Holoft

Augmenting working and living spaces into virtual work oases

Master Thesis

Human Aspects of Software Engineering Lab

Department of Informatics
University of Zurich

by
Jan Gugler

Supervised by
Prof. Dr. Thomas Fritz

March 18, 2021

University of Zurich[UZH]

Contents

List of Figures

Zusammenfassung

Die moderne Gestaltung von Büroräumen befindet sich in einem ständigen Wandel, mit der Absicht, das Wohlbefinden der Mitarbeiter zu verbessern und die Produktivität zu maximieren. Ein neueres Konzept, die Arbeitsoase, versucht dieses Problem zu bewältigen, um Mitarbeiter während der gesamten Arbeitswoche auf dem Höhepunkt ihrer Produktivität zu halten. Arbeitsoasen sind Räume, in denen sich Mitarbeiter ein paar Minuten Auszeit nehmen können, um sich zu entspannen, einfache Aufgaben zu erledigen, sich von der Arbeit abzulenken, Spiele zu spielen und Energie zu tanken. Da nicht alle Unternehmen ihren Mitarbeitern einen solchen Fringe Benefit anbieten können, wollen wir mithilfe von Virtual Reality eine virtuelle Alternative schaffen. Hierzu haben wir die "Holoft" Software entwickelt, die es den Benutzern erlaubt, ihre eigene virtuelle Arbeitsoase in den Räumen ihrer Wahl einzurichten, um ein ablenkungsfreies und entspannteres Arbeiten zu ermöglichen. Eine Pilotstudie zeigte, dass die Benutzer die virtuelle Arbeitsoase sowohl in den Pausen als auch am Ende des Arbeitstages mochten. Außerdem bot die Software einige der gleichen Vorteile wie die traditionellen Arbeitsoasen.

Abstract

Modern office space design is in a constant state of change, intending to improve employee wellbeing and maximize productivity. A newer concept, the work oasis, attempts to tackle this issue of keeping employees at the peak of their productivity throughout the workweek. Work oases aim to be spaces where employees can take a few minutes of downtime to relax, do simple tasks, get their minds off work, play games, and recharge. As not all companies can offer their employees such a fringe benefit, we aim to provide a virtual alternative using virtual reality technology. To accomplish this, we developed the Holoft software, which allows users to set up their own virtual work oasis in their rooms of choice to foster a distraction-free and more relaxed work experience. A pilot study showed that users liked the virtual work oasis both during breaks and at the end of the workday and that it provided some of the same benefits as traditional work oases.

Acknowledgements

I want to thank all the people who supported me in any way during this thesis. A big thank you goes to Prof. Dr. Thomas Fritz, for allowing me to work on such a fun project and for the valuable feedback provided during the implementation and writing of this thesis. Further, I would like to thank all study participants and people who tested the VR software in different states during development. A last thank you goes to my family and friends who helped me to occasionally clear my mind and return to work motivated.

Chapter 1

Introduction

There seems to be a constant state of change in the world of office space design. The last decade alone has seen many iterations, such as open offices, biophilic designs, water features, and dedicated task areas [Atkin and Brooks, 2015]. The goal behind this constant iteration is to improve employee wellbeing, as a poor work environment has been linked to higher stress levels in staff [Jennings, 2008, Owen, 1993]. Well designed offices, comparatively, have been shown to boost productivity, improve overall job satisfaction, and make employees more creative [El-Zeiny, 2012, Solomon, 2018]. Nevertheless, even the best designed and most comfortable offices do not stop employees from becoming tired and mentally drained during the workday. Exhaustion is becoming increasingly prevalent as employees are asked to spend an ever-growing portion of their waking hours at the office [Gray and Birrell, 2014]. Therefore, managing stress and energy levels throughout the week is very important. Research has shown that highly productive employees spend around 30% of their workday on break [Ericsson, 2015].

A newer concept, the recharge room or work oasis, attempts to tackle this issue of keeping workers at the peak of their creativity and productivity throughout the workweek [Pochepan, 2018]. These work oases are built in many different styles, but they all share common goals. They aim to be spaces where employees can take a few minutes of downtime to relax, do simple tasks, get their minds off work, play games, and, as the name implies, recharge [Vandeloo, 2014]. Various companies such as Unilever, Twitter, Google, and Nike have added such work oases into their offices to improve job satisfaction. For example, Google's Zurich office contains a "jungle lounge," where employees can work and relax surrounded by over one hundred different plant varieties.

While such extravagant work oases are great for employees of large multinational companies, the vast majority of companies do not have the budget to build these spaces. Additionally, due to the current global pandemic, many workers are forced to work from home [Hayes et al., 2020]. Therefore, even Google employees are without their work oases. Researchers from Stanford asked 2500 US residents about their room situation when working from home during the pandemic [Bloom, 2020]. Only half of the respondents stated that they could work privately in a room other than their bedroom, emphasizing the importance of a separate space to relax and recharge.

So what if one could turn any existing office or living space into a work oasis, a space for relaxation, recharging, and doing simple tasks without being distracted? This proposition is rapidly becoming a reality by using novel technologies, such as virtual reality (VR) and augmented reality (AR). While VR completely replaces a user's vision with a virtual scene, AR superimposes virtual elements onto a user's normal vision. Companies like Oculus, a VR headset manufacturer, are already working to augment the modern office into a more pleasant space using virtual reality. They are calling it "Infinite Office" [Matney, 2020]. Their approach is similar to other available virtual productivity applications, such as "Virtual Desktop" [Virtual Desktop, Inc., 2020] and "Immersed" [Immersed Inc., 2020], in that they focus on adding two-dimensional computer screens into a predefined virtual environment. However, this approach leads to a critical issue: the disconnect between the virtual environment and the real world office/living space. Often the positions of virtual objects, like walls, tables, and other items, do not match up with their real-world counterparts outside of VR. Thus, they cannot be interacted with in any meaningful way, effectively making them little more than set-dressing. As a result, most virtual reality productivity applications are intended to be experienced statically while sitting at a desk.

Based on the current research, we aim to provide a virtual alternative for employees who do not have access to a work oasis due to their company not offering such a fringe benefit or working from home. Additionally, we also attempt to resolve the disconnect between the virtual world and the real space by taking the users' actual office or living area into account when generating a virtual workspace. For example, if a user has a sofa in their living space, they should be able to add it into the virtual workspace, allowing them to see and use the sofa even when immersed in VR. The resulting customized workspaces are then augmented with various virtual environments to satisfy users' tastes and moods. Thus, our overall objective is to allow users to set up their own virtual work oasis in their rooms of choice to foster a distraction-free and more relaxed work experience.

To achieve our goal of developing a viable virtual alternative, this thesis consists of developing a software prototype called Holoft and evaluating the resulting prototype through a pilot study. Therefore we are also looking at two types of research questions: technical research questions related to the implementation and research questions related to the evaluation:

- Technical research questions
  - **RQ1.** Can we develop a system that allows for the setup of a virtual workspace in a variety of different rooms?
  - **RQ2.** Can we dynamically augment these workspaces into different styles of virtual work oases?
- Evaluation research questions
  - **RQ3.** Can participants use Holoft for their own room(s) to set up virtual workspaces/oasis?
  - **RQ4.** Does Holoft's virtual environment foster a (1) more focused/less distracted, and (2) more relaxed work experience?

The main contributions of this thesis are (1) an easily extendable virtual work oasis software, which allows users to create a customized virtual workspace that can be augmented with various environments, (2) a general-purpose alignment script to align virtual scenes with their real-world counterparts, (3) a system for creating customizable virtual workspaces, and (4) the results of a weeklong user study with three participants based on interviews. We believe these results show potential that, as VR technology improves, virtual work oases can provide many of the same benefits of traditional work oases while being accessible to more people.

To address these goals and research questions, the thesis is structured as follows. An overview of the existing related research is given in the following chapter. Chapter 3 provides the necessary background information for choosing the optimal hardware and software required to develop Holoft. In Chapter 4, the approach we used for developing the Holoft software and the resulting implementation is presented. Subsequently, in Chapter 5, we describe the pilot study used to evaluate the prototype. The pilot study results are presented in Chapter 6 and discussed in Chapter 7. In the closing chapter, the conclusion is drawn.

Chapter 2

Related Work

This master thesis aims to develop an application that will allow users to create a customizable virtual work oasis based on their surrounding physical space. These virtual work oases are designed to help the users relax and recharge during work breaks or accomplish simple work-related tasks while immersed in a more pleasing environment. Therefore, the literature research consists of four main focus points. First, the focus is placed on existing research regarding relaxing at work to show the importance of having work oases. Second, VR systems and applications intended for relaxation are identified while detailing their specific approaches. Third, existing research on office work in augmented and virtual reality is examined, as the developed application allows users to do simple work tasks in the work oases. Fourth, the focus is set on research about creating virtual environments and the inclusion of interactable virtual objects. The creation of such environments is an integral part of developing Holoft.

2.1 Relaxing at Work

As companies try to keep their employees operating at the peak of their productivity, the importance of taking effective breaks is growing. Therefore, we examined literature related to boosting productivity through relaxing at work. Additionally, this existing research showed the importance of allowing employees adequate time to recharge, leading to various health benefits and increased employee happiness.

Schwartz [2013] looked at different ways that work productivity could be improved. In his work, he states that paradoxically the best way to accomplish more is by spending more time doing less. Through naps, longer breaks, or more sleep during the night, the concept of strategic renewal has been shown to boost productivity and worker health. Schwarz summarizes that working in 90-minute intervals is optimal. After these 90 minutes, the level of alertness rapidly decreases. This result is backed up by Ericsson [2015]. Ericsson studied elite performers from various fields, such as musicians and athletes. By examining the effectiveness of their schedules, he synthesized the results into recommendations aimed at office workers. One such recommendation is to limit exhaustion to an amount they can recover from daily. This pacing enables workers to stay productive in the long-term. The findings by Schwartz [2013] and Ericsson [2015] show the importance of giving employees adequate breaks and allowing them time away from work.

Another way to boost productivity by allowing time away from work is presented by Pochepan [2018] and Vandeloo [2014]. They both examine a newer concept in office design called the "recharge room" or "work oasis." A work oasis attempts to keep workers at the peak of their creativity and productivity throughout the workday by providing a dedicated relaxation space. These spaces can take a multitude of different forms, from meditation spaces to game rooms. Vandeloo [2014] shows that workers making use of these work oases have a more productive and enjoyable workday. We hope to add to this body of research by examining the benefits virtual renditions of such work oases can provide.

2.2 Relaxing in VR

Researchers have experimented with a wide variety of technologies with the intent of reducing stress and fostering relaxation. One such technology, virtual reality (VR), is uniquely suited to accomplish these objectives. By replacing a user's vision and immersing them in a virtual world, VR can provide possibilities that traditional relaxation methods cannot.

Soyka et al. [2016] studied the possibility of enhancing existing stress management techniques through VR. They developed a virtual underwater environment to be used in combination with well-established breathing techniques. Soyka et al. [2016] compared this combination to using standard breathing exercises without VR. Interviews showed that participants found the VR variation more fun and were more likely to use it at home. These findings show the potential VR technology has for relaxation and provide a good basis for our own implementation of relaxing virtual environments.

Straßmann et al. [2019] extend the work of Soyka et al. [2016] by further utilizing the possibilities provided by VR. In their work, Straßmann et al. [2019] present an actively adapting VR application developed for relaxation. This application was developed as an alternative to the novel nap chambers found in many companies. Straßmann et al. [2019] found that participants immensely enjoyed the privacy that wearing a VR headset provided. Participants also reported that they would have liked to edit the environments to suit their moods and preferences. Based on these reports, we decided to include multiple different environments styles in our application.

A different look at the effects of relaxing virtual environments is provided by Annerstedt et al. [2013]. In their research, Annerstedt et al. [2013] examine the effect of a VR nature scene on users' stress level. They leveraged biophilia's well-studied effects, the innate tendency to seek connections with nature, to help with relaxation. Annerstedt et al. [2013] found that they could activate the participants' parasympathetic nervous system by playing nature sounds. This activation leads to a drop in heart rate and reduced stress. Similarly, Yin et al. [2019] looked at how nature elements, like plants and trees, can be used to relax in an office setting. By creating virtual office environments, they compared the effects of different office designs using VR. These designs ranged from the classic non-biophilic office to a combination of plants and natural light for a more "green" office space. The results showed that biophilic environments had a considerable restorative impact. Users reported feeling more revitalized after spending time among the virtual plants. Yin et al. [2020] later expanded upon their previous work and discussed the benefits of using VR to design and test new office spaces. Yin et al. [2020] found that the amount and position of plants and trees are essential to maximize their effect in decreasing stress. Overall, the works of Annerstedt et al. [2013] and Yin et al. [2019] provide the basis for successfully implementing our virtual work oases software's relaxing environments.

Additionally, the environments were designed with the intent to leverage the presented benefits of biophilia.

In their work, Thoondee and Oikonomou [2017] explore the addition of simple work-related information into a relaxing virtual environment. They examined whether employees could benefit from doing simple work tasks, such as reading emails in a more relaxing space. Participants in their study stated that they felt more relaxed after spending time working in the virtual environment. The application developed for this thesis is similar to that of Thoondee and Oikonomou [2017], as it also places users in relaxing environments. However, they differ by the amount of interaction provided to the user and the possible types of work. In addition to providing a way to read emails, the web browser we implemented also allows users to navigate any web content.

2.3 Office Work in Augmented and Virtual Reality

The possibilities provided by augmented (AR) and virtual reality (VR) are becoming increasingly evident as technological advancements are made. AR and VR systems are already being used in a variety of different fields, ranging from aiding in the construction of airplanes (e.g. Boeing [2018]) to applications for neurorehabilitation (e.g. Ma et al. [2014]). However, the use of these novel technologies has yet to see widespread adoption in an office setting. Nonetheless, there is a growing body of research on how AR and VR can benefit office workers.

Ruvimova et al. [2020] examined if working in VR can be used to mitigate distractions and improve performance in open offices. They performed a study in which they had participants try out different office styles, both outside and inside VR. Their results showed that while a closed office leads to the best performance, the VR conditions were superior in an open office setting. Thus, Ruvimova et al. [2020] showed working in VR can be used to foster flow.

Besides limiting distractions and fostering flow, VR/AR also allows the traditional seated workspace to be augmented. Berki [2019] examined how using additional virtual monitor space changes the way users work. She ran a study examining worker performance on different tasks involving multiple documents and webpages. One group of participants performed the tasks using a regular computer, whereas the other group wore VR headsets. The participants in VR were able to permanently display extra information onto virtual screens superimposed in the environment. This setup resulted in more efficient navigation through the documents compared to the users with regular computer monitors. Extending Berki's [2019] work, Mcgill et al. [2020] looked at how best to use this additional screen space. They analyzed different layout configurations by superimposing virtual monitors onto the user's view through an augmented reality headset. Mcgill et al.'s [2020] results show that too much screen width leads to excessive head-turning and results in fatigue. Thus, they recommend that developers be mindful of overly increasing horizontal screen space. Based on this research by Berki [2019] and Mcgill et al. [2020] we constrained the virtual screen in our software to a standard widescreen ratio of 16:9.

While working in VR has many benefits compared to the traditional office setup, there are also some drawbacks. One such drawback is examined by Walker [2017]. He tackled the issue that users cannot see their keyboard when typing in VR, as the head-mounted display occludes the user's vision of their surroundings. To combat this problem, Walker [2017] developed a system that shows a virtual rendition of the keyboard in VR. Keys pressed on this virtual keyboard illuminate to allow the user to see where their hands are currently placed on the keyboard. Similarly, Grubert et al. [2018] also discuss the issue of typing in VR. They propose that the focus should be on developing novel interaction techniques instead. The issues faced by Walker [2017] and Grubert et al. [2018] led to the decision to limit interaction to a laser pointer system in our implementation.

While the challenges of office work in VR have been explored from a technical perspective, little research has been done exploring the effects of extended working in VR on users. One notable exception is the research done by Guo et al. [2019], which focuses on working in VR with regard to Maslow's hierarchy of needs. They performed a study that involved users being immersed in virtual environments for 8 hours, the length of a typical workday. Factors like losing the sense of time became an issue, which led Guo et al. [2019] to recommend including a virtual clock in the environment. During the study, the users initially reported increased productivity due to being isolated in the virtual world. However, this feeling of isolation was reported to turn into loneliness as the study progressed. Unlike in Guo et al.'s [2019] study, while using the Holoft software, users will only be immersed in VR for shorter breaks. We, therefore, do not expect users to develop feelings of loneliness or similar adverse effects as experienced in Guo et al.'s [2019] study. Furthermore, to combat the loss of time perception, we followed Guo et al.'s [2019] recommendation to include a clock in our virtual workspaces.

While there is a large body of research regarding the benefits of working in VR, a handful of commercially available applications already enable working in VR. As of this thesis's writing, the most popular of these applications is "Virtual Desktop" [Virtual Desktop, Inc., 2020]. Virtual Desktop allows users to place virtual renditions of their computer screen into various predefined virtual environments. Thus, a user's office is replaced with unusual and exciting locations such as a beachfront cabin or a starship deck. This functionality allows workers to isolate themselves from their physical surroundings completely. "Immersed VR" [Immersed Inc., 2020], another productivity application, uses an opposite approach to improving the work experience through VR. Unlike Virtual Desktop, it does not aim to isolate the user but rather provide a more social work environment. Immersed VR was developed to allow for telepresence through virtual avatars in a shared environment. Thus, groups of workers wearing headsets can work and interact with each other in virtual offices without physically being in the same place. Immersed VR's overall goal is to combine the benefits of telepresence with those of creativity-stimulating virtual environments.

"Infinite Office" by Oculus [Facebook Technologies, 2020a], a VR headset manufacturer, aims to solve the issue of not being able to see the keyboard when typing [Matney, 2020]. Set to release in the third quarter of 2021, Infinite Office will use the Oculus Quest 2's infrared cameras to overlay a live video feed onto the virtual environment [Facebook Technologies, 2020b]. This overlay will allow users to see their keyboard and mouse while wearing the head-mounted display. Such technology can likely improve future versions of Holoft by facilitating the virtual workspace setup process.

Overall, the presented VR work and relaxation applications are all intended to experienced statically while sitting at a desk. While these applications inspired the Holoft software developed in this thesis, our application differs from them by allowing users to navigate around the virtual workspace freely.

2.4 Creating Virtual Environments

In order to provide an immersive VR experience, users are placed into well-designed virtual environments. Such environments range from wholly fictional worlds created by designers to near-identical virtual copies of real-world spaces.

Kanade et al. [1997] were some of the first to discuss the possibilities that constructing such virtual worlds from real scenes can provide. Their system used stereoscopic reconstructions of a scene. This approach allowed users to select different viewpoints, independent of where in the scene the original camera was positioned. A more modern approach to automatically reconstructing an indoor scene using video is presented by Zhu et al. [2019]. Their approach uses the Manhattan assumption commonly used in computer vision. This assumption states that any indoor scene mainly consists of planar surfaces with orthogonal normal directions. As a result, many of the captured flat surfaces can be identified as walls, floors, and ceilings in real-time. A similar automated room recognition approach was evaluated in Section 4.3. However, due to the complexity of the system implemented by Zhu et al. [2019] and the required high-quality camera images, we ultimately decided against using such a solution for our application.

Simeone et al. [2015] studied the effects of a novel type of virtual environment: substitutional reality. Substitutional reality makes up a class of environments where every real-world object has a virtual counterpart. Simeone et al. [2015] examined the factors affecting users' ease of navigating the environment and interacting with the objects. Their study showed that users were better at navigating the environment when they could see representations of physical obstacles. Simeone et al. [2015] created a set of guidelines for designing future substitutional reality applications. They recommend that developers should strategically minimize the mismatch between the virtual and physical objects. For example, the parts of a virtual object that a user can touch should look similar to the physical object, whereas the rest of the object can be embellished in the virtual version. Similar to the system developed by Simeone et al. [2015], the Holoft software allows users to see virtual representations of obstacles to improve navigating the environment. Additionally, the presented guidelines influenced the choice of objects included in our application and their visual design.

Overall, the findings in recent research presented in this chapter offer a strong knowledge basis, which proved vital in the practical implementation, further detailed in the following chapters.

Chapter 3

Background

Specialized hardware and software are required to develop the Holoft prototype. For the desired relaxing effect of a work oasis to be achieved, the users need to be truly immersed in their surroundings. Such immersion is best accomplished through the use of a virtual reality headset. A brief introduction to VR and the different popular VR headsets and their characteristics are presented in the following section. Furthermore, to create a virtual reality application, a game engine is required. Thus, the final section of this chapter provides an evaluation of different game engines.

3.1 Virtual Reality Headsets

Virtual reality (VR) is a simulated experience where the wearer of a headset can become immersed in virtual worlds [Goode, 2019]. Such a VR headset comprises one or more displays (usually stereoscopic displays providing separate images for each eye), speakers, and sensors for tracking the user's movement. Immersive VR adapts to user movement by updating the visuals shown inside of the headset [Psotka, 1995]. When the head is moved, the view is adjusted to show the new position's perspective.

The earliest known VR headset was shown by Sega in 1991 at CES but was never released to the public [Vinciguerra, 2015]. John Carmack, the co-founder of *id Software*, described these early prototypes as "looking through toilet paper tubes" [Onyett, 2016].

The first modern commercially available headset, the Oculus Rift, was crowdfunded back in 2012 [BBC News, 2012]. Since the Rift, there have been many advancements in headset design. These advancements include both increasing the lens resolution and performance, as well as improving usability. Many other companies like Sony, HTC, and Valve have are currently producing competing headsets. However, at the time of writing, Oculus and Sony currently dominate the VR headset market [Marvin, 2019].

Nonetheless, VR headsets are still a reasonably novel technology and choosing the correct device for a given use case is essential. A comparison of the most popular current VR headsets is as follows:

Playstation VR
The Playstation VR is developed by Sony Interactive Entertainment [Sony Interactive Entertainment, 2021]. It was released at the end of 2016 to be used together with Sony's Playstation 4. As a game-console powered headset, it allowed users to forgo buying an expensive gaming PC to run high-fidelity games. This characteristic made the Playstation VR one of the most affordable headsets at the time of its release. Additionally, due to the existing Playstation ecosystem of games and software, the headset quickly became an attractive option for people looking to get into VR on a budget [Pinno and Leger, 2020]. However, to achieve this low price, the tracking system used is less advanced than those on PC-based headsets released at a similar time. There have also been no hardware updates to the Playstation VR since its release more than four years ago.

Due to the nature of running on a console, developing for the Playstation VR is much more complicated than it would be for a PC or mobile-based headset. Sony only allows certified Playstation developers to create games and software for their consoles [Ralph, 2020]. Consequently, there is no easy way to load custom software onto the console manually. Overall, while the Playstation VR is a very budget-friendly headset for the consumer, developing for it without being backed by a large game studio is not feasible.

HTC Vive

The HTC Vive is a line of headsets developed by HTC and Valve [HTC Corporation, 2021]. The initial version was released in April 2016, with the newest iteration, the Vive Cosmos Elite headset, being released in March 2020 [Vive Team, 2020]. The Vive is a PC-based headset, using a cable plugged into the headset to provide power and display the image. All of the tracking calculations and graphics rendering are done on the computer and then sent to the headset. The tracking itself is done through small infrared sensors mounted to walls on both sides of the area where the VR headset will be used. While this setup provides superior tracking, it does mean that setting up the Vive takes longer than a console-based headset like the Playstation VR.

Developing for the HTC Vive is straightforward, as the headset connects to a computer like an additional monitor. This allows for runtime debugging directly from an editor, vastly speeding up the development process. Additionally, the HTC Vive does not require any certification to develop for it, limiting development costs to the headset's price and any game engine fees. Overall, the HTC Vive line of headsets is a good middle range between the more affordable but less powerful Playstation VR and the high-end PC-based headsets.

Valve Index

The Index by Valve was released in April of 2019 and is Valve's first solo developed headset [Valve, 2021]. It is widely regarded as the most powerful consumer-grade headset currently on the market [Pinno and Leger, 2020]. Like the HTC Vive, the Index uses a cable to connect to a gaming PC. However, to make the most of the Index's ultra resolution screen and 120 Hz refresh rate, a top of the line graphics card is required. The Index makes use of the same tracking system as the HTC Vive. Therefore, getting the Index set up also requires a significant amount of time and effort. At a base price of around a thousand Swiss francs, the Index is one of the most expensive headsets available. However, despite its price, stock shortages make purchasing an Index difficult at the time of writing.

Like the Vive, the Index connects to the computer like an additional monitor, allowing for easy development and in-editor debugging. Ultimately, due to its reliance on a top of the line gaming PC and high price, the Valve Index is a poor option for most use cases unless the absolute best fidelity is required.

Figure 3.1: The Oculus Quest line of headsets, with the Quest 2 on the left and the original Quest on the right.

Oculus Quest and Quest 2

The Oculus Quest and Quest 2 are headsets developed by Oculus, a subsidiary of Facebook Technologies [Facebook Technologies, 2021b]. The original Quest was released in May 2019, and its successor, the Quest 2, in October 2020. The Quest 2 boasts a sharper display and improved processing power while retaining a similar form factor as the original Quest. Both the Quest and Quest 2, as shown in Figure 3.1, are standalone VR headsets. Therefore, they do not need to be connected to a PC or a console to function. Instead, they rely on an Android-based operating system, with all computations being done directly on the headset's integrated hardware. Such standalone headsets' main advantage is the lack of tether cable, allowing users to move more freely without the fear of becoming tangled. There also is no need for wall-mounted tracking sensors, allowing the headset to be used in many different spaces with minimal setup required [Grey, 2020]. At a price of just under 300 Swiss francs, the newer Quest 2 is one of the most affordable headsets currently available [Pinno and Leger, 2020].

Running on an Android-based operating system means development for the Oculus Quest and Quest 2 is similar to developing for mobile phones. As a result, it is not as convenient as working with PC-based headsets due to several reasons. Mainly, each build must be transferred onto the device, with no way of debugging in-editor while running the software. Overall, the standalone nature of the Quest and Quest 2, in addition to their low price point, nevertheless makes them very attractive headsets for most use cases.

3.2 Game Engines

A game engine is required to create the interactive software that will run on the chosen VR headset. A game engine is a software development tool, which abstracts many of the complex development processes, like rendering shaders and calculating physics simulations [Ward, 2008]. This abstraction allows for the wide variety of people working on games, such as designers, programmers, artists, and sound engineers, to use the same tool. Additionally, a modern game engine provides many essential features built-in, allowing game developers to focus on the experiences they want to craft, rather than rebuilding basic systems for every game [Lewis and Jacobson, 2002].

As only a small amount of the people involved in making a game are programmers, most modern game engines also include a visual editor. Such visual editors allow large parts of the game making process to be completed without requiring any coding. Especially for more complex 3D games and software, having visual help when constructing environments is a significant benefit.

Four game engines are currently popular choices for VR development [ServReality, 2019b]. Their respective characteristics are as follows:

Unity3D
Unity3D, commonly referred to as simply Unity, is developed by Unity Technologies [Unity Technologies, 2021e] and is widely regarded as the most popular game engine [Thinkwik, 2018]. Unity's popularity can be attributed to two main reasons. First, it continues to offer a free version for non-commercial use. Second, Unity has a relatively shallow learning curve for beginner game developers. This shallow learning curve is mainly due to Unity using the easy-to-learn C# as its scripting language, instead of the more performant but challenging to learn C++ language [Xie, 2012]. Additionally, Unity uses an entity-component system of gameobjects as its architecture. This system allows for logic scripts to be directly attached to gameobjects without needing a large parent class. Besides the usual benefits of using an entity component system in software development, in Unity's case, this approach also means most adjustments can be made directly in the visual editor. Unity is also especially suited for novice developers with a large support community to answer questions.

Another benefit of Unity is that it provides cross-platform integration, quickly allowing developers to switch between game platforms like Android and Windows. This platform switching is especially important for VR development, as an increasing number of standalone headsets use an Android-based architecture. Paired with plug-ins from headset manufactures, such as Valve and Oculus, Unity is a useful tool for most developers who plan to work with VR [Facebook Technologies, 2021a]. Additionally, Unity Technologies has stated in their roadmap that they will continue to improve VR and augmented reality (AR) support [Unity Technologies, 2021d]. Overall, Unity is a well-rounded beginner-friendly engine, which is suitable for most smaller scale game projects.

Unreal Engine 4
The Unreal Engine 4 (UE4) is the second most popular engine available and is developed by the game studio Epic Games Inc. [Epic Games, Inc., 2021]. Like Unity, a free version is offered for non-commercial use. UE4 claims to be the most powerful real-time engine and consequently places a heavy focus on photorealistic rendering. This focus, combined with a well-developed particle system, allows developers to create very visually impressive games [Karis and Epic Games, 2013]. Accordingly, UE4 uses the highly performant C++ scripting language and expects developers to be familiar with its complex systems [ServReality, 2019b]. For these reasons, UE4 is considered more suited for experienced developers and larger studios [ServReality, 2019a]. In regards to VR development, UE4 aims to allow developers to create graphics-heavy games for high-end headsets. While this is desired for PC-based VR, standalone headsets' low performance can make little use of these features. Overall, UE4 is a powerful game engine that requires experienced developers to make the most of its features and systems.

Amazon Lumberyard
Amazon's Lumberyard engine uses a new approach to the traditional game engine business model [Amazon Web Services, Inc., 2021a]. Instead of requiring developers to pay either an upfront usage fee or royalties based on the game's revenue, developers are only charged for the "Amazon Web Services" features needed by the game. These features include any cloud-based calculations, such as multiplayer systems. As a result, this business model makes Lumberyard especially attractive for large-scale multiplayer games, with server hosting built

directly into the engine. Additionally, Lumberyard is well suited for games developed to be streamed on Twitch, a streaming platform also owned by Amazon [Amazon Web Services, Inc., 2021b]. However, Lumberyard is a fairly new engine compared to Unity and UE4. It, therefore, currently lacks many of the standard built-in features of its competitors. This lack of features can cause issues for smaller teams, who do not have the resources to build their own development tools in addition to the few offered in Lumberyard. Similarly, VR support is included, but only for the HTC Vive and Oculus' PC-based headsets [ServReality, 2019b]. There is currently no support for Android-based standalone headsets. While Lumberyard is likely to become one of the main engines used for VR development in the near future with the backing of a large corporation like Amazon, its current state makes it a poor choice compared to Unity and UE4.

CryEngine

Lastly, the German company Crytek developed the CryEngine [Crytek GmbH, 2021]. Its popularity can be attributed to its design's versatility, allowing it to be used for games of many different genres. Additionally, the CryEngine was one of the first commercially available engines to support VR development. Thus, many of the first successful VR titles, such as "The Climb" [Crytek GmbH, 2016] and "Robinson - The Journey" [Crytek Gmbh, 2016] were developed using the CryEngine. Since those games, Crytek has pivoted its efforts to focus on improving its engine's usability aspects. A C# layer has been added to help flatten the learning curve and make the switch easier for Unity developers [ServReality, 2019b]. However, this refocusing of their roadmap has left their engine lacking in many other aspects. There is currently little support for new standalone headsets, and Crytek has yet to port their engine to run on Mac computers. Ultimately, Crytek's lack of continued VR support makes it a poor choice for developers starting VR development.

Chapter 4

Approach

To evaluate our research questions, we designed and developed virtual reality software. As stated in the introduction, this software's overall objective is to allow users to set up a virtual work oasis in their rooms of choice to foster a distraction-free and more relaxed work experience.

For Holoft to be a viable alternative to the traditional on-site work oasis, it requires a specific set of features. Users need to be able to customize their own virtual workspaces and tailor them to their own space. Thus, we implemented a setup system that allows users to define the boundaries of their virtual workspace and create the objects within it. Additionally, users should also be able to move around their workspace to interact more naturally with the environment. This natural navigation is achieved by ensuring an accurate and reliable alignment of the virtual workspace with its physical counterpart. These workspaces can then be augmented with virtual environments to create a relaxing atmosphere and allow users to destress during their work breaks. To accommodate different tastes and moods, we included various virtual environments that the users can choose based on preferences and moods. As traditional work oases are also often used for quiet work, our virtual alternative should allow for simple work tasks to be done while immersed in VR. This is accomplished by providing users with a VR web browser. Additionally, we included an archery system as a fun activity to allow users to get their minds off work.

Besides proving the technical feasibility of the features above, to make Holoft a genuine alternative, some additional design requirements had to be followed. If employees should use Holoft, it must make financial sense for their employers to introduce such a system. A second necessary design requirement related to our hypothesis is that users without much VR experience can use Holoft. Thus, all processes related to setting up a virtual workspace would need to be as simple as possible.

The development of Holoft can be divided into five distinct parts. The initial part is deciding which hardware and software are best suited to develop Holoft. Our criteria and the resulting decision is presented in Section 4.1. The second part is implementing an alignment process that allows the virtual workspace to be positioned in relation to the real world. This alignment process provides the basis for resolving the disconnect between the virtual world and the real space and is presented in Section 4.2. With the base functionality completed, the virtual workspace can be set up inside Holoft. This workspace setup is the third part and is described in Section 4.3. The fourth part of development focuses on dynamically augmenting the user-created workspaces into work oases. The systems needed to fit these workspaces into virtual environments and the different environments' features are shown in Section 4.4. Lastly, in the fifth part, additional interactive functionality to allow users to work inside the work oasis or distract themselves from work was added to Holoft. This functionality is described in the final section of this chapter.

4.1 Hardware and software selection

As previously stated, specialized hardware and software are needed to develop the Holoft software. This hardware and software consist of a VR headset and a game engine, respectively.

When deciding which VR headset to use to develop and run the software, various factors needed to be considered. One such factor was the hardware cost, as employers would ideally distribute these headsets as an alternative to the on-site work oasis. Ideally, the headset should be in the price range of standard office equipment such as computer monitors and work phones. Moreover, employees would likely be asked to use these headsets in their own homes during the ongoing pandemic. Accordingly, the chosen headset should be straightforward to set up and not require the installation of wall-mounted sensors. Lastly, it cannot be expected that all users possess expensive gaming PCs or consoles. Thus, choosing a standalone headset was important.

Given these design requirements and the characteristics of the various headsets presented in Chapter 3.1, we ultimately chose to use the Oculus Quest and Quest 2 headsets. While not as convenient to develop for as the more expensive PC-based headsets, a tradeoff needed to be made to meet the design requirements. The low cost of the Quest/Quest 2 and their standalone nature has already made them a popular Christmas gift for many companies during the pandemic [Loom Inc., 2021].

As the Holoft software will likely be expanded upon in the future by other students, using an easy-to-learn game engine is essential. Additionally, the chosen engine should allow new features and environments to be added without changing much of the underlying code. Thus, careful consideration needed to be given when choosing the game engine for developing Holoft.

Based on the characteristics of the popular game engines presented in Chapter 3.2 and our previous experience, we chose to use the Unity3D engine to develop the Holoft software. The shallow learning curve and the extensive visual editor provided by Unity make it a beginner-friendly option. Furthermore, the entity-component system of gameobjects will allow for future expansions to be made with minimal knowledge of the underlying code.

Having decided upon the hardware and software to develop and run Holoft, we could implement the required systems. The second part of the development approach, the alignment process, is described in the following section.

4.2 Alignment

The alignment process provides the basis for resolving the disconnect between the virtual and real world. This alignment ensures that a user's physical room and virtual room share the same position and orientation. Without a good alignment, users could not freely walk around their virtual work oasis while in VR. They would not see the

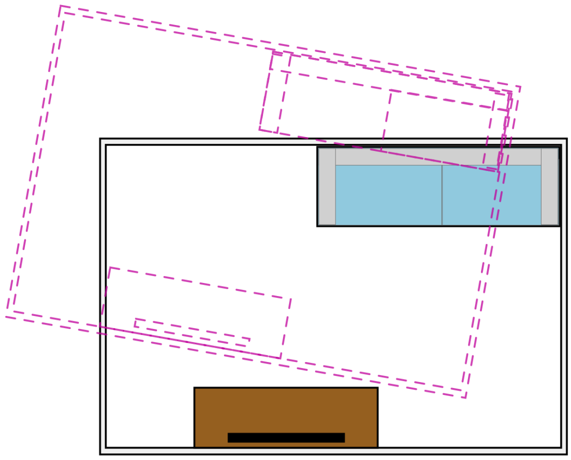

Figure 4.1: A top-down view of a poor alignment, with the virtual room (overlayed in pink) not matching the physical room.

furniture models at the correct place and risk bumping into something. This issue is visualized in Figure 4.1, where the virtual room overlayed in pink does not match the physical room. To enable natural interaction with the virtual workspace, a very accurate alignment is essential. Therefore, we had to develop a simple to use yet exact alignment process for Holoft. As this process would need to be performed for each session, it should also be reasonably fast.

The alignment process used in Holoft is inspired by the work done by Iranian game programmer and technical artist Shahriar Shahrabi. He used a similar approach in his software for aligning photogrammetry scans, which can then be explored in VR [Shahrabi, 2020]. Shahrabi first had to align his scans' position and orientation, then scale them to the desired size. For Holoft, the scaling step is not necessary. This is due to the users scaling the items, such as furniture, independently of the virtual workspace scale. Further, Unity and the Oculus Quest's tracking system both use meters as their base unit, eliminating the need for a scale conversion.

Our implementation's basic concept is to align the whole virtual world by moving and rotating a single Unity gameobject called *room*. All other gameobjects a user may choose to create, like walls and furniture, will be made children of *room*. This hierarchy results in all children inheriting the position and orientation of the parent. Thus, the child's local transforms (position, rotation and scale) will be the offset from the origin of the *room* gameobject. For example, if a child item is moved one meter forward, its local transform would be [0,0,1]. Consequently, if *room* itself is moved, all children are also moved but remain in the same positions relative to each other. This approach allows us to only worry about correctly aligning a single gameobject and thus requiring minimal interaction from the user.

To align *room*, we use two reference positions from the user's physical space. The first of these two points is used to define where the *room* gameobject's origin should be positioned. The second point is used to correctly rotate *room* so that the virtual space is orientated to match the user's room. These two points must remain at the same spot in the user's room between sessions in the work oasis. If the chosen points have moved between sessions, the entire room setup will have to be redone. Thus, we recommend the user choose a solid piece of furniture as a reference, like the corners of an office desk, which is unlikely to be moved.

The implemented process can be broken down into two stages: translation and rotation. The process begins with the translation stage. The user chooses the two previously described reference points in their physical room. Once they have selected which points they wish to use, they are asked to place the right controller at the first point and press the A button. The following code is run:

```
// If A button is pressed
if(OVRInput.GetDown(OVRInput.Button.One, OVRInput.Controller.RTouch))
{
    // Get position of the right controller
    Vector3 tempPosition1 = trackingSpace.TransformPoint(OVRInput.
        GetLocalControllerPosition(OVRInput.Controller.RTouch));
    // Normalize position
    tempPosition1[1] = 0.0f;
    // Move origin of room to normalized controller position
    room.transform.position = tempPosition1;

    break;
}
```

The right controller position is queried from the Oculus tracking system and saved in a 3D vector. This vector's Y coordinate, the up axis in Unity, is set to 0. This normalization is done to set the virtual world's origin to the same height as the real world floor. The *room* gameobject is then moved so that its origin matches the position of the 3D vector,

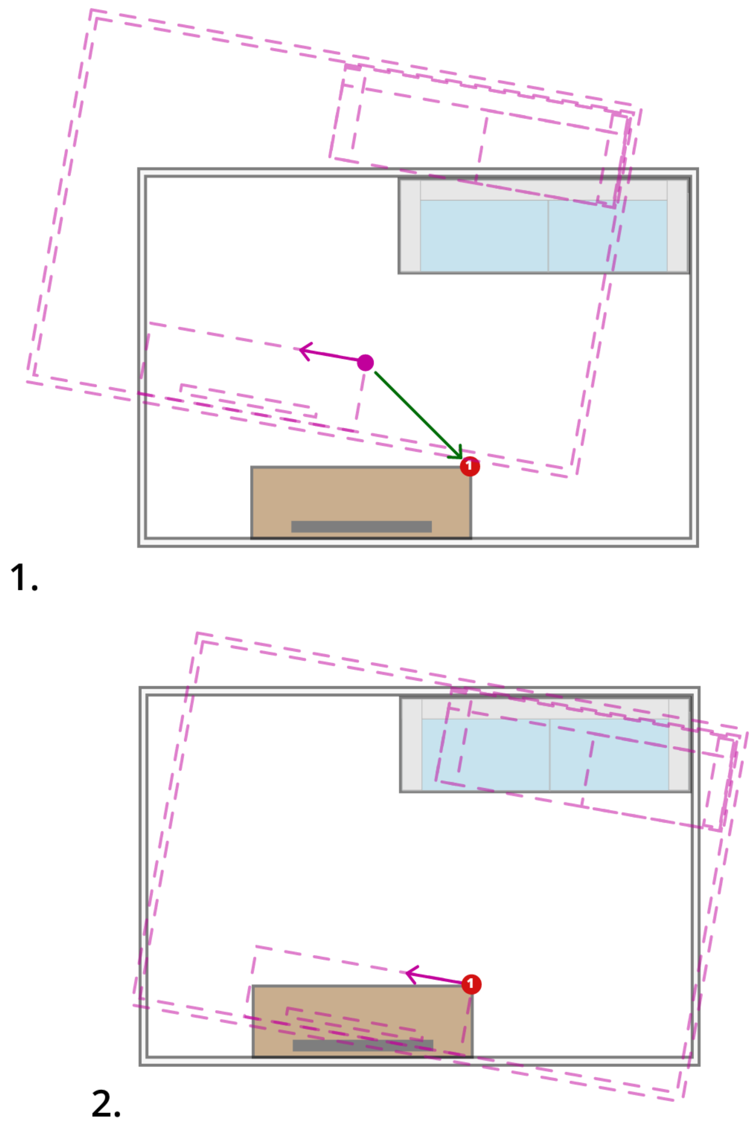

Figure 4.2: The translation stage of the alignment process. The first reference point is shown as a red dot. The *room* gameobject's origin is shown as a pink dot, and a pink arrow marks its forward vector. The green arrow shows how the virtual room needs to be shifted to be positioned correctly.

completing the translation stage. This positioning of the virtual world is visualized in Figure 4.2.

With *room* being at the desired position, the rotation stage can be performed to achieve the correct orientation. This is done by having the user move the right controller to the second reference point. By again pressing the A button the following lines of code are run:

```
// If A button is pressed
if(OVRInput.GetDown(OVRInput.Button.One, OVRInput.Controller.RTouch))
{
    // Get the second position
    Vector3 tempPosition2 = trackingSpace.TransformPoint(OVRInput.
        GetLocalControllerPosition(OVRInput.Controller.RTouch));
    // Normalize position
    tempPosition2[1] = 0.0f;
    // Rotate the room gameobject to face the second position
    room.transform.LookAt(tempPosition2, Vector3.up);

    break;
}
```

The right controller position is again queried, and the resulting 3D vector is normalized by setting the Y coordinate value to 0. Rotating the *room* gameobject is done with Unity's "LookAt" function. This function rotates a gameobject so that its forward vector points at a given target. In this instance, *room* is rotated to face the 3D vector, as shown in Figure 4.3. The *room* gameobject, and thereby the whole virtual room, is now correctly oriented to match the real world. The alignment process is now complete.

If the user has set the alignment but is not satisfied with the accuracy, they may press the B button to reset the alignment and restart the process. We also prompt the user to redo the alignment if they took off the headset while the Holoft software was running. This precaution ensures that the user is not at risk of bumping into any objects if the Oculus Quest's tracking drifts while the application was in sleep mode. The warning overlay is shown in Figure 4.4.

After successfully setting the alignment, the user may now load an already created virtual workspace. If none has been set up for a given room, the workspace setup process can be started. This process, as well as how it was implemented, is described in the following section.

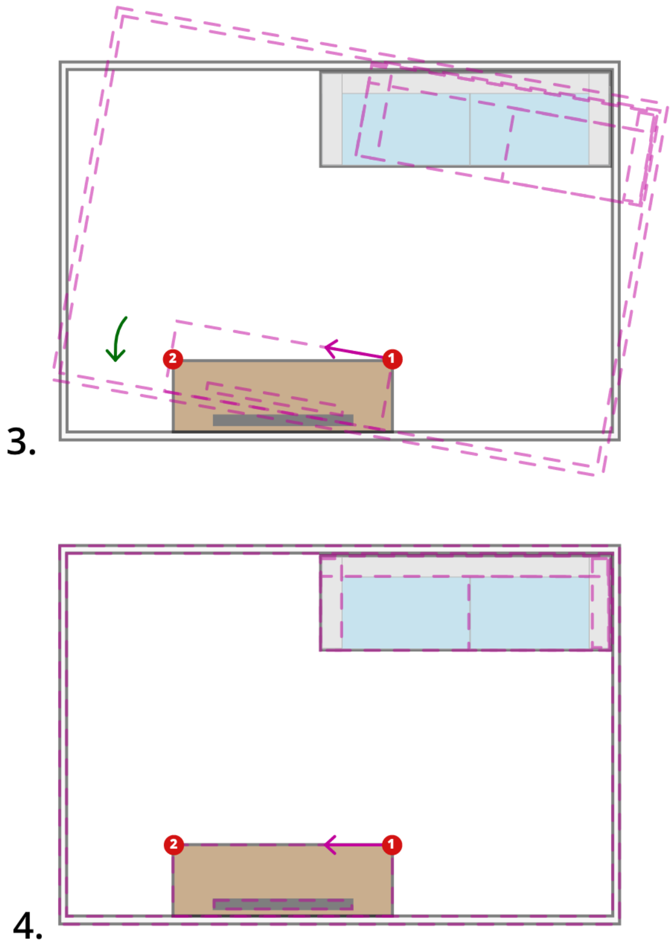

Figure 4.3: The rotation stage of the alignment process. Both reference points are shown as red dots. The pink arrow marks the *rooms*'s forward vector. The green arrow shows how the virtual room needs to be rotated to achieve the correct orientation.

4.3 Workspace Setup

Users wanting to create a virtual workspace out of a new room or space need to perform the workspace setup. This setup allows the recreation of physical objects, such as furniture, inside the VR world, as shown in Figure 4.5. For example, if a user has a sofa in their living room, it should have a counterpart in their virtual workspace.

Figure 4.4: The warning message shown to the user if Holoft detects a possible issue with the alignment. This message is overlayed onto everything and moves with the headset.

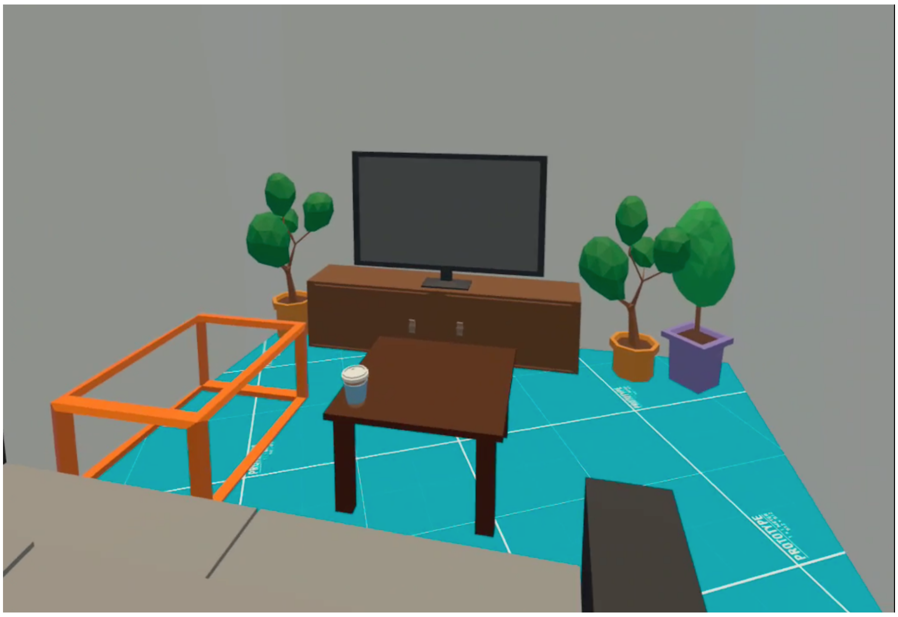

Figure 4.5: A virtual workspace with recreations of furniture and decorative objects, such as a television and plants.

The main benefit of recreating the physical space in VR is two-fold. First, the recreation allows the user to navigate the virtual workspace without bumping into any objects. If the setup process is done successfully, they will see virtual representations of any furniture that could be in their way. Second, the recreation improves immersion as the user's familiar space is augmented rather than replaced with something foreign. As a result, this augmentation allows the user to interact with their surroundings naturally while wearing the headset.

There are two distinct approaches to creating a virtual representation of a physical room or space. One can have a pipeline that automatically creates the virtual workspace or use a manual process. An automated room recognition system can quickly create a virtual environment fitted to a user's space. For such an automated process to function correctly, many cameras and depth sensors are needed to scan the surroundings. Once a scan has been created, the pipeline converts this scan into a 3D model using specialized software on a computer. Finally, this 3D model will be uploaded to the standalone VR headset.

In a manual approach, the user tells the system how to set up the virtual workspace. They are first tasked with defining the workspace's boundaries. Once this boundary has been established, the user is asked to populate the virtual area with any objects they would like to have in the workspace. These objects are manually placed at the desired location.

The main benefit of an automated process over a manual one is its speed and low user involvement. However, such an automated process also has significant drawbacks. The sophisticated cameras and scanners needed are often prohibitively expensive, especially as they are only needed for the initial workspace setup. Similarly, the required software for transforming the scans into 3D models creates additional costs. As Holoft should be a viable alternative to constructing work oases on-site for companies, ensuring that costs are kept to a minimum is essential. For these reasons, we decided against an automated approach for the current version of Holoft. Instead, we focused on an easy-to-understand and interactive manual setup process which requires no additional hardware and software.

In order to be accessible to as many people as possible, Holoft should allow users to set up their virtual workspaces in a wide range of different room sizes and layouts. To allow for such customization, the process we implemented can be split into three parts: creating walls, placing static items, and placing decorative items. Initially, walls are created to define the boundaries of the virtual room. This first part is described in the following section. In the second part, users can populate their virtual rooms with non-moving (static) items, such as furniture. How these static items are correctly position, oriented, and scaled is described in Section 4.3.2. In the final part, decorative items, such as plants, can be added to the virtual workspace to achieve the desired look. The final subsection is used to present how these decorative items can be used.

4.3.1 Walls

In order to define the boundaries of the available area in their rooms, users are asked to create virtual walls. These virtual walls are placed to match any real-world walls, to set the virtual workspace's size and layout. As a result, the users can see a representation of their room's walls, and thus, do not need to worry about accidentally walking into one while immersed in VR.

Our wall creation system uses three components: a start pole, an end pole, and a wall prefab. The start and end poles are cube-shaped gameobjects, which are scaled on the y-axis to be 2.5 meters tall. This size is considered to be the average height of Swiss walls. These cubes will be used to define the start and end of a given wall. The wall prefab is a Unity prefab asset containing the different wall 3D models for each work oasis style. Unity prefabs are reusable assets containing multiple gameobjects and their components, parameters, and scripts [Unity Technologies, 2021c]. Such prefabs allow for a single asset to be instantiated during run-time instead of each gameobject individually. This wall prefab will be positioned, rotated, and scaled to connect the start pole and end pole gameobjects, forming a wall between them.

To start creating a wall for the virtual workspace, the user is instructed to move their right controller to one end of the wall they want to replicate. By pressing the A button, the aforementioned start pole gameobject is placed at the controller's position. This position marks the wall's starting point, as shown on the left in Figure 4.6.

After setting this starting point, the user can now dynamically "stretch" the wall by moving the controller to make it the desired size. This is done using the following function, which is called from Unity's

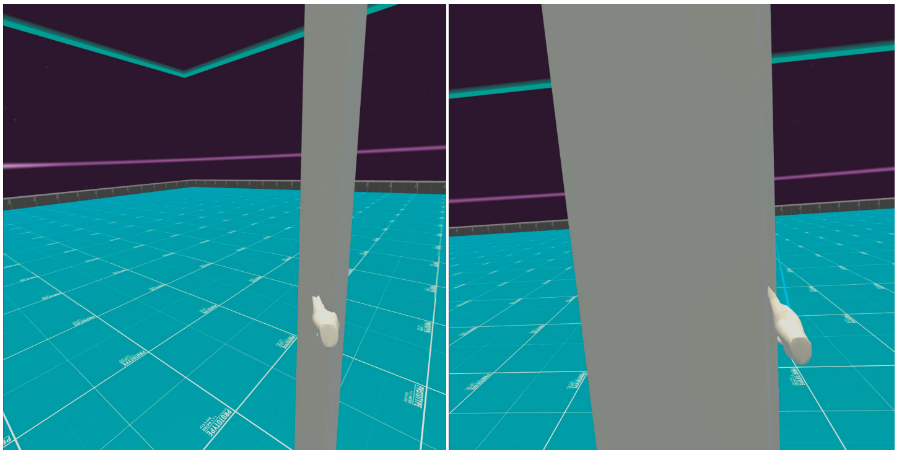

Figure 4.6: Left: The start pole is placed at the initial position of the right controller. Right: The wall prefab is continuously updated to connect both pole gameobjects, allowing the user to "stretch" the wall by moving the controller.

update loop. This update loop is run once every frame, allowing the wall to be updated in realtime.

```
void AdjustWall()
    {
        // Set end pole to controller position
        endPole.transform.position = GetWorldPointOfController();

        // Rotate poles to face each other
        startPole.transform.LookAt(endPole.transform.position);
        endPole.transform.LookAt(startPole.transform.position);

        // Transform wall prefab
        float distance = Vector3.Distance(startPole.transform.
            position, endPole.transform.position);
        wall.transform.position = startPole.transform.position +
            distance/2 * startPole.transform.forward;
        wall.transform.rotation = startPole.transform.rotation;
        wall.transform.localScale = new Vector3(wall.transform.
            localScale.x, wall.transform.localScale.y, distance);
    }
```

The controller's position is continuously queried from the tracking system, and the end pole is set to this position. Both poles are rotated using the "LookAt" function, so their respective forward vectors face each other, and the distance between them is calculated. The wall prefab is then placed in the middle of both poles and rotated to match the start pole's orientation. Lastly, the prefab is scaled using the previously calculated distance between the poles. The result is a continuously adjusted wall prefab, which always takes up the space between the defined start position and the end pole. When the wall's desired endpoint is found, the user presses the A button again to confirm the wall prefab's position, rotation, and scale.

This continuous adjustment allows the user to see the wall updated in realtime as they move the controller. It would have been easier to implement a system in which the user selects both ends of a wall, and only then is the prefab instantiated with the given dimensions. However, our approach has two advantages. First, seeing where the wall will be placed helps make precise adjustments before confirming the final position. Second, we hope the interactivity makes the workspace setup feel less tedious and more playful.

The user can place as many walls as are required to define the boundaries of their virtual workspace. After defining the walls of the virtual workspace, the workspace can now be populated with static items.

4.3.2 Static Items

Static items describe the virtual counterparts to non-movable objects, such as large furniture. By having these virtual representations of the furniture within the workspace, the user can navigate more naturally. For example, walking to a sofa and sitting on it while wearing a VR headset is only possible if the user can see a virtual sofa at the same position as their real sofa. Consequently, each static item needs to match the exact position and dimension of its real-world counterpart.

To allow the users to populate their workspaces with these static items, we have included models of sofas, beds, tables, wardrobes, and shelves. These items can be selected from a grid, as shown in Figure 4.7. However, it cannot be assumed that, for example, all sofas are the same height, length, and depth. Thus, the user needs to customize these dimensions when placing the virtual sofa into their workspace. To allow for this customization, each static item consists of a prefab gameobject containing the 3D furniture model and three dimension markers. An example of the "sofa" prefab is shown in Figure 4.8. The markers, named *Point A, B,* and C shown in green, are used to define the dimensions of the 3D model. When scaling the whole prefab, the

Figure 4.7: The static item selection screen, showing the different furniture the user can populate their virtual workspace with.

dimension markers scale together with the 3D model, staying at the same position relative to each other. This scaling relationship is integral for our implemented approach to work.

Our approach's basic concept is to compare the prefab's current dimensions with the desired dimensions and then scale it accordingly. We do this by comparing the Quest's controller position with the dimension marker position for each axis. For example, when scaling the prefab's Y-axis (height), we calculate how far *Point A* and the controller are away from the prefab origin on that axis. Using these two distance values, we can calculate a scale factor for how much the prefab should be scaled so that *Point A* would be at the controller's height.

The process to populate the virtual workspace with these static items is as follows. First, the user selects the desired item from the grid of available items. With an item selected, the user must then define where the origin of the item should be. To replicate a piece of existing furniture, like a sofa, the user is asked to place the controller at their sofa's right front corner and press the A button. The desired static item prefab is then instantiated with its origin at this position. If

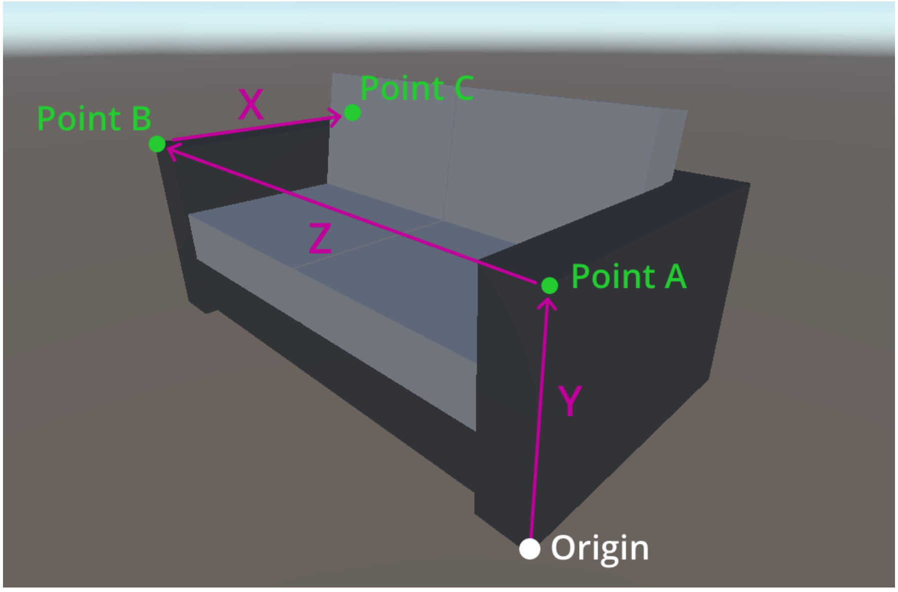

Figure 4.8: The sofa prefab, with the dimension markers (Point A, B, C) shown as green dots. The axis vectors are shown in pink.

the controller was positioned correctly, the prefab's front right corner matches the real sofa's front right corner.

With the position of the prefab confirmed, the next step is adjusting the prefab's height to match that of the sofa. Similar to when creating walls, the prefab is adjusted continuously to match the position of the controller. Thus, the user can find the correct height by moving their controller up or down. The following function is called by Unity's update loop every frame to have the prefab continuously adjust itself.

```
void AdjustPrefabHeight()
{
    // Get controller position and limit its change to the Y-axis
    Vector3 constrainedControllerPosition = GetControllerPosition();
    constrainedControllerPosition[0] = prefabOrigin.x;
    constrainedControllerPosition[2] = prefabOrigin.z;

    // Distance from the prefab origin to the controller itself
    float controllerHeight = Vector3.Distance(prefabOrigin,
        constrainedControllerPosition);

    // Distance from the prefab origin to point A
    float prefabHeight = Vector3.Distance(prefabOrigin,
        prefabToBePlaced.transform.Find("PointA").position);

```

```
    // Scale factor
    float scaleFactor = controllerHeight / prefabHeight;

    // Set the new prefab height
    prefabToBePlaced.transform.localScale = new Vector3(
        prefabToBePlaced.transform.localScale.x, prefabToBePlaced.
        transform.localScale.y * scaleFactor, prefabToBePlaced.
        transform.localScale.z);
}
```

We query the tracking system for the controller's position and store it in a 3D vector. We only allow the Y-value to change and fill the other values with those from the prefab's origin. This constraint allows the user to move the controller up and down without needing to stay in line with the real sofa's front right corner when adjusting the prefab height. We then get the distance from the prefab origin to the controller and the dimension marker *Point A*. These two distance values are used to calculate the scale factor, which is then applied to the prefab. Once the user has found the correct height to match the prefab to their sofa, they can confirm this by pressing the A button.

With the prefab's height set, the width and orientation can now be adjusted by the user. These two adjustments are made simultaneously. The user is asked to place the controller at the left front corner of the sofa. Setting the width is done similarly to setting the height. However, instead of measuring from the origin to *Point A* and the controller, we measure from *Point A* to *Point B* and the controller. This measurement gives us the Z-axis distance, as illustrated in Figure 4.8. Again the required scale factor is calculated and applied to the prefab. For the prefab to be oriented like the real sofa, it needs to be rotated on its origin. To do this, the following code is used:

```
...
    // Make point A face controller
    pointA.transform.LookAt(GetControllerPosition());

    // Set point A's forward vector to be perpendicular to the line A
         to controller
    pointA.transform.Rotate(0, 90, 0);

    // Apply rotation to prefab
    prefabToBePlaced.transform.rotation = pointA.transform.rotation;
...
```

Using Unity's "LookAt" function, we rotate the dimension marker *Point A* to face the controller's position at the left front corner of the

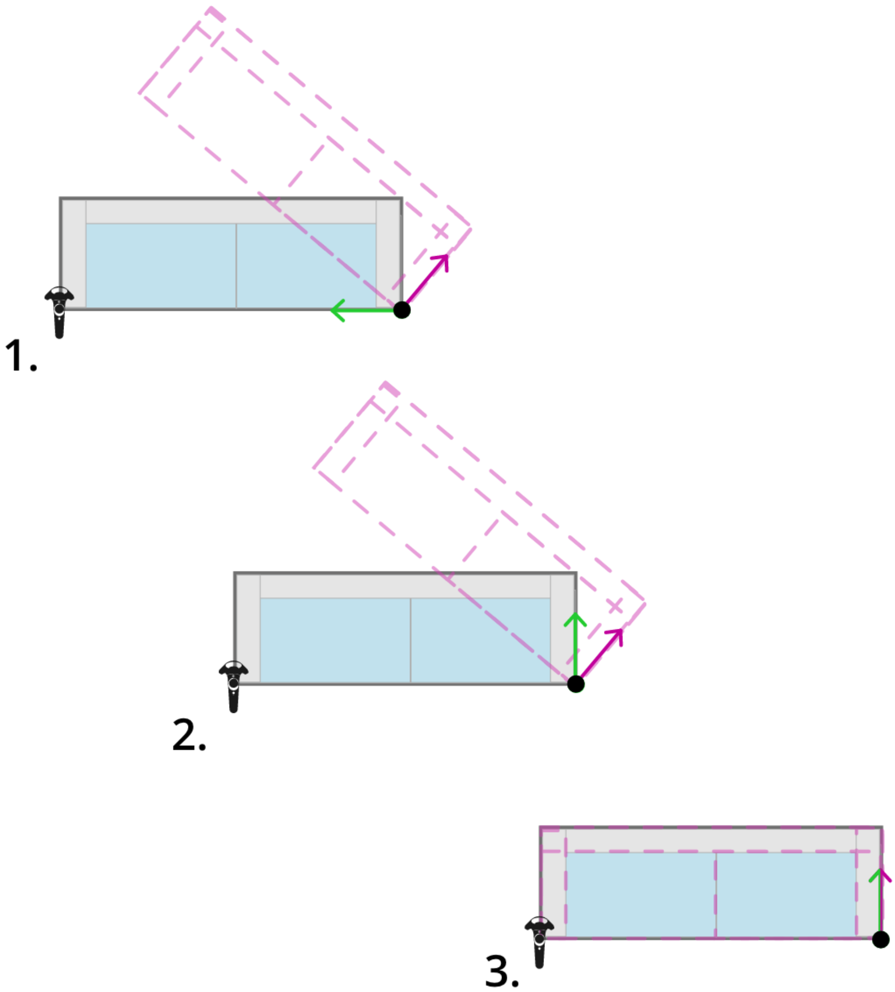

Figure 4.9: The static item rotation process, with *Point A*'s forward vector in green and the prefab's forward vector shown in pink.

real sofa, as illustrated in step 1 of Figure 4.9. Then we rotate *Point A* by 90 degrees so that its forward vector is perpendicular to the sofa's front side, as shown in step 2. This second rotation is needed as the prefab's forward vector points into the model. Lastly, the prefab is rotated to match the orientation of *Point A*, as illustrated in step 3. Again by pressing the A button, the width and orientation are confirmed.

Setting the final dimension, the depth, of the static item prefab also uses the same logic as the other two dimensions. Once the correct scale has been found, the depth is confirmed by pressing the A but-

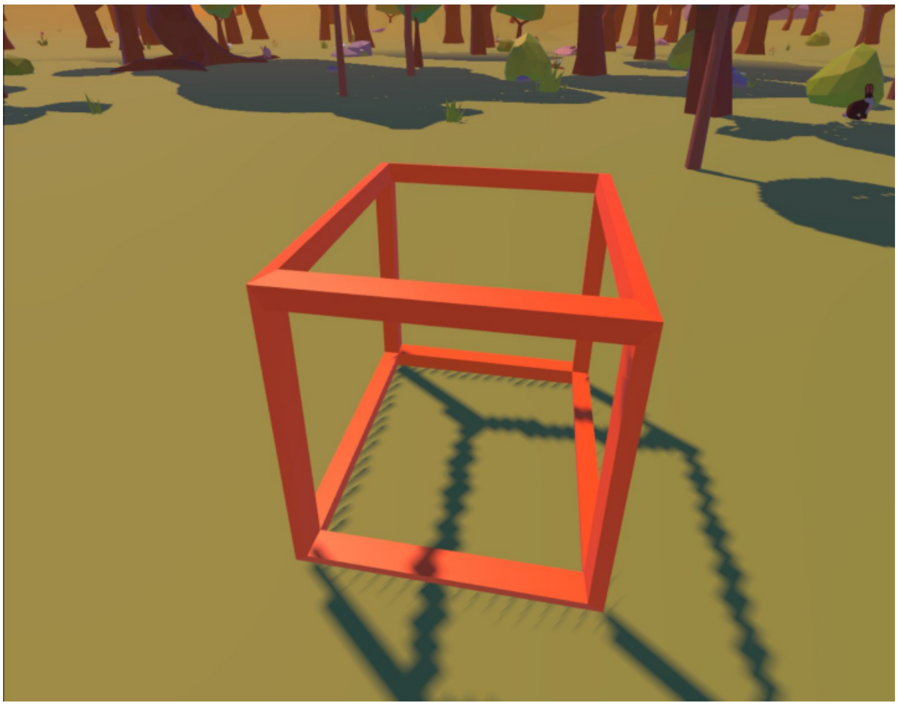

Figure 4.10: The *caution cube* static item, which is used to warn users that there might be furniture in that area.

ton. Thus, using the described process we implemented, the user can successfully position, rotate, and scale static items to match their real-world counterparts.

While this system allows for a wide variety of non-movable furniture to be placed in the virtual workspace, there is one issue. Not all furniture items in a traditional office are fixed in position. For example, an office chair will be moved around between work oasis sessions. Without knowing its current position, such a chair cannot be included in the virtual workspace, as the user would then see the 3D model in the wrong position. As a result, the user might bump into the physical chair because they believe it to be elsewhere. To mitigate this issue, we have implemented a static item called the *caution cube* shown in Figure 4.10. This *caution cube* is used to warn users of any objects which could not be included in the virtual workspace due to their changing positions. By scaling the prefab to encompass the area in which, for example, the office chair could be standing, the user knows where to be cautious when walking around. Additionally, the *caution cube*'s

Figure 4.11: The decorative item selection screen, showing the different decorations with which the user can populate their virtual workspace.

shape makes it an ideal stand-in for furniture not in the list of static items included in Holoft.

4.3.3 Decorative Items

The last part in creating a custom virtual workspace is adding decorative items. Available decorative items in Holoft consist of 3D models of a television, various plants, a computer monitor, and a wall clock, all shown in Figure 4.11. As the name implies, these items will further decorate the virtual workspace to increase the similarity with the user's physical room.

Decorative items differ from static items in that they cannot be scaled to match the dimensions of their physical counterparts. It is potentially dangerous if a user's virtual sofa is not the correct size, as they may miss the real sofa when attempting to sit down. However, there is no such danger with decorative items, as the user does not interact with them directly. Thus, their size does not need to match their real-world counterparts perfectly, making a predefined size sufficient.

Compared to the previously presented process for creating static items, creating decorative items is simpler. To populate the virtual workspace with such items, the user first selects the desired item from the grid shown in Figure 4.11. Once selected, the desired prefab is instantiated directly in front of the user by pressing the A button. The following code snippet handles this instantiation:

```
...
    // Get position of user and the direction they are facing
    Vector3 playerPosition = player.transform.position;
    Vector3 playerDirection = player.transform.forward;
    playerPos.y -= 0.35f;
    float spawnDistance = 0.5f;
    Vector3 spawnPosition = playerPosition + playerDirection *
        spawnDistance;

    // Spawn object in front of user
    prefabToBePlaced = Instantiate(objectPrefab, spawnPosition,
        Quaternion.identity);
...
```

To calculate the position where the decorative item prefab should be created, we first query the position and orientation of the user's head from the Oculus tracking system. We adjust the received position downwards by 35cm, as we want the prefab to be created below eye level. Using the resulting vector and the distance we want the item to be away from the user, the item can be instantiated.

To move the decorative item to its final position, the user can simply grab it with their controller. Once grabbed, they can freely move it to the desired location and rotate it as they please. However, for specific items, such as the television and the larger potted plants, we constrained their rotation to only rotate on the Y-axis. This constraint helps users more easily position items, which are meant to be placed on flat surfaces, such as a table or the floor.

After populating the virtual workspace with the desired decorative items, the user can save their customized workspace in an available save slot. The save system allows previously created workspaces to be loaded in later sessions. After saving, the workspace setup is complete.

To summarize, our implemented workspace setup consists of three parts: the creation of walls, placement of static items, and placement of decorative items. By creating walls to match a user's real walls, the virtual workspace's boundary is created. The resulting area is

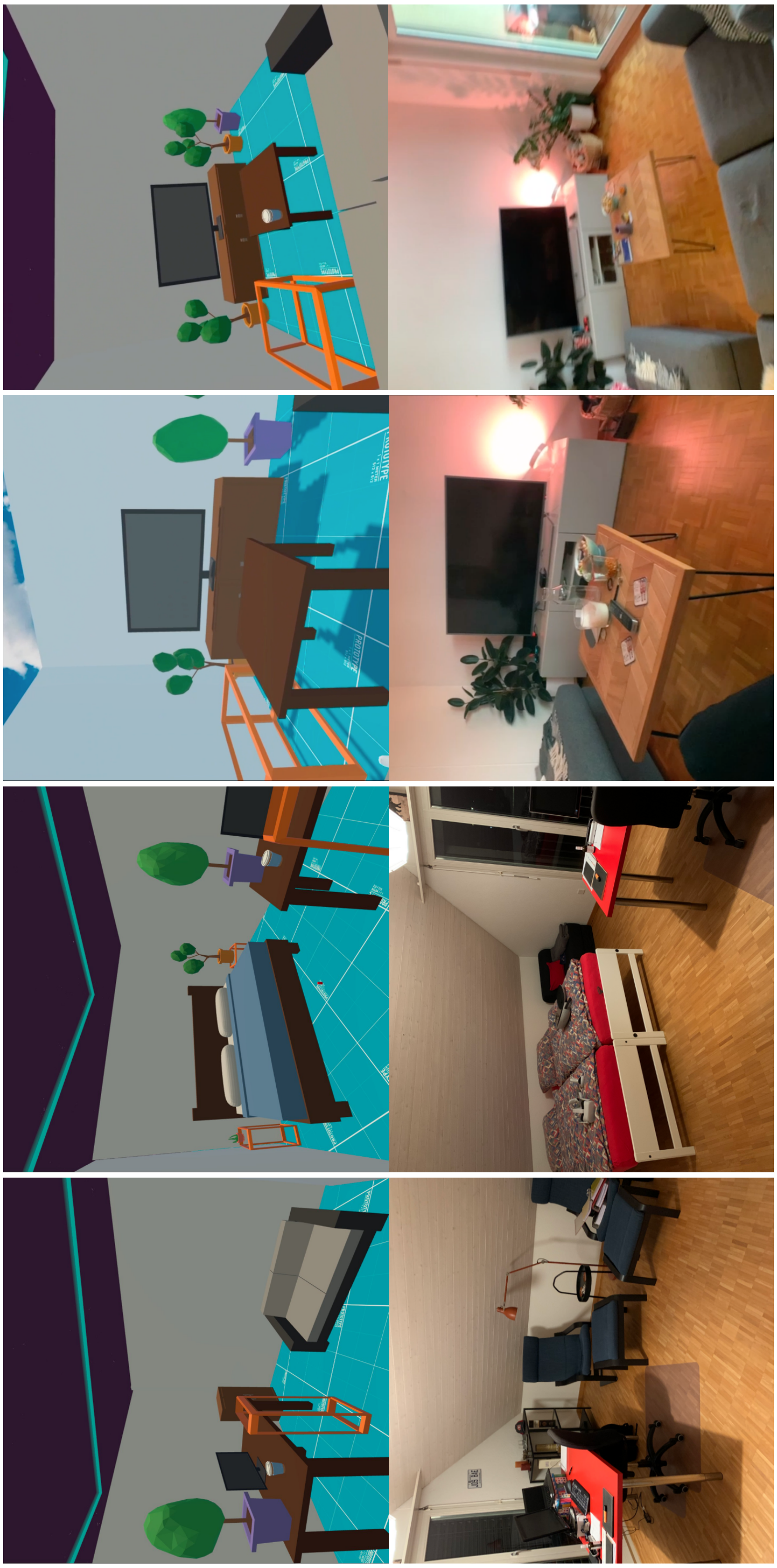

Figure 4.12: Two different virtual workspaces with their real-world counterparts.

then filled with static items, such as tables and sofas, positioned and scaled to match their real-world counterparts perfectly. Lastly, decorative items can be added to the virtual workspace. The customizability of this setup process allows users to create a wide range of different workspace configurations. Thus, we have successfully answered RQ1 ("Can we develop a system that allows for the setup of a virtual workspace in a variety of different rooms?"). A few different possible virtual workspaces are shown in Figure 4.12. These workspaces can then be transformed into work oases, as described in the following section.

4.4 Space Enhancement

Real-world work oases are more than simple office rooms that have furniture for lounging. They also include fancy furnishings and decorations to encourage employees to forget they are currently in the office and help them relax. Similarly, to transform the created virtual workspace into a true work oasis, the area around the workspace needs to be augmented. This enhancement consists of replacing the surroundings with predefined virtual environments. For the work oasis to achieve the desired effects, these environments should include relaxing or creativity-stimulating scenery.

The systems required to include these environments and their implementation are described in the following subsection. The choice of environments and their characteristics are presented in Section 4.4.2.

4.4.1 Systems

A variety of different systems were implemented to display the work oasis environments. These systems augment the user's virtual workspace with predefined environments to create the desired look and feel. While many different systems were implemented, two are especially important: (1) the system allowing the environments to be adapted to different workspaces, and (2) the environment loading system, responsible for triggering the different work oasis environments. These systems are described in the following subsections.

Adaptive Environment System

One of the main design requirements for Holoft is that it should function in a variety of different rooms and spaces. To achieve this, users can create customized virtual workspaces using the process described in Section 4.3. Thus, the workspaces can have many different sizes and layouts.

To fit these various workspaces into the predefined environments, we had to make two assumptions. The first assumption is that Holoft will predominantly be used in rooms with flat floors. Hence, the area in the environment in which a user can walk around should also be flat. If this were not the case, the user's eyes would tell them they are walking up or down, confusing their inner ear. In a worst-case scenario, this sensation could lead to simulator sickness, a type of nausea experienced in VR. Additionally, we assumed that all created workspaces would be smaller than 20 by 20 meters in size. As Holoft is intended to be used in offices or homes, this size is unlikely to be exceeded. Given these assumptions, each environment was created with a 20 by 20 meter flat area at its center to accommodate the workspace.

During development, we initially kept this flat area empty of any art assets to fit the different possible workspaces. However, this made the environment seem more like a pleasant-looking backdrop rather than fully immersing the user in a virtual world. Filling the flat area with various plants and trees greatly improved immersion but caused other issues. The art assets often obstructed the user's view and clipped through the virtual furniture. For this reason, the Holoft software needed to automatically adapt the environments based on the loaded workspace's size.

The basic concept behind our adaptive environment system is to detect which art assets are inside the workspace and, therefore, should be made invisible. Thus, leaving the assets directly outside of the workspace visible and achieving the desired immersion.

Detecting which assets are inside of the workspace was done using Unity's collision system. The collision system uses physics calculations to determine if two or more gameobjects are touching [Unity Technologies, 2021a]. Once a collision has been detected, custom scripts and functions can be triggered on the affected gameobjects. As a result, it is possible to disable a gameobject's mesh renderer on colli-

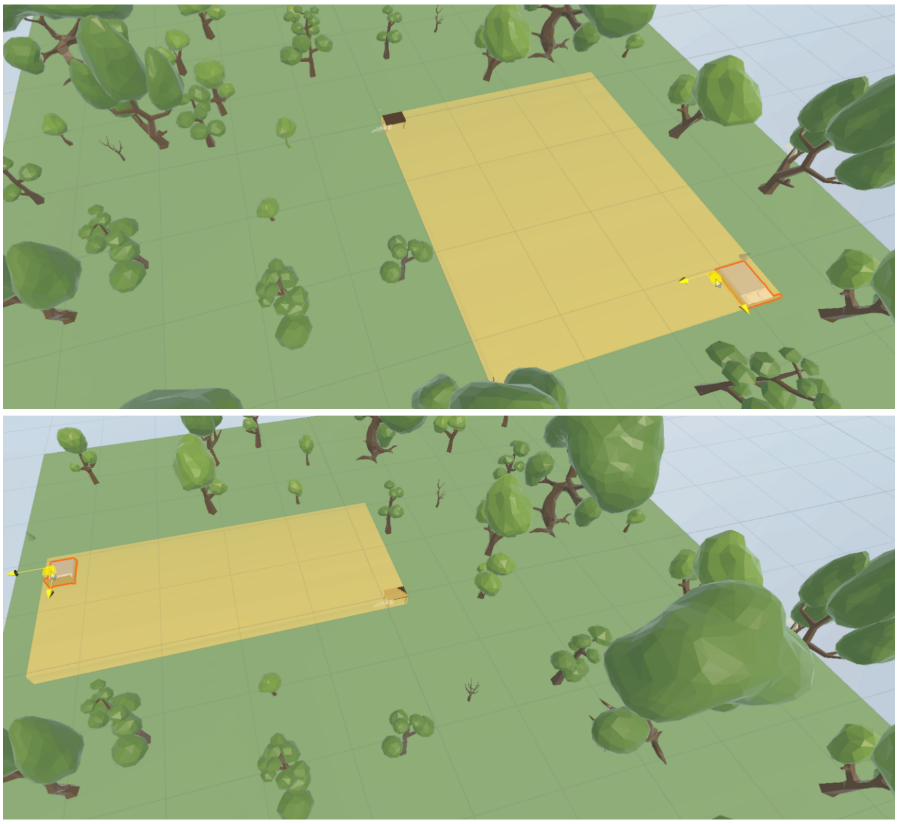

Figure 4.13: A debug view of the adaptive environment system, showing how the cube is scaled to encapsulate all workspace objects (e.g. a table and bed). The environment art assets inside the yellow cube are rendered invisible. During normal usage, the cube itself is not visible to the user.

sion. Disabling this renderer prohibits the camera from rendering the surface mesh of the gameobject, making it invisible. Therefore, this system can be used to make all art assets that are inside of the virtual workspace invisible. However, for a collision to be detected, the art assets need to collide with another gameobject. This gameobject should be the exact size of the virtual workspace, regardless of any changes made to the workspace during runtime. We decided to use a cube, as a primitive would allow for very performant physics calculations. Moreover, by scaling this cube in the X and Z axis to match the virtual workspace's boundary, any possible shape can be encapsulated. Even if a user were to create an L-shaped workspace, the cube would successfully encapsulate the whole workspace.

To scale the cube, we used the bounds of the *room* gameobject from the alignment process (Section 4.2). This *room* gameobject is the parent of every object in the virtual workspace, such as walls, furniture, and decorations. By querying the renderers of each of these child objects, we can calculate their combined size. After determining this optimal size, the cube can be scaled to match. Whenever an environment is loaded, this querying and scaling are performed. This ensures that even if the user changed the workspace size or layout during the session, the cube would be the correct size.

All art assets which remain inside the scaled cube will trigger a collision and are rendered invisible, as shown in a debug view in Figure 4.13. Ultimately, this adaptive environment system allows various predefined environments to function with the user-customizable workspaces in Holoft.

Environment Loading System

Users can choose from three different work oasis environments. When a user selects the desired environment through the interface, the old environment should be hidden and the selected one displayed. For this showing and hiding of environments, a loading system consisting of multiple scripts was implemented.

In a typical videogame, these different environments would be loaded using Unity's "scene" functionality. Scenes allow for games to be constructed in segments, giving developers the possibility of building up the game one part at a time [Unity Technologies, 2021b]. Scenes also help reduce clutter in the visual editor, as only gameobjects in the currently loaded scene are displayed. Without this, developers of large games with thousands of gameobjects would have severe difficulties finding what they are looking for in the editor. As a result, many games have dozens of scenes, with each level or world section making up a scene. These scenes can then be loaded when needed, either by replacing the current scene when switching to a new level or by additive loading. Additive loading allows multiple scenes to be loaded in memory simultaneously. This approach is advantageous if there is generic functionality that stays the same throughout the game, as the scene containing this functionality can remain loaded.

Figure 4.14: A workspace in the forest environment, showing the logs used to mark the edge of the available space.

In the case of the Holoft software, each environment could be its own separate scene. These scenes could then be additively loaded onto a base scene containing the user-created virtual workspace. However, due to technical limitations with the Oculus Quest's Android-based architecture, additive loading of scenes is impossible at the time of writing. With this in mind, we instead created a parent gameobject for each environment. This parent object had all of an environment's art assets as children. Thus, these gameobjects could be enabled and disabled to show or hide the environments.

Our chosen approach had both drawbacks and benefits compared to the typical scene-based approach. The main drawback was a small memory overhead during the software's initial startup, as all environment gameobjects had to be loaded into memory. However, these additional disabled gameobjects do not affect performance during runtime, as only enabled gameobjects are rendered and included in any physics calculations. A considerable benefit of our chosen approach was the possibility of instantaneous switching between environments. As all environments were already in memory, they only needed to be enabled instead of loaded, eliminating any delay.

When switching between environments, some adjustments are made in addition to enabling and disabling the parent gameobjects. First,

Figure 4.15: Google Zurich's jungle lounge and gondola work oases. Images: Schwär [2018]

the 3D model used for the workspace's walls is changed to one that better fits the chosen environment's style. For example, logs are used in the forest environment, as shown in Figure 4.14, instead of the generic white walls used during the workspace setup. Second, the fog colour and skybox are changed for each environment. A skybox is a wrapper around the entire scene, showing what the world looks like beyond the art assets. For example, in a daytime environment, a blue skybox would work well, but an orange skybox showing the sun at an angle would be preferable for dusk.

Overall, the environment loading system we implemented allows for fast switching of environments while working around the Quest's hardware limitations. Additionally, as each environment is contained in a single gameobject, other developers can easily extend this system in the future by adding extra gameobjects.

4.4.2 Work Oasis Environments

After developing a system to display a wide variety of different possible environments, we needed to decide what styles of work oasis environments to include. There is no formal guideline or standard for how a work oasis is supposed to look or be designed. Instead, companies work together with architects and interior designers to develop unique and exciting concepts for the given spaces. For example, the Google Zurich office contains a "jungle lounge", a room filled with hundreds of different plant varieties. There is also a room filled with fake snow and old gondolas on another floor. These two rooms are shown in Figure 4.15. Another example, from the Microsoft offices in Redmond, is a beach-themed room with lounge chairs for napping. A significant factor in these differing styles is that employees' tastes are diverse. Some might enjoy a very calm and quiet work oasis, while others might feel it is too eerie. For this reason, a choice of multiple different environments would be optimal. Accordingly, we decided to include three varying work oasis environments in the initial prototype version of Holoft.

These three environments had to achieve the desired look while at the same time being very performant due to the Oculus Quest headset's limited processing power. Like most VR headset manufacturers, Oculus recommends that all software and games run at a minimum of 70 to 90 frames per second (fps) to mitigate simulator sickness. This fps number is comparatively high, as even modern videogame consoles run at either 30 or 60 fps. For this reason, the initially envisioned photorealistic environments were not feasible. However, it has been shown that a realistic environment is not necessary to achieve immersion [Cheng and Cairns, 2005]. Instead, to reduce the performance required to render the environment, we chose a "low-poly cartoon" art style. This art style characteristically uses 3D models made out of a low number of polygons (or "polys"), resulting in a more blocky and less detailed look. Consequently, due to this low number of polygons, the models are very efficient to render. Using such a performant art style also allows for the total amount of assets displayed to be increased without the framerate dropping below 70 fps.

Ultimately, we decided on the following three environments: forest, ocean, and lookout. In the following three subsections, each of the environments is described in detail. Furthermore, the reasoning behind choosing to include the environment is presented.

Forest

Even though there is no standard for work oasis design, many include plants and greenery in their designs. The likely reasoning behind this choice is to leverage the positive effects of biophilia [Annerstedt et al., 2013]. Biophilia has been shown to decrease the heart rate and reduce stress [Yin et al., 2019]. For this reason, we choose to include a forest-themed work oasis environment in Holoft.

The forest environment was the first of the three environments to be implemented. As a result, it served as a prototype for testing what features users wanted in an environment. Initial testing showed that an environment without any moving elements gave some users an eerie feeling. They stated that while it looked real, it did not feel real. We implemented two additional features to alleviate this problem. First, background sounds, in the form of leaves rustling in the wind and birds chirping, were added. Second, we added virtual animals, which roam around the work oasis environment. Using a simple state machine, these animals transition between their walking, eating, and idle animations to provide a semi-realistic look. Subsequent testing showed these additions made the forest environment feel more alive.

The final environment is shown in Figure 4.16. The environment is a forest valley at dusk, with the sky changing from blue to orange. We chose to place the user in a valley surrounded by hills for two main reasons. Firstly, it gives the user the feeling of being entirely surrounded by nature. Secondly, these hills limit the user's sightlines, reducing the area in which art assets need to be placed. Consequently, the number of trees and plants could be increased in the area visible to the user without exceeding the performance limit. We used different tree models and colours to provide some variety. There are bushes, rocks, and flowers randomly spread across the ground to make the forest feel less "man-made". Ultimately, the design of the environment results in a dense and lush-looking forest.

Ocean

The second environment included in Holoft has an underwater ocean-themed style. This environment style was chosen as many real-world examples of work oases seem to include fish tanks. Research has shown that observing such fish tanks can decrease pulse rate and ease muscle tension [DeSchriver and Riddick, 1990]. While it would have been feasible to create a virtual fish tank, this would not have maximized the potential of VR. For this reason, we decided to allow the user to be underwater amongst the fish rather than only observing them from afar. Additionally, Prof. Dr. Fritz, the supervisor of this thesis, had requested we include an underwater environment.

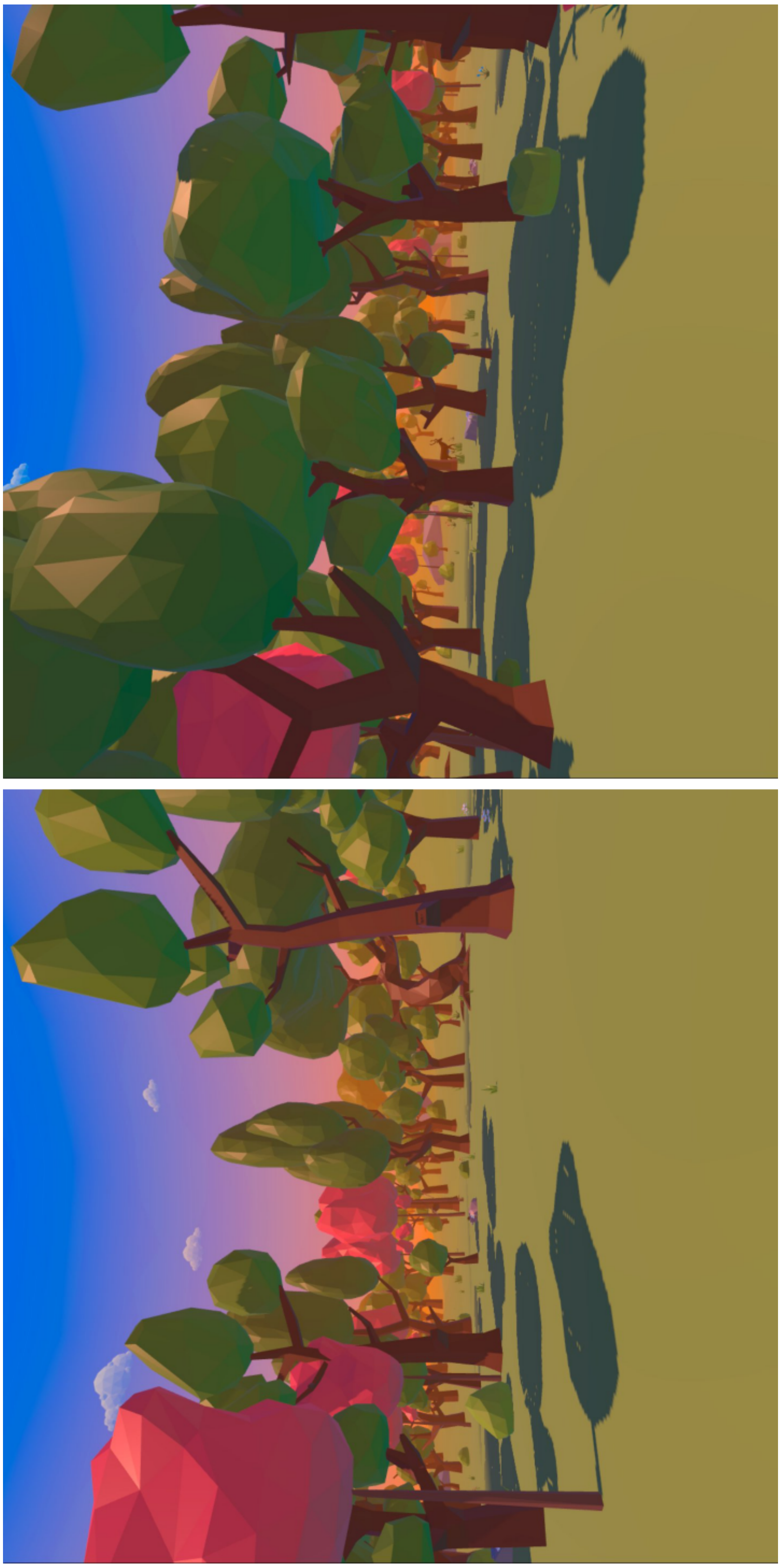

Figure 4.16: Different views of the forest work oasis environment, showing the dense forest and grassy hills.

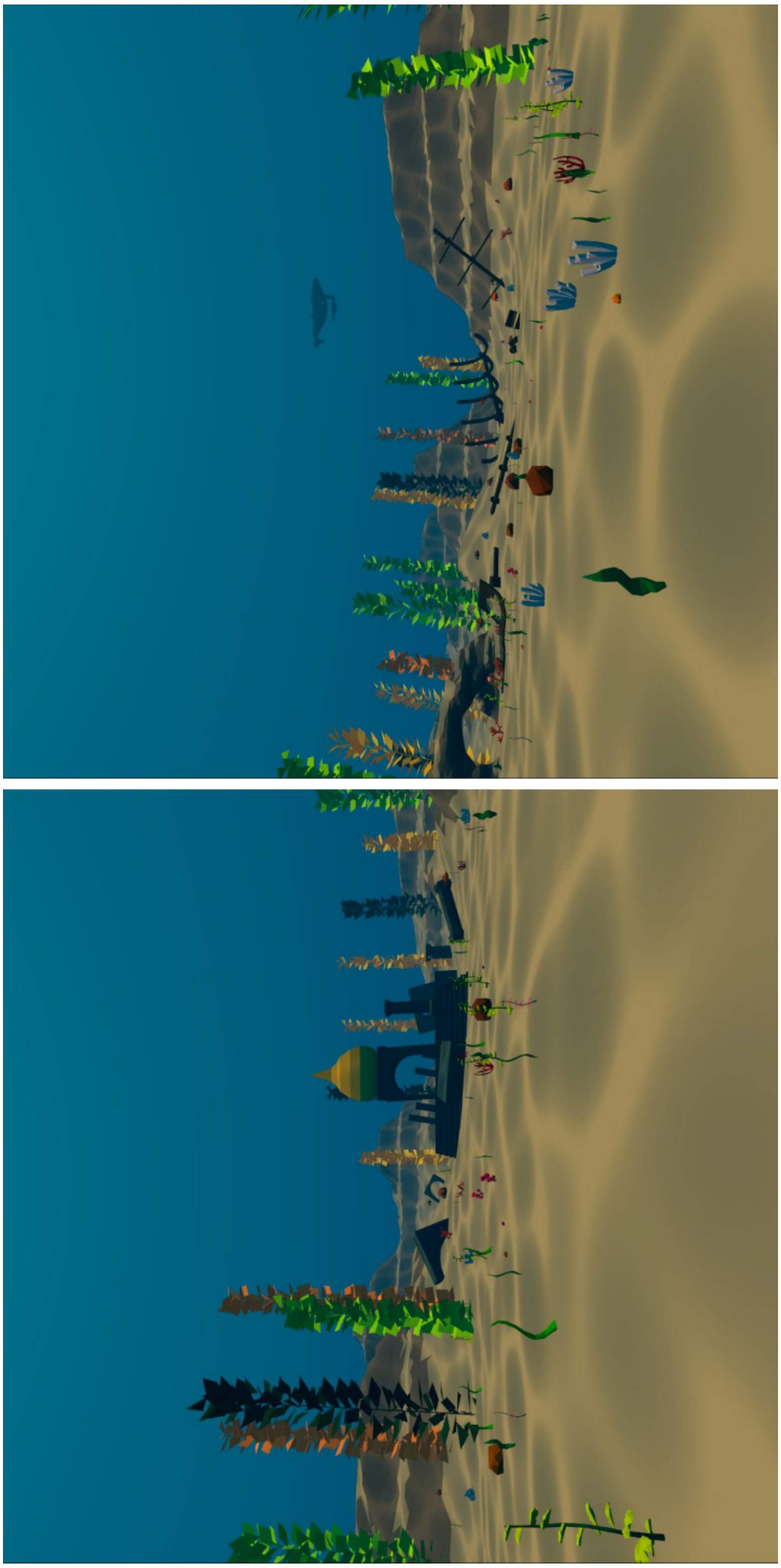

Figure 4.17: Different views of the ocean work oasis environment, showing the coral reef, underwater temple, and sunken shipwreck. The fish and whales can be seen in the distance.

As shown in Figure 4.17, the ocean work oasis environment consists of a sandy ocean floor surrounded by a coral reef. This tall reef is used to limit sightlines, similar to the forest environment's grass hills. Additionally, a shipwreck and a sunken temple were added to make the ocean floor more exciting, while kelp and coral are used to add a splash of colour.

Similar to the forest environment, animals have been added to make the ocean feel alive. We used various colourful fish, which are animated to swim around the lower parts of the reef. Further, two large humpback whale models have been added in the distance. To make the environment more immersive, we added muffled ocean noise as ambient sound. Overall, this results in a calm and relaxing environment which fully utilizes the possibilities provided by VR.

Lookout

The final environment users can choose is named "lookout". As the name implies, this environment is designed to be more open so users can see far into the distance. It consists of a nighttime environment with floating islands and airships, as shown in Figure 4.18.

A reason for including the lookout work oasis environment in Holoft was that it allowed users to see the horizon. Research has shown that looking at a horizon enables a visual mode in the brain called "panoramic vision" [Wapner, 2020]. This panoramic vision dilates the gaze to enable the viewer to see more of the periphery. Panoramic vision also reduces the stress response and is therefore associated with calmness, the desired effect of a work oasis.

Furthermore, studies have shown that participants exposed to non-realistic VR environments saw improvements in "out of the box thinking" and overall creativity [Thornhill-Miller and Dupont, 2016]. As one of the goals of Holoft is to help foster creativity in employees, we choose to include such a non-realistic environment. Thus, the lookout environment was purposely designed to be more fantasy-like and not adhere to the laws of physics.

The final lookout environment is a nighttime environment, with the moon illuminating the scenery. The user is placed on a free-floating island, surrounded by other islands and airships. There are village-

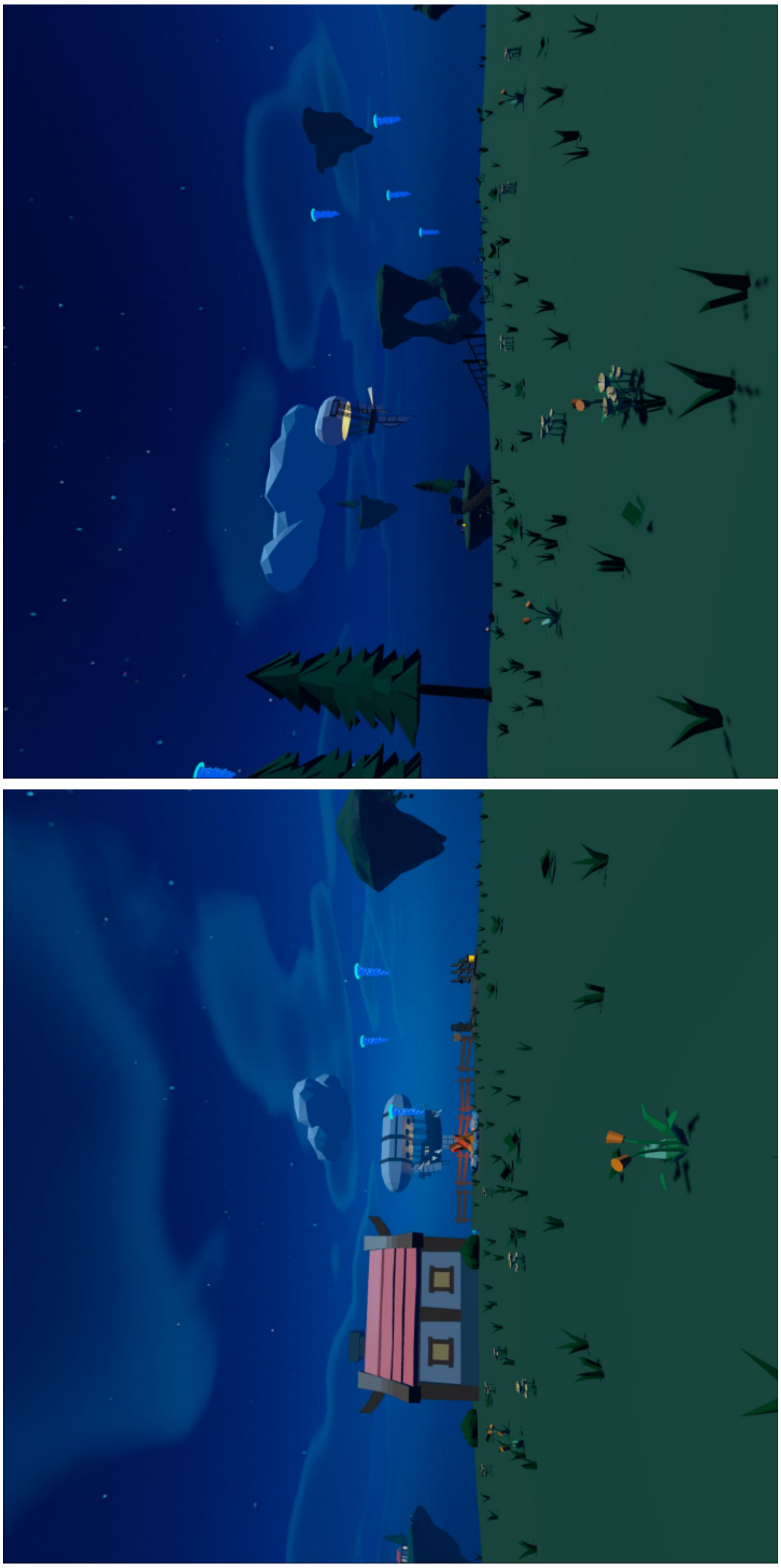

Figure 4.18: Different views of the lookout work oasis environment, showing the airships and floating jellyfish.

style houses with fireplaces on the islands to make the environment feel alive while adding to the fantasy feel. The fire's glow in combination with wood crackling ambient sounds is intended to help the user relax. While there are no real-life animals like in the other two environments, the lookout environment uses blue, glowing jellyfish floating around in the sky. The jellyfish arms are animated to slowly sway with the wind, as testing showed that quick movements could be distracting. Overall, the lookout environment provides a non-realistic and "fantasy-like" alternative to the other two environments.

To summarize, the environments were chosen based on prior research and common themes found in real-world work oases. The included environments: forest, ocean, and lookout aim to provide a good mix of styles to satisfy different tastes and moods. Using the system described in section 4.4.1, all of these three environments can dynamically augment the customized virtual workspaces. Therefore we can successfully answer RQ2, that it is possible to dynamically augment these workspaces into different styles of virtual work oases. To further improve the virtual work oasis, interactive features were added, as described in the following section.

4.5 Interactive Features

Real-world work oases are more than just a space in which employees can relax. Work oases also often provide some form of fun activity or interactive element to help employees get their minds off work when taking a break. These activities can include swings, playing darts, or ping pong. Work oases also provide a quiet place for employees to do simple work tasks when they require a "change of scenery". Such simple work tasks can include writing emails or reading documents.

As previously stated, the Holoft software's goal is to replicate all aspects of the work oasis experience in a virtual alternative. Implementing the final features needed to provide this experience makes up the fifth and final part of the development process. For quiet work and simple tasks, while immersed in VR, we implemented a web browser, as described in the following section. To give users a fun activity while on break, we implemented an archery system. The implementation of this archery system is described in Section 4.5.1.

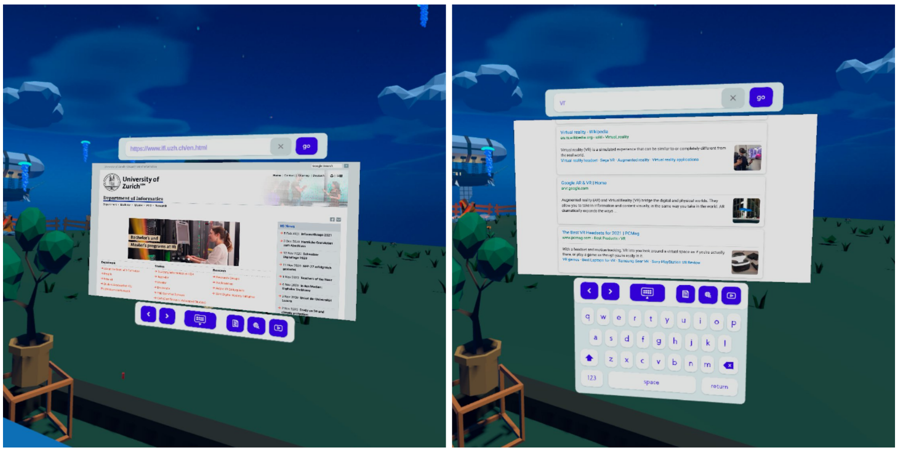

Figure 4.19: The VR web browser being used in a virtual work oasis. The custom user interface surrounds the browser window. The onscreen keyboard can be seen in the image on the right.

4.5.1 VR Web Browser

A central goal of work oases is to allow employees to do simple work tasks while relaxing. Further, many people browse the web or watch internet videos during work breaks. For these reasons, we developed a VR web browser that can be used directly inside Holoft. Our implementation allows users to see a floating browser window in front of them while immersed in the virtual environment, as shown in Figure 4.19.

As the Oculus Quest and Quest 2 are standalone headsets based on the Android architecture, our browser needed to run on mobile devices. Such browsers are immensely complex, and developing one from scratch would have exceeded this master thesis's scope. Thus, we used a Unity mobile browser prototype developed by Ian Philips [Philips, 2020] as a basis for our implementation. Philips' browser uses the "Gecko" browser engine developed by Mozilla for rendering web content. This browser engine is Mozilla's current mobile browser system designed to work with various architectures, including Android [Mozilla, 2021].

While Philips had implemented some basic functionality, such as establishing an internet connection and loading URLs, most features required to use the browser in virtual reality were missing. On a mobile phone, many features are provided by the phone's operating system (OS). For example, the user can interact with the browser using the touchscreen, and the keyboard is automatically displayed when a text field is selected. However, in VR, this functionality is not provided by the OS and needs to be implemented manually.

To interact with the browser in VR, we implemented a pointer system. This system allows the user to use the controller as if they were holding a laser pointer to control a cursor in the browser window. Another benefit of this system is that the browser can be placed farther away from the user, as they do not have to press the onscreen buttons physically. This placement also allows for a more comfortable viewing angle when the user is seated.

As the OS provides no browser interface, we designed a custom user interface, as shown in Figure 4.19. Basic functionality, such as navigating forward and backward, was implemented and connected to GeckoView wrapper. Further, a fully functioning onscreen keyboard with numbers and special characters was developed. This keyboard is only shown when needed, such as when an input is selected.

The final version of the implemented VR web browser allows users to surf the web and watch online media while immersed in the virtual environments. The browser also provides a way to do simple work tasks, such as reading and answering emails through a web-based email portal. All in all, the web browser allows users to do most of the same tasks they would do in the real-world work oasis.

4.5.2 Archery System

As Holoft is a single user experience, any included activity needs to be enjoyable alone. For this reason, popular office breakroom games such as ping pong or foosball (German: "Kicker") were not possible. After brainstorming and prototyping different activities, we decided to implement an archery system, shown in Figure 4.20. Such an archery system also shows off the possibilities provided by VR. It would be impossible to have an archery area in a real-world work oasis due to the danger of shooting arrows indoors. Having new arrows "magically" appear is also more comfortable than having to go pick up the arrows once the quiver is empty.

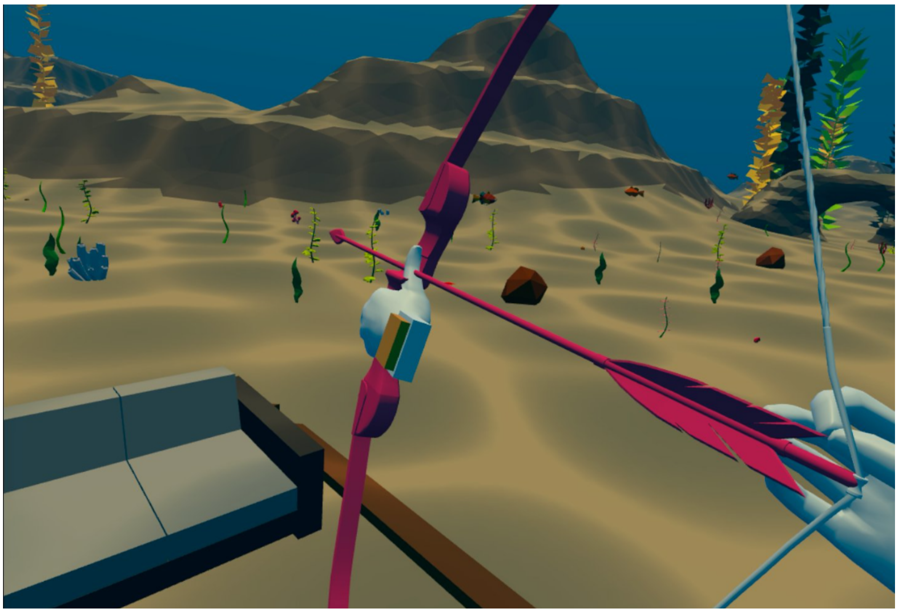

Figure 4.20: The bow and arrow models used in the implemented archery system. The arrows can be pulled back by grabbing the string with the controller.

We used two Unity prefabs to implement our archery system, one for the bow and one for the arrow. As the arrows are shot away from the bow, splitting up the 3D models into multiple prefabs was necessary. This split also allowed for the complex shooting logic to be divided up into multiple scripts. The bow prefab contains all logic related to instantiating arrows, pulling the string back, and calculating the arrow's force when the string is released. The arrow prefab has scripts for collision detection and for despawning itself after a specific time.

To use the bow, the user grabs it with their left hand and pulls the loaded arrow back with their right index finger, as shown in Figure 4.20. When fired, the distance the arrow was pulled back determines the force applied to the arrow, affecting its flight path. After firing an arrow, a new one is instantiated on the bow. After a couple of seconds, the fired arrow will be deleted from the environment to ensure the user can fire as many arrows are they like.

Each arrow has a script, which continuously checks if the arrow is colliding with another gameobject in the environment. Once a collision has been detected, meaning the arrow has "hit" something, it freezes at the current position. This halting of the arrow simulates it getting stuck in the object with which it collided. The arrows utilize the Unity built-in physics system for this collision detection. Thus, any object in the virtual workspace can be used as a target. Nevertheless, we also included a target disc as a decorative item, which can be added to the virtual workspace.

Initial testing showed that users enjoyed the archery system, with most immediately firing arrows at the various furniture items. One tester even commented that they found it cathartic to shoot arrows at their virtual computer monitor. Ultimately, we believe this fun activity will help users of Holoft to get their minds off work when taking a break in the virtual work oasis.

To summarize, this chapter presented the five-part approach used to develop a virtual reality alternative to the traditional on-site work oasis. First, we evaluated different hardware and software options before deciding on the Oculus Quest line of standalone headsets and the Unity 3D game engine, respectively. An alignment process was implemented in the second part to allow users to position the virtual space in relation to their real-world rooms. Third, using the alignment as a basis, we successfully developed a system that allows the setup of a virtual workspace in a variety of different rooms. In the fourth part of the development, we were able to dynamically augmented these user-created workspaces into different styles of work oases. Lastly, we added interactive functionality in part five, such as a VR web browser and archery system. Ultimately, we managed to answer the technical research questions by showing that a virtual work oasis alternative can successfully be developed in the form of Holoft. In order to evaluate this novel software and address the remaining research questions, we conducted a pilot study. This study is described in the following chapter.

Chapter 5

User Evaluation

In Chapter 4 we showed that it is possible successfully to implement a virtual work oasis solution. To test this initial prototype of the Holoft software with actual users in authentic scenarios, we conducted a pilot study. This pilot study focused on testing our hypothesis that general users are able to use Holoft to set up their own virtual reality work oasis in their rooms of choice to foster a better work experience. To answer this hypothesis, we were interested in the following research questions:

- RQ3: Can participants use Holoft for their own room(s) to set up virtual workspaces/oasis?
- RQ4: Does Holoft's virtual environment foster a (1) more focused/less distracted, and (2) more relaxed work experience?

Therefore, our pilot study included the process of setting up a virtual workspace and having the participants use the virtual work oasis for relaxing and work. We hope to simulate accurate conditions under which Holoft would be used if deployed to employees of a real-world company. The study should also provide feedback to inform future iterations of the Holoft software.

5.1 Participants

As this pilot study was done in the scope of a master thesis, participants were recruited through personal contacts. However, due to the ongoing global pandemic at the time of writing, participant recruitment proved to be exceedingly difficult. We aimed to find participants who had access to a suitable VR headset or who could receive such a headset through the University of Zurich. Additionally, participants had to be working in an office or from home.

Ultimately, we were able to recruit three participants for the pilot study. Two participants are male and one female. The average age was 38, and the median was 28. All participants had some previous experience with VR but did not own any headsets. Moreover, all participants reported working from home due to the pandemic but would otherwise work from their company's offices.

5.2 Location and Technical Setup

Location. As all of the participants were working from home, the pilot study was conducted remotely. Participants were instructed to set up and use Holoft in whatever rooms they pleased, just as they would if their employer had given them such software to use.

Technical Setup. Participants used VR headsets provided by the experimenter. These headsets were part of the Oculus Quest line of headsets, which we decided upon in Section 4.1. One participant used a Quest 2, while the others used the first-generation Quest. The Quest 2 has a higher resolution display running at 90hz instead of 70hz. Besides this, extraneous variables related to the headsets were kept minimal. Both headsets had the same software version installed and had the same home screen background to make them as similar as possible.

5.3 Procedure

Each study session lasted five workdays and was divided into four stages: introduction, regular usage, reading task, and wrap-up. These stages consisted of the following:

Introduction
An Zoom call was scheduled to guide the participant through the initial setup process of the VR headset. The Holoft software was installed on the headsets prior to the study or installed remotely together with the experimenter. The participant was asked to familiarize themselves with the steps required by Oculus to calibrate the floor height and guardian system. Following this, the participant could start the Holoft software. The experimenter guided the participant through the interactions required to perform the alignment process and set up their virtual workspaces. Afterwards, the participant was asked to try out the three work oasis environments included in Holoft. The experimenter noted down the participant's initial reaction to seeing these environments. Lastly, the web browser functionality was explained to the participant, and the experimenter answered any remaining questions.

Regular usage
For five workdays, the participant was encouraged to use the virtual work oasis when taking breaks from work as they saw fit. This optional usage was intended to simulate real-world behaviour. As not every break is spent in a real work oasis, the same would apply to the virtual alternative. However, we encouraged the participant to use Holoft at least twice for 10 minutes during the five workdays. The participant was also instructed to switch between the different environments to suit their mood and whether they were looking to relax or do simple work tasks.

Reading task
On the last day of the weeklong study, the participant was asked to read three articles using the VR web browser. The participant was given six articles with similar lengths and comprehension complexity to choose based on their interests and preferences. Each text was expected to take roughly five minutes to complete. The participant was instructed to read each article in a different environment (forest,

ocean, and lookout). This task was intended to make the participant concentrate while immersed in VR, replicating working conditions in the work oasis.

Wrap-up
After completing the reading task, the participant was interviewed by the experimenter for approximately thirty minutes, during which their answers were audio recorded. This interview was to gain an understanding of their experience using Holoft, as well as their preference for the different environments. Additionally, the participant was asked about any usability issues that arose during the workspace setup process and navigating the virtual work oasis. Finally, the participant answered demographic questions.

5.4 Data Collection and Analysis

The data collected and derived from the usage of Holoft in the week-long pilot study includes the participants' initial impressions and the final interviews. Thus, for this pilot study, we performed three semi-structured interviews. These interviews were held in Swiss-German, German, and English, with the non-English interviews being translated to English. Subsequently, all interviews were transcribed for further analysis. Using these transcripts, we applied an open coding approach [Khandkar, 2009, Burnard, 1991] in which we categorized statements made by participants to identify the main themes and findings. To answer the research questions, we focused on statements regarding the setup of the virtual workspace and the virtual environment's potential to foster a more focused/less distracted and more relaxed work experience.

Chapter 6

Results

Based on the transcripts of the semi-structured interviews performed with all three participants at the end of the week-long study, we examined the statements made and identified common themes. Our results and main findings are structured in terms of our research questions as follows:

RQ3: Can participants use Holoft for their own room(s) to set up virtual workspaces/oasis?

RQ4: Does Holoft's virtual environment foster a more focused/less distracted and more relaxed work experience?

Whenever we refer to specific study participants, we use *P*. For example, *P3*, would be the participant of our pilot study with the identifier *3*.

6.1 RQ3: Can participants use Holoft for their own room(s) to set up virtual workspaces/oasis?

As a first step in evaluating if general users can use Holoft, we asked participants about creating their own virtual work oasis. We looked at what participants thought of the workspace setup process and their ability to navigate around the workspace.

6.1.1 Workspace Setup

Each of the participants set up their virtual work oasis in a different room, with one choosing their office, one their bedroom, and one their living room. All participants completed a full setup in their first session using Holoft. One participant reset the workspace during the second session: *"I was not happy with the initial setup, and I liked playing around with it, so I did the setup again on the second day" (P1)*.

We also asked participants about any issues encountered during the workspace setup process. While many stated that they initially had issues, for instance, that they *"got a little frustrated at first, because I didn't read the instructions" (P3)* and *"kept pressing the wrong button on the controller" (P2)*, all participants commented that it was relatively easy once they got over these initial hurdles. For example, one participant commented: *"Once I read that I had to start with a specific corner when creating furniture, it became a breeze. I had my whole room done in 10 minutes." (P1)*. Hence, our results show that RQ3 can be answered positively, as participants are able to successfully use Holoft for their own rooms to set up virtual workspaces.

Nevertheless, all participants explicitly mentioned that they would have liked a way to see their physical rooms when setting up their virtual workspaces, as *"setting up the walls was especially difficult. The only way to know where I am in the room is by looking out of the small gap between the headset and my nose." (P2)*. All three participants asked if it would be possible to show the *"black and white video" (P1)* from the passthrough cameras (this video feed is shown when setting up the playspace area through the Oculus Guardian System). Finally, one participant also commented on the virtual furniture items available in Holoft: *"Maybe in a second version there can be more furniture models? I was not able to find an exact match for all the objects in my room." (P3)*.

Participants were able to successfully use Holoft to set up their own virtual workspaces. However, participants would have liked a way to see their surroundings during the setup.

6.1.2 Navigating the Space

As eliminating the disconnect between the virtual and physical world was a central aim of the Holoft software, we asked participants about their experience walking around the virtual environment. Many experienced initial trepidation, stating, for instance, that they *"were afraid of walking into furniture" (P1)* and that it was *"like wearing a blindfold at first" (P2)*. Despite this, participants became more comfortable as they spent more time in VR, commenting: *"already in the second session, I stopped being afraid of bumping into something" (P2)* and *"I stopped checking if my sofa was actually there and began sitting down without even thinking about it." (P3)*.

Despite being comfortable navigating around the space, two participants mentioned that they would like a way to include virtual office chairs in their work oasis, saying that *"it was hard to find where [the] chair was, when I wanted to sit down" (P1)* and *"I had to remember where I left my office chair, so I didn't walk into it." (P3)*. When asked about their use of the "caution cube", the consensus was that while *"useful for showing where the chair could be" (P3)*, it did not help, as they *"still had to search around the area for where exactly the chair was." (P1)*.

> Participants had initial worries about moving around the space but became increasingly more comfortable throughout the study.

6.2 RQ4: Does Holoft's virtual environment foster a more focused/less distracted and more relaxed work experience?

As part of our fourth research question, we asked participants about their experience of doing simple work tasks in Holoft. We primarily focused on the effects of the virtual environments and any distractions they caused.

6.2.1 Relaxing in VR

In our interviews, we asked if the virtual work oasis helped participants relax throughout their workday. Only a single participant used the virtual work oasis during work breaks, while the others used it after finishing work, as further described in Section 6.3.1, Nevertheless, all participants commented that Holoft successfully helped them relax. One participant, for instance, stated: *"When I used the VR system for that half an hour after work, I was way more relaxed for the rest of the evening. When working from home, it is so difficult to transition from work to personal time, so having this period in between where I'm in VR really helped with separating those two parts of my day." (P1).* For the participant who used Holoft during work breaks, it helped them take more efficient breaks: *"It's an extra barrier that forces me to take a real break. When I'm wearing the headset, I cannot see my phone lying on the desk, or any new emails coming in." (P3).*

Participants were able to use Holoft to relax, either during breaks or at the end of their workday.

6.2.2 Effect of Virtual Environment

As part of their post-study interview, participants were asked to rank the three environments included in Holoft according to preference. The forest environment was ranked the highest, followed by the lookout environment. Interestingly, each of the three participants ranked a different environment as their least favourite. The overall lowest-ranked of the three environments was the ocean environment. Many positive comments supported the high ranking of the forest environment. For example, participants stated that the forest was *"vibrant" (P2)* and *the blue sky made me happier, especially on rainy days" (P3).*

However, during the interviews, it became apparent that participants preferred different environments depending on if they were taking a break or doing work tasks. Two of the three participants mentioned that they enjoyed using the ocean environment during the reading task on the final day of the study, even though they did not like it when relaxing. One participant stated *"the ocean is great for reading, as there simply is not a lot going on around me." (P1).*

Environment preference varies greatly by individual and task, with lively environments being preferred for relaxing and more plain environments for working.

6.2.3 Distractions

Participants mentioned a variety of different factors which distracted them while using Holoft. In general, they differentiated between auditory distractions, such as non-repeating background noise, and visual distractions, such as the moving animals in the environments. Overall, auditory distractions were perceived as more distracting than visual ones and were mentioned more in our interviews. One participant explained this as *"when I'm reading, I have the browser window in front of me, so most of my vision is filled. There is only a little bit on the sides where I could get distracted by something. However, the sound is always there." (P2)*.

For visual distractions, all three participants commented on the animated animals in the different environments. The fish in the ocean environment were liked the most, being described as *"relaxing, they just slowly swim around in the distance" (P1)*. The bunnies in the forest environment were well-liked when taking breaks. However, when doing work tasks, participants felt they were distracting: *"the bunnies are fun to look at, but their constant hopping was distracting when I was reading the articles." (P2)*.

Auditory distractions were seen as more distracting than visual ones when participants focused on work tasks.

6.2.4 Effect of Background Sounds

When asked about the soundscapes of the different virtual environments, many stated that the *"sound is such an important part of the whole experience" (P1)*. However, not all of the background sounds used in the virtual environments were well-liked. Especially the non-repeating nature sounds of birds chirping in the forest environment was deemed *"annoying. I will be reading something on the web, and then* *all of a sudden, a bird starts singing." (P1).* In contrast, the less distracting soundscape in the ocean and lookout environments was *"calming" (P3)* and *"easy to tune out when concentrating" (P1).* Although not always optimal, the presence of these background sounds seemed to affect some participants' overall immersion. For instance, two participants tried the option of lowering the volume or turning the sounds off completely. One commented: *"it was weird. When I turned off the sound, I became more aware that I was sitting in my living room with a device strapped to my face, I was less immersed." (P2)*, while the other preferred *"to be in the quiet virtual environment" (P1).* Additionally, the desire to be able to play music instead of the ambient sounds was voiced: *"When taking a work break, I'd really enjoy being able to listen to some of my favourite music. I often listen to music when working too, so that would be a nice feature to add." (P2).*

> Suitable background sounds are an essential part of the VR experience, with their absence negatively affecting some participants' immersion.

6.3 Further Insights

In addition to our research questions, we evaluated the overall experience our participants had while using Holoft. We focused on their usage of the software and the general viability of using VR for work and leisure, finding the following additional insights.

6.3.1 How Participants Used Holoft

In our interviews, all participants stated that they used the Holoft software at least twice, in addition to the final session involving the reading task. One participant even reported using the virtual work oasis for *"roughly 30 minutes every day" (P1)* during the study.

When asked at what time they used the virtual work oasis, there were some differences. Only one participant used Holoft during the workday while on breaks, whereas the other two participants used Holoft after work in the evenings to help relax. One participant stated: *"Dur-*

ing the workday, I rarely take breaks long enough to warrant putting on the headset, and over lunch, I'm busy with eating. However, at the end of the day, it was nice to be able to use [Holoft] to help get my mind off work." (P1).

The tasks for which the virtual work oasis was used also differed between participants. One participant only used Holoft for relaxing, stating *"I just liked looking at the environments. There is already enough going on at work, so I don't need to read more during my breaks" (P2).* Other participants mentioned they frequently used the web browser to look at blogs or *"watch Youtube videos while sitting on a floating island among the clouds." (P1).*

> Holoft was used for a variety of tasks, such as reading web content, watching videos, or simply relaxing. Some participants used the software during breaks, while others preferred to use it after work.

6.3.2 VR Comfort

While not being directly asked about the comfort of wearing a VR headset, the short time in VR was mentioned to be fine for all participants. However, they stated that they would not like to be in VR for more than a one-hour break due to comfort. Two participants complained about the weight of the headset: *"The first 15 minutes are fine, but then [the headset] starts getting heavy" (P1)* and *"when you move around it's fine, but when sitting for a while you notice the weight." (P2).* One participant, in particular, commented about the headset *"occasionally sliding down [their] face" (P2).*

> Due to comfort concerns, VR should only be used for shorter time periods.

6.3.3 Virtual Escape

When discussing whether they could see themselves continuing to use a virtual work oasis in the future, all participants commented on Holoft's potential as an alternative to going outside. One participant, for instance, mentioned: *"I can see myself using such software to relax and fight off cabin fever when it is cold or raining, but going for a nice walk in a real forest is still better for my mental health." (P1)*. Another stated that they would use it when they *"didn't have enough time to go outside during shorter breaks" (P3)*, adding *"it's not quite the same as being outdoors but I can see that with better headsets it'll get pretty close." (P3)*. Further, one participant commented that they would like to use Holoft as a general relaxation tool, saying *"it would be great to combine these calming environments with a yoga session or breathing exercises. I would enjoy that in the evenings...to feel like I am somewhere else for a while." (P2)*.

> Participants enjoyed the virtual escape that Holoft provided but still preferred to go outside if possible.

Chapter 7

Discussion

Our pilot study's goal was to test the hypothesis that users can use Holoft to set up their own virtual reality work oasis in their rooms of choice. Additionally, the study was intended to examine whether the use of virtual work oases would lead to the desired relaxing effects and help foster a less distracting work experience. The qualitative results of our study show that our approach has potential. The interview findings reveal that participants enjoyed using Holoft as a work oasis alternative and can see themselves continuing to use the software periodically. In the following chapter, we will discuss the implications of our research.

7.1 VR as an Effective Alternative to Traditional Work Oases

A considerable amount of thought goes into designing modern office spaces to improve overall job satisfaction and keep employee productivity at its peak [El-Zeiny, 2012]. Research has shown that providing adequate break times and dedicated recharge areas can significantly aid in achieving these goals [Pochepan, 2018]. While some large companies have the budget and space available to construct elaborate on-site work oases for their employees, the vast majority of companies do not.

Our study results show the potential of using VR to provide an effective virtual alternative to the traditional work oasis. Users were able to use Holoft to set up their personal virtual work oases and felt comfortable moving around in it. These work oases were then used to relax during breaks or at the end of their workday, either by enjoying the virtual environments or browsing the web through the built-in web browser. The participants using Holoft at the end of the day enjoyed that it aided them transition from work to personal time. During the workday, participants stated that Holoft helped them take effective breaks, blocking out any distractions such as their phones or work notifications. Ultimately, based on our results, we can successfully answer RQ4, as Holoft managed to foster the desired more focused/less distracted and more relaxed work experience.

With VR technology rapidly improving, such virtual work oasis alternatives can allow employees to experience the benefits of relaxing during the workday and managing their energy levels. We believe our approach can help improve wellbeing, even when working from home during the current pandemic, where finding an adequate work-life balance can prove challenging.

7.2 The Importance of Personalizing the VR Environment

The virtual environments featured in Holoft, presented in Chapter 4.4.2, provided a good basis to show the potential that relaxing in VR can provide. However, the data from our post-study interviews show that there is no one ideal environment. The optimal virtual environment and soundscape for a given user are highly dependent on their preference and current mood. Further, there is also a difference in preference based on whether users perform work tasks or take a break.

Some participants prefer to work in complete silence or with monotonous noise while doing work-related tasks, yet others prefer more lively background sounds. Hence, some participants found the non-repeating nature sounds in the forest environment too distracting. Correspondingly, the white-noise-like soundscape in the ocean environment was well-liked for the reading task at the end of the study. Similarly, the environments' visual aspects should be kept nondistracting and straightforward when the user is working. In contrast, when taking a break or during their spare time, participants commented on how they enjoyed the more lively environments and did not mind the non-repeating background sounds. Especially, the forest environment with its jumping bunnies was liked when relaxing. Our findings also accentuate more clearly why some approaches (e.g. Annerstedt et al. [2013], Yin et al. [2019]) focused explicitly on the benefits of biophilia to create relaxing environments and used little to no moving elements in their scenes.

Optimally, when users take a break from work, they could choose a more lively environment to keep their minds occupied and stop their thoughts from wandering back to work. Likewise, when doing work tasks, a more plain environment might be more suited to limit possible distractions. However, other environments might have even more positive effects. For instance, there exist large amounts of research on how colours can change peoples' moods (e.g. Zraati [2013] and Dijkstra et al. [2008]), which could be applied to future versions of the environments. Fortunately, a benefit of VR is that the virtual environments are easily customizable, and the software can be extended to include other environments. Moreover, with the advancement of biometrics, it might even be possible to create personalized VR experiences by adapting the environments based on an individual's needs (e.g. Bonis et al. [2013]).

7.3 Using VR as a Virtual Escape when Working from Home

Our study's goal was to examine the possibility of using VR as an alternative to the traditional on-site work oasis, allowing users to dive into a virtual world to relax from the stress of work. While discussing the potential of Holoft in the post-study interviews, participants expressed their interest in using Holoft to "escape" their current surroundings in favour of a more pleasant space (Section 6.3.3). The desire for such a tool is likely due to the fact that the amount of time spent outside is limited due to the ongoing pandemic and the wintery temperatures.

The potential for VR to provide such a "virtual escape" has been well documented in the fields of nursing and senior care. VR has previously been used to great effect with bed-ridden hospital patients, allowing them to "escape" to pleasant locations and reducing patients' pain by 24 percent on average (e.g. Spiegel [2016] and Metz [2016]). Further, companies like Viarama [Viarama, 2021] are adding joy to the lives of senior citizens who are receiving end-of-life care, for example, by allowing them to virtually travel back to where they got married.

Our study results show that VR could also provide a similar enticing escape to people dealing with cabin-fever when working from home. However, the optimal feature set for such software likely differs from that provided in Holoft. For example, one could imagine the inclusion of other gamification elements to make the overall experience more exciting. Thus, we suggest further research should be conducted on how to best use VR to provide a "virtual escape".

7.4 Using VR at the Workplace

Virtual reality has great potential to help various employees improve their work experience and job satisfaction while achieving productivity goals. However, we acknowledge that using VR in the workplace will not be an ideal solution for everyone. The headsets currently on the market have various limitations, both in terms of performance and wearer comfort. Additionally, using VR around other people can lead to social detachment. Our study participants mentioned that they had no concerns using Holoft while working from home but were worried about donning a VR headset in an open office setting. We believe this fear of not seeing their surroundings and "looking like a dork" in front of their colleagues would disappear after some time, as people grow accustomed to it. When nap chambers/pods were initially proposed, employees had similar concerns [Cassidy, 2017]. However, such napping solutions have since found broad adoption in many companies.

Future studies should examine for which situations the use of VR could provide a benefit to workers. Additionally, we must consider the advancements made in technologies adjacent to VR, such as augmented (AR) and mixed reality (MR). Unlike VR, AR/MR involves the superimposing of virtual objects onto the user's view of the real world, effectively augmenting our current reality [Azuma, 1997]. Thus, AR/MR would eliminate the need to include a vast number of 3D furniture models to replicate a user's workspace. Such systems could allow for more natural interactions with the real world while still providing the benefits of a more relaxed environment. Ultimately, it would be interesting to study how these novel technologies can be used to develop the workplace of the future.

Chapter 8

Threats and Limitations

One threat to the validity of our study is the small number of participants. As a pilot study in the scope of a master thesis, this number of participants allowed us to identify if the developed software prototype had potential. However, to generalize our findings, we would need to run longitudinal studies with a large number of employees from various sectors in a real office setting.

Some extraneous variables were potentially problematic in our pilot study. While all of our participants had some previous experience with VR, none had used the current generation of headsets before the study. Thus, the excitement of using more advanced VR technology may potentially affect their assessment of the Holoft software. Further, most of our participants had little experience with gaming controllers, leading to difficulties finding the correct buttons to press. Consequently, their assessment of the virtual workspace setup process may have been impacted by their lack of familiarity with the controller layout. A longer-term field study would likely reduce these limitations over time as participants grow accustomed to both the controllers and the novel headsets.

A limitation of the Holoft software is not being able to see one's surroundings while setting up the virtual workspace. While the Oculus Quest and Quest 2 headsets include front-facing cameras, the grayscale video feed they provide is not accessible by third-party developers. As a result, users are forced to peek through the small gap between the headset and their noses to see their physical rooms. We hope that in future iterations of the Quest line of headsets, this video feed is accessible to all developers, as it would significantly improve the usability of Holoft.

Finally, the main limitation of the system as a whole is that it can only be used in spaces in which the headset's tracking works. As a result, the areas in which Holoft can be used are constrained to single rooms, as the tracking system does not work with multiple rooms connected by a hallway. However, the Holoft software itself can handle such elaborate layouts. Thus, once tracking technology improves, it would be interesting to explore what benefits transforming larger spaces into work oases would bring.

Chapter 9

Conclusion

The recharge room or work oasis concept attempts to tackle the issue of keeping workers at the peak of their productivity throughout the week while also improving employee wellbeing. Such spaces continue to see growing adoption from large multinational companies, such as Google and Microsoft, providing a dedicated area for relaxing, doing simple tasks, and getting one's mind off work. However, even though the benefits of well-rested employees have been widely documented, such work oases cannot be used by all companies. Some companies lack the necessary budget, while others simply do not have the floor space.

In our thesis work, we have designed and developed a virtual alternative to these traditional on-site work oases. To accomplish this, we first implemented a general-purpose alignment script for aligning virtual scenes with their real-world counterparts, enabling users to move around the virtual world freely. Further, we successfully developed a system that allows the setup of a virtual workspace in a variety of different rooms. This system lets users define their virtual workspace's boundaries and create the objects within it to replicate their physical surroundings. To complete the work oasis experience, these customizable workspaces are dynamically augmented using different styles of virtual environments, which the users can choose based on preference and mood.

We have evaluated our software prototype in a week-long pilot study with three participants. Our findings indicate that participants could successfully use Holoft to set up a virtual work oasis in their rooms of choice. Further, our results show that participants became more relaxed when using Holoft either during breaks or when taking their minds off work at the end of the day. While we found that our software is not yet ideal for providing the optimal environment for all types of tasks, our work shows that VR can provide pleasant relaxation spaces regardless of physical limitations.

We believe the software developed in this thesis shows promise that, especially as VR technology improves, virtual work oases can provide many of the same benefits of traditional work oases while being accessible to more people. Ultimately, regardless of the approach taken to further develop the presented work, it is crucial to keep in mind the overarching goal of this thesis: to improve employee wellbeing. Though tempting, placing too large a focus on productivity and similar output-oriented metrics is unlikely to lead to long-term success. As previous research has shown, highly productive employees can be characterized by their ability to adequately recharge throughout the workweek. Thus, by focusing on improving wellbeing and work satisfaction, the desired productivity improvement will often follow.

Bibliography

Amazon Web Services, Inc. Fully customizable game engine - amazon lumberyard -amazon web services. https://aws.amazon.com/lumberyard/, 2021a. (Accessed on 01/04/2021).

Amazon Web Services, Inc. Amazon lumberyard: Features. https://aws.amazon.com/lumberyard/details/, 2021b. (Accessed on 01/04/2021).

Matilda Annerstedt, Peter Jönsson, Mattias Wallergård, Gerd Johansson, Björn Karlson, Patrik Grahn, Åse Marie Hansen, and Peter Währborg. Inducing physiological stress recovery with sounds of nature in a virtual reality forest — results from a pilot study. *Physiology & Behavior*, 118:240 – 250, 2013. ISSN 0031-9384. doi: https://doi.org/10.1016/j.physbeh.2013.05.023. URL http://www.sciencedirect.com/science/article/pii/S0031938413001650.

Brian Atkin and Adrian Brooks. *Total facility management*. John Wiley & Sons, 2015.

Ronald T. Azuma. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4):355–385, 1997. doi: 10.1162/pres.1997.6.4.355. URL https://doi.org/10.1162/pres.1997.6.4.355.

BBC News. Oculus rift virtual reality headset gets kickstarter cash - bbc news. https://www.bbc.com/news/technology-19085967, August 2012. (Accessed on 01/05/2021).

Borbála Berki. Desktop vr as a virtual workspace: a cognitive aspect. *Acta Polytechnica Hungarica*, 16:219–231., 04 2019. doi: 10.12700/APH.16.2.2019.2.13.

Nicholas Bloom. How working from home works out. *Institute for Economic Policy Research (SIEPR). Policy Brief June*, 2020.

Boeing. Boeing: Boeing tests augmented reality in the factory. `https://www.boeing.com/features/2018/01/augmented-reality-01-18.page`, 2018. (Accessed on 02/19/2021).

Bill Bonis, Spyros Vosinakis, Ioannis Andreou, and Themis Panayiotopoulos. Adaptive virtual exhibitions. *DESIDOC Journal of Library and Information Technology*, 33(3):183–198, 2013.

Philip Burnard. A method of analysing interview transcripts in qualitative research. *Nurse education today*, 11(6):461–466, 1991.

Anne Cassidy. Clocking off: the companies introducing nap time to the workplace | guardian small business network | the guardian. `https://www.theguardian.com/business-to-business/2017/dec/04/clocking-off-the-companies-introducing-nap-time-to-the-workplace`, December 2017. (Accessed on 02/21/2021).

Kevin Cheng and Paul A. Cairns. Behaviour, realism and immersion in games. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, page 1272–1275, New York, NY, USA, 2005. Association for Computing Machinery. ISBN 1595930027. doi: 10.1145/1056808.1056894. URL `https://doi.org/10.1145/1056808.1056894`.

Crytek Gmbh. Robinson: The journey - vr first person sci fi adventure game. `https://www.crytek.com/games/robinson`, 2016. (Accessed on 01/04/2021).

Crytek GmbH. The climb - a stunning vr rock climbing game. `https://www.crytek.com/games/climb`, 2016. (Accessed on 01/04/2021).

Crytek GmbH. Cryengine | the complete solution for next generation game development by crytek. `https://www.cryengine.com/`, 2021. (Accessed on 01/04/2021).

Mary M DeSchriver and Carol Cutler Riddick. Effects of watching aquariums on elders' stress. *Anthrozoös*, 4(1):44–48, 1990.

K. Dijkstra, M.E. Pieterse, and A.Th.H. Pruyn. Individual differences in reactions towards color in simulated healthcare environments: The role of stimulus screening ability. *Journal of Environmental Psychology*, 28(3):268–277, 2008. ISSN 0272-4944. doi: https://doi.org/10.1016/j.jenvp.2008.02.007. URL `https://www.sciencedirect.com/science/article/pii/S0272494408000145`.

Rasha Mahmoud Ali El-Zeiny. The interior design of workplace and its impact on employees' performance: A case study of the private sector corporations in egypt. *Procedia-Social and Behavioral Sciences*, 35:746–756, 2012.

Epic Games, Inc. The most powerful real-time 3d creation platform - unreal engine. `https://www.unrealengine.com/en-US/`, 2021. (Accessed on 01/04/2021).

K Anders Ericsson. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Academic Medicine*, 90(11):1471–1486, 2015.

Facebook Technologies. *Oculus*, 2020a. URL `https://oculus.com`.

Facebook Technologies. *Quest 2*, 2020b. URL `https://www.oculus.com/quest-2/`.

Facebook Technologies. Oculus developer center | downloads. `https://developer.oculus.com/downloads/`, 2021a. (Accessed on 01/05/2021).

Facebook Technologies. Oculus quest: All-in-one vr headset | oculus. `https://www.oculus.com/quest/`, 2021b. (Accessed on 01/05/2021).

Lauren Goode. What is xr, and how do i get it? | wired. `https://www.wired.com/story/what-is-xr/`, 05 2019. (Accessed on 01/05/2021).

Tonia Gray and Carol Birrell. Are biophilic-designed site office buildings linked to health benefits and high performing occupants? *International journal of environmental research and public health*, 11(12): 12204–12222, 2014.

Jess Grey. The 3 best vr headsets and some games to play (2020) | wired. `https://www.wired.com/gallery/best-vr-headsets-in-this-reality/`, September 2020. (Accessed on 01/05/2021).

J. Grubert, E. Ofek, M. Pahud, and P. O. Kristensson. The office of the future: Virtual, portable, and global. *IEEE Computer Graphics and Applications*, 38(6):125–133, 2018.

J. Guo, D. Weng, Z. Zhang, H. Jiang, Y. Liu, Y. Wang, and H. B. Duh. Mixed reality office system based on maslow's hierarchy of needs: Towards the long-term immersion in virtual environments. In *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pages 224–235, 2019.

Sherrill Hayes, Jennifer L Priestley, Namazbai Ishmakhametov, and Herman E Ray. "i'm not working from home, i'm living at work": Perceived stress and work-related burnout before and during covid-19, 2020.

HTC Corporation. Vive™ | discover virtual reality beyond imagination. https://www.vive.com/eu/, 2021. (Accessed on 01/05/2021).

Immersed Inc. *Immersed*, 2020. URL https://immersedvr.com/.

Bonnie M Jennings. Work stress and burnout among nurses: Role of the work environment and working conditions. In *Patient safety and quality: An evidence-based handbook for nurses*. Agency for Healthcare Research and Quality (US), 2008.

T. Kanade, P. Rander, and P. J. Narayanan. Virtualized reality: constructing virtual worlds from real scenes. *IEEE MultiMedia*, 4(1): 34–47, 1997.

Brian Karis and Epic Games. Real shading in unreal engine 4. *Proc. Physically Based Shading Theory Practice*, pages 621–635, 2013.

Shahedul Huq Khandkar. Open coding. *University of Calgary*, 23:2009, 2009.

Michael Lewis and Jeffrey Jacobson. Game engines in scientific research. *Communications of the ACM*, 45:27–31, 01 2002.

Loom Inc. Here, there, anywhere: How to plan a virtual offsite for a distributed team - loom blog. https://www.loom.com/blog/virtual-offsite-tips, February 2021. (Accessed on 02/19/2021).

Minhua Ma, Lakhmi C Jain, Paul Anderson, et al. *Virtual, augmented reality and serious games for healthcare 1*, volume 1. Springer, 2014.

Rob Marvin. Oculus and playstation vr jockey atop the virtual reality market. https://uk.pcmag.com/sony-playstation-vr/122904/oculus-and-playstation-vr-jockey-atop-the-virtual-reality-market, October 2019. (Accessed on 01/05/2021).

Lucas Matney. *Facebook debuts Infinite Office, a virtual reality office space*, 2020. URL https://techcrunch.com/2020/09/16/facebook-debuts-infinite-office-a-virtual-reality-office-space/.

Mark Mcgill, Aidan Kehoe, Euan Freeman, and Stephen Brewster. Expanding the bounds of seated virtual workspaces. *ACM Trans. Comput.-Hum. Interact.*, 27(3), May 2020. ISSN 1073-0516. doi: 10.1145/3380959. URL `https://doi.org/10.1145/3380959`.

Rachel Metz. Better than opioids? virtual reality could be your next painkiller | mit technology review. `https://www.technologyreview.com/2016/07/18/70616/better-than-opioids-virtual-reality-could-be-your-next-painkiller/`, 2016. (Accessed on 02/21/2021).

Mozilla. Gecko - mozilla | mdn. `https://developer.mozilla.org/en-US/docs/Mozilla/Gecko`, 2021. (Accessed on 02/05/2021).

Charles Onyett. The future of gaming in virtual reality - ign. `https://www.ign.com/articles/2012/08/04/the-future-of-gaming-in-virtual-reality`, July 2016. (Accessed on 01/05/2021).

David D Owen. *Facilities Planning & Relocation: A Complete Management System: Including Comprehensive Text, Sample Specifications, Over 50 Forms–Reproducible and on Disk*. RS Means Company, 1993.

Ian Philips. Ianphilips/unityoculusandroidvrbrowser: 3d browser based on geckoview and oculus sdk for unity projects built on android (oculus go/quest, maybe gearvr). `https://github.com/IanPhilips/UnityOculusAndroidVRBrowser`, 2020. (Accessed on 01/19/2021).

Nick Pinno and Henry St Leger. Best vr headset 2020 for games, movies and more | techradar. `https://www.techradar.com/news/the-best-vr-headset`, November 2020. (Accessed on 01/05/2021).

Jeff Pochepan. *'Recharge Rooms' Are the Next Trend Your Employees Need in the Office*, 2018. URL `https://www.inc.com/jeff-pochepan/recharge-rooms-are-next-trend-your-employees-need-in-office.html`.

Joseph Psotka. Immersive training systems: Virtual reality and education and training. *Instructional Science*, 23(5/6):405–431, 1995. ISSN 00204277, 15731952. URL `http://www.jstor.org/stable/23370939`.

Ralph. How do i develop to playstation® platforms? – unity. `https://support.unity.com/hc/en-us/articles/212064606-`

How-do-I-develop-to-PlayStation-platforms-, November 2020. (Accessed on 01/05/2021).

Anastasia Ruvimova, Junhyeok Kim, Thomas Fritz, Mark Hancock, and David C. Shepherd. "transport me away": Fostering flow in open offices through virtual reality. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, CHI '20, page 1–14, New York, NY, USA, 2020. Association for Computing Machinery. ISBN 9781450367080. doi: 10.1145/3313831.3376724. URL https://doi.org/10.1145/3313831.3376724.

Tony Schwartz. Relax! you'll be more productive. *The New York Times*, 2013.

Hannah Schwär. Inside google's zurich office, home of over 2,000 'zooglers'. https://www.businessinsider.com/google-zurich-headquarters-tour-2018-1?r=UK, 01 2018. (Accessed on 03/10/2021).

ServReality. Choosing between unity and unreal: Two leading game development engines - servreality. https://servreality.com/blog/choosing-between-unity-and-unreal-two-leading-game-development-engines/, 2019a. (Accessed on 01/04/2021).

ServReality. The best game engines for virtual reality applications - servreality. https://servreality.com/blog/the-best-game-engines-for-virtual-reality-applications/, 2019b. (Accessed on 01/04/2021).

Shahriar Shahrabi. Shahriar shahrabi on twitter: On the alignment. https://twitter.com/IRCSS/status/1231523329183559681, February 2020. (Accessed on 01/09/2021).

Adalberto L. Simeone, Eduardo Velloso, and Hans Gellersen. Substitutional reality: Using the physical environment to design virtual reality experiences. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, CHI '15, page 3307–3316, New York, NY, USA, 2015. Association for Computing Machinery. ISBN 9781450331456. doi: 10.1145/2702123.2702389. URL https://doi.org/10.1145/2702123.2702389.

Tony Solomon. Great office design boosts productivity: workspace. *HR Future*, 2018(Jan 2018):16–17, 2018.

Sony Interactive Entertainment. Playstation vr | live the game in incredible virtual reality worlds | playstation. https:

//www.playstation.com/en-us/ps-vr/, 2021. (Accessed on 01/05/2021).

Florian Soyka, Markus Leyrer, Joe Smallwood, Chris Ferguson, Bernhard E. Riecke, and Betty J. Mohler. Enhancing stress management techniques using virtual reality. In *Proceedings of the ACM Symposium on Applied Perception*, SAP '16, page 85–88, New York, NY, USA, 2016. Association for Computing Machinery. ISBN 9781450343831. doi: 10.1145/2931002.2931017. URL https://doi.org/10.1145/2931002.2931017.

Brennan Spiegel. Top 10 lessons learned using vr in hospitalized patients | mygihealth. https://mygi.health/blog/expert-opinions/top-10-lessons-learned-using-virtual-reality-hospitalized-patients, 2016. (Accessed on 02/21/2021).

Carolin Straßmann, Sabrina C. Eimler, Alexander Arntz, Dustin Keßler, Sarah Zielinski, Gabriel Brandenberg, Vanessa Dümpel, and Uwe Handmann. Relax yourself - using virtual reality to enhance employees' mental health and work performance. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems*, CHI EA '19, page 1–6, New York, NY, USA, 2019. Association for Computing Machinery. ISBN 9781450359719. doi: 10.1145/3290607.3312946. URL https://doi.org/10.1145/3290607.3312946.

Thinkwik. Cryengine vs unreal vs unity: Select the best game engine | by thinkwik | medium. https://medium.com/@thinkwik/cryengine-vs-unreal-vs-unity-select-the-best-game-engine-eaca64c60e3e, April 2018. (Accessed on 01/04/2021).

K. D. Thoondee and A. Oikonomou. Using virtual reality to reduce stress at work. In *2017 Computing Conference*, pages 492–499, 2017.

Branden Thornhill-Miller and Jean-Marc Dupont. Virtual reality and the enhancement of creativity and innovation: Under recognized potential among converging technologies? *Journal of Cognitive Education and Psychology*, 15(1):102–121, 2016.

Unity Technologies. Unity - manual: Colliders. https://docs.unity3d.com/Manual/CollidersOverview.html, 2021a. (Accessed on 01/31/2021).

Unity Technologies. Unity - manual: Scenes. https://docs.unity3d.com/560/Documentation/Manual/CreatingScenes.html#:~:text=Scenes%20contain%20the%

20objects%20of,building%20your%20game%20in%20pieces., 2021b. (Accessed on 02/01/2021).

Unity Technologies. Unity - manual: Prefabs. https://docs.unity3d.com/Manual/Prefabs.html, 2021c. (Accessed on 01/10/2021).

Unity Technologies. Roadmap - unity. https://unity3d.com/unity/roadmap, 2021d. (Accessed on 01/04/2021).

Unity Technologies. Unity real-time development platform | 3d, 2d vr & ar engine. https://unity.com/, 2021e. (Accessed on 01/04/2021).

Valve. Valve index® - upgrade your experience - valve corporation. https://www.valvesoftware.com/en/index, 2021. (Accessed on 01/05/2021).

Mariel Vandeloo. An exploration of the effects of creative office design within workplaces, 2014.

Viarama. Home - viarama. https://viarama.co.uk/, 2021. (Accessed on 03/07/2021).

Robert Vinciguerra. Tom kalinske talks about his time overseeing sega as its ceo in the 90s; reveals that sega passed on virtual boy technology, considered releasing 3do. https://web.archive.org/web/20150924024256/http://revrob.com/sci-tech/264-tom-kalinske-talks-about-his-time-overseeing-sega-as-its-ceo-in-the-90s-reveals-that-sega-passed-on-virtual-boy-technology-considered-releasing-3do, September 2015. (Accessed on 01/05/2021).

Virtual Desktop, Inc. *Virtual Desktop*, 2020. URL https://www.vrdesktop.net/.

Vive Team. Htc vive unveils complete vive cosmos series - vive blog. https://blog.vive.com/us/2020/02/20/htc-vive-unveils-complete-vive-cosmos-series/, February 2020. (Accessed on 01/05/2021).

James Walker. Improving everyday computing tasks with head-mounted displays. 2017.

Jessica Wapner. Vision and breathing may be the secrets to surviving 2020 - scientific american. https://www.scientificamerican.com/

article/vision-and-breathing-may-be-the-secrets-to-surviving-2020/?fbclid=IwAR1ufFRAeMapsyO4fkRdEp8nCCWjOPh0vku9iIogY5pbN2mtm43b4ik6TpU, November 2020. (Accessed on 01/18/2021).

Jeff Ward. What is a game engine?- gamecareerguide.com. https://www.gamecareerguide.com/features/529/what_is_a_game_.php, 2008. (Accessed on 01/04/2021).

J. Xie. Research on key technologies base unity3d game engine. In *2012 7th International Conference on Computer Science Education (ICCSE)*, pages 695–699, 2012. doi: 10.1109/ICCSE.2012.6295169.

Jie Yin, Nastaran Arfaei, Piers MacNaughton, Paul J. Catalano, Joseph G. Allen, and John D. Spengler. Effects of biophilic interventions in office on stress reaction and cognitive function: A randomized crossover study in virtual reality. *Indoor Air*, 29 (6):1028–1039, 2019. doi: 10.1111/ina.12593. URL https://onlinelibrary.wiley.com/doi/abs/10.1111/ina.12593.

Jie Yin, Jing Yuan, Nastaran Arfaei, Paul J. Catalano, Joseph G. Allen, and John D. Spengler. Effects of biophilic indoor environment on stress and anxiety recovery: A between-subjects experiment in virtual reality. *Environment International*, 136: 105427, 2020. ISSN 0160-4120. doi: https://doi.org/10.1016/j.envint.2019.105427. URL http://www.sciencedirect.com/science/article/pii/S0160412019336347.

Zunjie Zhu, Feng Xu, Chenggang Yan, Ning Li, Bingjian Gong, Yongdong Zhang, and Qionghai Dai. Real-time indoor scene reconstruction with manhattan assumption. *Multimedia Tools and Applications*, 78(1):713–726, 2019.

Parisa Zraati. Color consideration for waiting areas in hospitals. In Amaresh Chakrabarti and Raghu V. Prakash, editors, *ICoRD'13*, pages 1369–1379, India, 2013. Springer India. ISBN 978-81-322-1050-4.

Typeset March 18, 2021