continuum (Milgram & Kishino., 1994)

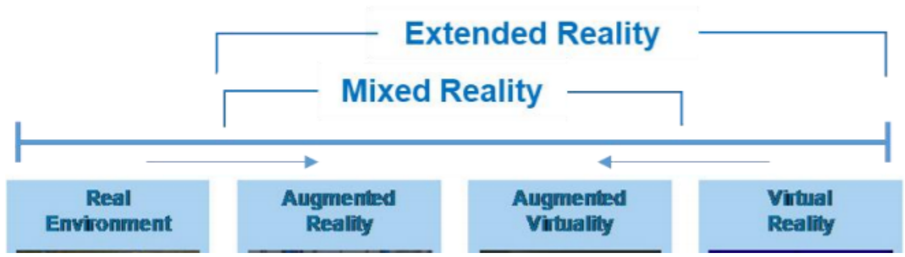

Figure 2.2 Extended reality[1]

2.1.1 Definitions

For this thesis, the following definitions are adopted:

Virtual Reality (VR)

Virtual Reality is an environment in which the participant is fully immersed in a synthetic world which he is able to engage and interact with (Milgram & Kishino. 1994, p. 2).

Augmented Reality (AR)

Augmented Reality is to be considered as present in any case where a real environment is extended in some way using virtual computer graphics (Milgram & Kishino. 1994, p. 4).

Augmented Virtuality (AV)

Augmented Virtuality refers to cases in which a virtual environment is extended by elements from a real environment. (Milgram et al. 1994, p. 285)

Mixed Reality (MR)

Mixed Reality contains a mixture of AR and AV. Real and virtual worlds are blended together to form new environments (Schreer et al. 2019, p. 10)

[1] Retrieved 12.04.2021 from (Oliver Schreer et al., 2019)

2.2 Immersion

For a virtual collaborative environment to be efficient, it should resemble something that feels familiar to a physical environment. This can make the transition from physical to virtual collaboration less cumbersome and more natural for the users. Preece et al. (2015) describe Natural User Interfaces (NUI) as interfaces that allow users to interact with a computer the same way they would interact with the physical world. This can be done by using their voice, hands, and bodies rather than a mouse and keyboard. A NUI can be experienced as something familiar, since people use skills they already inherit, such as talking, writing, gesturing, etc. In order to allow the user to interact with the virtual environment as she interacts with the real world, she needs to be immersed into the virtual environment. Immersion and presence are closely related terms and are often used interchangeably, although Slater (1999, 2003, 2004) makes a distinction between Immersion and Presence. He defines presence as the subjective sense of being in a place, while immersion is the objective measurable properties of the system and or environment that lead to a sense of presence (Dalgarno & Lee, 2010). Immersion relies on the capabilities of VR technology and the degree to which it can create stimuli. Presence is more context-dependent and influenced by an individual's subjective psychological responses to VR (Dalgarno & Lee, 2010). Our senses play a major part in becoming immersed; to achieve full immersion all our senses should be stimulated by the technology. For instance, a VR system will be more immersive than another if it can provide higher resolution imagery, or if one provides sound or haptics while the other does not. Once the user is encapsulated in the VE, she can turn her head to orient herself in 360 degrees, and use her legs to walk about in three dimensions. Once this is achieved the NUI could be considered incorporated into the system, as the user is relying on her natural skills.

2.2.3 Technological Requirements

In the previous section, it was identified that immersion is a condition for presence, but does not necessarily guarantee it. In this section, some of the most important technological requirements for a good immersive experience are presented and explained.

Bowman & McMahan (2007) report on a study where the goal was to identify how much immersion is enough to create a good experience. They have several interesting findings relating to how immersion alters the experience of VEs. Some of the requirements listed by Bowman & McMahan (2007) are; *Field Of View, display resolution,* and *frame rate.* As Bowman & McMahan (2007) don't go into the minimum requirements of each requirement, I will use other literature to explore this.

To discuss the minimum needed requirement, I look towards the gaming industry. At Steam Dev Days, Valve developer Abrash (2014) presented the minimum requirements needed for a VR system to be able to achieve immersion. Abrash (2014) present a long list of requirements, for this research, I have chosen to focus on the same as Bowman & McMahan (2007)

Field of View (FoV)

The Field Of View (FOV) can be understood as the amount of the virtual world that is visible within the headset at any given moment. Humans naturally have a FOV that is close to 180°. The closer the FOV is to our natural field of view of the world within the headset, the more familiar it would feel, and a larger FOV equals higher immersion. Lin et al. (2002) carried out a study where they measured the impact of FOV in relation to presence, enjoyment, memory, and simulator sickness. They concluded that the impact on users would be similar at 100°, 140° and 180°. While using a 60° FOV negatively impacted the experience. This concurs with the requirements presented by Abrash (2014) who defined the minimum requirement for FOV should be 80 degrees. Most HMDs today offer a FOV between 100°-120°. The Oculus Quest used in our studies has a FOV of 100°.

The resolution of an HMD

Resolution in an HMD refers to the visual dimensions of the visual display, I.e., the number of pixels. Higher resolutions create a sharper and clearer image for the user, a lower resolution could result in individual pixels becoming visible for the user. Due to the close proximity between the user's eyes and the displays in the HMDs, low resolution can easily ruin the experience due to pixelation. According to Abrash (2014), 1080p or better is adequate for VR. The Quest has a resolution of 1440x1600 meaning it has 1440 pixels width and 1600 pixels height.

Refresh rate

Refresh rate in the context of VR refers to how many times the display is able to refresh each frame per second. The higher the amount of refreshed frames, the smoother the visual experience is perceived. Most VR HMDs offer a refresh rate between 60hz - 120hz. Abrash (2014) describes the minimum needed refresh rate should be 60hz, but it is preferable if it is higher. The Quest has 72hz, while the Quest 2 can go as high as 120 Hz.

2.3 Presence

The previous section looked into the importance of Immersion in VEs. Some technical terms relating to achieving immersion were explained, including how immersion is reliant on the capabilities of the technology, and how presence is dependent on immersion. This section examines the importance of presence and how it can be achieved. We distinguish three forms of presence: Place Presence, Social Presence and Co-Presence.

2.3.1 Place presence, Social Presence and Co-Presence

Saniye Tugba Bulu (2011) discusses the relationship between different types of presence and their influence on satisfaction in virtual worlds. This paper functions as a base for further discussion.

Place Presence

Whereas Immersion refers to the degree to which the user's senses are stimulated by the virtual environment, presence refers to the subject's experience of being present in that virtual environment. Slater (1999) describes presence as a subjective and psychological sense consisting of three aspects: (1) 'The sense of Being there', (2) individuals' response to what is 'there' as real or present, and (3) whether the individual' recall of the environment as a place like in real life (Bulu, 2011, p. 155). A simpler definition is given by Witmer and Singer (1998) and is more appropriate for the explorative research in this thesis: Place presence is the *"subjective experience of being in an environment, even when one is physically situated in another"* (p. 225).

Social presence

The concept of Social presence was introduced by Short et al. (1976) and they defined it as the "degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships" (p. 65). It considers the degree to which one perceives another's presence in the communication. A system does not have social presence, but it can facilitate it. Different mediums influence intimacy and immediacy and affect how personal our communication is (Bulu, 2011). The feeling of social presence is influenced by several factors, for instance Argyle & Dean (1965) pinpoints how verbal and visual cues affect the feeling of social presence (e.g., physical distance, smile, eye contact, and so on). Some media convey the feeling of social presence better than others, as they allow for different ways of transmitting verbal and visual non-verbal cues. For instance, Zoom has a higher level of social presence than e-mail, as it can transmit verbal and, to a degree, non-verbal cues. Social presence is dependent on how well a medium can convey the psychological perception that others are physically present.

Co-presence

While presence is to be understood as 'being there', co-presence extends the concept to 'being there together'. What should be regarded as co-presence has been widely discussed amongst scholars. Goffman (1963) considers co-presence as a sense of being together in a virtual environment where the individuals become accessible, available, and subject to one another (Bulu, 2011). Biocca et al. (2003) also argue that co-presence should take into consideration not only the 'being together' but also a mutual awareness of the individuals and the virtual environment. Co-presence has two dimensions, the sense of perceiving others in the VE and at the same time having a sense of others in the environment actively perceiving you (Bulu, 2011). Co-presence is differentiated from social presence, in that social presence relates to the quality of the medium and how users perceive the medium. Co-presence addresses the psychological interaction between individuals (Bulu, 2011) For instance, one could experience social presence over a phone call, but to experience co-presence one needs to feel present together with another person in an environment.

2.3.2 Presence and Satisfaction

Presence is dependent on the immersive capabilities of the system, and to achieve satisfaction in a virtual world, the person must feel present in it. Co-presence and Social presence are distinguished by the way that social presence relates to the quality of the medium and how users perceive the medium, and co-presence addresses the psychological interaction of individuals (Bulu, 2011). The relationship between presence and satisfaction is illustrated in figure 2.3. The study by Bulu investigated how the forms of presence and their relationship influence satisfaction and immersive tendencies in virtual worlds (Bulu, 2011). In the study, 43 teacher students participated in a virtual world, *Second Life*. Findings from the study showed a positive correlation between place presence and co-presence (Bulu, 2011) and it was found that participants who felt present in the VE also experienced the presence of their fellow participants. The study revealed that participants who reported a higher level of place presence also perceived high co-presence (Bulu, 2011). When it comes to different types of presence and the participants' satisfaction in the VE's, social presence turned out to be most influential. Participants who experienced higher levels of social presence tended to be more satisfied with the virtual experience. It is reasonable to assume that this is because the participants were enabled to connect with their peers in the VEs, opening up for more informal conversation and creating a trustworthy and comfortable situation (Bulu, 2011).

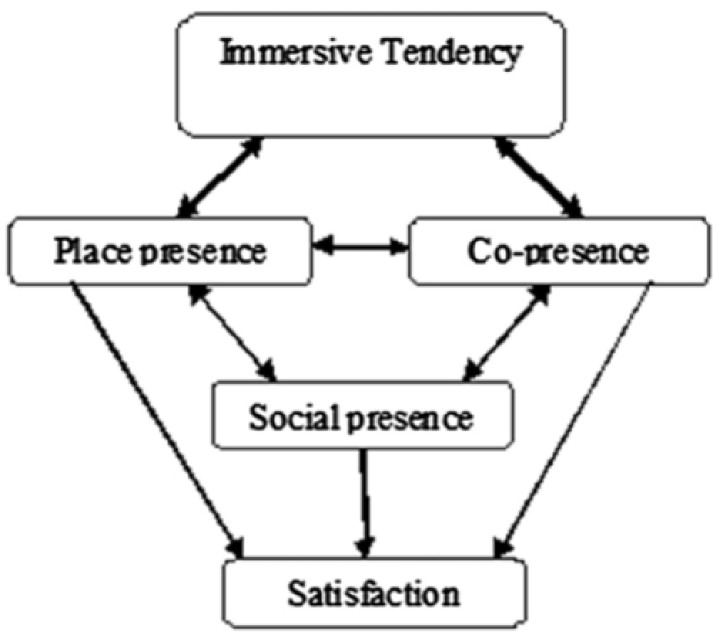

Figure 2.3 relationship between immersion, presence and satisfaction (Bulu, 2011)

2.3.3 Embodied VR

Having a sense of place, time and feeling of embodiment in VR also impact presence. Embodiment can be achieved by rendering a user's movements onto a virtual representation of oneself in the form of an avatar. A key idea for the entirety of this research is exploring how we can create virtual collaboration tools that feel somewhat familiar to what we know from the physical world. Harrison & Neff (2018) highlight how *embodied VR* allows for an experience that is familiar to real world F2F interaction.They write:

> *Embodied VR provides a high level of social presence with conversation patterns that are very similar to face-to-face interaction. In contrast, providing only the shared environment was generally found to be lonely and appears to lead to degraded communication*. (p. 1).

Their study consisted of 60 participants who were to solve two tasks under different conditions. The first task was to negotiate room use, and then to negotiate which participant where to stay in which room. The second task was to place furniture in the apartment for which they had just assigned rooms (Harrison & Neff, 2018) The tasks were completed under three different conditions: F2F; embodied VR with visible full body avatars; and, none-embodiment VR, where participants shared a visual space but had no avatars (Harrison & Neff, 2018). The participant engaged in a shared visual space, meaning that they could always see the same as the other participants.

An interesting finding from the Harrison & Neff (2018) study was how people communicate when faced with different conditions. For instance people tended to use a lot more words and turns while only using audio. On the other hand, people located in an shared virtual environment that allows for body gestures, used deictic utterances such as (“that”, “those”, “there”) (Harrison & Neff., 2018), no longer relyid on long and descriptive phrases such as “Could you pass me the glass one the table close to the door”. The conclusion from the studies showed that F2F and embodied VR had similar verbal and nonverbal communication behaviour, while non embodied VR negatively influenced the communicative behavior (Harrison & Neff, 2018) It should be noted that for the research in this thesis only partial body tracking was used (head and hands), which offers somewhat limited embodiment compared to the study by Harrison & Neff (2018). Such body tracking, however, does give the users the ability to see where others are seeing, as well as point and orient themselves towards objects, which can provide comparably valuable non-verbal cues to what is represented by Harrison & Neff (2018).

2.4 State Of Videoconferencing

To form a better understanding of why I consider VR to be a good alternative to digital collaboration, I find it important to look into some of the challenges related to how it is commonly realized today. To emphasize this, I will examine some of the challenges related to current common implementations.

Although there are some who are already using VR for conferencing and digital collaboration, the common approach today is to use video conferencing tools. For example, for almost an entire year the MIX Masters students (my co-students) have met using Zoom. For quite some time scholars and businesses have predicted that video conferences will replace much of the traditional workflow; less commuting to and from work, changes in our social patterns, and no more physical meetings. *Zooming* has become almost as normal of a term as *googling*. Zoom went from having about 10 million users in December 2019, to over 300 million users 5 months later (Iqbal, 2020). As Zoom has become integrated into our everyday, the term *zoom fatigue* was also introduced, referring to the tiring state one experiences after hours of video conferencing[2].

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[2] I personally experienced the physical and mental strains after passively participating in a six hour long digital workshop.

Stanford professor Jeremy N. Baileson identified four potential causes for zoom fatigue.The four causes of Zoom fatigue described by Bailenson (2021) are as follows; *eye gaze, cognitive load, mirror effect* and *reduced mobility*

Eye gaze

When one is having a meeting on Zoom, the person finds himself in a situation of constantly having a screen filled with colleagues. Most people sit relatively close to the screen creating the illusion of only being a few centimeters away from colleagues. Bailenson (2021) compares this scenario to physical encounters in an elevator. In an elevator you are forced to violate a non-verbal norm, by being forced to stand very close to both known and unknown people, which might lead to discomfort. To solve this discomfort people tend to look down or in some way avert the gaze of others at all times. This is not as easy on Zoom, and as a result you get the feeling of people constantly intruding into your personal space.

Cognitive load

In F2F interactions our non-verbal communication flows seemingly naturally and effortlessly. In video conferencing on the other hand, non-verbal behavior is a more tedious and complex process (Bailenson 2021). Using videoconferences the user constantly monitors other participants for nonverbal cues and responds accordingly. When compared to F2F interaction, it turns out that people tend to raise their voice by 15% (Bailenson, 2021). Raising one's voice for an entire day can become quite tiring, further exaggerating small non-verbal cues is likely to increase the cognitive load, resulting in fatigue.

Mirror effect

On platforms such as Zoom or Teams there is always a small mirror on the screen where we constantly see ourselves in real time. Although there is a setting that allows for 'hide self view', the default setting is that it's turned on. Most people are self conscious regarding their own looks, and having to continually evaluate how you look takes a lot of focus and energy. Bailenson (2021) describes a study by Duval and Wicklund (1972) that concluded that people become a lot more judgemental and self-conscious about their looks when faced with a mirror, and as a result starts to self-evaluate. Bailenson (2021) compares the digital mirror effect to spending an 8 hour workday in a physical workspace always followed by an assistant who directs a mirror towards you. Constant self monitoring would for most feel extremely uncomfortable and have a negative impact on both work and self-image.

Reduced Mobility

In a Zoom meeting, people tend to to stay within the cameras *frustrum*. The cameras frustrum is the conical shape where the camera sees, close up the field of view of the camera is small, while far away the field of view increases (Bailenson, 2021). To be able to see other participants you have to stay within this frustrum and since most meetings are done by the computer people tend to sit close enough to reach the keyboard (Bailenson, 2021). This forces participants into sitting in a rather static manner during meetings compared to physical meetings where you tend to move around, fill some water, or write down some notes. Bailenson (2021) also describes how video conferencing breaks the illusion of having everyone's full attention. Compared to a phone call where you have the feeling that the person on the other line gives you all their attention, while in reality they might be folding clothes or cooking dinner at the same time. He argues that since video conferencing destroys this illusion, as we are able to see what the other person is doing, it will become the reason for its downfall.

We return to the notion of Zoom fatigue in chapter 5: Results & Discussion, where it is discussed in light of the findings in this study.

2.5 Technology

This section gives a short review of some technological aspects that affect the current state of VR user experience today. This is useful in order to better understand the current potential of VR, but also the future potential.

When designing and developing new solutions it is important to have a good understanding of the technology with which you plan to work with, as this allows one to undertake more informed decisions throughout the development. The potential for digital collaboration using VR is influenced by multiple factors. How accessible is the technology? How affordable is it? Is the technology good enough to make users immersed into the virtual world?*.* This section reviews the most important factors identified as crucial for a good VR experience.

2.5.1 Degrees of Freedom (DoF)

Several major companies are offering VR products to their consumers, however, how advanced the technological solutions are varies a lot. A key component in VR is *Degrees of Freedom* (DOF). DOF refers to the number of ways a user can move through the virtual space (Barnard, 2019). The degrees of freedom varies from headset to headset, from *Three-degrees-of-freedom* (3DOF) or *Six-degrees-of-freedom* (6DOF)*.* 3DOF only tracks the rotational movements of a user: Looking left or right, rotating head up or down and pivoting left or right (Barnard, 2019). 6DOF allows for both translational and rotational tracking; in addition to the previously mentioned movements, it will also track movement forward and backward, lateral and vertical, and up and down in three dimensions (Barnard, 2019). We can refer to HMDs that only offer 3DOF as simple VR, while those who offer 6DOF qualify as advanced VR.

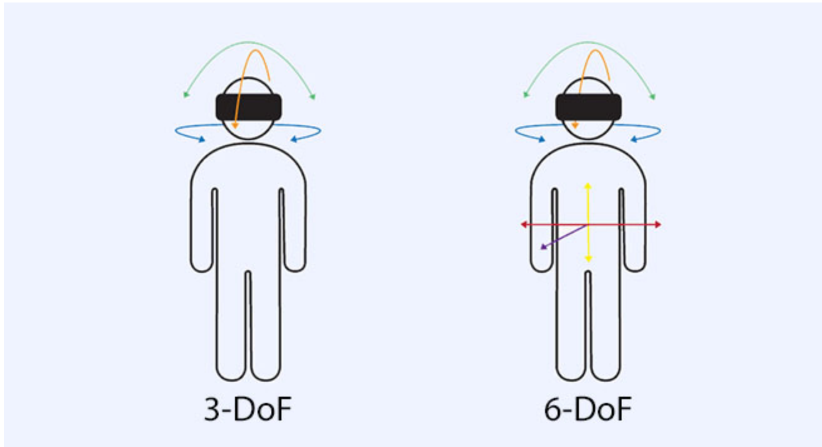

Figure 2.4. 3-DoF vs 6-DoF comparison (Barnard, 2019)

Some of the most popular simple VR headsets are *Google Cardboard, Oculus Go* and *Samsung Gear.* All the mentioned headsets offer only 3DOF, thus they fall in the simple VR category. All HMDs except the Oculus Go are also dependent on an external phone in order to be used. Although HMDs that offer simple VR often come at a much lower price compared to advanced VR, to achieve a high degree of presence, tracking both translational and rotational movements is essential. Therefore, simple VR was not a viable alternative for the development in the research. Examples of HMDs that fall within the advanced VR category are: *HTC Vive, Oculus Rift, Windows MR, Oculus Quest, Valve Index* and *Playstation VR.*

2.5.2 Standalone vs Stationary

The accessibility of the technology determines how likely it is to be adapted by consumers. As mentioned above, most simple VR HMDs are dependent on a standalone phone to function. Being dependent on a secondary device lowers the accessibility. Also, some advanced VR HMDs rely on secondary devices in the form of expensive gaming computers. This makes them less accessible due to the fact that the cost is greatly increased, but also because it needs more physical space to be used.

Stationary VR

Stationary VR is dependent on a PC and a designated area where the VEs can be experienced. The VR headset has to be connected to a PC by wire or through a wireless connection, and most of the processing is done on the external computer. Often a quite expensive PC with a high end *graphical processing unit (GPU)* is required. The tracking is usually done by *outside-in tracking* where external sensors are placed out in the room; this is illustrated in figure 2.5. The sensors are responsible for tracking the relative position of the HMD, controllers and other tracking devices. Stationary VR reduces mobility greatly; the wire limits a person's movement in the physical space as you have to be careful not to step onto the wire or fall on it. Even if the wire would be removed, the user still is in need of a powerful PC, without it the HMD is useless. A benefit of using Stationary VR is the PC’s ability to render pictures of a much higher quality than a standalone headset. Therefore, if the quality of graphics is the most important factor of a VE, stationary VR is the way to go.

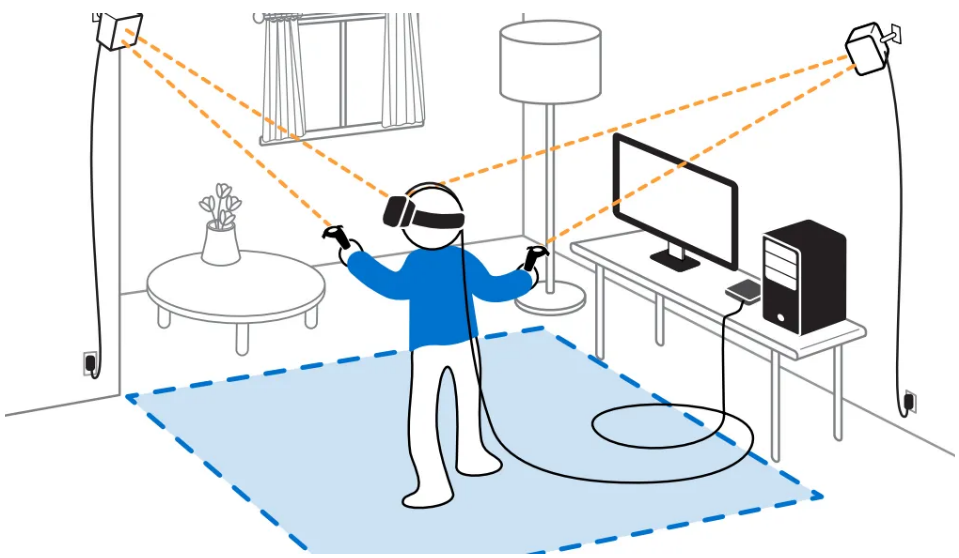

Figure 2.5.Illustration of Outside-in tracking with a stationary VR rig (LearnVR, n.d)

Stand-alone VR

A standalone VR headset is not dependent on any external source of computing. All the components such as the screen, processor and battery are built into the headset. As it is not connected to a PC, all processing is done internally in the headset, leading to a lower processing capacity compared to stationary rigs. Tracking with Standalone VR is done by inside-out tracking where the sensors are mounted within the headset. This is commonly done by using computer vision. Standalone Headsets are superior to stationary when it comes to mobility. Since it's not dependent on external sensors or computers, it's very mobile and could in theory be used anywhere, at any time. The pricing can often be cheaper for standalone as you do not rely on a seperate expensive computer to do all the processing.

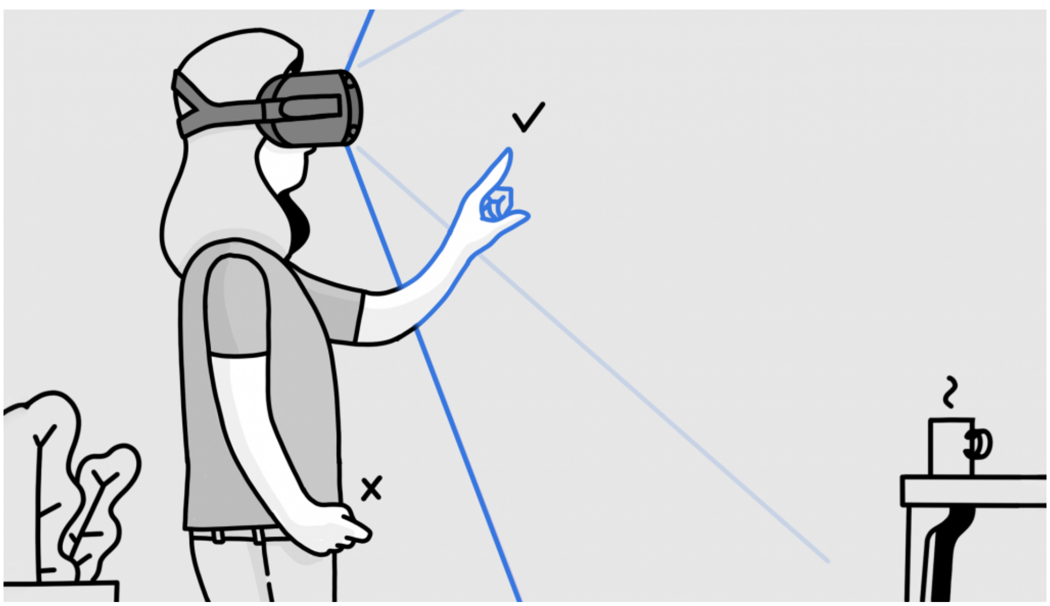

Figure 2.6. Inside-out tracking using an oculus quest HMDs (Lang, 2020)

Whether one should decide on using a stationary or stand-alone solution depends on the situation. If you are dependent on mobility and the ability to access the

HMDs in different locations, a stand-alone is the better solution. If the purpose of use is gaming with high visual fidelity, or the use is dependent on rendering of very high quality, a stationary rig might better fulfill the requirements.

2.6 Summary

This chapter described literature that is relevant for investigating the research problem of this thesis. By doing a literature review, I am able to form a solid understanding of already existing knowledge within the relevant fields, and the review functions as a solid foundation on how the prototype should be designed.

Based on the advantages and disadvantages, it was decided that for this research, the stand-alone solution is the most adequate, and the HMD that will be used for the development is an Oculus Quest. The decision to use the Quest was based on multiple factors: it is mobile and can be used in different locations easily; it offers 6 DoF; and, it offers partial embodiment by tracking both hands and head. The full specifications of the headset can be seen in table 2.1.

Table 2.1 Oculus Quest specifications (Rogers, 2019)

Display	OLED
Resolution	1440 x 1600 per eye
Refresh Rate	72 Hz
Tracking	Inside Out
Field of View (FOV)	90-100 Degrees
Processor	Qualcomm Snapdragon 835 processor
Battery time	2-3 Hours depending on usage
Ram	4 GB
Controllers	Two
Weight	571 gram

3 Research Method

In this chapter the research and development methods that will be used for this research are explained and presented- The research questions introduced in Chapter 1 are as follows:

RQ1: Can virtual reality facilitate improved digital collaboration?

RQ2: How does embodied interaction impact digital collaboration?

To answer the research questions, it is crucial to involve users early in the development process. Therefore, this research takes an iterative approach with users involved in each iteration. Thus, Research through Design (RtD) is chosen as the underlying method for the research. This chapter describes the RtD method and the particular methods used for planning and development of the prototype as well as the analytical methods used for analysing user interaction.

3.1 Research Through Design

The research described in this thesis is based on Research Through Design (RtD), a method developed by Zimmerman et al. (2007). The model aims to create an approach that enables HCI Designer to deliver good research and to create the 'right thing' (Zimmerman et al., 2007).

The method allows for interaction designers to generate new knowledge while pursuing something that is yet to be created. This is in contrast to the more traditional scientific research where the things that are already existing and universal are in focus.

RtD was chosen as the underlying methodology for this project as it acknowledges prototyping as a way of generating new knowledge. Zimmerman et al. (2007) pinpoints 4 criterias for the RtD model that can be used to evaluate research contributions in interaction design, they are described as follows:

Process

Zimmerman et al. (2007) highlights that when judging the quality of the research contribution, there should be no expectation that the same process would yield the same result if reproduced. Nonetheless the process has to be well documented so that the process employed can be reproduced. To achieve this, the technologies used, the development process and the software solutions must be explained.

Invention

The produced artifact must clearly demonstrate that it is produced to solve a specific problem. The researchers must do a thorough literature review to get an overview of what is the current state of the art within the relevant field. This should be done in order to be certain that the contributions of the studies help move the current state of the art forward (Zimmerman et al., 2007).

Relevance

Traditionally research has had a focus on validity. Zimmerman et al. (2007) explains that in for instance the field of engineering validity is a “demonstration of the performance increase or the function of their contribution” (p. 499). In interaction design validity should not be used as a standard, instead relevance should be the benchmark for interaction design. Relevance must be argued in a way that demonstrates what impact this contribution has on the world. An example here can be to ask why VR is relevant for solving challenges of digital collaboration

Extensibility

The final criterion states that the research must be well documented for future practice. *"Extensibility means that the design research has been described and documented in a way that the community can leverage the knowledge derived from the work*." (Zimmerman et al. 2007, p. 500)

3.1.1 RtD summary

To conclude, RtD offers a framework for generating new knowledge. Through our research we intend to generate new knowledge and gain insight into how VR could offer an improved way of digital collaboration. To generate this knowledge, a prototype will be developed and tested on potential users. Several methods were employed as part of the RtD framework, these are presented in the upcoming sections.

3.2 Preliminary Studies

In the spring of 2020 a preliminary study investigating the use of VR as a relaxation tool was carried out (Helland & Meling, 2020). The study was carried out as a diary study, exploring the efficiency of VR as a relaxation tool. The study was done during a time period where many people had recently adapted to a home office work situation. The study ran over two weeks, during this time slot the participants tried different VR experiences as an alternative to how they normally would spend their break time. The study was based on the assumption that people struggled to distinguish between work and break while working from home. In addition to the diary, a questionnaire that investigated what challenges employees were faced with both when working from home, and when situated in an open office landscape. The findings from the study showed a clear link between difficulties from working at home and having a good structure around taking breaks. The findings from the study gave insight into potential use areas and challenges relevant for the prototype developed for this research

3.3 Desk Research

To fulfill the requirement in RtD of invention, a desk research was carried out. This was done to form an overview of already established knowledge within the fields of research, upon which this research could build upon. This included gathering knowledge of VR technology and relevant topics such as; collaboration, immersion, presence, and motion sickness. The data gathering was carried out using the following sites: Google scholar, ScienceDirect and Springer. To map out the relevant papers the abstract was read before reading the paper in its entirety. The results of the desk research were presented in Chapter 2.

3.4 Design and Development

This section describes the methods used for designing and developing the prototype.

3.5 A User-Centered approach

When taking a user-centered approach the focus and driving force should always be on the real users goals (Sharp et al., 2015). For a fluent integration with the overarching methodology RtD, User Experience (UX) Design was chosen for the development of our prototype. Figure 3.1 illustrates how UX design is a discipline that involves multiple fields. The term UX was introduced to the research field in the 90’s by Norman (Norman & Nielsen, 2019). In an interview Norman explained the reason for the need for such a term in the following way:

> "*I invented the term because I thought human interface and usability were too narrow. I wanted to cover all aspects the person's experience with the system including industrial design, graphics, the interface, the physical interaction, and the manual*" (Lyoannis, 2017)

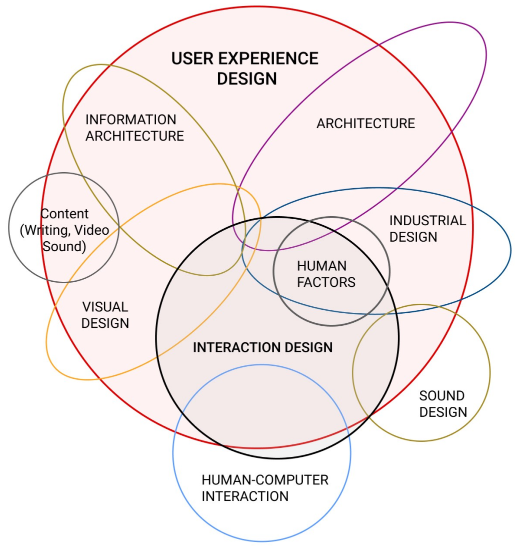

Figure 3.1. Diagram of UX design (UX Planet, 2020)

Early Involvement of Users

A key factor of the design and development approach is to include the future users early in the development process. As a result, we ended up basing our development on *Agile Principles.* Agile can be understood as an umbrella term for a set of practices and frameworks such as *Scrum, Lean Software methodology* and many more. It is based on 12 principles expressed in the *Agile Manifesto* (AgileAlliance, n.d). A key component in Agile development is the idea of an iterative approach for the development. This differs from the more traditional *Waterfall Method* where the development follows a more sequential flow from start to end (Guru99, n.d) Agile uses short, time-boxed iterative development cycles which are called sprints. Welcoming change is important in Agile Methodology. The Founders of the Agile Manifesto, Beck et al., says satisfying customers should be one of the main priorities, and this should be done through early and continuous launches (2001).

Agile and RtD Compatibility

Agile software development and RtD work well together and offer few to no contradictions. RtD aims to generate new knowledge through prototyping, and to gain this knowledge there should be some involvement with the future users. Agile methodology allows continuously launching product versions, which make iterative user feedback possible. The system requirements of the prototype will be continuously updated based on the results of each agile sprint.

Agile Sprint

As mentioned, Agile sprints comprise shorter development cycles for continuous launching of the product. Each cycle consists of five steps, before reaching the final launch step (see figure 3.2). Since this is a student research project, it was decided that user tests would be the last and final step for each iteration. Through each sprint the work will be documented thoroughly. Documentation is an important part of RtD, as the research must be well documented so that others can leverage the knowledge derived from the work.

Figure 3.2. Agile methodology sprint example. (Musaka, 2020).

System Requirements

Sharp et al. (2015) describes a requirement as something that specifies what the intended product should do or how it should perform. At the end of each sprint iteration the requirements are to be reviewed and if needed, redefined before heading into the next iteration. *Functional requirements* captures what the system should do (Sharp et al., 2015) To identify the functional requirements for the prototype, it is important to gain insight into the users' needs through continuous user testing. *Non-functional Requirements* say something about the constraints of the system and its development (Sharp et al., 2015). Examples of Non-functional requirements are the look and feel of the product, usability requirements and performance requirements, etc. (Sharp et al., 2015).

3.4 Prototyping

RtD acknowledges prototyping as a way of generating new knowledge and therefore a prototype is a manifestation of the design that allows for interaction and exploration with future stakeholders (Sharp et al., 2015). Prototyping is an efficient way to involve stakeholders early on and get feedback on the design in order to improve and find better design alternatives. For this research, a *low-fidelity prototype* will be developed in the beginning of each sprint, and at the end of each sprint the improved version of the prototype will be accessible. At the end of the last sprint, we aim to have produced a *high-fidelity prototype*. A comparison of different prototype fidelities is shown in table 3.1.

Low-fidelity prototype

In the early stages of an agile sprint, sketching can be useful to illustrate how the VE is envisioned. Sketching could in itself be considered as a *Low-Fidelity Prototype* as it does not look much like the final product and does not have full functionality. Low-fidelity prototypes are useful as they are quick to produce (Sharp et al., 2015). Sketching is done during the design step in the agile sprint.

High-fidelity prototype

A high-fidelity prototype should feel and look similar to a final product and provide more functionality than a low-fidelity prototype (Sharp et al., 2015) A high-fidelity prototype is useful for the user to experience the look and feel of what a final product might look and feel like. The plan for this research is to end up with a high-fidelity VR prototype developed using the game engine *Unity.*

Table 3.1 Comparison of prototype fidelities (Sharp et al., 2015, p. 395)

Type	Advantages	Disadvantages
Low-fidelity prototype	Lower development cost Evaluates multiple design concepts Useful communication device Addresses screen layout issues Useful for identifying market requirements Proof of concept	Limited error checking Poor detailed specification to code to Facilitator-driven Limited utility after requirements established Limited usefulness for usability tests Navigational and flow limitations
High-fidelity prototype	Complete functionality Fully interactive User-driven Clearly defines navigational scheme Use for exploration and test Look and feel of final product Serves as a living specification Marketing and sales tool	More resource-intensive to develop Time-consuming to create Inefficient for proof-of-concept designs Not effective for requirements gathering

3.5 Evaluation

This section describes the methods that will be used for evaluation. Evaluation is carried out in order to gain insight into the different aspects of the user experience and to see if there is a need for a re-definition of the requirements.

3.5.1 Triangulation

Gathering data from only one source could lead to misleading or uncertain data. To avoid this, both qualitative and quantitative data will be collected in a process of triangulation. Researching or investigating something from at least two perspectives is called *triangulation.* Preece et. al (2015) identifies four different ways of practicing triangulation.

Triangulation of data

Triangulation of data means that the gathering of the data is done from different sources, such as either different places or from different people (Preece et al. 2015). In our case, this involved combining observation and questionnaires.

Triangulation Of Researchers

Investigator triangulation means the involvement of different observers in the process of observing, gathering data, doing interviews and interpreting the collected data (Preece et al. 2015). In this research we are always two working on gathering and analysing data, and this is important to look beyond our own biases and presumptions.

Theory triangulation

To triangulate the theoretical frameworks means to use different frameworks to view the data or findings. This is done to view the problem trying to be solved from different angles.

Methodological Triangulation

Methodological triangulation is to use different forms of data gathering techniques. To achieve methodological triangulation, we plan to gather data from observations, interviews and questionnaires.

3.5.2 Expert evaluations

Consulting experts for participation in the user tests can generate valuable insight into the functionality of the prototype. For this research, an expert in VR and in interaction design will be consulted.

3.5.3 Warmup questions

When meeting with participants, it is important to make them as comfortable as possible to reduce any anxiety of participating. This can be done by sparking a casual conversation and reassuring them them that we are not interested in evaluating the participants' skills or effort, but rather in their user experience with the product

3.5.4 User test - Direct observation in a Controlled Environment

The first two User tests will be carried out as direct observations in a controlled environment with both participants physically and virtually co-located. For the third test, one participant will be physically located in Media City Bergen, while the other participant will participate from a remote location, sharing only the virtual space. Observation is a great way to understand the user context, tasks and goals (Preece et al. 2015). By combining virtual and physical reality, the goal is gaining insight into how this affects the way people collaborate. Do the communicative patterns change when participants are not physically co-located?. During the tests the participants will be asked to collaborate on solving a set of tasks.

3.5.5 Post questionnaire and evaluation

After the user tests participants will be asked some follow up questions and asked to fill out a *Simulator Sickness Questionnaire* (SSQ). SSQ is a widely used tool to assess simulator sickness symptoms. The questionnaire will be handed out after the participants are done exploring a VE, in order to form a better understanding regarding which factors negatively influenced the comfort in the different VEs.

Figure 3.3 shows an example of a filled out SSQ. The participants' answers to the SSQ will be used as cues for the interview that follows. The interviews will be recorded and transcribed for further analysis. Based on both feedback from the interviews and looking through the video recordings, negative, neutral and positive feedback will be mapped, and together with results from the tests it will be determined what changes are needed during the next iteration.

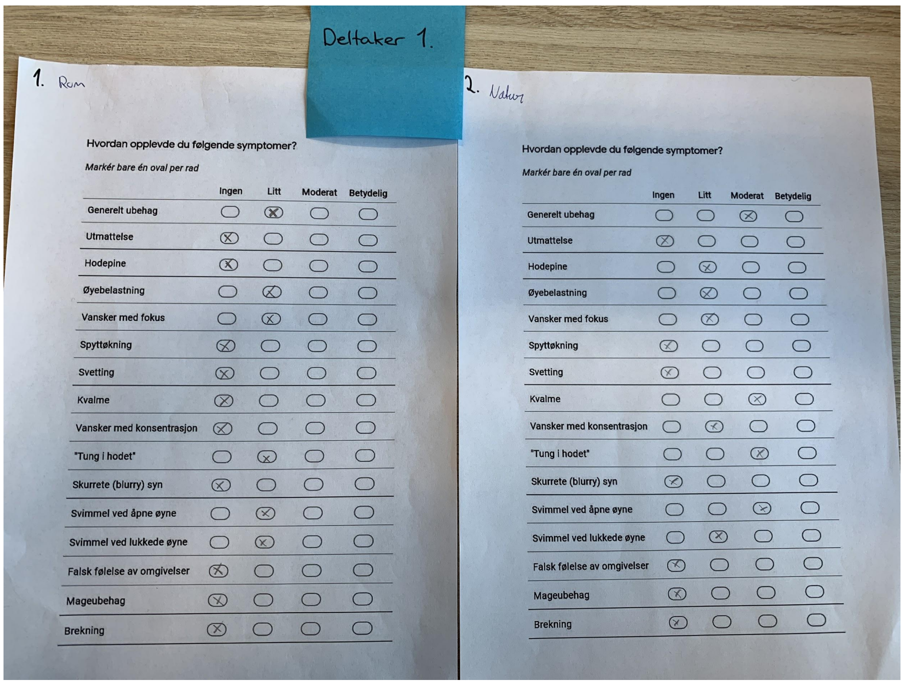

FIG 3.3. A *sickness simulator questionnaire was filled out by participants straight after the test.*

3.5.5 Recording

The participants are recorded in both the physical, as well as in the virtual world. To record the participants in the physical world a iPhone XS will be used; to record them in the virtual world the built-in screen recording software within the Oculus HMD is used. This allows for observation and comparison of the user's point of view (POV) with the footage from the iPhone. Being able to observe participants in both physical and virtual contexts simultaneously, will allow for a broader understanding of how they interacted with the environment. This will give us insight into how participants communicate using both verbal and non-verbal communication.

4. Development

[3]This chapter describes the details of the agile development method, introduced in Chapter 3 in a more comprehensive matter. The 3 agile 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.

4.1 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, they had varying experience engaging with Virtual reality, as seen in table 4.1.

4.1.1 Plan

The start of sprint 1 was used to prepare the sprint's 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 4.1

[3] 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.

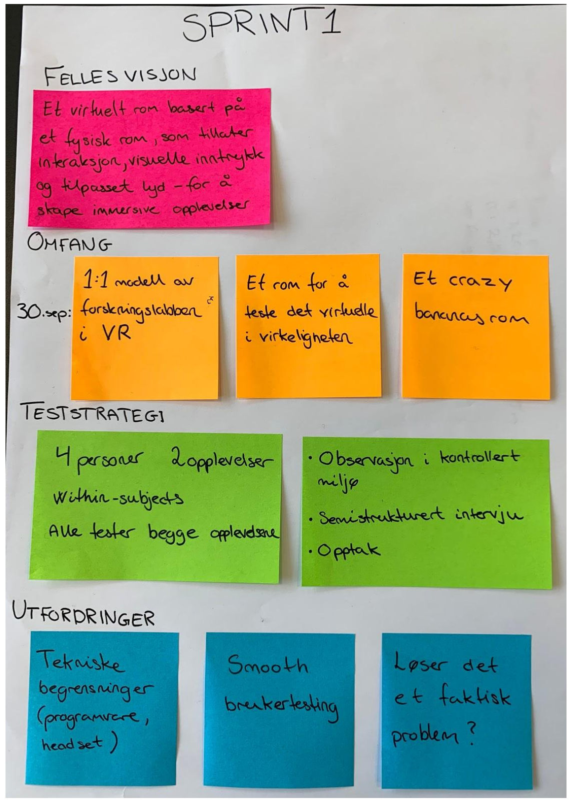

Figure 4.1. Common grounds set for sprint 1 development

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'. 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 ',
- 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 4.2.

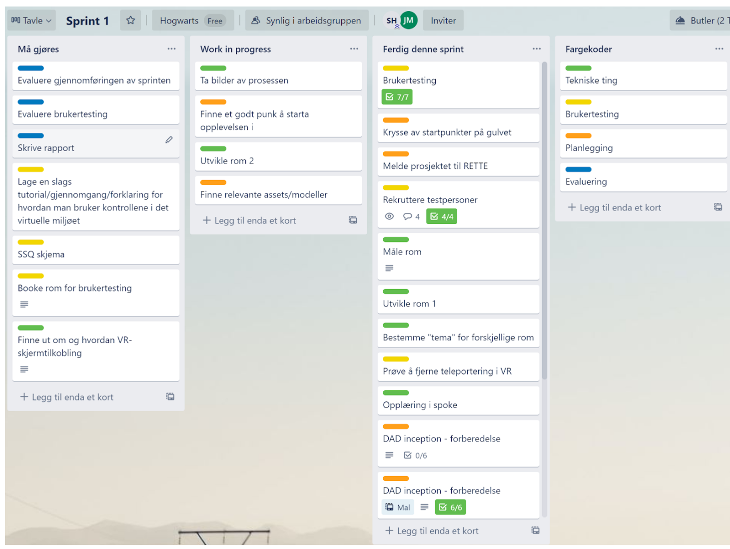

Figure 4.2. Screenshot of the scrum board during sprint 1

4.1.2 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 4.3

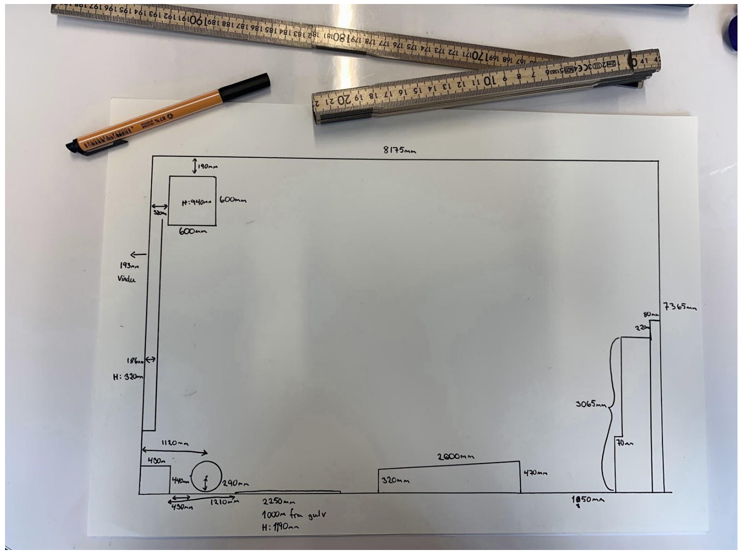

Figure 4.3. Carefully measured walls and objects on a floor plan sketch

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 4.4. In the section of the sprint where we sketched and designed we did not pay attention 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.

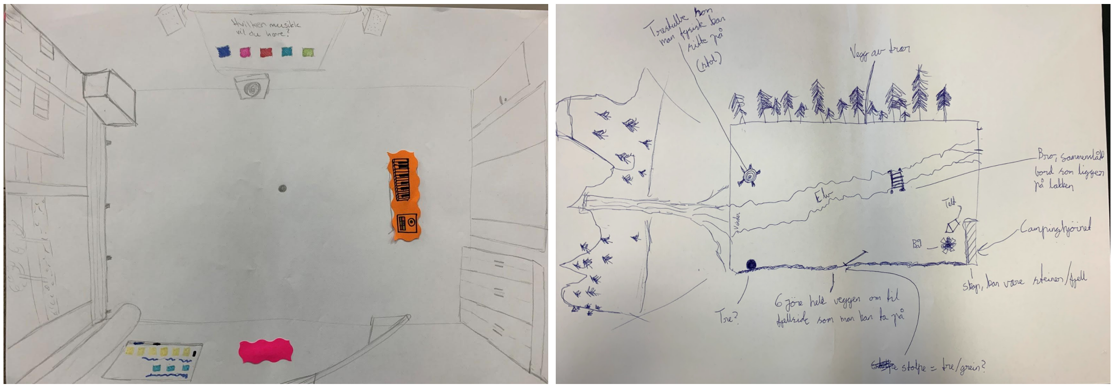

Figure 4.4. Two of the prototype drawings. To the left: close to reality drawing with some extra elements. To the right: drawing of the potential “crazy” room with text explanation.

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.

4.1.3 Build

During the building stage implementations from the design phase were turned into functional VEs that were to be tested with future users. In the first sprint, the prototyping was done 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 centimeters 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 4.5.

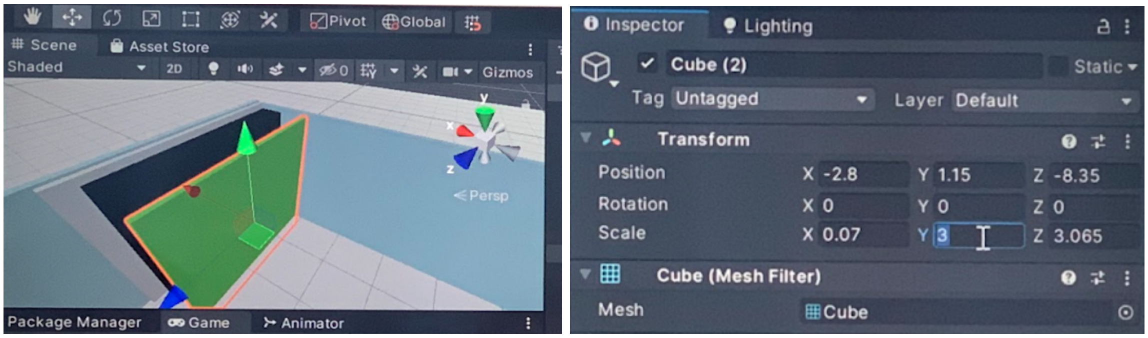

Figure 4.5. Screenshot of an object in Unity and how it is scaled and positioned.

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 were crucial. If a calibration spot was only a few centimeters 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 4.6

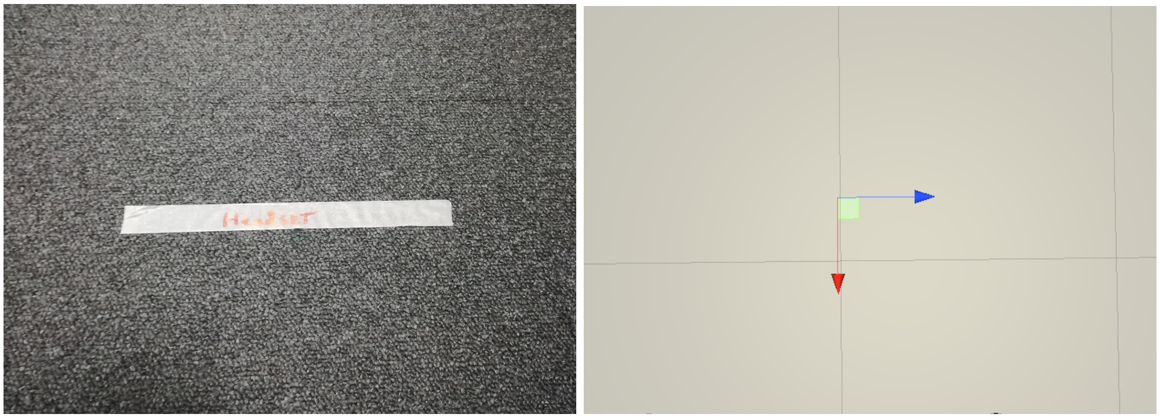

Figure 4.6: The calibration point for the user's spawn position; making sure the user is located in the same position in both the physical and virtual environment

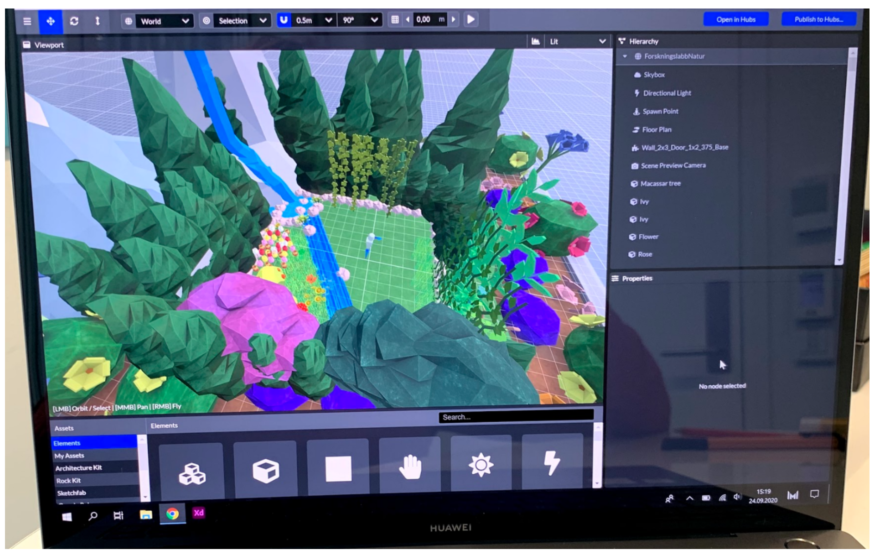

Figure 4.7. Screenshot of one of the environments developed using Mozilla Hubs

The environment created in Hubs 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.

4.1.4 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 **Forsknigslab** 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 4.1.

Table 4.1. 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 4.8 shows two different participants testing environment 1, a MR experience, while being observed.

Figure 4.8. 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 4.9 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.

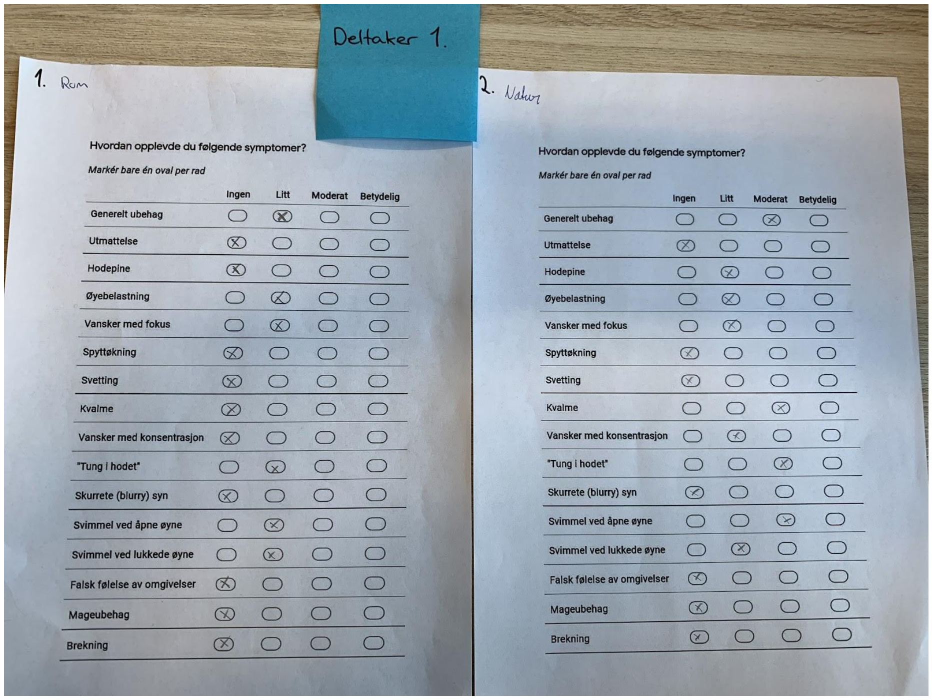

Figure 4.9. SSQ filled out by participant 1 after testing each of the environments

After the participants had tested both environments and filled out a SSQ 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 4.2.

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 subchapter.

Table 4.2. Interview questions

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 enhanced experience?

4.1.5 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 were 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.

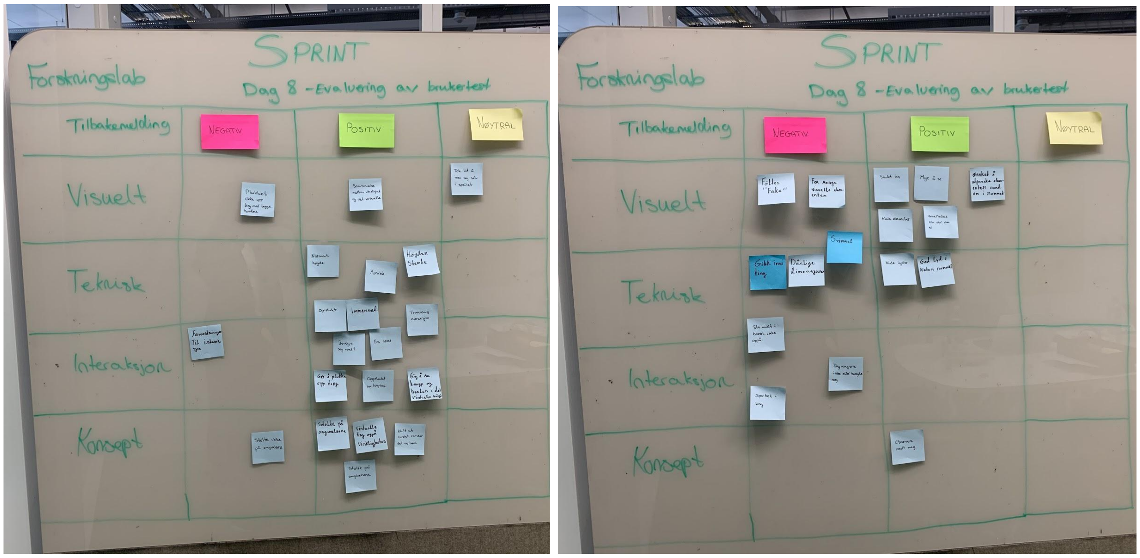

Figure 4.10. Board to visualize findings from sprint 1. Virtual representation of the Forskningslab to the left. Nature environment to the right.

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 be done in 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 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).

4.2 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.

4.2.1 Plan

To plan the second sprint the 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 4.11.

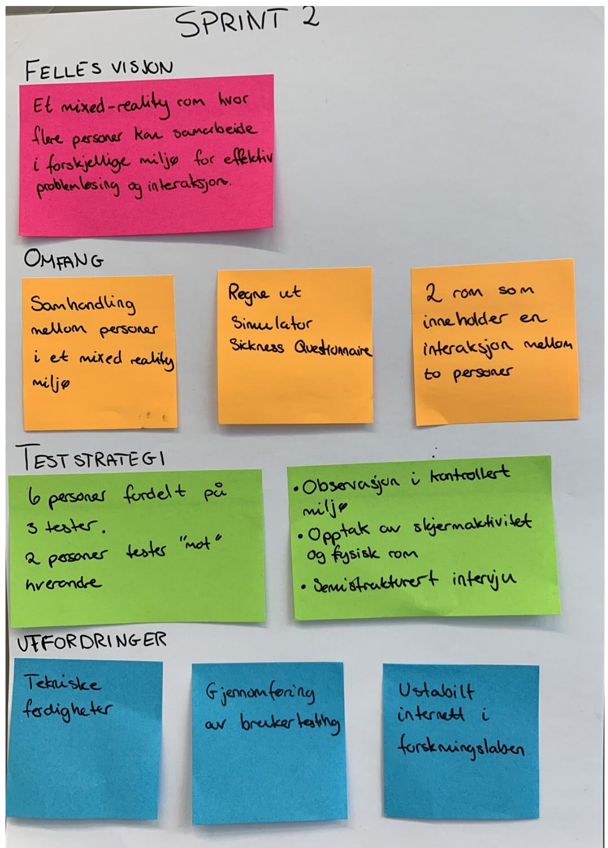

Figure 4.11. Common grounds for sprint 2

The revised vision from sprint one was written on the common grounds questionnaire, "*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 4.12.

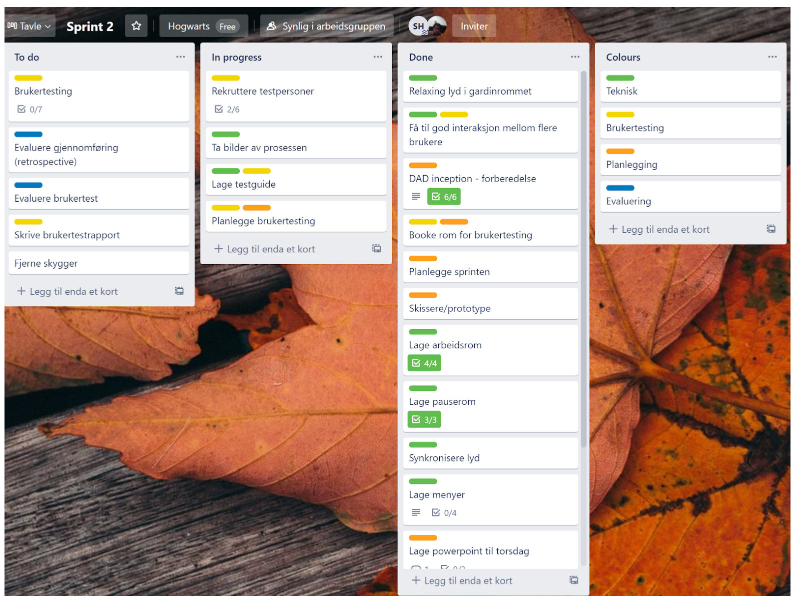

Figure 4.12. The Trello board for the second sprint

4.2.2 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 4.13 , 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.

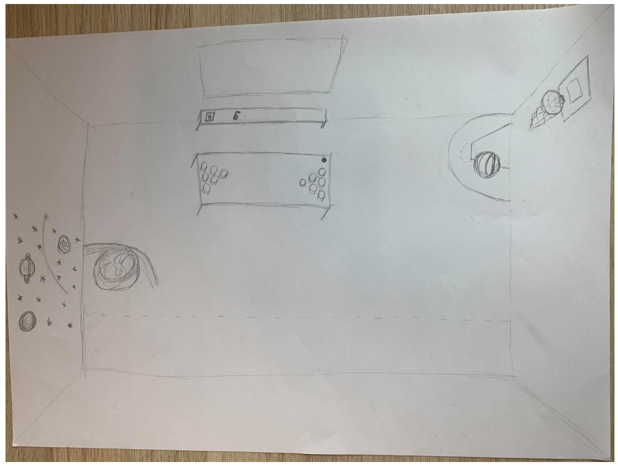

Figure 4.13. The sketch for the recreational room

4.2.3 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 spent 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 to 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.

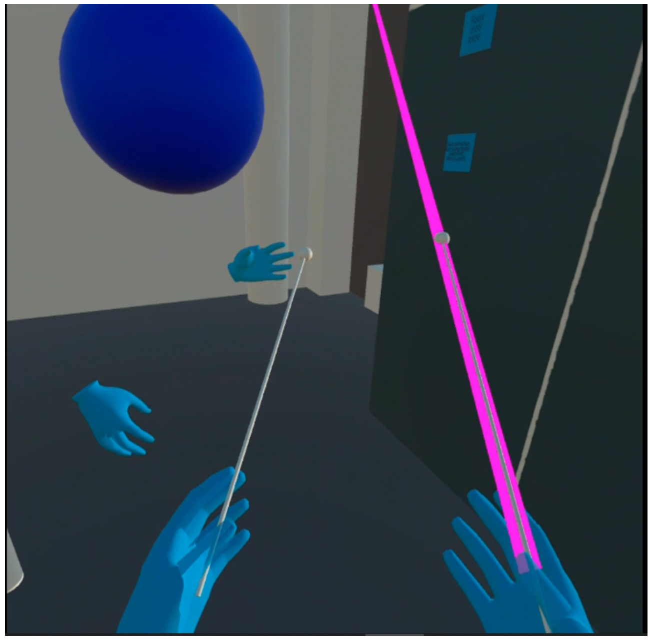

Figure 4.14. The two participants working together to solve a task from the whiteboard

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 4.15 The work room, virtual and real, can be seen from the same angle.

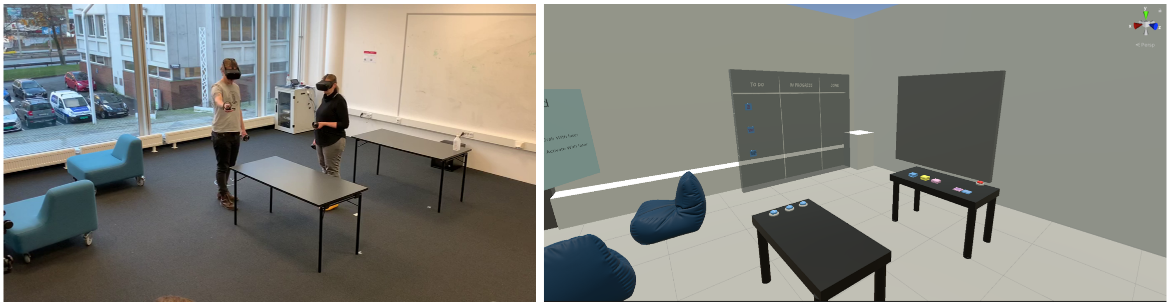

Figure 4.15 Sprint 2 Virtual and physical environment

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”.

Environment switch

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 4.16.

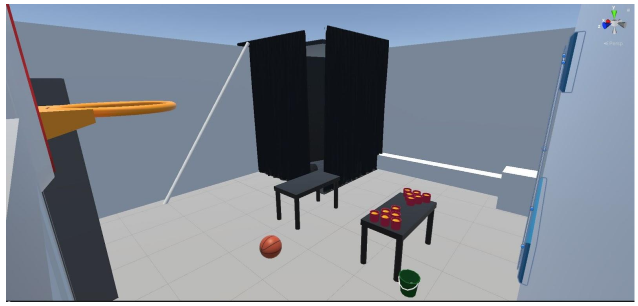

Figure 4.16. An overview of the recreational room with a relaxing area at the back, a basketball game and a beer pong setup.

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.

4.2.4 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. As a consequence, 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 4.3. 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 4.3. Details of the experts recruited to user tests in sprint 2

Subject	Gender	Age	VR exp.	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 4.4.

Table 4.4. 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?

How did you experience 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 limitations?
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 relation with work and break? Are you able to separate between them?

Data collected during this sprint included a video of the participants VR exploration and an audio of the interviews.

4.2.5 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 4.17.

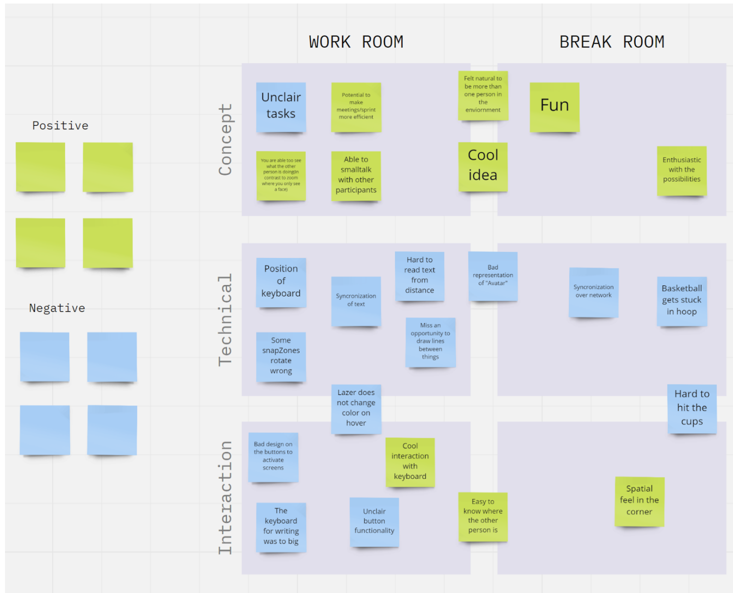

Figure 4.17. Miro board with findings from the user test in sprint 2

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.

4.3 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 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.

4.3.1 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 4.18. 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. In addition to the new set of common grounds, for this user test we planned to test with the participant not co-located in the physical space.

Figure 4.18. 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 4.19 . 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.

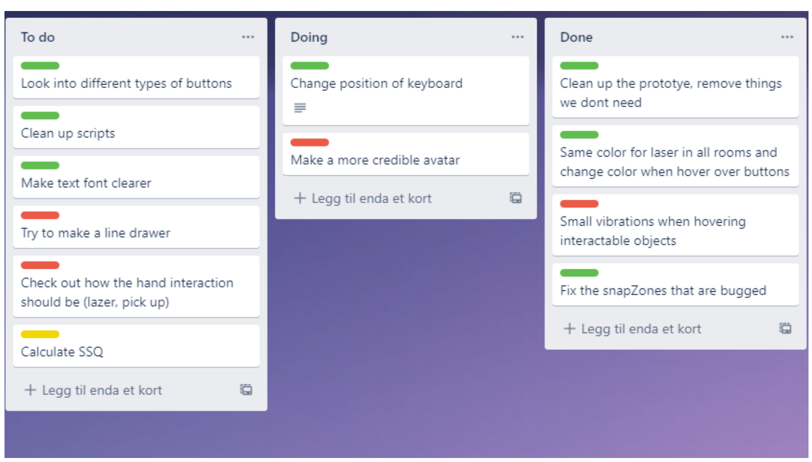

Figure 4.19 Sprint 2 improvement tasks

4.3.2 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 focuses 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 4.20 shows the advancement of the button design during the sprint.

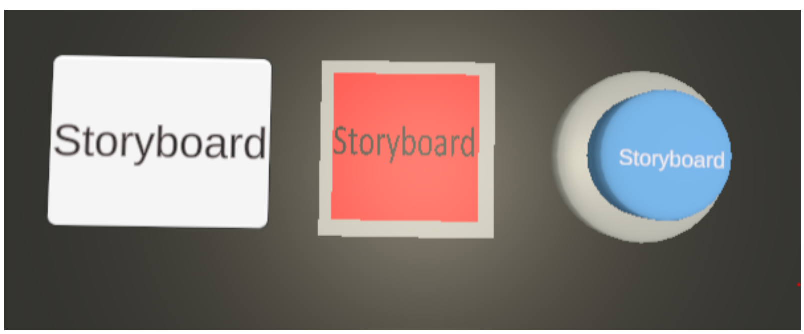

Figure 4.20. Evolution of button design.

The button to the left in figure 4.20 was the one causing difficulties in sprint 2. During sprint 3 this evolutionized 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 colored white, when a user points at an interactable object it changes color to red signaling 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.

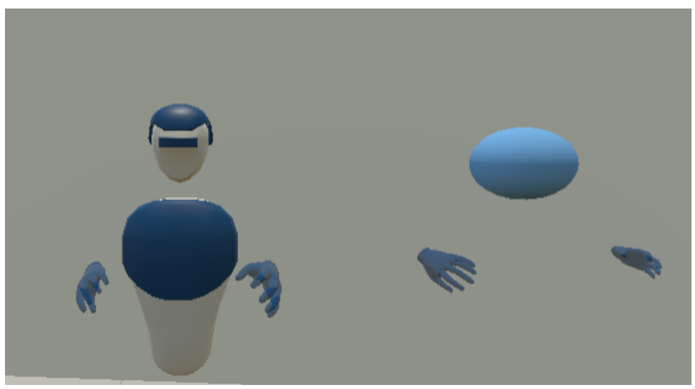

Figure 4.21. The original avatar on the right. The newest implemented avatar to the left.

4.3.3 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 as long with the controller as long as 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 VE's, 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.

4.3.4 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 4.5 were asked to gain some fundamental knowledge of the participants and their experience with VR.

Table 4.5. Interview questions for before 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 4.6. Interview guide for after 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 auditative 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 at any point become very aware of objects or surroundings instead of the task you were solving?
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?

4.3.5 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.

4.4 Chapter Summary

This chapter has 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 5: Results & Discussion

5 Results & Discussion

The aim for this research was to respond to the following two research questions:

RQ1: Can virtual reality facilitate improved digital collaboration?

RQ2: How does embodied interaction impact digital collaboration?

In this chapter, an analysis of the data gathered throughout the research will be discussed in light of the research questions. The purpose of the research was to investigate the future potential for using VR as a tool for digital collaboration. To answer the two research questions, the results of the literature review and an analysis of the data collected in the evaluation phases will be used.

The literature review was carried out in order to gain an overview of current knowledge and to identify relevant methods and theories in existing research. The next step was developing a high-fidelity prototype taking a user-centered approach. To evaluate the prototype, several methods were used: feedback from VR and interaction experts; user testing; and, interviews and different questionnaires and observing of recordings of participants in both virtual and physical environments. The data gathered from the development process was analysed qualitatively. The first step of a qualitative analysis is gaining an overall impression of all the data and start looking for recurring patterns (Sharp et al., 2015). Sharp et al (2015) describes three simple types of qualitative analysis; identifying recurring patterns and themes, categorizing data, and analyzing critical incidents (p. 291).

5.1 Findings from literature review

The literature review showed that there are multiple factors for enhancing digital collaboration that VR as a medium offers that video conferencing tools does not. By doing a literature review we were made aware of how VR offers a way for people to practice non-verbal communication. Particularly, the study by Harrison & Neff (2018) showed how embodied or partial embodiment allows for people to engage in VEs in ways that feel familiar to the physical world. With support for interaction and transparency of bodily comportment in 6DoF, VR facilitates for non-verbal communication close to F2F interactions. Understanding how the immersion influences the users feeling of presence in the VEs, made us more conscious regarding design choices through the development. The literature review was an important factor for the development process in this research, the review highlighted the advantages of VR as well as documenting some of the challenges relating to traditional video conferencing tools.

5.2 Findings from the prototype development

The focus guiding the analysis of how participants' experienced and interacted with the prototype, was identifying recurring patterns, themes and behaviours as well as identifying how different technological solutions influenced the experience. This involved looking at how participants communicated and collaborated in the VEs. The analysis consisted of comparing data gathered from video in virtual and physical environments, interviews with participants and questionnaires filled out by the participants. I have divided the findings into three different categories: *non-verbal communication, embodiment and presence* and *immersion and technology*. For each category, I will highlight a selection of examples from interviews and user tests.

5.2.1 Non-verbal communication

Non-verbal communication refers to actions such as eye contact, pointing, nodding and other gestures not involving speech. To identify non-verbal communication, an analysis of the video material was conducted. The analysis showed that non-verbal communication was extensively used in all user tests where there were two people in the same environment.

The most common practice of non-verbal communication between the participants was pointing and directing themselves towards whatever they were discussing. Even in the first user test which only involved one participant at a time, there were tendencies of non-verbal communication. For example one of the participants asked "*Am i supposed to do something with that..?",* pointing towards an object on the virtual table, forgetting that we were not able to see what the participant pointed towards in the VE. The occurrence of pointing and or directing themselves towards the object of discussion was common for all tests. One of the tasks in the user test was to place a virtual screen containing some statistics. Initially, when the participants discussed how to solve this task, after some time, one of the participants noticed the buttons on the table, turned towards it and pointed and informed the other participant: "*there is a button over here that says statistics, maybe we should use that one?"* The other participant immediately turn toward where the other participant was pointing, and activated the statistics button. These types of interactions were typical. In addition to pointing and directing themselves towards objects, the participants frequently held eye contact while discussing something. In figure 5.1 there is an example of this. One of the participants remembers that they are supposed to continuously update the virtual scrum board as they solve tasks, one of the participants said; "*You know what we forgot? We forgot to move the post-it to in progress"*. They then turned towards each other as they discussed this, as one would do in a F2F conversation.

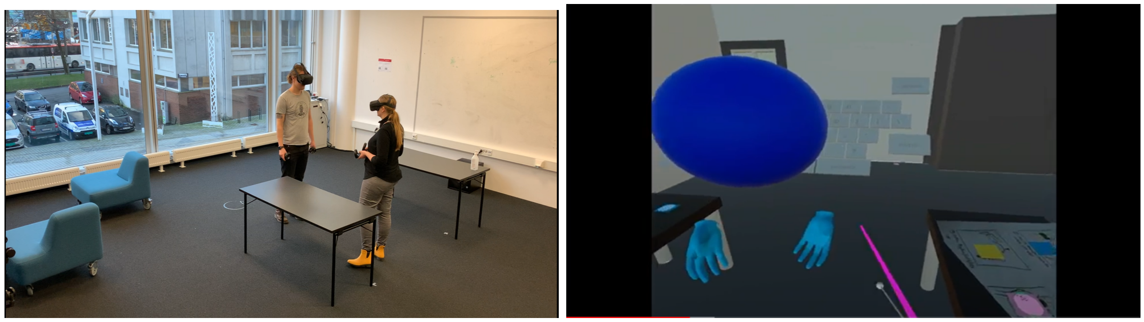

Figure 5.1 One of the participants reminding the other that they forgot to update the virtual scrum board.

5.2.2 Embodiment and presence

In addition to gaining a broader understanding of how participants used non-verbal communication in VEs, the research aimed to study to what degree the participants experienced presence in the VE. Some of the questions used to gain insight to this were gathered from Presence Questionnaire by Witmer and Singer (1998). During the interview after the user test one of the participants commented that she was very happy to move around with another participant in the environment: "I *really liked that I always could see where the other person was moving, and in a way I felt like I was actually together with someone*". When the participant later was asked how she felt collaborating in VR compared to Zoom, she commented that she very much enjoyed the feeling of actually solving the task together with someone. This could indicate that the participant experienced social presence in the VE. The participant also commented that sometimes she felt unsure what button to use on the controller to interact with an object, breaking some of the presence she otherwise experienced, resulting in abruption the flow. During the last user test both participants answered that they felt like they were interacting and collaborating with a real person. In the recreational room, two participants decided to throw the basketball back and forward to each other trying to catch the ball midair. While playing this little game, one of the participants tried several times to kick the ball as it was coming towards him, forgetting that there was no tracking of his feet. When asked a question about this after the user test the participant commented that he forgot that he did not have any legs in the VE. This could indicate that the participant experienced the sensation of embodiment in the VE. Another clear indication that the participants experienced embodiment is how they moved in the VE. In the third user test when they were not physically co-located, the video recordings show clear tendencies that they always respected each other's intimacy sphere and avoided walking into, or standing too close to each other.

5.2.3 Immersion and technology

As mentioned in chapter 2, immersion is a condition for achieving presence, but does not necessarily guarantee presence. During the development of the prototype and during the user tests we faced several technical difficulties. For example, during the last user test where participants were collaborating from remote locations, there were some technical difficulties with the proximity chat only working fully for one of the participants. To solve this, we decided to let the participants talk to each other using an external voice chat program. Both participants commented that the challenges with the audio made it difficult to collaborate and understand what the other person was currently working on. One of the participants compared it to how she often feels during Zoom calls "*Sometimes I could not understand what he said.. So the part with sound felt a bit like on Zoom when it is like wh. wha. what did you say? and this makes the flow not as good as this*" (referring to the interview). Another participant answered similarly that at times it was hard to understand what the other participant was working on due to the poor sound. This was an important reminder for us as researchers that all elements influence the overall experience, at times it was easy to forget about proper sound as the main focus was visuals and functionality. Multiple participants also experienced some confusion relating to how they should use the controllers to interact with objects, at times losing focus on the task they were solving. In an interview, one participant commented that this would not be a big problem had she only had a bit more training in how to use the controllers.

The results from the SSQ also showed a clear tendency of the participants experiencing a much higher level of discomfort in the environment developed using Mozilla Hubs. The biggest difference in symptoms in the two environments were; general discomfort, nausea, headache and dizziness, this is shown in figure 5.2.

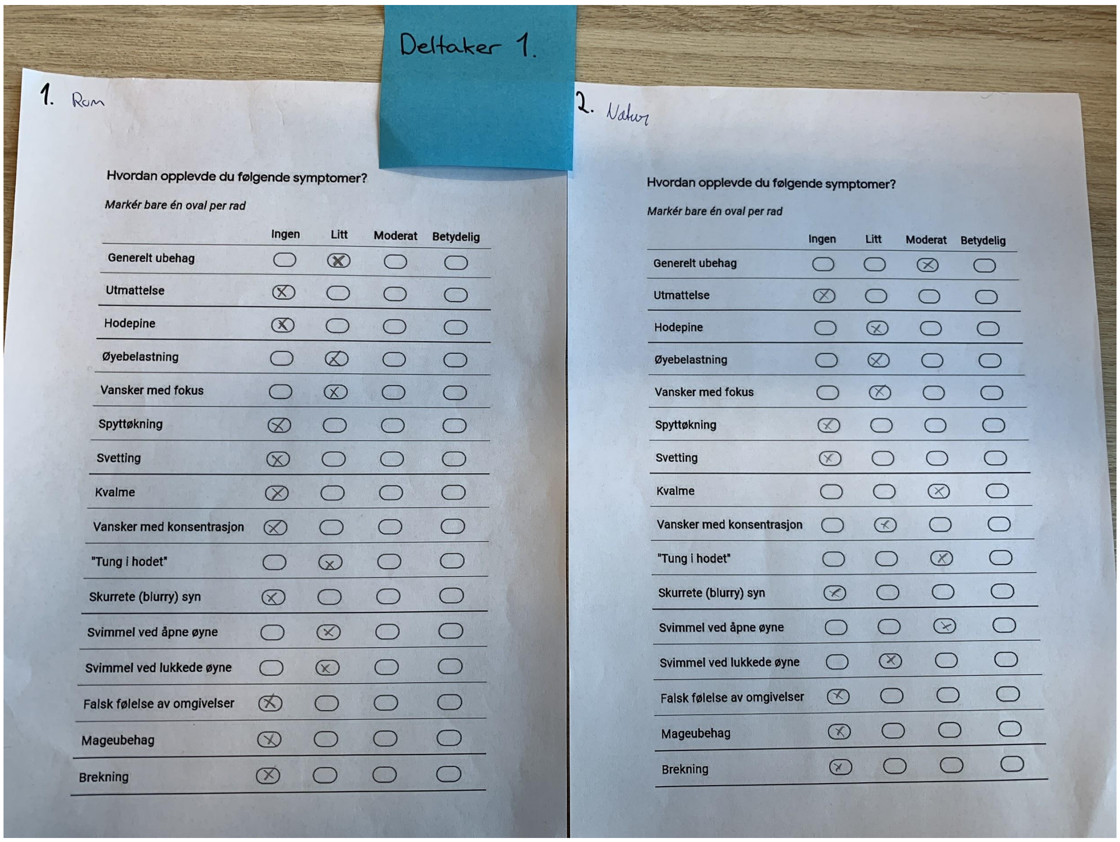

Figure 5.2 A participant filled out SSQ of both VEs. l.h.s the environment developed using unity, r.h.s the one developed in Hubs.

5.3 Answers to research question

In this section, the findings from 1) the development of the prototype 2) the user tests 3) Participants answers to the questionnaires as well as the findings from the literature review will be taken into consideration, in order to answer the RQs.

RQ1: Can virtual reality facilitate improved digital collaboration?

As has been documented in this thesis, we developed a prototype in order to inquire into how VR can be used to improve digital collaboration. The evaluation of the prototype showed that people experienced a feeling of presence in VEs and the medium of the VR appears to be able to solve several of the challenges relating to collaboration using video conferencing tools. Using the prototype, users are offered an environment that feels more familiar to F2F interactions. It directly addresses the four causes for Zoom fatigue identified by Bailenson (2021). The user tests showed that participants tended to relate to the other participants similar to F2F, reducing the challenges of eye gaze as they did not feel like they were constantly watched. Participants also used a lot of non-verbal communication which can make the cognitive load lighter as they don't have to exaggerate and having to monitor other participants' for non-verbal cues. The prototype also addresses the mirror effect mentioned by Bailenson (2021). In the VE the users will move around a lot, interacting with other users and objects, which stands in contrast with collaboration over Zoom or teams. The users no longer sit in a static matter for hours, they engage and participate in the task similarly to how they would do while physically co-located. Participants also commented how they felt present in the VEs and that they felt like they were interacting with a real person. To conclude, VR allows for interaction that is closer to F2F, because it supports non-verbal communication.

RQ2: How does embodied interaction impact digital collaboration? Embodiment in VR allows the user to experience the sense of having a body in the virtual environment. During the user test we saw a clear tendency that embodiment made the participants feel more aware of their own movements but also the other participants in the VE. During the user test with the expert, one of them commented that it was strange not knowing what direction the other person was looking. At his stage the avatar only consisted of a blue circle representing the head. This shows that if not done properly it can affect the interaction in a negative way. When a new avatar was implemented the participants in the study commented that it felt like interacting with a real person. We saw clear tendencies during our user studies that even though we only used partial embodiment, the participant experienced a high level of social presence and engaged in communicative patterns familiar to traditional F2F conversation. These findings match the results from Harrison & Neff's (2018) study. Embodied VR offers an experience similar to F2F conversation, making it easier to collaborate digitally as it feels similar to something already known to the user.

6 Conclusion

This research has investigated how VR can be used to improve the current state-of-the-art in digital collaboration. This was done by developing a VR application and reviewing articles related to the research problem. The application was developed as a part of RtD methodology, as a means to generate new knowledge and give answers to the research question. The application allows for multiple people to collaborate in VR, it can be used by people co-located physically as well as remotely.

The development of the application was done through several design iterations, where each iteration ended with a user test or expert evaluation. The user test aimed to form an understanding of how people experienced solving tasks in a VE. The user test showed that participants tended to use a lot of non-verbal communications such as pointing, nodding, eye contact, etc. At the same time, the application faced some technical challenges such as problems with voice and synchronization. This unfortunately had a negative impact on the immersion of the participants', faulty technology made it harder to become fully immersed into the VEs. Still, the participants commented that they felt present in the environments and that they felt like they were in fact interacting with a real person.

In terms of presence, the findings strongly indicated that participants experienced both place presence and co-presence, resulting in social presence. The findings from this research match the results from the study by Bulu (2011) on the relationship between presence and satisfaction in virtual worlds.

When it comes to embodiment, the findings seem to indicate that it plays an important role in facilitating how the users collaborate. Even though we only offered partial embodiment, it was clear that participants felt aware of their own, as well as others' bodies in the VE. This led to a collaborative process that the participants experienced as closer to F2F interaction, compared to other solutions for digital collaboration

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Overall, the research showed that VR offers a way to address many of the challenges of digital collaboration that arises using video conferencing tools. However more research is necessary to understand the potential pitfalls of using VR for collaboration, such as; VR Fatigue, how natural does it feel to collaborate in VR and how high is the cognitive load compared to other mediums.

6.1 Research contribution

The aim of this research has been to contribute to the research field of HCI by generating new knowledge into how VR can be used to improve digital collaboration. An artifact has been produced to illustrate how VEs can be used to better facilitate digital collaboration. As mentioned earlier in ZImmerman et al. (2007) model for RtD four criterions for evaluation are presented: *Process, invention, relevance* and *extensibility.*

Process Zimmerman et al. (2007) refers to how researchers must provide enough detail so that the process employed can be reproduced, and also a rationale for the selection of methods that were employed (p. 499). For this research RtD was chosen since it acknowledges prototyping as a way of generating new knowledge and the prototype is considered a research contribution in itself. The methodology chapter provided argumentation for the selection of methodology and methods used through the research.

Invention To fulfill the criteria of invention, a desk review was done to investigate what is the current state of the art. Zimmerman et al. (2007) argues that researchers must demonstrate how their invention pushes the current state of the art forward in the research community (p. 499). The literature review showed that there are challenges relating to digital collaboration and the current popular video conferencing tools. It also provided insight into how VR can address some of the problems. This research addressed these challenges by developing an environment that allows for digital collaboration in VEs. The development was done through a user-centered approach where the focus was always to identify and understand user needs.

Relevance This research aims to generate knowledge around the potential of using VR for digital collaboration. The prototype developed aims to demonstrate how VR can help solve some of the challenges relating to video conference tools such as Zoom and Teams. The research investigates how factors such as non-verbal communication, feeling of presence and embodiment influences the way people collaborate.

Extensibility Refers to how the research must be well documented in a way that lets others utilize the knowledge gained (Zimmerman et al., 2007, p. 599). Through this research the generated knowledge has been documentation through reports, transcription of interviews, video recordings and images. After each iteration during the development phase a report was written to document all results and findings.

6.2 Limitations of the research

The main limitations found for this study relate to time constraints and Covid-19 restrictions.

As for most studies, time is a crucial factor for success. When initially setting up a plan for the entire development process, four weeks were set-up to learn Unity and other necessary skills to develop the prototype. We quickly realised that this was a much bigger task than something that could be done in four weeks. Had we spent more time on learning and mastering the necessary skills before we started developing, it is likely that some of the challenges that ended up taking a lot of time could have been solved quicker and more efficiently. With more time it would be possible to solve some of the bugs that ended up in the final version of the prototype, as well as implementing features we did not have time to implement.

In addition to time constraints at times Covid-19 made it impossible to run the user tests as planned. We initially planned to involve more participants during the user tests. This resulted in less gathered data than planned. With more participants we would be able to see clearer tendencies and patterns in the way people collaborate and communicate in VEs.

6.3 Future work

This section will present ideas for future work within this research topic.

In future research the prototype should be tested with more users and under different conditions. A major limitation of this study was that we were not able to test with as many as planned. It should also be investigated how the collaboration feels with more than two people at a time and how users feel when some are co-located physically and virtually, while others participate from remote physical locations. Experimental conditions comparing similar tasks on Zoom and in VR would also complement this research.

It would also be interesting to see how the VR application would work with full embodiment and not only partial embodiment. With full embodiment the participants would be able interact with others in a way that feels even more familiar to F2F interactions. It would also be interesting to see how the interaction felt using hand tracking instead of controllers, which would allow users to interact even more similarly as they do in the physical world.

A more complete version of the prototype should enable users to run a full sprint/workshop in the VEs. It would be interesting to study and compare how efficient a VR sprint is compared to a sprint done F2F or over a video conferencing software. In addition, a longitudinal study could also gather interesting data on how participants experience fatigue after spending a longer period of time in a shared virtual space with others'.This could compare the cognitive loads the participants experience after a longer session in a collaborative VE.

A further investigation into how familiar the appearances of the VEs should be to the real world could be useful. This could be carried out as a comparative study, where the efficiency of the participants' collaboration is measured based on the appearance of the VE. Does an environment that already feels familiar increase the level of experienced presence for the participants? Or should the designers of the VE embrace the fact that a VE does not share the same limitations as the physical world. This would be an interesting research inquiry.

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