TU WIEN Informatics

Game Design in Virtual Reality

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieur

im Rahmen des Studiums

Media- and Human-Centered Computing

eingereicht von

BSc. Onur Gürcay
Matrikelnummer 00827880

an der Fakultät für Informatik

der Technischen Universität Wien

Betreuung: Ao.Univ.Prof. Mag. Dr. Horst Eidenberger

Wien, 1. Jänner 2021

Onur Gürcay	Horst Eidenberger

TU WIEN Informatics

Game Design in Virtual Reality

DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieur

in

Media- and Human-Centered Computing

by

BSc. Onur Gürcay
Registration Number 00827880

to the Faculty of Informatics

at the TU Wien

Advisor: Ao.Univ.Prof. Mag. Dr. Horst Eidenberger

Vienna, 1st January, 2021

Onur Gürcay	Horst Eidenberger

Technische Universität Wien
A-1040 Wien ▪ Karlsplatz 13 ▪ Tel. +43-1-58801-0 ▪ www.tuwien.at

Erklärung zur Verfassung der Arbeit

BSc. Onur Gürcay

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.

Wien, 1. Jänner 2021

Onur Gürcay

Acknowledgements

First of all, I would like to thank Prof. Eidenberger for supporting me through my years at TU Wien and helping me restore my self-confidence.

I would also like to thank Ahmed Othman who also worked on the Vreeclimber project and prepared the template everyone is currently using for their virtual climbing applications. He always tried to make time whenever I needed someone's help during the development and evaluation stages of the thesis.

I also want to thank my sister, Burcu Gürcay-Morris, who has always been there for me and ready to help no matter what.

And lastly, I want to thank my test group for making time for me in the current state of the world.

Kurzfassung

Das letzte Jahrzehnt hat sehr große Verbesserungen in der Virtuelle Realität (VR)-Technologie gezeigt. Neben Gaming wird VR in vielen unterschiedlichen Bereichen wie im medizinischen Bereich verwendet. Beispielsweise können Chirurgen lernen, komplizierte Operationen mehrmals in VR durchzuführen, ohne das Leben ihrer Patienten zu riskieren. Die Möglichkeiten wie in diesem Beispiel erweiterten die Anwendungsbereiche bedeutend, als der führende Sektor, Gaming, für die Verbraucher attraktiver wurde. Viele Spieleentwicklungsunternehmen begannen, immersive Erlebnisse zu produzieren, welches zu der Stärkung ihrer Position auf dem Markt durch die Gewinnung neuer Benutzer führte. Trotz all dieser Entwicklungen bleibt VR-Gaming jedoch immer noch hinter dem traditionellen Videospielerlebnis zurück, hauptsächlich aufgrund des Mangels an hochwertigen Inhalten und der zusätzlichen Kosten, die mit VR-Geräten einhergehen. Der Hauptgrund für die Knappheit an hochwertigen Inhalten ist, dass das Erstellen von VR-Spielen immer noch das Ausprobieren neuer Ideen erfordert, in dem das allgemeine Wissen über Spieldesign verwendet wird, das aus der Entwicklung von Videospielen stammt. Die Tatsache, dass der Spieler in VR-Spielen präsent ist, sollte die Perspektive der Spieledesigner beim Aufbau der Erfahrung ändern. Die Spieledesigner müssen Spieldesign-Elemente wie Ästhetik, Herausforderungen und Wiederspielbarkeit anpassen und so ändern, dass die VR für die Spieler immer noch überzeugend sein kann. Um diese inhaltlichen Probleme anzugehen, untersucht diese Diplomarbeit die Anwendbarkeit verschiedener digitaler Spieldesignelemente auf VR-Spiele durch die Entwicklung eines VR-Spiels namens Astroclimb. Astroclimb ist ein Science-Fiction- und Weltraumspiel, bei dem es darum geht, eine Himmelswand im Weltraum hochzuklettern. Der Kletterteil des Spiels findet dank des Vreeclimber-Projekts der TU Wien auch in der Realität statt, einem VR-Klettersystem, das eine unendlich rollende Kletterwand ermöglicht.

Während der Entwicklungsphase von Astroclimb waren die Verbesserungen der Qualität der Benutzererfahrung und des Ermöglichens einer hohen Immersion-Stufe die Hauptziele von Astroclimb. Die endgültige Version des Spiels wurde von einer kleinen Testgruppe mit Fragebögen und optional kurzen unstrukturierten Interviews sowie die Beobachtung des Spielers während des Durchspielens evaluiert. Die Auswertung zeigte, dass die Anwendung verschiedener Spieldesign-Elemente erfolgreich die Immersion im Spiel steigerte und das Spiel für die Spieler attraktiver machte.

Abstract

The last decade showed immense improvements in Virtual Reality (VR) technology. VR is used in many different areas other than gaming such as in the medical area. As an example, surgeons can learn how to perform certain complicated surgeries over and over in VR without risking anyone's life. The possibilities such as this example widened its application areas significantly as the leading sector, gaming, became more appealing to consumers. Many game development companies started to produce immersive experiences which led to strengthening their position on the market by attracting new users. However, VR gaming still falls behind the traditional video gaming experience mainly due to the lack of quality content and the additional costs that come with VR devices. The main reason behind the scarcity of quality content is that creating VR games still involves trying out new ideas by using the general knowledge of game design inherited from developing video games. The fact that the player is present inside VR games should change the perspective of the game designers while building the experience. They need to adapt game design elements such as aesthetics, challenge, and replayability and change them in such a way so the VR can be still compelling to players. To address these content-related issues, this thesis investigates the applicability of different digital game design elements onto VR games by developing a VR game called Astroclimb. Astroclimb is a science fiction and space-themed game that revolves around climbing a celestial wall in outer space. The climbing part of the game also takes place in reality thanks to the Vreeclimber project of TU Wien, which is a virtual reality climbing system that enables an infinitely rolling climbing wall.

During the development stage of Astroclimb, improving the quality of user experience and the level of immersion were the two main goals for Astroclimb. The final version of the game was evaluated by a small test group with questionnaires and optional short unstructured interviews as well as observing the player during the playthroughs. The evaluation showed that the application of different game design elements successfully increased the immersion level in the game and made the game more compelling to players.

Contents

CHAPTER 1

Introduction

1.1 Problem Statement and Motivation

This diploma thesis focuses on applying traditional game design elements used for video games to virtual reality games without making any concessions to the most important aspect of virtual reality "immersion" [97] and improving it if possible. Virtual reality is still a fairly new technology. Game development in this area has not gained the popularity of PC, console, or mobile gaming yet. There are several reasons for this unpopularity which can be divided into hardware and software-related problems. One of the main hardware-related issues is the price of the device and the additional costs it brings with itself. Apart from the price drawbacks, virtual reality devices are still clunky to use and discourage users to even try them out. Technology still needs time to improve the hardware and increase the usability of virtual reality devices.

Software-related issues are mainly content-based because people do not want to pay for a relatively expensive device if the amount of the game content they will receive with it is lacking or not as high quality as on PC or console platforms. These reasons and many more have been causing a deficiency of consumer attraction to virtual reality compared to PC, console and mobile gaming which did not help with shaping the necessary game design properties for virtual reality. To shade a light on the content-related problems and define possible game design principles for virtual reality, the diploma thesis investigates the following research questions:

- Are common and generally accepted game design practices and methods directly applicable to the virtual reality platform? In what way do core concepts of digital game design such as immersion, usability, and game feel mean differently when applied to the virtual reality experience?
- At what level can problem solving, critical thinking, elements of surprise and

suspense, physical training and activity, engagement, and competition be applied while designing a game for virtual reality platforms to increase the quality of user experience without any negative side-effects for virtual reality?

The thesis explores the mentioned points in order to make virtual reality game design more appealing and enjoyable to users without causing any disadvantages such as decreasing the immersion or bolstering cybersickness that comes with it.

1.2 Aim of the Work

The thesis aims to design a game for the ongoing virtual reality project called Vreeclimber [35]. Vreeclimber's infrastructure consists of a vertically rolling climbing system that enables the climber to experience the sensations of climbing in a perfectly safe environment. Since the mechanical and logical aspects of the project are finalized, it opened up opportunities to create content for the project. The content of the game is based on a playground in a deep space where the player has the mission to climb a celestial wall. The pure reason behind this choice is providing players with an environment that would give them a unique experience.

Vreeclimber's template project comes with algorithms that enable climbing in virtual reality via a calibration process. The calibration process initially detects the trackers on the wall to align the physical wall and the climbing holds with their virtual representation in the virtual environment. In addition to the initial calibration process, the climbing holds remain aligned during the rotation of the wall. Avatar hands and shoes used in the virtual environment are the second part of the calibration process, enabling players to track their hands and feet accordingly.

The implementation of the game aims to include various game design elements which should make sense with the planned gameplay for the game. The first gameplay ideas that were considered are listed below:

Difficulty levels The difficulty level of the climbing can be adjusted by rendering out a certain number of available climbing holds which leaves the climber with a smaller pool of climbing holds to choose from during the climb. The smaller the number of climbing holds the more challenging the climb becomes.

Sandbox mode This mode represents no winning or losing as the term "sandbox" states. However, a scoring system can be defined for using specific types of grips during the climb. Grasping those grips would yield a higher score in the end. Competition elements can be added by creating a global scoreboard or the climbers can simply try to beat their personal bests.

Transitions between scenes The look of the virtual environment can be changed based on the progression players made throughout the game.

The implementation is mainly based upon these gameplay ideas with some modifications and adaptations to the game design elements. During the game design and implementation processes, the differences between designing a video game and a virtual reality game should be considered in order to take advantage of the virtual reality aspect. The applied game design elements should furthermore be in harmony with each other to increase the quality of user experience without lowering the immersion levels. The prototypes should be created following these points.

After each game prototype, the functionality and the effects of the added game design elements should be tested. Based on the given feedback, the appropriate parts of the game should be adjusted to meet the requirements and improve the overall user experience. After the creation of a satisfactory prototype, a test group corresponding to the scope of a thesis should be used to evaluate the success rate of the used game design elements, their impact on the quality of user experience and immersion.

1.3 Methodological Approach

The methodological approach compromises of the following steps:

1. **Literature Review:** Firstly, research on the definition of "game design" and its elements is done while investigating how they changed over the years with the advancements in technology and if virtual reality played a role in these alterations. This part of the research was important to understand the influence of virtual reality on game design. Since there was not a single set of game design elements that are accepted globally, a long list of different game design elements and their sub-elements was created. The next step was narrowing the list down by eliminating the ones that are not compatible to virtual reality. The elimination happened per definition and choice since it is impossible to include every single game design element that is mentioned in the literature. The result of this part of the research was a new categorization of game design elements that are commonly accepted and game design elements specific to virtual reality games. Another part of the research was determining the advantages and disadvantages virtual reality brings to the table while designing games. The gathered information helped with filtering the game design elements further. In addition to these findings, further research on the effects of using chosen game design elements on the players helped improve the user experience. Furthermore, it improved forming directives to come up with better game-play ideas.

2. **Implementation:** The implementation of the game prototype was performed by using Unity game engine with the help of Steam virtual reality software for virtual reality capabilities. Previously mentioned game-play ideas were the starting point for the implementation part. Since the center point of the game is climbing a physical climbing wall with supporting virtual representations, some of the used assets were pre-defined such as the virtual climbing wall and avatar hands. They

were a must-have to achieve simple climbing in a virtual reality environment. The composition of the objects in the virtual environment was created by modeling and using game-ready assets. Adding game design elements to the game started with creating the environment and continued with implementing the gameplay. Some game components were modified or removed throughout the implementation process to meet the requirements and provide players with a better experience. Furthermore, the calibration process received some adjustments to meet the gameplay requirements. During the whole implementation process the most important aspect of virtual reality, immersion, is kept in mind so the ideas or added game components do not break it.

3. **Playtesting:** During the whole implementation process, every added feature was tested and feedback was given based on the experience from the test sessions. The testing sessions and received feedback helped with improving the weak points of the game. Moreover, playtesting also proved and disproved some ideas that sounded reasonable during the brainstorming process.

4. **Evaluation:** The evaluation process consisted of different methods to gather data from the participants. The initial method was using a questionnaire to gather information about participants' gaming and climbing habits and experiences before the climb. The participants were further encouraged to think aloud during their game sessions. A second questionnaire was handed over to the participants after their experience with Astroclimb to gain insight into their experience regarding the immersion level they perceived, the impact of using different game design elements, and quality of user experience. Moreover, a short unstructured interview was conducted afterwards to receive further feedback to improve the game and user experience.

1.4 Thesis Structure

The second chapter of the thesis presents the current state-of-the-art. The section starts with giving some information about the evolution of virtual reality over the last decade, virtual reality application areas, and its possible interaction techniques. It then explains the stages developing a game goes through. The subsection also includes some virtual reality game examples on the market and their comparison with each other. The game design subsection covers the definition of "game" which gives insight into game design elements. It also explains what game mechanics mean for a game and how playtesting is a crucial part of the game design life-cycle. All these aspects are then reflected in virtual reality. It further clarifies the advantages and disadvantages virtual reality brings. The importance of immersion in virtual reality and motion sickness covers the next subsections. Moreover, climbing in virtual reality and the tools that enable this experience forms the last sections together with the related work done in the research area.

The third chapter covers the conception of the game. The first subsection explains the research questions and requirements that are necessary to create a specific concept of the game. The design approach covers the ideas behind designing the game and why this approach is chosen based on given tools to work with. The section also informs about the chosen game design elements and their effects in the game. Lastly, the possibilities to improve the game are discussed.

The fourth chapter includes all relevant aspects of technically designing Astroclimb while the fifth chapter reflects results from the evaluation. The last chapter gives a short summary of the whole work done for the thesis and possible future work that can be achieved with the project Vreeclimber.

CHAPTER 2

State-of-the-Art

2.1 Virtual Reality

2.1.1 Evolution of Virtual Reality over the Last Decade

Virtual reality has been around for decades, however, it has only recently started to gain momentum due to advancements in science and technology. These improvements brought the current state of virtual reality to a point that made it look far different than how it started with Sutherland's "The Ultimate Display" [26]. How we view and use virtual reality changed over the decades with the impacts of multiple breakthroughs in research and innovation.

One of these breakthroughs happened with Google introducing Street View in 2007 [53]. Street View is a virtual representation of our surroundings all over the world that is supported by Google Maps [52]. It consists of millions of panoramic images that enable people to virtually explore the world. Google, then released a virtual reality version of Google Earth [51] for Valve's Steam computer gaming platform and integrated Street View into Google Earth VR. This update lets the user explore Street View imagery from 85 countries right within Earth VR by using VR controllers [79]. Figure 2.1 shows a user using an HTC VIVE headset with its controllers to navigate through the world.

Another crucial breakthrough for VR was the design of the first Oculus Rift VR headset prototype in 2010 [83]. Palmer Luckey, the inventor of the Oculus Rift VR headset, kickstarted his design in 2012 for enthusiasts to back his project. John Carmack's [109] short demonstration of an early version of the prototype at the E3 event [33] helped Luckey receive more than enough endorsements to reach his goal. Figure 2.2 shows how the very first prototype was assembled for its display at the expo. The modest campaign goal of $250,000 broke 2 million dollars in a short time with the generous help of known gaming industry names such as John Carmack, and Gabe Newell of Valve

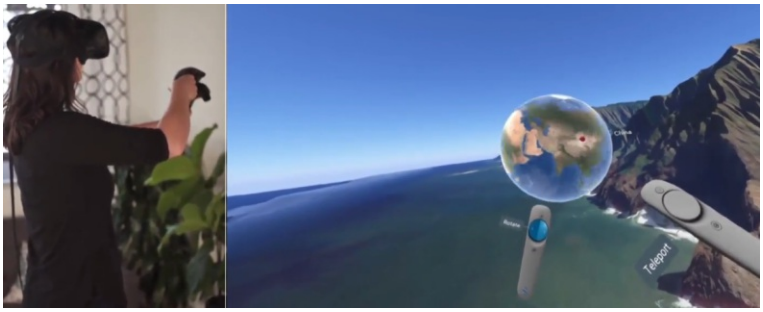

Figure 2.1: With the help of the controller the user is able to select a location on the small globe and fly towards it. [56]

[77]. A week before Facebook bought the Oculus VR company for $2 billion in 2014 [31], Luckey released a new version of Oculus Rift called Developer Kit 2 (or DK2). This new version fixed and improved upon some of the original headset's flaws such as switching the technology powering their display from LCD to OLED, decreasing the latency of the headset from 60 milliseconds to 30 milliseconds, and inserting entirely black frames in between other frames to see smoothly moving images [87]. The improvements also helped with reducing the occurrences of motion blur which is one of the main reasons for motion sickness [102]. The acquisition of Oculus VR by Facebook did not change the main goal of making games but expanded the use of it in other areas such as education and healthcare with social networking built-in.

Facebook buying the Oculus VR company was a defining moment in VR's history because VR gained momentum after this. Sony announced the development of a VR headset for the PlayStation 4 (PS4) under the name Project Morpheus [39] which then evolved and became a part of the equipment for PlayStation5 (PS5) VR games. Google joined the race with the release of the Google Cardboard [55]. Google Cardboard(Figure 2.3) is a low-cost and do-it-yourself (DIY) stereoscopic viewer for smartphones. It works by placing a smartphone at the optimal distance away from the lenses that create a 3D effect when held up to the eyes. However, it requires compatible apps to work with. Samsung Gear VR [139] announcement in 2014 was another advancement for VR. Samsung Gear VR, a headset, uses Samsung Galaxy smartphones as a viewer with similar built-in functionalities as Google Cardboard has. It then became a part of Sony's PlayStation VR (PSVR) in 2016.

In 2015, the use of VR expanded and became widely available to the general public:

- The Wall Street Journal launched a VR roller coaster that followed the ups and downs of the Nasdaq Stock Market. [137]
- The BBC created a 360-degree video where users view a Syrian migrant camp. [106]
- The Washington Post released a VR experience of the Oval Office at the White

Figure 2.2: An interviewer tries out one of the first prototypes of Oculus VR at E3. [42]

Figure 2.3: A variety of Google Cardboards. [54]

House Correspondents' Association Dinner. [1]

- RYOT, a media company, exhibited Confinement, a short VR film about solitary confinement in US prisons. [138]

More releases followed in 2016 that focused on the free movement of users while wearing a headset. HTC VIVE SteamVR headset [134] was one of them. This was the first commercial release of a headset with sensor-based tracking which allowed users to move freely in a space. Two years after that Facebook released its untethered Oculus Go headset [117].

Further developments such as many companies developing their own VR headsets including Google, Apple, Amazon, Microsoft, Sony, and Valve accelerated the advancement for VR headsets. Valve Index [71] was released in 2019 and is currently if not the best one of the best VR headsets on the market [47]. It provides an optimized pixel layout with dual 1440x1600 RGB LCDs greatly reducing the "screen door" effect [113] VR headsets had to deal with especially in the early stages of developments. Moreover, the headset runs at 120Hz with an experimental option of 144Hz improving the realism and optical comfort of the users which also reduces the possible occurrence of motion sickness [78]. Besides these features, increment in field of view (FOV) to 130 degrees (perceived as 120) makes the users feel more present in the experience [75].

Virtual reality has significantly advanced and is now being used in a variety of ways, from providing immersive gaming experiences, to helping treat psychological disorders, to teaching new skills and more. Now that we are aware of important technological advancements in VR, the next subsection dives into a collection of application areas of VR and informs how different areas take advantage of these improvements.

2.1.2 Application Areas

VR has attracted a lot of people in the last decade which led companies to adopt and improve it [122]. With the help of the tools VR brings to the table users are able to

manipulate the simulated world in a natural way. Since the simulated world can be designed in an infinite number of possible ways, VR opens many doors for people to get creative and achieve their goals in different areas. Figure 2.4 shows which application areas VR favors in terms of market share. The remaining of this section focuses on how VR got embraced by different application areas and what kind of great benefits VR provided them.

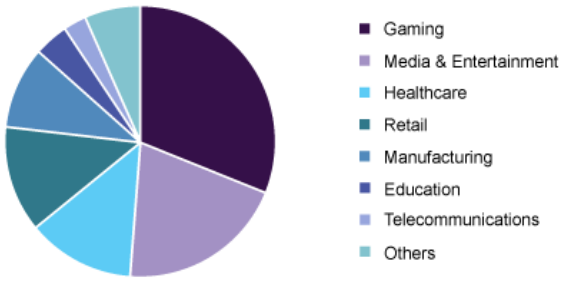

Figure 2.4: Global VR headset market share, by application, 2020 (%) [130]

1. **Gaming:** Gaming with VR gives players a truly immersive, first and third-person perspective of game action. VR lets players experience and influences the game environment through a variety of VR gaming devices and accessories, including VR headsets, sensor-equipped gloves, controllers, trackers, and more. The next subsection goes into details about these interaction devices and methods. VR games can be played on standalone systems, specialized game consoles, or using PCs and laptops that can power VR headsets. PC and console-tethered headsets usually have better performance and provide a more immersive experience, while mobile headsets are relatively inexpensive and easier to set up and use. Although the bodily movements in real life are not translated to that in VR for standalone headsets except the head rotations to view the space in 360-degree environments, companies such as Facebook, Google, and HTC are developing cheaper mobile VR devices to attract more users to adopt VR headsets [95]. Gamers have a higher average outlay for upgrading their gaming PCs and consoles compared to people who do not indulge in gaming. This has encouraged companies to capitalize on VR games within the reasonable price range for gamers [136]. These VR games have the same scope as traditional video games including single, cooperative, and online multiplayer games. Some of these games place players in physical combat environments, while others provide more relaxing letting players traverse worlds and various spaces. Other VR games take players on adventures by challenging them to solve problems and explore unknown places. Section 2.1.5 gives more insight into different types of games and provide examples.

2. **Entertainment:** Although gaming is also a part of the entertainment application area, it deserves its own section because of the influence it alone has on the

market. Besides gaming, VR has other applications for entertainment such as providing virtual museums [136] and galleries [8]. These setups make visitors the center point of interactive exhibitions so that they can take a tour in these virtual environments. Some of these environments also provide scene manipulation options such as arranging the position of artworks and changing the lighting and color of the walls as needed. Virtual theme parks [32] are another great example of using VR for entertainment purposes. VR gives people the opportunity to visit theme parks and join rides such as Tron at Shanghai Disneyland [131] and Jurassic World The Ride at Universal Studios Hollywood [63] while they are sitting on their couches. Another entertainment source VR provides is letting people join music concerts and be on the stage to experience live music. Virtual concerts [86] come with many benefits for the user from seeing admired artists without having to leave home, to not worrying about getting a good seat, to being able to adjust the volume, and more. Although these remote entertainment opportunities come with benefits there is still room to improve. Improving the visual quality and making the audio more spatial would be essential improvements to increase immersion and therefore the user experience.

3. **Healthcare:** Due to VR's interactive nature and simulative aspect, medical training and mental health rehabilitations stood forward for this application area. Medical and dental students have begun using VR to practice surgeries and procedures [160], allowing for a learning environment without having consequences of making mistakes. Therefore, the risk of inflicting harm on patients while practicing is eliminated. OssoVR [181] is one of the well-known platforms that provide surgical training and assessment. With the help of VR, students can develop skills in various simulations which can later be applied in real-world scenarios. Besides the benefit of training high-skill personnel, VR creates a great opportunity to optimize costs [27]. Patient treatment has also become one of the core application areas in healthcare. Pain management is an example where VR captures the mind's attention and blocks pain signals from reaching the brain [14]. Stress and depression treatments are further examples in this area. Moreover, VR also proved to be a promising and motivating platform to safely practice and rehearse social skills for children with Autism Spectrum Disorders (ASD) [29].

4. **Education:** VR provides various ways to enable education between students and teachers. VR education gives the opportunity to make learning experiences social by allowing students to communicate with each other. Using avatars and mapped facial expressions [38], students can come together to discuss, synthesize, and learn from one another. All of these can be achieved by distance learning [128]. Students can be put together in the same room with digital representations of themselves while teachers guide them through their knowledge and experiences. Another possibility VR provides is letting students experience places across the world without leaving the classroom. The technical part of this possibility includes using the 360 VR technology. 360 VR contents are interactive and immersive

experiences that completely surrounds a user as if they are standing in the middle of a scene. The user can look in any direction, allowing them to see and interact with the content as they would in real life [2]. Real-world locations are captured with special equipment using 360 VR and then the footage is used to create these captured locations into VR environments. Although VR is currently not as popular as other application areas such as gaming and healthcare, the growth of VR within education in previous years [72] shows potential for VR to become one of the most used learning tools in near future. ClassVR [180] is a step in the right direction to expand the horizons of VR in education. It presents an open platform, supporting virtual, augmented, and mixed reality curriculum content, as well as allowing students and teachers to create, upload, and share their own content, creating a collaborative community of global educational resources.

5. **Retail:** VR usage favors both retailers and customers in this application area. The focus point of using VR from the retailer's perspective is training employees. In 2017, Walmart provided VR headsets to Walmart Training Academies to train associates in handling daily tasks and situations such as managing the frozen section and various events like Black Friday [69]. Another mention-worthy VR advancement in retail is eBay's VR store which functions via gaze-based interaction. eBay launched the world's first virtual reality department store in partnership with Australian retailer Myer in 2006 [104]. In this virtual shop, customers can select their areas of interest at the beginning of the experience and the store builds itself around these needs. Customers are additionally able to browse through the products, gain detailed information about them and purchase them.

The application areas of VR are, of course, not limited to the ones listed above and the ones seen in Figure 2.4, however, this section covers only some of the most important ones. VR needs various interaction techniques and devices to serve its purpose in order to enable human and computer interaction in these application areas. The next section dives into these different types of interaction techniques and devices.

2.1.3 Interaction Techniques

VR users can enhance their experience in virtual environments by increasing the level of immersion they perceive. One of the most important ways of achieving this is using various interaction techniques that would make the environment feel natural. This section explores some fundamental interaction concepts such as selection, manipulation, locomotion, and social interaction with the specialized devices that enable these concepts.

1. **Selection:** Selection involves telling the system which object or UI element the user wishes to interact with. Once an object or UI element is selected it becomes the center of focus, so further interaction inputs can be processed for it. Selection can be performed using controller input, gestures, or gaze. Vanacken et al. [173] came up with design guidelines for selection techniques that include the selections in

virtual environments to be fast, accurate, easy to understand, produce low levels of fatigue, and more. The devices that were developed in the last decade followed this suit to improve the quality of user experience. Controller input is one of the most widely used techniques for this purpose. In this technique, a virtual laser-pointer (ray-cast) is fired from the controller to select objects. The user can change the controller orientation to aim the laser beam at desired objects. Although as of right now there are different variations of VR controllers on the market (Figure 2.5) that are used in many application areas, this type of selection technique is still used. Using gestures is another way to select objects in virtual environments.

Figure 2.5: From left to right: HTC VIVE [178], Sony PlayStation Move [126], Oculus Touch [118], Valve Index [70] controllers.

Precise tracking of hands and fingers is a requirement in order to achieve selection via gestures. Leap Motion controller [166] was one of the first devices that achieved finger tracking in short distances. It is based on an optical hand tracking module that captures the movements of hands without any further requirements such as wearing a piece of clothing. Manus Prime II [101] motion capture gloves are another example of precise finger tracking that involves wearing a sensor-equipped piece of clothing. As the technology for hand tracking evolved, this type of tracking started to get integrated into VR headsets. Newer devices such as Oculus Quest [119] support native hand tracking. Common interaction techniques such as using a laser beam cast from a hand coupled with a pinch gesture can be used to confirm the selection of an object. Nearby objects can, of course, be grabbed naturally by the visual representations of tracked hands without any further combination of selection techniques.

Gaze-based selection involves the head-pose or actual eye-gaze which can be tracked by the gyroscopes inside VR headsets [92]. The selection interface usually consists of a reticle or a cursor displayed in the virtual world as seen in Figure 2.6. The process of selecting through gazing starts with the user looking directly at the object. Then the selection can be confirmed via either an external controller input or staring at the target for a certain amount of time.

2. **Manipulation:** Once an object is selected, the user may also want to manipulate the object. Resizing, moving, reorienting, scaling, and rotating it are some of the available manipulative actions the user can apply to objects. The limits of these

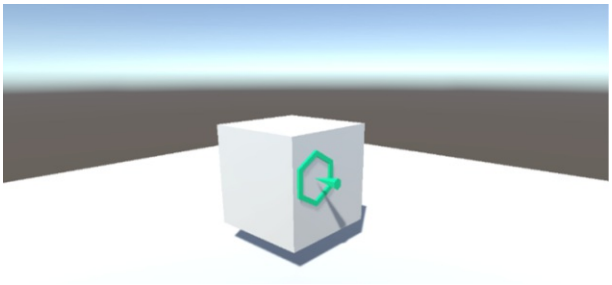

Figure 2.6: An example for a gaze-based selection cursor in Unity. [94]

interactions depend on the available input controller's capability. These can change from simply rotating the controller itself to complicated actions such as performing hand gestures. One of the widely used manipulation techniques is simply rotating an object just to inspect it while holding it in possession. If the held object has a complex structure and just rotating the object is not sufficient to inspect it in detail, then it might require simultaneous inputs from different devices such as multiple controllers or tracked objects such as avatar hands [91]. In this case, while the object can be held and rotated with one controller, a part of the object can be further manipulated by the inputs of the second controller. Moreover, the user could even hold a real object in hand that is tracked by external cameras and manipulate it which would yield haptic feedback to the user. Another way of tracking objects is using special trackers such as VIVE Trackers [179] that can be attached to real objects. The user then can manipulate these objects e.g. with their tracked hands or feet in the virtual world.

3. **Locomotion:** While selection and manipulation focus on the interaction with objects in the virtual environment, locomotion enables user movement within the virtual world. These movement types mainly consist of repositioning and reorienting the user. There is a decent number of locomotion interaction techniques that are used widely in different application areas [94]. One of them is called "On-Rails" where the user has no control over their movement in VR [6]. VR roller coaster describes this experience best because the user rides along while only being able to look around. The most important challenge on-rails locomotion interaction poses is reducing or eliminating the feeling of disorientation [94]. Section 2.2.7 goes into details regarding this type of VR sickness.

   Gaze-directed steering[84] is an extension to on-rails movement type where the user moves in the direction they look. The velocity of the movement can be constant or vary throughout the movement segment by different input triggers. The Jumpcube [34] project includes various gaming applications where the movement is based on gaze-directed steering. "Mission TU Mars", a solar system flight application developed in Unity, includes this type of locomotion interaction technique where the user traverses the space and changes directions based on the direction they

look.

Teleport is another locomotion technique to traverse large spaces in a short time. Users can use controller-based or gaze-based raycast to select an area of the virtual environment they want to move to and trigger the teleportation by a controller input. More advanced teleportation methods can include rotation specifications where the user can specify the direction they want to face when they teleport.

Real movement also counts as one of the locomotion interaction techniques where the user can simply walk around the virtual world. However, walking around without seeing the real environment increases the risk of collision with real-world objects. Some manufacturers such as Oculus provide some sort of proximity alert system to protect users from possible accidents [116]. Other solutions to limited traversing area problems include omnidirectional treadmill simulators such as Virtuix Omni Platform [68] and The Virtualizer [76] that use a special platform to simulate endless locomotion in every direction. However, these devices are currently only available for commercial providers and not for end-users.

4. **Social Interaction:** Social VR gives users the opportunity to meet other people and talk to them in virtual reality. The spatial presence aspect of social VR can give people a sense of belonging and fulfillment in a simulated world. The current state of the world due to the Covid-19 pandemic increased these needs immensely [149][88]. Social interaction includes some or all other interaction techniques presented in this section, however, it uses these interaction techniques to enhance the ability of people to interact with each other as they are present in a simulated world.

This section provided us with valuable information on how to use different interaction techniques in VR. Before using this information and investigating how VR games took advantage of these interaction techniques, we will look into game development in the next subsection to build a base for the last section of Section 2.1.

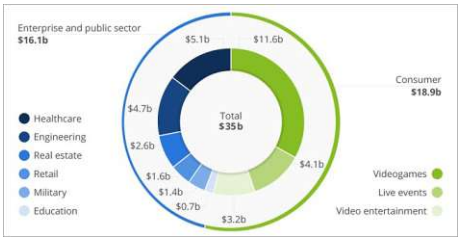

Figure 2.7: The potential of VR applications by category. [60]

2.1.4 VR Game Development

The advancement in VR made VR game development become a popular investment [73]. VR headset sales hit their peak over the last few years and the demand for especially standalone VR devices is expected to grow dramatically at least until 2022 [122]. According to research by the International Data Corporation (IDC), VR and

AR market will reach 15.5 billion euros by 2022, and as seen in Figure 2.7 the video game sector will keep leading the highest market value of VR applications [60]. Besides showcasing the popularity and importance of VR game development in the market, this brings us to explaining the crucial points of developing these high-value VR applications. Instead of explaining every game development stage, we will focus on the points that are decisive to the virtual reality aspect of game development.

Game development starts with a game idea and planning. During the planning stage, the target audience should be defined and the characteristics of the game should be constructed. These characteristics should help with answering the question "Why should my game use VR?" [174]. Once these initial steps are completed, the target VR devices for the game should be chosen. The reasons behind this decision are tightly related to the genre and the playstyle of the game. Light mobile VR is a good choice if the game does not require motion sensors and head movements. These types of games fall under the category of mobile games. Google Cardboard is an example of this kind of device which also carries the title of being the least expensive VR headset on the market by costing around €10 [54]. Premium Mobile VR devices such as Samsung Gear VR [139] and Google Daydream [50] are further choices for mobile games with an additional set of sensors for head movements. PC and console VR are the high-end platform options for games. As explained in Section 2.1.2 and 2.1.3, these high-end VR headsets provide high-level immersion and various interaction techniques a VR game would need. The tools this equipment offer to developers possess a high range of possibilities to bring their game ideas alive and as imagined.

The next step would be deciding on the type of graphics for the VR game. A VR game development cost depends significantly on the game's graphic design. Below is a list of types one can use for game graphics [23]:

- 2D graphics
- 3D graphics
- Photorealistic graphics
- 360 panoramic views

As 2D graphics usually adopt the cartoonish style, they can still look professional, detailed, and complex which brings this option on par with 3D graphics. On the one hand, photorealistic graphics require significant investment and budget especially if the game imitates nature but on the other hand, they can provide the most realistic aesthetics possible for a game. The other option, 360 panoramic views, gives the opportunity to add a panoramic view to the background of the games. Adding interactive elements to the video can, however, presents challenges and become computationally expensive [23].

The development platform would be another important decision to make during the game development cycle. Although there is a definite diversity of VR development tools on the

market for the end-users, Unity [161] and Unreal Engine [44] take the lead because of being free of charge and their wide support in tools, graphics type, operating systems, and ease of use. Once all these decisions are made and other fundamental game development stages [124] are processed accordingly, the next step would be publishing. For this matter, there is a variety of markets for VR games that include Oculus Store [115], Google Play Store [125], Apple App Store [7], Steam [172], and VIVEport [177]. Although the popularity of these markets may vary, they form the default way to distribute content on a range of devices.

Creating a VR game is at base not much different than developing a traditional video game. The limitations, advantages, and additional requirements it brings create that difference during the development process. This section clarified how developing a VR game has its deciding points that would affect the outcome significantly. Now we will look into some of the most successful games in VR history from different genres that are played by millions.

2.1.5 Game Releases

This section is an overview of some of the most successful VR games on the market. The main goal of this subsection is to investigate different types of games while looking into the reasons behind their success.

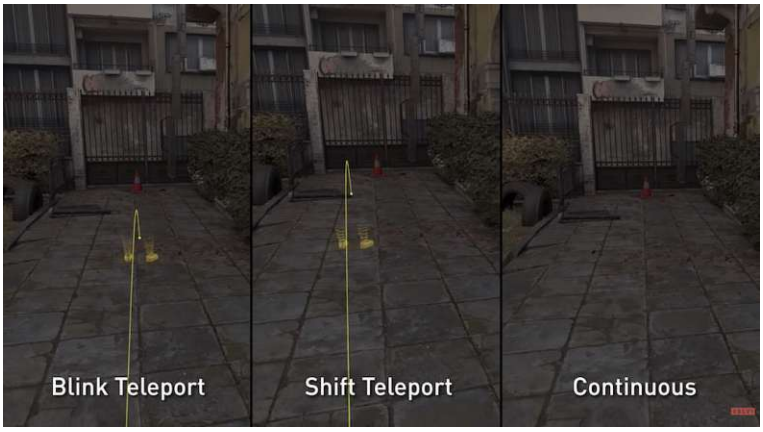

Figure 2.8: Traversing options in Half-Life: Alyx. [11]

1. **Half-Life: Alyx:** Half-Life: Alyx [151], released in 2020, is a first-person shooter (FPS) game that tells the story of an impossible fight against a vicious alien race known as the Combine [151]. The main gameplay consists of looting and shooting enemies that are encountered throughout the game. Half-Life: Alyx is considered one of the most successful VR games in VR history [89] as it became Steam's [172] best and most rated VR game less than a year after launch. Valve's game designers Robin Walker and Greg Coomer stated the points that made the game a success

story in an interview with Norman Chan [140]. Besides its beautiful graphics, the game provides simultaneous 2-hand input to make the player more immersed with the use of specially designed avatar hands. Players are able to interact with many objects in the area with different input combinations applied to controllers. Moreover, the duo informed that the density of interaction played a crucial role in constructing the environment. Because of the high number of interactable objects in the environment testers tend to traverse the space slower than a player would do in a normal video game. This changed the way they designed the levels in the game and made the interaction with objects rewarding. Another important point mentioned was the way players traverse in the game. They did not want to ignore the ability to traverse space and made it for players so that they can move slowly with the help of controller inputs. However, they still kept the possibility of blinking from one point to another to appeal to different types of gameplay. Figure 2.8 displays the types of movement in the game.

2. **Beat Saber:** Beat Saber [43], released in 2019, is a VR rhythm game that evolves around slicing blocks representing musical beats with a pair of contrasting-colored sabers. In an interview [16] one of the game designers, Vladimir Hrincar, mentioned that the surrealistic neon environment created for players is inspired by the movie TRON: Legacy [105]. Beat Saber provides the player two lightsabers which can be controlled by rotating the controllers. As the cubes of different colors that are supposed to be sliced fly towards the player, the player tries to slice the cube with the lightsaber of matching color (Figure 2.9). All levels created in the game have different difficulty levels which encourage players to retry and beat their scores. Although the gameplay is pretty simple the game became popular on the market and made the game one of the most successful VR games.

3. **The Room VR: Dark Matter:** The Room VR: Dark Matter [46] is the first VR game of the well-known puzzle video game series The Room [45]. It expands various types of puzzles around small environments at first before luring players into bigger places such as an ornate church that holds its own series of secrets. Each scene has a collection of hot spots for players to stand in, look around, grab objects to add to their inventory, and try to figure out what is going on. The clues players find throughout the game teach how to think about these puzzles for future reference as much as how to solve the particular puzzle in front of them [82]. The occurring events and the dark atmosphere in the game add the horror genre to the game. Interaction with in-game objects is performed by a pair of avatar hands that are directed by controller inputs (Figure 2.10). Traversing the space only consists of the teleport mechanism similar to in Half-Life: Alyx.

4. **Microsoft Flight Simulator:** Microsoft Flight Simulator [108] is a flight sim that offers its player base a first-person viewpoint to fly over the whole world while in a cockpit of a plane. Players can examine all the buttons and switches a real plane cockpit would offer up close. The simulation concept provides a high level of

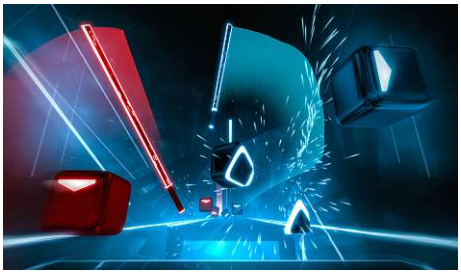

Figure 2.9: The player has to slice cubes with the correct ligtsaber of color. [62]

Figure 2.10: Players use their avatar hands to interact with various objects. [80]

immersion as players take off and land at airports around the world, fly through the clouds and admire the landscapes below. If players choose to just enjoy the flight, the game's autopilot system takes care of the challenging part of controlling a plane. However, the option to feel like a real pilot is still there by taking over control of everything in the cockpit [100]. The interaction part of the game consists of controller inputs without any in-game body part representations. Microsoft Flight Simulator's sandbox style of gameplay lets players enjoy the sight and proves that VR games can exist without complicated mechanics and still be successful as a game [164].

So far, the thesis explained the virtual reality side of the main topic with memorable mentions about gaming and game design aspects. The next section goes more into details about the game design topic and provides broad information about its building blocks.

2.2 Game Design

2.2.1 Definition of Game

Before giving detailed information about game design, it is important to understand what really "game" means. This subsection follows rather a philosophical approach with quotes from renowned researchers who were or are still having a relationship to games that will help with coming up with an acceptable definition for "game".

"A game is something you play." This is most likely the simplest form of game's definition but it does not give us any details rather than stating that it is something you play. "A game is something that is fun to play." is another definition everyone can agree on which also includes the fun aspect. Understanding the building blocks of a definition is as important as understanding the word you are trying to define, hence "fun" and "play" need to be defined as well. Having "fun" is usually associated with having experiences that give pleasure. However, "Fun is pleasure." is alone not good enough because reading your newspaper in the morning while having a coffee can give pleasure but it does not mean

your morning routine is fun. Having fun with something requires that something involve surprises [143]. “Fun is pleasure with surprises.” is a solid definition that distinguishes fun from pleasure. “Play” is rather hard to express although we all know what play is when we see it. The German playwright, poet, and philosopher Friedrich Schiller defined play as follows:

> *Play is the aimless expenditure of exuberant energy.* [48]

This definition expresses the outdated surplus energy theory [107] of play which claims that the purpose of play is to expend extra energy. It also states that play has no goals, which it most certainly does.

Early-twentieth-century philosopher Goarge Santayana describes play as “whatever is done spontaneously and for its own sake” [112]. This definition makes sense to an extent because play is often spontaneous when we describe the playfulness of a game. However, that is not always the case when we think about competitive games. The participants of competitive games have a long preparation time. Regardless of the competitive side of plays, spontaneity is an important part of play. “For its own sake” part of the quote can be interpreted as people do what they like to do. This is also an essential characteristic of play because if we do not like to do it, then it is not play.

“Play is manipulation that indulges curiosity.” [141] by American video game designer Jesse Schell is another definition for play that focuses on the curiosity aspect and the willful action of changing something you are curious about.

Although none of these definitions explain play perfectly, it sheds light on various aspects of what game can mean. Jesse Schell further defines game as follows:

> *A game is a problem-solving activity, approached with a playful attitude.* [142]

This is a definition that covers many points of what a game can have and also makes us aware that problem-solving should be playful since not every activity that involves problem-solving is a game.

None of these definitions are perfect since it is a subjective topic, however now we have a general idea of what game means. This subsection already sneak-peaked some of the game design elements that are hidden in the definitions. The next subsection includes these game design elements and more as it shows the categorization of them by different views.

2.2.2 Digital Game Design Elements

Developing a game starts with an idea that usually describes or hints about the game's core which can be described as a particular pattern of actions that repeats itself over and over [110]. Expansion of the game's core happens by adding some of the game elements that are available in all games. This brainstorming process shapes the game with every added game element that helps to design the game.

Before getting specific about game design elements, it is important to mention basic elements that form a game. For this matter, there are different views with many common elements. Andreas Alexiou et al. express in their work [4] that game mechanics, narrative, and aesthetics form the main digital game elements. Game mechanics are procedures and rules that are applied to the game that describes how players can or can not try to achieve their in-game goals. These procedures facilitate the development of cognitive skills such as problem-solving, creativity, and spatial skills [57]. Section 2.2.3 gives more insight into game mechanics. A narrative or story is a series of events that unfold in the game. With the help of the story element, players can construct reality and make sense of the environment they experience [162]. On the one hand, branching and emergent stories are not always the case while designing games, however, even in games where storytelling is not essential such as in Pacman [183], it is still possible to at least guess the reasons why their worlds are the way they are. On the other hand, a vast majority of games rely on good storytelling to drive the game and to immerse players further into the simulated worlds. Some adventure games prove the importance of story by the success they achieved. "What Remains of Edith Finch" [36] is a great example of an extremely successful story-driven game in which the player is playing as Edith, a member of the Finch family, that discovers strange tales about her family members as she traverses through the huge abandoned Finch house. Game aesthetics refer to the sensory phenomena that the player encounters in the game [148]. In other words, it is how games look, sound, taste, smell, and feel. Aesthetics count as a crucial aspect of game design since they have the most direct relationship to a player's senses [143].

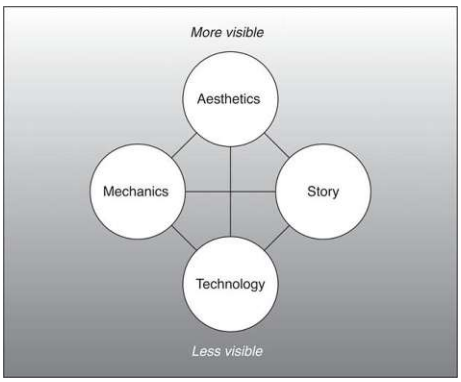

Figure 2.11: The Elemental Tetrad [143]

Jesse Schell adds the "Technology" element to the mentioned core design elements above and describes these four core elements as "Elemental Tetrad" as seen in Figure 2.11 [143]. He states that technology does not always mean "high technology" but any tool and interaction that can make the game work as it is supposed to. While choosing the right technology enables your game to accomplish certain things, it also prohibits the designer from doing other things. Moreover, it is also essential for these four core elements to work in harmony and benefit from each other. When a set of game mechanics is considered to be implemented, the technology should be able to support it. Additionally, the aesthetics should emphasize these game mechanics clearly to players and the story should help the mechanics to make sense to the players. For the sake of harmony, similar requirements also apply to other core game design elements while characterizing them. The game mechanics should strengthen the story, aesthetics should reinforce the idea of the story, and the technology should suit how the particular story plays out. From the aesthetics point of view, it is important to choose the right technology to provide and amplify the certain look and feel that is planned to make players experience. A story with a set of events lets the aesthetics emerge at the right place and have the biggest impact [3].

The core design elements can be further expanded such as George Kalmpourtzis did with his "Elemental Pentad" [3]. Here, however, the design purpose of the game becomes educational. Kalmpourtzis believes that the need of "pedagogy" as the fifth element is highly required in the basic fundamental elements of educational games. In his design, every other element should complement pedagogy directly and improve the experience for its users.

Besides fundamental game design elements, there are many other digital game design elements that can be included in games. The rest of this subsection covers some of these elements while explaining what they mean and how they impact the game [143].

- **Fun:** Fun is a desirable element in nearly every game that increases the quality of the game and the player experience. It is necessary to analyze the game during playtesting to find the segments that do not give the feeling of fun. These parts should be revised by questioning the reasons behind the lack of fun. Improving the fun aspect of the game is essential because keeping the fun aspect at all stages of the game gives that game an enjoyable flow.

- **Surprise:** Surprise is a crucial part of all entertainment and acts as a building block for games. Since human brain is hardwired to enjoy surprises as research states [144], it is an essential element to increase the enjoyment players can take from a game. The previous subsection already mentioned this element while defining what a game is. That alone emphasizes the importance of this element for games but it is also necessary to understand how it can be triggered in various ways:

  – The visual aesthetics in a game can be so incredible or one of a kind that might exceed player's expectations which can cause a pleasant surprise.

  - The player can learn a new in-game skill that can enhance their abilities to move in the game and explore areas that seemed impossible to reach at first. The capabilities this new skill gives to players can create a feeling of surprise.
  - Horror games can contain unpleasant surprises such as jump-scares.
  - Used technology can surprise players such as enabling interesting in-game interaction techniques players could not think of.
  - Game stories can end in unexpected ways which can surprise players.

- **Curiosity:** Curiosity is an element that has a direct impact on the player's motivation to play. The game should present players with compelling goals to reach and give them reasons to reach those goals. As an example, setting a timer to complete a challenge would plant the question "Am I going to be able to complete this task in the given time?" into player's minds and make them curious about the result. Another way to keep player's attention and make them curious would be to condition them to receive rewards throughout the game and make them think about what the next reward will be.

- **Problem-solving:** Problem-solving involves encouraging players to solve problems in order to succeed at the game. Besides the obvious problems that are thrown at players, there can be hidden or optional problems that need solving. Other than enticing players to solve problems through critical thinking, creating additional problems can attract more players. Some players are only interested in solving the crucial problems and some other players, mostly completionists, do not hesitate to spend extra time to find the hidden problems. This would also improve the time spent in a game and make players keep coming back.

- **Competition:** Competition in games enables replayability of the game by giving players something to improve on. Competition element can be added to a game in two ways: The players can compete with themselves and improve their own scores or achievements or they can compete with each other by beating each other's scores. Besides the replayability, competition also adds the socializing aspect to the game if challenging one another is possible.

- **Challenge:** Challenges in a game make the game more appealing by giving players the feeling of struggle towards a goal. However, it is important to mention that badly designed games have little challenge, or too much challenge. If the game has a little challenge it is highly possible that the player can lose interest in the game very quickly. Too much challenge would also make the game unplayable for most players and cause frustration instead of enjoyment. The games should have just the right amount of challenge to be successful.

- **Endogenous value:** Greg Costikyan defines game as follows:

  > *A game is an interactive structure of endogenous meaning that requires players to struggle towards a goal.* [58]

The biological term “endogenous” shortly means “having an internal cause of origin”. In his game definition, Costikyan means that things that have value in the context of the game have value only inside of the game. This game design element as a measurement describes how compelling a game is. The more compelling a game is, the greater the “endogenous value” that is created within the game. So, increasing the value of items or objects that are frequently used by players in the game also increases their attention to the game and their will to play the game.

This section provided us with knowledge about digital game design elements a game must or can include in itself. One of the fundamental game design elements, game mechanics, however, needs more explaining, and therefore, the next section covers what is really meant with game mechanics and gives details about some of its cornerstones.

2.2.3 Game Mechanics

Game mechanics are the interactions and relationships between the player and the virtual environment that gives the game its soul [37]. This soul includes methods, rules, game dynamics, goals, and actions players are allowed to take with the sole purpose of satisfying the player by providing a compelling experience. The provided experience is received in an endless cycle as long as the player keeps playing the game. This endless cycle starts with the player interacting with a virtual environment that receives inputs from the player and then changes its status based on the received inputs. The player, then, analyzes these changes and makes decisions to take the next step in the game. This series of actions become repetitive once the player interacts with the simulated world again. Figure 2.12 visualizes this interaction cycle. The interaction cycle is moderated by the

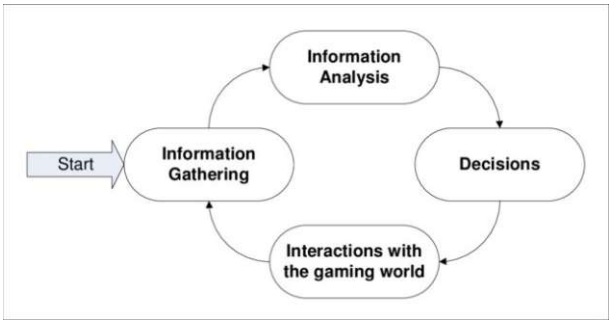

Figure 2.12: Interactive cycle in the play experience by Fabricatore [37]

rules of the game. Since the interaction affects both sides, the player and the game, there are different rules the player and the game itself should follow [17]. The rules the player should follow can be a written set of rules which can be given to players before starting the game or they can be introduced to the player as they progress in the game, or they must be figured out by the player on their own. An example for such a rule can be the requirements stated in the game to craft a tool. In such a scenario, the rules the game should follow depend on the progression the player makes throughout the game. If the

player has the correct amount of materials to craft a tool, the game should provide the player with that tool.

So far this section gave the impression that game mechanics basically equal rules. On the one hand, this approach is adopted by some researchers such as Lundgren and Björk [13]. They define game mechanics as "any part of the rules system of a game that covers one, and only one, possible kind of interaction that takes place during the game, be it general or specific (...) mechanics are regarded as a way to summarize game rules." In this view, game mechanics are accepted as low-level descriptions of game rules and there is no need for a definitional distinction between rules and game mechanics. On the other hand, there are counterarguments such as stated in Problem Machine Blog [98]: "A rule is a directive of behavior that must be observed for the game to proceed. Conversely, 'mechanic' is distant and impersonal, implies something that happens as a natural consequence of something else occurring." This view sees rules as intimate, as they require the player to actively participate in order for the game to continue which also requires the player to have an understanding of rules. In comparison, game mechanics are impersonal which means that they do not require player participation or game understanding by the player.

Although rules are the most fundamental of all game mechanics and they give the game its identity, the rules alone do not define the game mechanics of a game. Skill is one of these elements where every game requires players to exercise certain skills. Based on the player's skill level a game can feel challenging and give something to work towards for the player. Skill is also a source of enjoyment for players as long as it stays interesting, rewarding, and balanced for different skill levels of players if the game possesses these characteristics. Chance is another element of game mechanics. Leaving certain outcomes to luck is a great way to create surprises. As mentioned in Section 2.2.1 surprise is one of the most important game design elements that bring joy and excitement to players.

Since game mechanics is a part of the game design elements, all of its cornerstones can be further added to the list of other game design elements mentioned in Section 2.2.2. The next section emphasizes the playtesting step in game development and how it affects the changes made for planned game design elements.

2.2.4 Playtesting

Playtesting is one of the most important development steps during game design. It can be described as a form of a usability test where the tester can observe how players read and react to the game. It is always better to start playtesting as soon as possible. The time a prototype of the game is available the designer should start with playtesting.

Since every comment from playtesters is crucial to improving the game, both positive and negative feedback should be embraced. While positive feedback signals that the designer has done something appealing, negative feedback makes the designer rethink the validity of that specific part in the game. Although positive feedback is good to hear and

important to build up confidence, negative feedback includes essential information about improving the game further. The tester should not hesitate to ask playtesters what is wrong with the game and explicitly encourage them to be as brutally honest as possible while giving feedback [132].

Another key point is choosing the playtesters carefully. Friends and family are good starting points to test the game prototype with, however, their feedback will most probably be biased due to the relationship. Sticking to only relatives as playtesters can cause missing major flaws in the game, hence seeking people that can give honest and constructive feedback is a major step to receive the information needed to revise the game.

Welcoming negative feedback is one thing, but adapting your ideas according to feedback is another. Taking negative feedback to the heart can ensure you do not get too attached to the specifics of an idea [132]. The same goal of an idea can be achieved in other ways which can also improve the game at the same time.

Playtesting has a direct relationship to the game design elements that are included in the game. This enables playtesting to examine the game on multiple levels. On one level, as an example, the game needs to have the right amount of challenge and be balanced. If the game feels too difficult to play for a playtester which, however, can not be the case for everyone, the tester can ask questions about the parts that make the game difficult for that playtester. The received feedback can help rebalance the game for the casual audience. On a higher level, a playtest can reveal how the players react to a game's theme, and whether the theme fits the mechanics [121]. If we continue with the balance example, this higher level can be achieved if the changes made in lower levels mean something within the game. Stardew Valley's [24] building crafting mechanics is a concrete example for creating balance with numbers and making these numbers meaningful within the game. If the player wants to build the lowest tier barn, one set of resources the player needs to provide is 350 pieces of wood. In comparison to this, a higher-tier barn requires 500 pieces of wood instead. This higher-tier barn allows the player to house more animals in it. It is fine to think about the required number of resources just as a numerical value but it also makes sense because building a bigger barn would logically need a lot more pieces of wood. Moreover, playtesting can reveal if the game is fun, and can assist with finding out the correct audience for the game. Fun is a subjective term, therefore different groups of playtesters will have fun in different ways. However, different views can help the designer narrow down the audience and pitch the game to the players who will like it most. Given examples in this section show that various game design elements can be tested through playtesting.

The next subsection is a brief reflection of previous subsections: game design elements, and game mechanics on VR which informs about limitations, advantages, and disadvantages of VR while applying the mentioned points to VR.

2.2.5 Reflection on Virtual Reality

Immersive VR experiences are basically illusions during which users may experience being in another place where the events taking place are real [165]. In addition to place and plausibility illusions, embodiment illusion is another tool to make the experience more immersive [103]. To achieve this, an avatar body can be used in the virtual world that can represent player's physical body. These illusions are the main power of VR that fools the brain into believing that the artificial environment and the events occurring in it are real. As long as these lies are believable players can live these experiences without breaking the illusion and they can experience them in person. Experiencing events or the environment in person is the most distinguishable feature VR games provide in comparison to games played on PCs and other similar screen-based platforms. However, the illusions are both the strength and the weak point of VR. While it is hard to create illusions that satisfy players, they can be easily broken. The human brain is good at noticing unusual events and if the created illusion does not make sense with the way the virtual world is presented, the illusion can result in breaking the immersion.

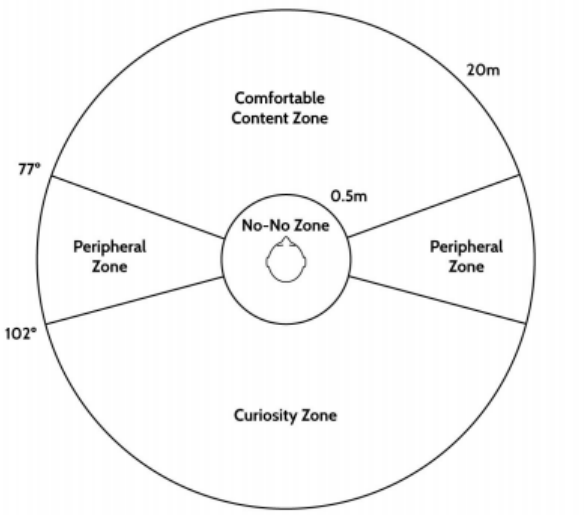

Figure 2.13: Content-zone diagram for a comfortable user experience [5]

Since VR is still a developing technology, one must take the capabilities of the system and the people using the system into consideration. It is essential to understand the limitations the hardware brings and how it can affect users. Once these technical limitations are recognized and necessary measures are taken, the next step is understanding users and the issues that may come up during their VR experiences. There are various ways to solve these issues or prevent them from happening. One of them is providing users with physiological comfort. If the game includes too much movement, it should be controlled by the player to prevent motion sickness. Section 2.2.7 goes more into details about the causes and solutions for it. Another key point is providing spatial comfort to players. This

perk is directly related to understanding the scaling in the virtual environment. Players may get uncomfortable due to small, large, or high spaces. Guiding players through the environment is another important aspect to keep player's focused and prevent them from having the feeling of getting lost in the environment. Audio and light support can be used to reveal paths in order to direct players into the directions they are supposed to go. The same guidance methods that have proven successful are used while designing other non-VR digital games. If the game includes UI elements it is essential to take ergonomics into account. Alger et. al describes the comfortable range of motion zones in their work [5] which are illustrated in Figure 2.13 and Figure 2.14.

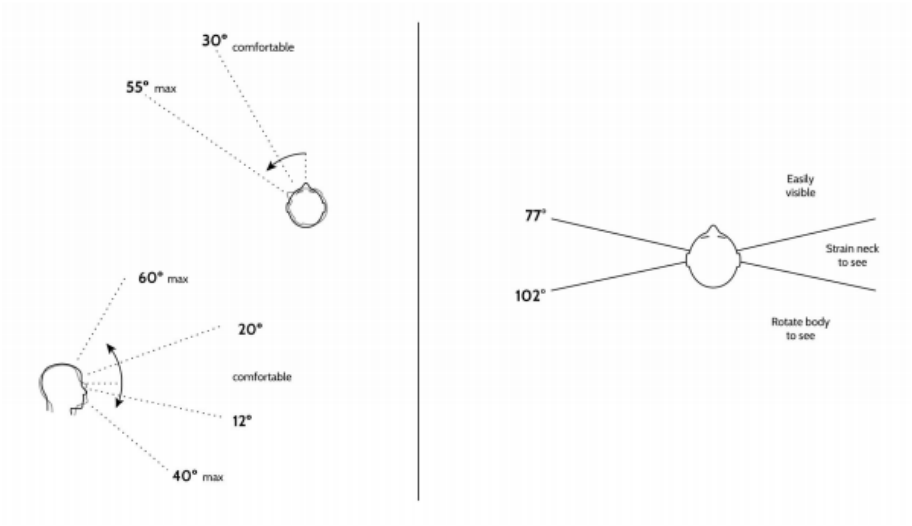

Figure 2.14: Comfortable angles of neck rotation [5]

Sound is another tool used in VR to increase immersion and create the phenomenon of synesthesia [49] in order to make up for the lack of tactile feedback in VR. Since tactile feedback mostly consists of vibrations that are coming from the VR controllers, sound is a great tool to enhance the feedback players receive when they touch objects. Besides combining haptic feedback with sound, providing holophonic sound is great to have because, in addition to left and right channels in stereophonic sound, holophonic sound allows players to tell if sound is coming from above, below, or behind [19].

Since the player is the center point in VR and present in the virtual environment, artificial sensory sensations such as visual, auditory, and haptic feedback should be provided as much as possible to make the player feel more like a part of the environment. Although providing visual and auditory feedback in games is at an acceptable level to make things feel real to players, other sensations lack or are non-existent for VR experiences. Sensations such as equilibrium [159] and olfaction remain unaffected partly because of their unavailability in general or inaccessibility to the end-user.

Although non-VR games can create immersive experiences, it is hard or not possible for them to reach the immersion level of a VR game can provide to its users [129]. Because of the way VR affects its users, the usual game design elements and game mechanics have to go through some alterations to be as effective in VR. The ideas that create the game design elements must adapt to the limitations and possibilities VR lays out to improve the user experience.

Immersion is mentioned in this subsection and previous subsections many times so far. It is essential to understand what it really means and why it is important for VR. The next subsection informs about immersion and its types to give an in-depth understanding of it for game design.

2.2.6 Immersion

Immersion is the user's engagement with a VR system that results in being in a flow state [10]. This is a simple definition of immersion, however, it encompasses so much that its components need to be explained further. Staffan Björk and Jussi Holopainen proposed different types of immersion in their work which can be listed as follows [13]:

- Spatial immersion
- Emotional immersion
- Cognitive immersion
- Sensory-motoric immersion

Björk and Holopainen described spatial immersion this way [12]:

> *Spatial immersion occurs when the simulated world is perpetually convincing. The player feels as if he or she is really "there" and that the simulated world looks and/or feels "real". (...) Spatial immersion as such is the real result of extensive maneuvering in the game world in real-time games and can even be occasionally felt in movies as well.*

The VR experience offers a new way to exist in the virtual world as a spatial presence and keeps the simulated world as Björk and Holopainen mentioned "perpetually convincing" with the help of encapsulation of head-mounted-display (HMD). The HMD serves as a remedy to immersion disconnects since users can stay connected to the virtual world as long as the HMD is worn. However, wearing an HMD is not the sole solution to these disconnects because technical factors and in-game implementations such as reconfigurable game worlds or invisible walls can cause further disconnects [97]. Locomotion is another major point as the player may have to traverse the simulated world. As previously mentioned in Section 2.1.3 there are many ways to achieve this in VR, however, the preferred way needs to feel natural and fitting to the world's reality logic.

Björk and Holopainen's take on emotional immersion is as follows [12]:

Emotional immersion is obtained by responding to the events that characters are part of during the unfolding of a narrative structure and is like the immersion that books, theater or movies provide.

Most VR games tend to have a narrative side to the gameplay regardless of their genre because it helps the player feel more involved and more immersed in the game. As in any type of game no matter what platform the game is played on, the game's story can evoke positive and negative emotions. Pallavicini et al. concluded in their study [120] that VR games appear to be effective tools to elicit positive emotions and to decrease negative emotions and state anxiety in individuals. Although this effect of VR is possible, it is also proven that VR content may lead to strong and persistent negative emotions [93]. The same study further found out that VR enhances the level of absorption into the scenario and creates more intensive emotions compared to games played on non-VR platforms.

Cognitive immersion is the immersion in abstract reasoning about actions, events, and goals in games while playing the game [167]. Freedom of choice is the only requirement cognitive immersion has which makes players consider what actions to perform throughout the gameplay. Cognitive immersion depends heavily on providing the right level of difficulty which can be achieved by providing consistent reality logic [168]. Consistent reality logic can regulate having the right amount of difficulty by removing the need to have to deal with special cases within a complex environment. If the difficulty is not balanced correctly, low or high-level complexity may cause players to experience analysis paralysis [169] or downtime [170] which would result in players losing interest in the game.

Sensory-motoric immersion is the result of feedback loops between repetitous movements players make to perform the actions in the game and the sensory output of the game [97]. When a player performs an action in a game, the available visual, auditory and haptic response that emerges has to be synchronized and make sense with what the player would expect from that action. If the sensory response does not match the expectations at all, it may cause a disconnect in immersion. Sensory-motoric immersion is tightly coupled with cognitive immersion in terms of correct use of complexity in the game. Keeping the player feel challenged continuously would ensure and maintain sensory-motoric immersion [97].

Keeping the immersion intact in VR games at all times has the highest priority to keep the players interested in the game, thus, providing them with a high-quality experience. As mentioned in this and previous sections it is not always easy to keep the high immersion level up from a design and technology viewpoint. The next section adds another problem to the list of issues to solve while gaming in VR: motion sickness.

2.2.7 Motion Sickness

VR motion sickness is primarily caused by a mismatch between movement cues sent to the brain. If the user is standing still in the real world but the virtual environment around the user is moving, this disturbs the brain's equilibrium and the user starts to feel nauseous. Nausea and dizziness count as the most common symptoms of motion sickness in VR [163]. Since VR motion sickness is also categorized as simulator sickness, there are other symptoms such as headaches, feeling tired, eye fatigue, and disorientation [20]. There are also additional factors that can influence the occurrence of VR motion sickness in individuals. A study shows that women are more susceptible than men to experience nausea in VR, which can be explained by women having a wider field of view, hormonal differences, or different in-depth cue recognition [18].

There are various factors that influence VR motion sickness. These factors can be divided into two categories as technology-influenced and design-influenced factors [163]. One of the technology-influenced factors is the headset that is used for tracking the position of the player. First released 3-degrees of freedom tracking (3DoF) headsets did not provide free movement and were only good for viewing 360-degree videos. In case the user tries to move around with a 3DoF headset, the user would feel disorientation and unbalance because the scene would not move with the user. Compared to the 3DoF headsets, 6DoF headsets provide freedom of movement within the virtual environment and solve motion sickness problems 3DoF VR headsets would create. Using VR controllers is another factor that helps with reducing motion sickness. Having hands in the simulated environment reduces the effect of disorientation which can be caused by looking down in VR and not seeing anything the user would normally expect. Latency is another technology-driven aspect that affects motion sickness. Oculus made intensive research on the topic [40] to figure out the comfortable delay people can accept between the actions they take in a real-world environment and the representations of their actions seen and heard in the simulated world without causing motion sickness. Gaze behaviors also affect motion sickness in VR. The unfamiliar eye motion that is required to keep the virtual scene stable on the human retina cause this unwanted effect [21].

Design-influenced factors mainly focus on problems that come with rotation and locomotion in the virtual environment. As previously mentioned in Section 2.1.3 teleportation is a way for players to traverse the environment. It is proven that teleportation helps reducing motion sickness [30] in games. The way it works breaks the illusion, however, it keeps players moving through the world without tricking their mind into thinking they are walking. Besides teleportation, running in place [74] and redirected walking [90] are other ways to move in the virtual world without creating any conflict between the sensory and vestibular systems. As much as these methods eliminate the occurrence of motion sickness, these methods are not preferred in games possibly because of the additional space requirements and forcing players to physically move most of the time. There are other tricks learned by the developers that using static artwork or controlling where the player focuses their attention decreases motion sickness [156].

Motion sickness is still a key topic for VR and it is a major problem to be solved in order to increase the number of VR users. With the information given about motion sickness in VR, this subsection concludes the game design part of this chapter. Besides VR and game design, the designed game for this work immensely focuses on climbing. Therefore, climbing in general and especially in VR need to be clarified which is presented in the next chapter.

2.3 Climbing in Virtual Reality

2.3.1 Traditional Indoor Climbing

Although this subsection is dedicated to climbing in VR, one should have a knowledge base about climbing in general since virtual climbing is based on traditional climbing at its core. There are three main points climbers have to accustom themselves to: the equipment they have to wear during the climb, the rope system which acts as a safety measure during the climb, and the technique they need to adopt to make the climbing experience easier and safer [184].

Indoor climbing presents the climber with the opportunity to climb in a controlled environment with extra safety measures. Non-wearable equipment can include mats on the floor to provide a soft landing in case of a fall accident, carabiners on the walls to which climbers can attach themselves as they progress further up, and chalk to remove moisture from hands and ease gripping the handholds. Wearable equipment mainly consists of a harness that combines a waist loop and two leg loops tied together, and special climbing shoes that give more edging power to the climber as seen in Figure 2.15. In addition to non-wearable equipment, the climber has to have a partner also called belayer to hold them. The belayer should be very careful and pay attention at all times to catch a fall every time the need arises. Climbing shoes are usually advised to be worn without socks because during climbs with small climbing holds, the foot-to-shoe contact matters a lot more due to additional grasping power [184]. For the climbing systems that are based on climbing high, the climber needs to be belayed. As mentioned before, this means that someone is belaying the climber on the ground, and the rope that is attached to the climber's harness via carabiners passes through an anchor fixed on the wall and clips into the belayer's harness as seen in Figure 2.16. Moreover, it is also recommended to make the climber let themself go in the early stages of the climb to get a feeling for falling and build trust with the belayer. Another option is to use an auto-belay [59], a device that is anchored to the top of the wall and automatically takes up slack as the climber climbs. This method is usually recommended for beginners because it allows beginner climbers to focus on only climbing without worrying about whether the belayer is doing their job properly.

Climbing technique is something that needs to be learned by the climber with experience. Professional climbers suggest climbers look at their feet instead of their hands during the climb and plan their moves based on them. Climbing should be about walking

Figure 2.15: Harness and climbing shoes for indoor climbing. [150]

Figure 2.16: Rope system setup for indoor climbing. [9]

yourself up instead of pulling yourself up [184]. Adopting this move-set also reduces forearm fatigue along with holding arms straight as much as possible while not using them actively. Keeping hips over feet as much as possible and the torso close to the wall are further suggestions to stay strong and in control of your movements because your center of gravity stays in the middle of your body this way.

Mentioned points summarize the key elements during a climb in a real-world scenario. The next subsection takes a look into how climbing in VR is achieved by various applications so far and how much of the information given in this subsection affected the design of these scenarios.

2.3.2 Virtual Climbing

With the advent of VR in the commercial scene, VR sports games also became popular among consumers. Archery, fishing, bowling, dancing, and climbing are some of the most notable sports that made into VR. This subsection, however, will focus on the climbing games which is a focus point for the developed game Astroclimb.

Figure 2.17: What competition looks like in The Climb 2. [25]

Figure 2.18: The climber's vertical movement on the wall is mostly restricted. [81]

The Climb, developed by Crytek for Oculus Rift and The Climb 2, developed for Oculus Rift and Oculus Quest, are two memorable VR climbing games that made a positive impact on the market. The games are characterized above all by appealing and realistic aesthetics. There is a wide variety of landscapes such as snowy mountains, city with skyscrapers, and desert areas players can climb in. The game focuses on enabling players to climb dynamically and quickly on certain routes. It is possible to compete against friends and have their position visible as additional ghostly gloves climbing with you as seen in Figure 2.17. In order to control the avatar hands, players have to use the corresponding controllers Oculus Rift and Oculus Quest provide. The game's haptic feedback is limited by the signals the controllers can issue to players. Since there are no other body representation models in the game and the virtual world is not supported by any physical objects in the real world, the climb happens only with the player's hand gestures and arm movements. These characteristics also make it clear that no measures like the ones mentioned in the last subsection are needed.

There are other similar games such as To The Top [154] which combines climbing with the platformer genre and Lucid Trips [153] that focuses on exploring surreal environments with a bit of climbing in them. As in The Climb series, these VR games provide players only with in-game hand representations to be able to move around. Just like in The Climb, VR controllers are the equipment here to control the avatar hands in artificial environments. Kosmalla et al. investigated in their research [25] the common issue in these games, the missing feedback when interacting with virtual objects, to enable realistic, haptic feedback in a realistic-looking virtual world. In their application, they used an artificial climbing wall as a haptic feedback device. The climbers have to use a head-mounted display with Leap Motion Controller [166] attached to be able to move in the virtual environment and have their hands tracked at the same time. This setup allows climbers to actually climb on the physical climbing wall to be able to traverse the virtual mountains. Since the physical wall has a height of 2.5m, there were not any safety measures such as the use of ropes or harnesses. As Figure 2.18 shows, the climber

(a) SteamVR Base Station 2.0 (b) HTC VIVE Pro Headset (c) VIVE Tracker

Figure 2.19: VR equipment used for Astroclimb. [176]

is mostly encouraged to move sideways.

This subsection already mentioned some of the equipment used when it comes to climbing in VR, however, there are still other options in terms of equipment. Section 2.3.3 focuses on the technologies used for Astroclimb while including some of these other options.

2.3.3 Virtual Climbing Technologies

Section 2.1.3 already mentioned some of the well-known technologies for VR, however, this subsection goes more into technical details and the purpose of HTC VIVE Pro, VIVE Trackers, and the calibration algorithms for the developed VR game Astroclimber.

HTC VIVE Pro

HTC VIVE Pro is a commercially available head-mounted display for generating virtual reality via connection to a PC. Here is a list of some of its most important features [145]:

- **Resolution:** 1440x1600 pixels per eye (2880x1600 pixels combined)
- **Field of view-headset:** 110 degrees
- **Field of view-base stations:** 150 degrees
- **Refresh rate:** 90 Hz
- **Screen:** Dual AMOLED 3.5” diagonal
- **Sensors:** SteamVR Tracking, G-sensor, gyroscope, proximity, IPD sensor
- **Room-scale:** Up to 10m x 10m trackable area using four SteamVR Base Station 2.0

HTC VIVE Pro headset has some comfort upgrades which were missing in its predecessor HTC VIVE. The VIVE Pro includes a solid strap, integrated headphones, and a comfort system that consists of a dial at the back of the headset which allows for easy fit and comfort adjustment. Besides these improvements, VIVE Pro also has enhanced ergonomics that balances out the weight of the headset for game sessions. Astroclimb uses VIVE Pro to track the position of the player on the wall. The tracking also includes the use of 4 different base stations. The base stations emit wide-angle two-dimensional IR laser beams across the play area. Each tracked device contains an array of IR photodiodes connected to a chip. This chip measures the time between the IR flash and being hit by the laser sweep for each axis. From this received information, the position of tracked objects can be determined. Astroclimb uses four strategically placed SteamVR Base Station 2.0 for tracking.

VIVE Tracker

The VIVE Tracker is a small motion tracking device that can attach to any object in real life so that it can be tracked via the base stations. It has a 270-degree field of view for sensing the SteamVR Tracking base stations. The bottom part of the device deliberately avoids using sensors with the expectation that it will be mounted to something. Moreover, objects should be made of non-reflective material to maintain maximum tracking performance, presumably to avoid reflections from the tracking lasers which could confuse the device or even the VIVE headset while in use [175]. Astroclimb uses a total of eight VIVE Trackers, half of them mounted on the wall to track the wall's rotation, two of them placed on the player's hands and the other two for tracking the feet.

Calibration

Astroclimb includes two different calibration procedures that take place at the start of the application. Both calibration algorithms are implemented by BSc. Ahmed Othman as part of the Vreeclimber project [35]. The first calibration process calibrates the positioning of the hands and the feet of the player. For that to happen, the player has to wear two trackers on top of their hands, and two of them on top of their feet. Once all set, in a standing position, the player should keep their toe tips and fingertips facing forward. In addition to that, their palms should be parallel to the ground. Figure 2.20 shows how the player's stance should be during the hands and feet calibration process. The second calibration process involves aligning the physical wall and its climbing holds with their virtual representations in the virtual environment. In order to achieve this, there should be two visible trackers mounted on the wall on one side. Based on the distance between the headset and these two trackers on the wall, the position of the headset is adjusted which results in aligning the wall. This concludes the initial calibration process for the wall. Since the physical wall keeps rotating during the game, the position of the climbing holds change with varying speeds. With the speed information gained from the engine that makes the wall rotate and the position information acquired from tracking the wall,

Figure 2.20: The stance the player has to take for calibrating hands and feet.

the climbing holds' positions on the wall update themselves via the algorithm which keeps the climbing holds aligned with their representations in the virtual environment.

2.4 Related Work

As mentioned in previous sections, the decisions game developers make to design the game and meet the users' expectations highly depend on the state of the current technology. Moreoever, game design in VR is still a playground for game designers and developers considering the impactful growth of VR in game industry only happened in the previous decade as mentioned in Section 2.1.1 and 2.1.2. Therefore, the fusion of game design and VR will still take time to be in harmony and appealing to users. This section introduces other related research papers that focus on game design in VR.

Shelstad et al. investigate in their research [146] how VR technology impacts the game as user satisfaction by using the Game Use Experience Satisfaction Scale (GUESS) [123] which is a comprehensive and psychometrically validated game scale that includes nine subscales contributing to video game satisfaction. These subscales consist of various game design elements some of which are already mentioned above. They can be described as follows:

- **Usability/Playability:** This subscale describes the ease of control inside of the game for the player and whether the game has clear goals for players to fulfill.
- **Narratives:** This is the story aspect of the game that can have an influence on player's emotions towards the story elements of the game which is also responsible for keeping players interested in the game.
- **Play Engrossment:** This perk describes the degree of interest a game can hold for the players.
- **Enjoyment:** The fun factor describes the pleasure players can perceive by playing the game.

- **Creative Freedom:** This is the extent to which the game is able to foster the player's creativity and curiosity and allows the player to freely express his or her individuality while playing the game.
- **Audio Aesthetics:** This subscale includes all auditory aspects the game offers and how they enrich the gaming experience.
- **Visual Aesthetics:** These include the visuals in the game and how appealing they appear to the player.
- **Personal Gratification:** This perk involves the motivational aspects of the game such as challenge which can promote the player's sense of accomplishment and the desire to succeed and continue playing the game.
- **Social Connectivity:** This subscale describes the degree to which the game provides social interactions between players with its tools.

Although GUESS represents a broad scaling tool for measuring player satisfaction, the research states that there should be doubts about its evaluation simply because of the VR aspect of the games. Considering VR provides a richer and more immersive experience, GUESS scores should vary for a game played using VR and no VR.

Furthermore, the study shows that some of the game design elements listed under GUESS subscales are successfully applied to VR gaming experience and there was a significant difference in the overall satisfaction scores between the VR and traditional computer monitor experiences.

Nolan et al. emphasize in their study [114] player experience, comfort, and design processes that are important while designing games for VR. They point out the importance of player comfort and categorize it under physical, psychological, and social comfort. While physical comfort focuses on the orientation and the movement of the player in the virtual environment, psychological comfort states that the VR experience should refrain from trauma-inducing and unpleasant content. If the game includes social aspects, it should include safe zones and places for players to rest and potentially remove their headsets to get out of that social environment to recharge. Section 2.2.5 of the thesis prioritizes the physical comfort aspect of player's comfort in general and provides in-depth knowledge about what Nolan et al. mentioned in their research.

Besides player comfort, the study directs attention to the possibilities and limitations of VR as well. These possibilities and limitations include the interaction techniques in VR, player expectations, tracking, and locomotion methods. These subjects also create an essential part of the thesis that is mentioned in Section 2.1 and 2.2. VR playtesting is another topic of Nolan et al.'s research which states the importance of it and what should be taken into account while performing playtesting. Section 2.2.4 of the thesis is specifically related to this topic.

Immersion and Engagement in a VR Game by Pradeep et al. [127] is another work that involves VR and game design. The researchers compare the levels of user engagement and task performance based on a VR game. The study furthermore focuses on a comparison between desktops and the HMDs and explores exocentric versus endocentric approaches, the level of confusion factor, and the effect of the virtual avatar representations. During their observations, they also take note of the situational awareness of the user when they play the game. The goal of the study is to answer the following questions:

1. What is the level of engagement that the user experiences?
2. What is the task performance and time elapsed for the task for each user within the designed time?
3. What path does the user take to complete the task?

As seen in the questions they used some specific game design elements such as engagement, problem solving, and player performance to get answers.

Alexander Lund's paper [97] investigates immersion, game feel, and flow states for VR, and how these elements can either enhance or reduce the quality of player experience. In order to support the investigation, the researcher makes use of a story-driven VR experience called Norn [96]. The paper includes a large variety of different types of definitions for immersion which also inspired Section 2.2.6 of the thesis. The author emphasizes that the mechanics and interactions designed for a VR game should feel natural to perform and should not be taxing for the players during extended play sessions. The designer should, moreover, keep the VR equipment and the in-game interactions in mind while designing the game around them. As in previously mentioned papers, Lund points out the significance of the player's physical comfort while playing the game. Besides these points, world and player scaling form a major part of his work. According to Lund, the game should be designed for the physical space provided. The locomotion in this designed area should feel safe and should not cause disconnects between the time before and after the teleportations if that is the chosen locomotion technique for traversing the virtual environment. Various sections of the thesis include knowledge about most of these key points mentioned in Lund's work.

Desurvire et al.'s research paper [28] is another example that focuses on VR and game design. They created in their study design guidelines called the VR PLAY guidelines to assist in evaluating and designing improved VR user experiences. VR PLAY guidelines consist of five main categories called Usability, Playability, VR Immersion, Creative VR, and New Player Experience (NPE). These five main categories have a total of 33 guidelines which includes some of the mentioned game design elements in the thesis such as challenges, goals, engagement, and presence. As Desurvire et al. state, not all guidelines are applicable to all VR experiences because the created VR experience may not contain certain common game mechanics to which these guidelines apply. This is another commonality with the present thesis that a game can not contain all possible game design elements.

Although the presented related works in this subsection vary by their questions to answer, the common point is providing a compelling user experience to the user within the designed VR game. The next main section goes more into details about the designed VR game for the thesis starting with the conception of the game.

CHAPTER 3

Conception of Astroclimb

3.1 Requirements for Designing the Game

There were various requirements for designing Astroclimb which branch out from the thesis questions. This section is the starting point to explain these requirements that led to creating this specific concept of the game. A brief list of the main requirements would be appropriate before explaining them in detail:

- The game should revolve around climbing a wall.
- The gameplay should be as flexible as possible to address a diverse gameplayer base.
- The game should be immersive and compelling.
- Included game design elements should match the VR aspect of the game.

While designing the game, the main focus was making the game as flexible as possible in terms of gameplay while keeping in mind that the game includes a physical climbing wall. Taking advantage of the climbing aspect of the setup, the conception of the game creates a clear distinction between the experience a player can have while playing a VR and a non-VR game. Astroclimb makes the player interact with objects as much as possible while giving haptic feedback which is one of the main distinctions of this VR game compared to traditional video games. The idea of in fact climbing a physically present wall also enabled physical training for the players. Enabling physical training in a playful way was another feature of the game that distinguishes this game from other video games and even most VR games. These features of the game were to create a basis to investigate the applicability of game design practices to VR platforms. Applying common game design practices to a VR game with these features would create a fair

testing environment and help with answering whether these methods are appropriate for VR experiences or not.

In order to keep the game immersive and compelling to the players at all times, the use of technology played a crucial role in addition to the aesthetics that are used for creating the environment. Especially the calibration algorithms used to keep the physical objects aligned with their virtual representations contribute to the level of immersion significantly. The technology and the aesthetics directly influence the game feel. Game feel is a combination of different aspects which include tactile sensation that dictates how entertaining or engaging the act of playing the game is, how quickly the character responds to control input and how much audio and visual feedback it is provided for doing something within the game [157]. In addition to audio and visual feedback, Astroclimb also provides haptic sensations which enhances the game feel.

The gameplay in Astroclimb has a substantial influence on the chosen game design elements. Since the game mainly revolves around climbing a wall, most of the game design elements such as problem-solving, elements of surprise, physical training, fun, and competition have a direct relation to what the player is capable of doing in the scenery. As previously mentioned in Section 2.2.5 VR comes with limitations and possibilities, hence the application of the game design elements required adaptations based on the physical availability of the players and other aspects which are discussed later in Section 3.3 in detail. The next subsection goes into detail about the chosen design approach to create Astroclimb.

3.2 Design Approach

The game design idea is mostly affected by the structural design of Vreeclimber. As previously mentioned in Section 1.2 Vreeclimber's structure is based on a vertically rolling wall that can enable climbers to climb indefinitely. The physical structure needed a virtual representation in the artificial environment, so the first steps were designing a wall with climbing holds on them that match the physical wall as perfectly as possible. The height of the wall and the material used for it were the most crucial points during the design process of the virtual wall. On the one hand, the height of the virtual wall has a measurable influence on the usability and game feel. A very high wall could reduce the usability for some players that are not used to climbing. This would additionally affect the game feel in a way so that the players might just give up in the middle of the game because their physical endurance for climbing could not match the strength required to finish the game. The playtesting sessions also showed that the initial height of the designed virtual wall was too much for most players so the number of grip blocks got reduced during the development. On the other hand, the height would also affect some of the game design elements such as physical activity and engagement in a negative way. Again as an example, a higher wall might cause the application of the physical activity element to be unsuccessful by creating an exhausting experience. Making the

game physically not enjoyable would also take away the engagement aspect of the game and render it unappealing.

The chosen material for the virtual wall also plays a key role in designing the game. Creating a fully transparent material for the virtual wall makes up for some of the disadvantages of climbing a regular wall while enhancing the visual aesthetics of the game. If the virtual wall were opaque, that would mostly limit the view of the climber with side directions during the game besides seeing the wall. As previously mentioned in Section 2.3.1 climbers usually focus on their hands and feet during the climb which means their focus of direction to the front. Focusing on what is in the front would also make the objects placed behind the climber not or hardly noticeable. Giving a transparent wall to the player and populating the backside of the virtual wall with interesting objects would improve the visual aesthetics of the game. Since the player's front view is mostly the focus point in such a case, this would also reduce the additional head movements the player has to perform in order to be able to see the environment. These quality of life improvements in the game would help players with regulating their stamina during the climb efficiently and reduce possible causes for motion sickness.

The root idea of designing Astroclimb in outer space comes from the discussions during Ms. Natascha Machner's master's thesis [99] defense. Climbing in outer space is something that would not be possible at least with the technology we currently possess. The combination of this impossibility and the unknown knowledge that lies in outer space encourage humankind to fill this knowledge gap [147]. This curiosity inducing hunger for information makes space an excellent theme for games. The high number of outer space related games on Steam [152] emphasizes the popularity and success of using outer space as a game environment.

The idea of having a climbing wall in outer space automatically adds the science-fiction genre to the game which also opens many doors for creativity. In comparison to science-fiction, sticking to reality would limit the design options especially for a game that is played in outer space. Although designing a game with an unrealistic setup gives freedom about ideas to the designer, it also adds the challenge of making the game immersive. It is important to design the environment in such a way so that the setup can make sense to the player and the player can still immerse themselves in it. In this matter, Astroclimb provides the needed immersion with different aspects it possesses such as aligning the physical and virtual objects at a high level, having futuristic-looking objects, matching soundtracks and effects, and a story that makes sense to players. All of these aspects of Astroclimb with the given gameplay options create a game feel that aims to satisfy the player.

The design evolution of Astroclimb went through some changes to match the previously mentioned requirements for designing Astroclimb better and improve the experience players can receive from the added game design elements. Besides changing the height of the virtual wall, the way of keeping players safe and preventing them from reaching the

very top of the physical wall was altered. Since the physical wall has a certain height and the virtual wall is taller than the physical one, it is a common occurrence that the player reaches the top end of the physical wall during the climb. When this happens, for safety reasons, players have to pause climbing until the wall rotates long enough for players to slide back to the planned climbable area of the wall. The first idea was to add a thick fog to the top border of the climbable area and make everything above that point invisible. After numerous playtesting players still tended to reach to the climbing holds above the fog although they did not see them which showed that fog was not an adequate solution. Furthermore, the fog prevented players from seeing some of the gameplay cues such as an asteroid hitting the top of the wall causing the wall to tilt. An alternative way was to give the player a virtual astronaut helmet and use its glass surface for displaying warning texts and information. The warning text is also supported with audio feedback. The playtesting afterward showed that the alternative solution encouraged players to pause climbing when they saw the warning text. Another improvement to motivate players to replay the game was a change made in the gameplay. The next subsection goes more into the game design elements Astroclimb possesses and explains how they are achieved in the game to give players an engaging gaming experience.

3.3 Included Game Design Elements

Astroclimb's conception includes various game design elements. Section 2.2.2 lists only a subset of the game design elements that were actually used in the present game. Those game elements and the additionally included ones are listed below:

- **Experience:** The main goal of Astroclimb is to give players an experience they can not receive anywhere else by climbing a celestial wall in outer space while they can enjoy the environment and the events occurring throughout the climb. The story of the game, the aesthetics used to build the environment, the mechanics provided to players, and the unique playstyle VR technology creates help to define the essence of Astroclimb and bestow it upon players.

- **Surprise:** Astroclimb injects this game design element in various ways. Some of them just come with technology such as the precise tracking system for the player's hands and the high-resolution perk of the used headset which renders the environment as if it was real. Game aesthetics such as giant spaceships warping in and out all of a sudden, the sound of an asteroid crashing the wall, and the whole climbing wall getting sucked into a black hole are a couple of examples that create a sense of surprise for players when they experience these events. The gameplay also contains some unexpected events such as touching a relatively smaller climbing hold gives extra points.

- **Curiosity:** There are many ways Astroclimb awakens the feeling of curiosity in players. The way they are injected into the game is mostly through visual aesthetics and game mechanics. At the start of the game, the player finds themselves in a

hangar waiting behind a huge door to be opened. The possibilities behind this door should make players curious about how the game will play out. Another example is when players are presented with different orbs that have the ability to enhance the gloves players are wearing in the virtual environment. The intention behind the way they are presented is to make players intrigued about how their choice will impact the gameplay. Players being able to pick only one of the orbs also adds to the feeling of curiosity about how the game would play out if they were to pick another orb.

- **Problem Solving:** This game design element is only achievable through gameplay in Astroclimb. In the game, players gain points by interacting with the climbing holds and as mentioned before the points they gain from climbing holds is inverse to their size. If the player wants to get a higher score they should seek the smaller climbing holds and traverse the wall based on their positions. Changing the route based on this goal represents a problem they can solve by observing the grips and move on the wall accordingly. The enhancements gained from orbs add another layer to this problem since the enhancements change the way the player's gloves interact with the climbing holds. Additionally, problem-solving directly awakens critical thinking for players to overcome the problems that are thrown at them.

- **Endogenous Value:** The most important items players care about in Astroclimb are their avatar hands and the wall they climb because without them they would not be able to play the game at all. These objects are also directly related to succeeding in the game with a high score. Figuring out to which items players put value in, gives the designer the chance to make the game more compelling by increasing the value of those items. Improving or changing the most valuable items to players in Astroclimb is achieved by adding enhancements to the gloves and changing the climbing hold layout throughout the game.

- **Goals:** Although it might seem like the sole goal of Astroclimb to reach the end of the wall, the main goal of the game is giving players a unique experience in VR. The game's goal is self-explanatory for players, however, the way Astroclimb is designed gives players choices about how to enjoy the game. Being present in outer space alone can be satisfying enough for some players and they can see Astroclimb just as a sandbox game for having quality time. Players with a competitive mindset can still try to go for scoring high scores and pay attention to their time score as well. Experienced climbers can focus less on the aesthetics game provides and just enjoy the physical activity part of the game. Enabling these different goals for players also makes the game more inviting to audiences with different backgrounds.

- **Fun:** It is hard to determine alone whether a game is fun or not. Only the feedback received during the playtesting can help with assuring the fun aspect of the game. As mentioned in Section 2.2.1 the definition of the game includes problem-solving, playfulness, and goals. Including these elements in the game can at least be a starting point to be able to judge the game as entertaining.

- **Unification & Theme:** Astroclimb has a clear space theme that is supported by many visual aesthetics such as the huge spaceship that brings the player to the climbing spot, the nebula the player is able to gaze upon during the climb, the black hole positioned below the climbing wall to encourage the player to climb up, an asteroid belt that occurs at some stage of the game, the spaceships that warp in and out, the moon colony, and the mechanical interactable objects. All of these visuals in harmony give the game a unified theme.

- **Physical Activity:** The fact that Astroclimb includes a physical wall to climb gives players the opportunity to perform physical training as they play the game. Since climbing is rather a tiresome activity for players with no or little experience, it is crucial to balance the game so that players with no experience can enjoy the game as well. As previously mentioned in Section 3.2, corresponding measures are taken throughout the design process to balance the height of the virtual wall.

- **Challenge:** Astroclimb gives three different types of challenges in the game. The first one is the physical challenge every player has to face to make progress in the game by climbing up the wall. The second type is hidden in one of the options presented via orbs that renders some of the climbing holds invisible to the player. The third type involves beating your own or your friend's score which also creates a competitive environment.

- **Engagement:** Player engagement is the level of continuation desire experienced in-game, during play, or over a longer period of time when players dedicate themselves to coming back and playing a game again and again [61]. Astroclimb tries to achieve this by the scoring system and giving the player a single chance to pick an orb during the orb selection phase. The scoring system encourages players to play the game again to beat their or others' scores. The orb picking system makes the player curious about the outcome of the game if they were to pick another orb. Both systems increase the chance of replayability of Astroclimb.

These game design elements are all included in Astroclimb in different areas. Although the application of these game design elements was successful, there is always room to improve the game. The next subsection gives ideas about how to improve the current state of Astroclimb with different design approaches.

3.4 Possibilities for Improvement

The current state of the game was generally satisfying for all the players that tested the game, however, it is still possible to improve the game. The possible improvements include gameplay and the positioning of objects in the scenes.

The rotation mechanism of the physical wall has a speed limit which makes pausing the climb a common occurrence during the game. Although the safety side of this problem is taken care of as mentioned in Section 3.2, the gameplay still suffers because players

with climbing experience are too fast for the counter-rotation speed of the physical wall. A new game mode could be designed for players with climbing experience that would prevent them from pausing the climb too often. This game mode could focus on making the player traverse sideways on the wall so it would give the mechanism enough time to roll down. Forcing the player to traverse sideways might require some limitations to the freedom of the player. Providing them with a route to follow would force them to use a specific set of climbing holds, but in the end, it would be a solution for frequent stalling.

When the player reaches the end of the first part of the virtual climbing wall, a mechanical owl appears at the left backside of the player. Placing the owl relatively behind the player caused some problems for players to notice the owl and the interaction of the player seemed rather uncomfortable while picking an orb. The positioning of the owl could be optimized which might improve the usability and the overall comfort experience of the player.

The point and time scores are currently displayed on the gloves of the player at all times, however, there is no way to keep track of the personal bests or scores of other players. A global leaderboard could be a good solution for players to check out the overall high scores when they decide to play the game again. Creating a global leaderboard would also improve the challenge aspect of the game and act as an amplifier for competition.

Of course, there is always room for improvement and more ideas to make Astroclimb more appealing to players. This section covered some of the possible improvements that can be applied to the game. The next main section informs about how the game was implemented in detail.

CHAPTER 4

Implementation of Astroclimb

4.1 Overview

This chapter focuses on how Astroclimb is implemented based on the design concepts discussed in the previous chapter. First, the planning of different scenes in the game is explained by pivoting the objects placed that give the outer space and science-fiction atmosphere to the game. The remaining aesthetics such as audio and further assets that build and enhance the game's atmosphere is handled as next. Gameplay is the following main topic that includes the events players face during the different scenes in the game. Since the gameplay is immensely affected by the requirements mentioned in Section 3.1, the section about gameplay also covers its relation to fulfilling these requirements. The ways how various game design elements are integrated into the game are the next focal point of this chapter before concluding it with the technical aspects of the implementation.

4.2 Created Scenes in the Game

4.2.1 The Moon Scene

The game's starting point is included in the moon scene which gives the player the first impression of the environment. Other than acknowledging the purpose of the placed objects in the virtual environment, it is essential to understand the role of this part of the game, how it affects the player's experience overall, and how it helps with fulfilling at least some points of the previously listed design requirements. These aspects should be investigated for every part of the moon scene in order to see how they are planned to influence the player.

The moon scene itself can be divided into two different parts: The first part is where

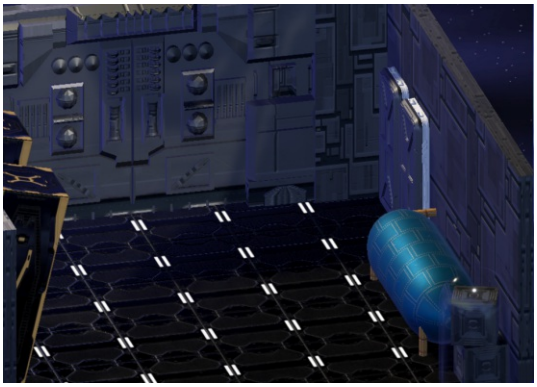

Figure 4.1: A cross-section of the hangar - the starting point of the game.

Figure 4.2: The massive spaceship that brings the player to the climbing wall.

the player finds themselves once they enter the game, the hangar of a spaceship. The second part is when the player makes out of the spaceship and starts climbing above a colonized moon. The hangar area is a large compartment (Figure 4.1) at the bottom of an immense spaceship (Figure 4.2) with some equipment lockers, an oxygen tank, some crates, and storage places. It also has a huge blast door that opens and allows the player to leave the spaceship. The objects and the textures chosen for these objects have a modern look and a sci-fi feeling which can convince players that they are in a spaceship. This first impression is crucial because it is the first step to make players believe that they are actually present in a space environment. If they can immerse themselves in this scene the remainder of the game will make more sense to them although most of the aesthetics are designed unrealistically. The only disadvantage of this area is that the whole compartment is not traversable by the player because of the physical limitations of the VR room setup. The player is only able to move to the left or right in front of the blast door besides being able to freely observe the whole area.

Once the blast door opens, the player becomes able to access the outer space by stepping on a hoverboard that is waiting for them in front of the climbing wall. The hoverboard gives the player time to get ready for the climb as well as observe the scenery surrounding them. The most noticeable objects in this scene are the moon below the player and the climbing wall floating in front of the player. The moon's surface is inspired by the Earth's moon and has a white-gray color pattern. The colonization on the moon has living hubs, transporters, communication satellites, a command base, platforms, and mining vehicles. All of these objects' color palette is heavily white-centric. The main purpose of picking a moon very similar to Earth's moon, keeping the type and the diversity of used objects not far from reality, and focusing on white color is to give players something similar and familiar to what humankind is capable of doing in outer space right now and in possible near future. This familiarity can help players to get used to the scene faster by recognizing the functionality of seen objects easily and keep them immersive at all times. In comparison to these familiar visual aesthetics, the climbing wall stands out as

an anomaly in outer space. As previously mentioned in Section 3.2, the climbing wall is made of a material that is fully transparent, so it does not block a part of the moon and the spaceships that fly, warp in and out as the player climbs higher. The spaceships that appear throughout the game have height triggers where once the player reaches certain heights on the wall they join the game. While the purpose of the climbing wall is self-explanatory for Astroclimb, the main reason behind the spaceship events is to keep the game interesting and interrupt the routine climbing activity with some visual surprises. Once the player reaches a certain height the second main scenery comes in which is explained in the next subsection.

4.2.2 The Owl Scene

Astroclimb has a single transition point which is handled in the owl scene. Similar to the moon scene mentioned in the previous subsection, this scene also has a special purpose in the gameplay and helps further fulfilling some of the design requirements mentioned in Section 3.1. The remainder of this subsection looks into these points and clarifies the goals behind applying these points to the game.

The owl scene has two main tasks:

1. Acting as a bridge between the moon scene and the asteroid belt scene.
2. Offering the player a choice which affects the gameplay dramatically.

Once the player reaches a certain height on the climbing wall, they notice that it is not possible to climb higher in the virtual environment because there is no wall to climb. However, they see that another part of the climbing wall is bent backward as seen in Figure 4.4. This certain height triggers the abrupt change of the scene where everything but the climbing wall disappears and the darkness descends only allowing the player to see certain objects. One of the goal of this abrupt change in the scene is to catch the player off guard and surprise them while planting curiosity in their minds about what is going to happen next. Another goal of this segment is forcing players to pause climbing for a while as they figure out what is happening. Climbing can be an exhausting activity for inexperienced climbers, so giving players time to rest their bodies by just hanging up on the wall should help with reducing the exhaustion the game creates. While the player is in this state another surprise element joins the game: the mechanical owl designed to change the game flow.

The mechanical owl (Figure 4.3) is inspired by the owl statue that stands at the top of the library building of Vienna University of Technology. It appears slightly behind the climber's left side and presents three transparent orbs for the player. The player is supposed to choose one of these orbs by touching them with their avatar hand. The orb selection triggers the changes to the gloves or to the climbing wall which are explained in Section 4.3.1. The structure of the designed owl and the chosen texture make it fit into the sci-fi style of the game perfectly. The idea behind creating this harmony

Figure 4.3: The mechanical owl designed for Astroclimb.

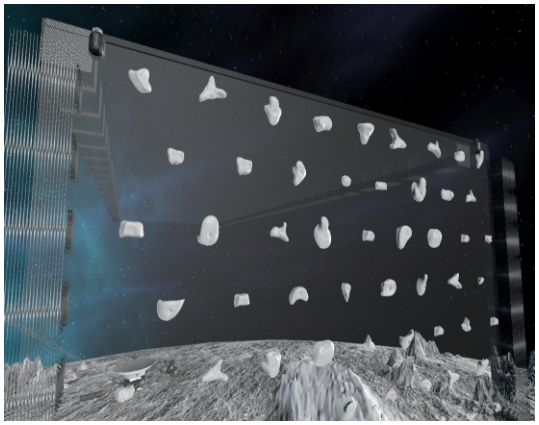

Figure 4.4: The end of first segment in the game.

with the design of elements is to help players with making sense of the environment with current settings. Awakening this feeling in players should directly translate into improving the immersiveness of the artificial environment for them. Considering the odds of encountering a mechanical owl in outer space are close to zero, the appearance of the owl should surprise the player and make them curious about it. Moreover, the changes applied to the gloves or the wall based on the player's selection should trigger a feeling of satisfaction for players since these objects are considered the most valuable to them. The purpose of these events is to make the game more engaging for players so they want to continue playing the game with more expectations.

Once the orb selection phase is complete and the corresponding changes are applied, the owl disappears. This ends the owl scene segment and starts the asteroid belt scene which is explained in the next subsection.

4.2.3 The Asteroid Belt Scene

Besides the climbing section, the asteroid belt scene also includes the end scene for Astroclimb. The asteroid belt scene setup has various purposes that satisfy the previously mentioned requirements further. The primary objectives this scene tries to achieve are listed below:

1. Completing the scene transition that starts with finishing the first part of the climb to give players a feeling of switching places in outer space.

2. Creating a more dynamic environment to keep players interested in the game.

3. Finding solutions for the problems that come with VR-related limitations such as player space and the physical climbing wall's capabilities.

4. Giving players the chance to try out the changes that happened with selecting an orb.

5. Creating an extra challenge for players by tilting the wall forward.

The remaining of this subsection looks into these objectives and how they are achieved in the game.

The scene translation is easier in games where the player can move around the environment. The objects in such environments do not need to be adjusted abruptly. In games like Astroclimb, the space provided to players to move around is limited. The climbing aspect of the game adds more to these limitations and keeps the player on the wall at all times. The physically available space VR setup provides and the motion sickness aspect of VR take away the ability to dynamically transition scenes in Astroclimb. The designed space for all Vreeclimber related games is approximately 4 meters by 2.5 meters. Considering players only move on the wall except for the intro scene in Astroclimb and climbing the wall is the main mechanic, they do not have too much freedom in terms of movement. Although the space in the virtual environment is limitless, moving the player around the outer space with the wall while their body is not moving in the real world would cause motion sickness as explained in Section 2.2.7. Hence, changing the scene abruptly while keeping the most important objects, the climbing wall and avatar hands, in place was the solution to prevent motion sickness and change the scene. The so-far in-game experience of sci-fi feeling would also give the player the tolerance and acceptance of such unrealistic occurrences. Once the owl scene is completed, the environment changes back to outer space, however, this time everything is different in the scene. There is a totally different color of the nebula that states this new place is somewhere else. The moon colony, the spaceships, and the floating hoverboard are gone. The major objects in the new scene consist of a black hole far below the climbing wall, and the asteroid belt which holds the climbing wall in the middle of it. The asteroids are floating back and forth as the player climbs up the wall. The main goal of these changes is to give the player a feeling of suspense and make the game more appealing to them. The increased dynamism during this part of the game is added to take the player's attention from climbing occasionally and gaze upon the scene more often. Another reason behind this is again to slow down the player's climbing which would also help with reducing the negative effects of the physical climbing wall's limited speed explained in Section 3.4. There are other measures taken to help with this main issue of players' climbing speed exceeding the rotation speed of the physical wall: The changes applied to the avatar hands and the virtual climbing wall.

When the owl appears halfway through the game, it presents three different orbs which include small representations of the outcomes of picking them. These are animated representations that point out these possible outcomes:

1. The first orb renders one of the avatar hands invisible randomly for a couple of

seconds and it occurs occasionally and repeatedly. This changes the gameplay for the player in a way that they have to make different decisions for the rest of the game. If the player does not feel safe by not seeing one of their tracked hands during the game, they would want to wait until it is visible again to continue climbing. Another option is guessing the position of the invisible avatar hand and still trying to hold onto a climbing hold.

2. Choosing the second orb would duplicate the avatar hands and place them a little far above the avatar hands that are tracked by VIVE trackers. These copies mimic the rotations and translations of the real avatar hands. Being able to climb with four hands yields more points since the number of hands touching the climbing holds is doubled. This option is considered for players that focus on scoring a high score for the game. Controlling four hands would also be confusing for some players that can make the climb more challenging. Since the positioning of hands is more important with four hands, players can aim for the small grips which would allow them to score even higher scores. The time spent by critically thinking about choosing specific climbing holds to gain more points should also slow down the player's climbing speed.

3. The last orb is rather an alteration applied to the virtual climbing wall than the avatar hands. Selecting this orb renders some of the climbing holds invisible for the remainder of the game. This option restricts the number of available climbing holds for players. This restriction should make the game more challenging and force players to think about how to position themselves on the wall better for a smooth climb.

The outcomes of selecting an orb are not the only source for making the game more challenging and interesting. Tilting the wall forward is another challenge players have to face in the game.

Once the player reaches a certain height in the game a massive asteroid is launched from far away in outer space. This asteroid slowly approaches the upper side of the virtual wall and hits it which results in tilting the wall forwards. All this motion is perfectly mirrored with the physical climbing wall. The tilting of the wall creates an additional physical challenge for players towards the end of the game.

Once the climbable part of the wall is over, the black hole below the climbing wall sucks everything into itself except the player. While the player floats in outer space an alien spaceship suddenly warps in which indicates the end of the game. The ending of the game should leave the player with mixed feelings. The appearance of an alien spaceship might worry or excite players about what is going to happen to them. They might as well be disappointed in the massive spaceship that brought them to the celestial climbing wall and did not come back for them. If the game can rise such feelings in players, it means that the game was an immersive experience for them.

This subsection explained the main scenes in Astroclimb while trying to not go into details about the gameplay. The next subsection gives more information about how the gameplay is structured and how the atmosphere in the game is created.

4.3 Gameplay and Atmosphere in the Game

4.3.1 Game Chapters and Events

The previous subsection already informs about the game flow by mentioning the environmental design of the three main scenes. The game, however, should be divided into parts differently which includes parts from different scenes. Each of these chapters includes various events that possess distinct influences on the game flow and game gameplay. It is crucial to understand the reasoning behind these events in every single chapter and how they can affect players.

Astroclimb mainly consists of three chapters which can be called the intro part, the climbing part, and the outro part. The intro part starts with the game and ends once the player touches the first climbing hold on the wall. Since this segment is fairly short, there are only a few events happening in this part: Once the player is out of the spaceship and on the hoverboard, the massive spaceship ascends slowly and then warps out after reaching a certain speed. This event leaves the player alone with the climbing wall, and the hoverboard they are standing on. The departure of the spaceship also unlocks a lot more space to look at that gives the player the perfect time to look around and see what this outer space offers. Besides starting the game, the first interaction with a climbing hold also triggers the hoverboard to leave and make it glide around the climbing wall as the player climbs up. The events happening in the intro chapter are pure aesthetics to make the environment compelling for the player. The following climbing chapter includes similar events that improve visual aesthetics as well as events that impact the gameplay.

Once the player starts climbing, various events occur until the end chapter of the game. The first events consist of spaceships warping in and out, and having pursuits on each other. The goal behind these purely visual aesthetics-related events is to prevent the game from becoming dull and make players take a moment by giving them something to observe as they climb. As previously mentioned in Section 4.2, the orb selection phase that comes with the mechanical owl forms the important event that impacts the gameplay. Building upon the already existed mechanics, being able to touch the climbing holds with avatar hands and gain points in this case, should give players a feeling of progression and something to look forward to for other possibilities. The main purpose of changing and improving the way players can gain points, and the different distribution of climbing holds on the wall is to keep the gameplay and game flow dynamic. Keeping the dynamism in the game should force players to react to changes and adapt accordingly. As players try to adapt to the changes after the owl's visit, the next important event is the crashing of an enormous asteroid to the climbing wall. If the player pays enough attention, it is possible to see this asteroid slowly making its way to the upper side of

the wall. Noticing this before the crash would make the player nervous and maybe stop climbing for a moment thinking that it might hit them. When the crash happens, the event changes the game flow as well as some visuals in the environment. On the one hand, as mentioned in Section 4.2, the tilting of the wall challenges players physically. On the other hand, the crash destroys a part of the upper wall which causes many wall fragments to spread into outer space. Since climbing a tilted wall can be very challenging for some players, this event is put towards the end of the game.

The last event occurs at the end of the game as the black hole sucks everything but the player in and an alien spaceship arrives. Taking away the climbing wall from the player should signal the player the end of the climb and therefore the end of the game.

The next subsection goes more into detail about gameplay and explains how scoring works and changes throughout the game, and what other information such as a timer and a height indicator is there for players.

4.3.2 Score, Timer, and Height Indicators

Astroclimb possesses various indicators attached to the lower side of the avatar hand models as seen in Figure 4.5. These indicators help with creating the gameplay for Astroclimb and induce distinct game design elements into the game. This subsection informs about how these indicators work and how they contribute to the requirements explained in Section 3.1. Scoring in Astroclimb is achieved by interacting with climbing

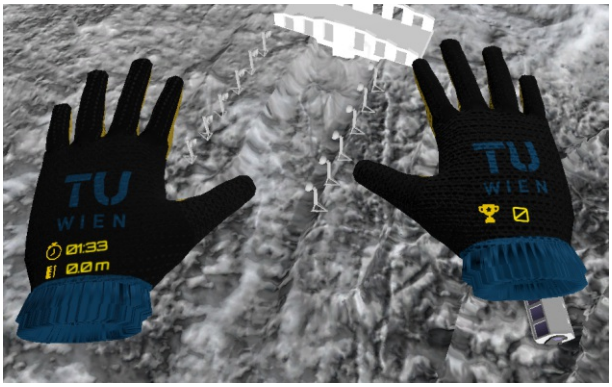

Figure 4.5: Time and height indicators are placed on the left avatar hand, while the score is on the right avatar hand.

holds. These climbing holds are worth 10 points if their size is considered large, 20 if they are small. If the player already touched a climbing hold, its color changes to green indicating that this climbing hold is marked, and touching it again will not issue any additional points. In order to prevent players interact with many climbing holds in quick successions to abuse the pointing system, the following measure is taken: The player has to stay in contact with the climbing grip for at least 1,5 seconds and the points apply

once that climbing hold's color turns into green. This sums up the basics for the scoring system, however, the scoring changes for most cases as following once the player selects an orb:

1. If the orb that duplicates the avatar hands is chosen the scoring system stays the same, however, the copies of avatar hands are also able to score points if they come in contact with climbing holds.

2. If the orb that makes one of the avatar hands randomly invisible is chosen, the scoring system rewards the player by doubling the point gain for each climbing hold that is touched by an invisible avatar hand.

3. If the orb that renders some of the climbing holds invisible is chosen, the point gain for every single climbing hold is doubled.

The alterations made in the scoring system after selecting an orb are to balance the game in terms of scoring as fairly as possible. The orb choice for players that focus on scoring high scores would be the third orb explained above since that choice doubles the point gain in all cases. Instead of scoring high points, if players focus on completing the game as quickly as possible to get a good time score, the game provides a timer for elapsed climbing time. The timer starts as the player touches a climbing hold and ends once the player reaches the very end of the climbing wall. Players that focus on achieving a short climbing time would benefit more by picking the first orb option listed above. Occasionally not being able to see the avatar hands and a climbing wall with missing climbing holds might cause players to stall and think about their next steps longer than usual. Besides providing challenging and competitive gameplay, the timer and the score indicators also aim to reach players with different preferences to create a diverse gameplayer base.

Unlike score and timer indicators, the height indicator is added only to give interesting statistics to players. The number on this indicator change as the player climbs higher on the wall. This piece of information is available to the player at all times just by looking at their left avatar hand.

The next subsection switches from gameplay and mechanics to building the visual aesthetics that create the sci-fi atmosphere in the game.

4.3.3 Modeling and Use of Game-ready Assets

Astroclimb uses a mixture of many self-modeled and game-ready assets that create an outer space atmosphere with sci-fi elements in it. These elements directly improve the visual aesthetics of the game. The remainder of this subsection informs about the objects and areas designed for the artificial space scene and where the inspiration comes from for using these specific objects.

Figure 4.6: An early design stage of the mechanical owl in Blender.

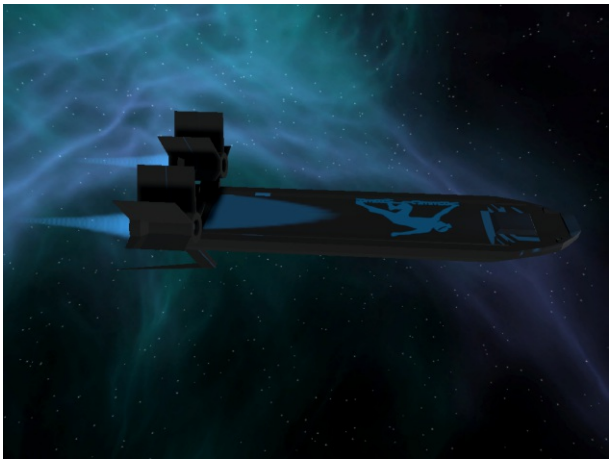

Figure 4.7: The hoverboard designed for players to stand up on before the climb.

One of the initial steps to create this outer space was building the skybox for the environment in Unity. For the first part of the climbing, a nebula with light colors that include green and blue is chosen to give players a feeling of relaxation. In contrast to this choice for the asteroid belt scene, a red-heavy nebula was chosen to signal the danger of the objects in the scenery. One of the first objects specifically designed for the scene was the hoverboard seen in Figure 4.7. Blender [15] is used for modeling this object which is then textured with Vreeclimber's logo and colored with matching colors to the nebula's blue & green. The idea of using a hoverboard is inspired by the movie series Back to the Future [65].

The mechanical owl is another object designed specifically for the game by using Blender again. Figure 4.6 shows an early mesh version of it in Blender. The textures are provided by free online resources. Shiny textures are used for the owl to make it stand out in the dark.

The moon colony (Figure 4.8) is one of the largest objects in the game, consisting of many self-designed and modeled objects and game-ready 3D assets provided by NASA [111]. The terrain of the moon is made by Unity's official terrain tool to create an area for the colony. This colony area includes living hubs for astronauts, debris that shows unsuccessful attempts of the folk on the moon, structures they build such as giant communication satellites, a command center, spaceship launcher platforms, and mining equipment. These objects are placed in a manner so that they can give the impression of a colony to the player.

The spaceships (Figure 4.10) used in Astroclimb are free assets, including destroyers and TIE fighters from Star Wars series [67], and Vipers from the Battlestar Galactica [64] TV show. The goal behind using known spaceships from successful TV shows and movie

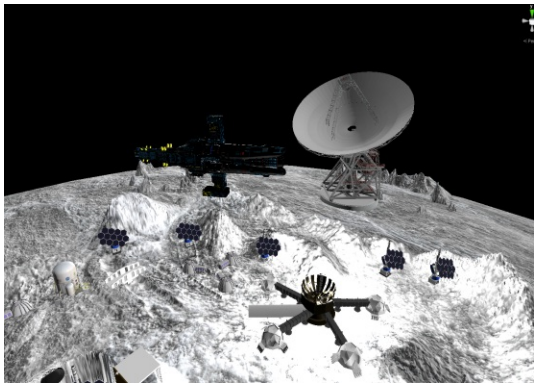

Figure 4.8: The moon scene.

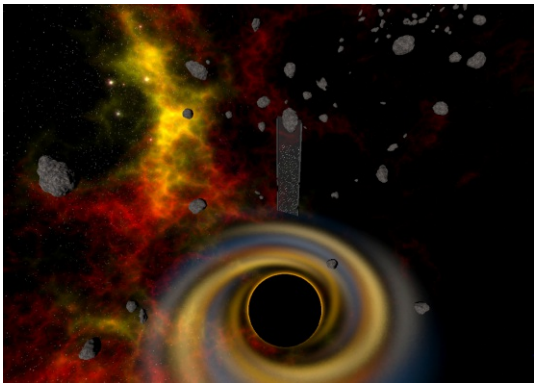

Figure 4.9: The asteroid belt scene.

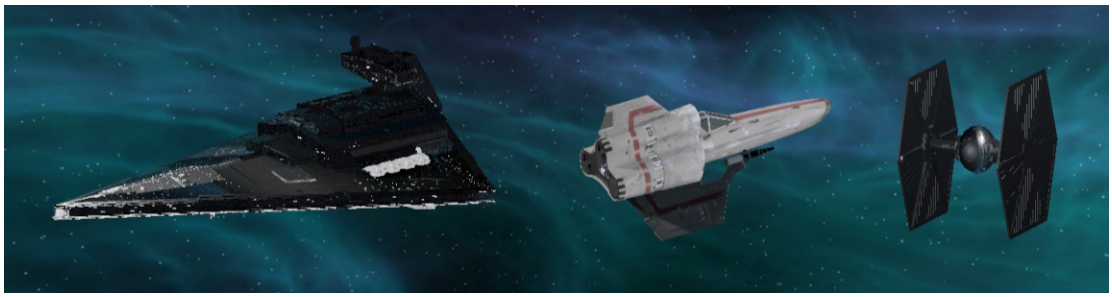

Figure 4.10: From left to right: The destroyer, Viper, TIE fighter.

series is to create a surprise effect for players when they see them in the game.

The asteroids in the asteroid belt scene (Figure 4.9) are taken from Unity's asset store and stored as prefabs in Unity. The algorithm that creates the asteroid belt picks one of these prefabs randomly, adds a random velocity and tumble rotation to it, and sends it through the outer space towards the climbing wall. Dozens of these asteroids are launched at the same time which creates the asteroid belt. The other mention-worthy object in the asteroid belt scene is the black hole (Figure 4.9) which is created by using the particle system in Unity. The purpose of placing the black hole below the climbing wall is to encourage players to climb higher up.

The use of these objects created satisfactory outer space scenes that fit the concept of Astroclimb. Besides visual aesthetics, background music and sound effects also improved the aesthetics of the game which are explained in the next subsection.

4.3.4 Music and Sound Effects

One of the most influential aesthetics types that improve immersion overall is audio. Astroclimb provides this kind of aesthetics in different ways such as playing music in the background at all times and supporting events with sound effects. This subsection

investigates the reasoning behind choosing multiple background music tracks and playing sound effects in certain situations.

Background music is the most noticeable auditory aesthetic of Astroclimb that changes overtime during the game. As previously mentioned in Section 4.3.1, the game is divided into three main chapters that reflect the game states the player can be in. For the intro part, a country-western song called Benson Arizona [185] performed by John Yager is picked. The song's relaxing tunes were considered an adequate fit to get the player ready for the climb. It is also one of the soundtracks from the movie Dark Star [66] which is an old American science fiction comedy in which the story involves funny events in outer space. The next background music that follows Benson Arizona is Echoes [186] by Pink Floyd. This song is purely instrumental at most parts and has a fairly slow pace at the start. Since Astroclimb only uses the first three minutes of this track at most, this makes the song a fine fit for the longest part of the game. The idea behind picking this song was to keep the player focused on the climbing and the events that occur at certain stages of the game. In comparison to Echoes, Mr. Spaceman [187] by The Byrds, which is used for the outro scene, is a fast-paced song with the genre of country-rock. It was planned that this dramatic change of tunes would create a wake-up effect on the player and signals the end of the game. Science fiction and space are the common themes in these songs. The use of *Benson Arizona* in a science fiction movie, *Echoes* evoking an outer space feeling with its melody, and *Mr. Spaceman* including lyrics that describe aliens create their own relationships to these themes. Besides these background music tracks, the owl phase also has a special background sound which can be described as static noises. The goal behind this change is to give the player a feeling of being somewhere unexpected such as in-between dimensions. Jiulin Zhang et al. also point out the importance of background music in video games for increasing immersion [41], however, it is not the only source for auditory aesthetics. Sound effects are another source that complements them to increase the immersion level in the game.

Since Astroclimb takes place in outer space, logically it does not make sense if someone hears noises or sound effects in such a scenario, however, excluding sound effects from a digital game would cause a less immersive experience [135]. In Astroclimb, sound effects are assigned to important events that happen throughout the game. Here is a list of some of these events that are supported with auditory feedback:

- When the hangar door opens at the start of the game
- When the massive spaceship that brings the player to the climbing location in the game leaves
- When spaceships warp in and out
- When the player scores points by using a climbing hold
- When an orb is selected and the changes are applied in the scene

- When the second part of the wall straightens up after the owl phase
- When the large asteroid hits the wall and a part of the wall breaks into pieces

With the addition of the background music tracks and various sound effects, Astroclimb aimed to improve the immersion level of the game and provide a better experience to players. This subsection finalizes the conception of the game in terms of gameplay and game atmosphere. The technical aspects of the game such as the implemented core scripts and how these scripts ensure the gameplay are explained in the next subsection.

4.4 Technical Aspects

4.4.1 Calibration Process

Astroclimb's core template consists of scripts that enable the climbing logic in the game. These scripts are responsible for calibrating the scene by aligning the physical objects with their virtual representations and keeping them aligned at all times throughout the game. There are two distinct calibration processes that make climbing in the virtual environment possible:

1. Calibration of avatar hands and feet
2. Calibration of the climbing wall

Calibration of the avatar hands and feet starts with finding the correct VIVE Trackers in the environment with the help of *TrackerIdentifier.cs* script. Then, *AvatarCalibration.cs* orients the hand and feet avatars towards the wall plane. In order to achieve this, the hand and feet avatars are rotated around all three axes until the avatars' *wall-facing* and *ground-facing* planes are oriented towards the predefined wall and ground plane in the game. With the help of these scripts, players are able to use their hands in the virtual environment to interact with objects without suffering from any nonalignment issues. This calibration process is crucial due to the fact that it enables players to use their hands accordingly without breaking the immersion. Besides hand and feet calibration, climbing in Astroclimb also requires a perfect alignment of the physical wall.

The wall calibration process consists of two parts: The initial calibration and the ongoing calibration during the game. The initial calibration process is accomplished mainly by the *SceneCalibrator.cs* script. First, the script tries to find a wall tracker on the right side of the wall and another one on the left side. Once these two trackers are found, the program needs to figure out which pair of trackers are found, as there are four possible combinations of wall trackers. Therefore, the vertical distance between both trackers as well as their horizontal positions is used for the identification. After the identification, the VR environment is shifted along the x- and z-axis depending on the position of the identified tracker and its corresponding position on the virtual board. Then, the climbing holds are shifted along the y-axis depending on the vertical difference between the tracker and the predefined position of the tracker on the virtual wall. This series

of processes take place at the beginning of the game, however, in order to keep the climbing holds aligned, additional measures have to be taken due to the rotation of the physical wall. *CorrectVerticalError.cs* and *CameraShift.cs* are responsible for this task. *CameraShift.cs* moves the VR environment upwards while the physical wall is rotating. It also adjusts the speed of this movement whenever the speed of the physical wall's rotation is changed. The upward movement is implemented by increasing the velocity of the VR environment's *Rigidbody* in its local y-Direction. *CorrectVerticalError.cs* has hardcoded upward movement speeds for the VR environment. Although these speeds are very close to the physical wall's rotation speeds of different levels, they do not exactly match the actual speed of the physical wall's rotation. Therefore, in time a vertical offset between the hands & feet and the climbing holds appears. This script is responsible for compensating for this loss in accuracy.

Although the virtual environment is slowly shifting upwards in the game, this slow but steady shifting is not noticed by any testers due to their focus being on somewhere else at all times. With the combination of these calibration processes, the climbing experience does not break immersion in Astroclimb. Besides climbing-oriented scripts, there are, of course, scripts that enable the gameplay. The next subsection explains some of these scripts.

4.4.2 Scripts

The scripts used to manage the logic in the game can be divided into two different types: The scripts that are tightly coupled to each other and react to game state changes handled in other scripts, and scripts that are mostly independent of the events happening throughout the game.

Scripts such as *GameplayController.cs* that is responsible for dictating the game's current state, *MusicController.cs* which changes the music playing in the background based on the game's state, *MilestoneController.cs* that sets the second stage during the climbing part of the game by changing the environment and enabling the second part of the climbing wall are dependent to each other. The triggers that change these game states are based on the player's players movements and position. As an example, touching a climbing hold changes the game state from *intro* to *climbing*. Since the game is a sequence of events and each small change that is supposed to happen, has triggers, the order of the events is regulated by using one of Unity's scripting concepts called *Coroutines* [171] and supported by *boolean* values to control their repetitiveness. Other than scripts that control the general flow of the game, there are also multiple scripts that are responsible for dictating the outcomes of certain events. These scripts work in harmony to be able to create the desired logic. *OwlController.cs*, *ManipulateFirstOrb.cs*, ManipulateSecondOrb.cs, and ManipulateThirdOrb.cs together handle the owl's and its orbs' animations once the player reaches a certain height on the climbing wall. In addition to these scripts, *ChoiceManipulator.cs* prepares the events dependent on the chosen orb which includes making changes to the avatar hands and the wall's climbing

holds. *WarningController.cs* is another highly-dependent script that needs to know the current height of the player on the wall all the time so it can display a warning text to the player stating that the player should pause climbing if the player gets too close to the upper side of the physical wall. These scripts are some of the core building blocks for the logic of the game, however, the game also consists of some semi-independent scripts.

The semi-independent scripts only get informed about the state of the game once and handle the logic accordingly. *BlinkBlink.cs* that is responsible for making certain light sources of the massive spaceship blink, and *Asteroidshower.cs* that spawns different types of asteroids towards the wall's direction are good examples for this type of script. The combination of these scripts and the core ones create the game logic that creates an essential part of the Astroclimb experience.

CHAPTER 5

Evaluation

This section covers the evaluation of the previously described implementation. It starts with going into details about how the setup is done to create an appropriate testbed for the evaluation. The Covid-19 measures forms the second part as they were crucial to enable the evaluation and testing in the first place. Then the way how the testing is handled composes the next subsection. Finally, the results are evaluated and discussed further. The evaluation methods include answering questionnaires, one before and one after the test session, observation, and an optional short unstructured interview after the test.

5.1 Setup

As mentioned before in Section 1.2, the implementation was built upon the Vreeclimber project. The wall is 4.6m high that consists of a combination of 28 wide block rows which hold a total of 238 climbing grips and 4 VIVE Trackers. As seen in Figure 5.1 of a row block, each row contains 8 or 9 climbing holds. The arrangement of these climbing holds on the wall is done in a way that the whole mapping of grips can resemble a bouldering experience. The wall can roll downwards with a maximum speed of 4.78m/min which can simulate endless climbing. Furthermore, the wall can tilt up to 20° to create the feeling of an overhanging cliff. The whole system does not produce noise beyond 68 decibels in good condition[1]. During the evaluation, all described features of this rotating wall played a central role in the outcome.

Additionally, strict safety measures were taken. The participants had to wear a suit with safety ropes attached to it. As seen in Figure 5.2, an operator had the duty of holding the climber's ropes to prevent unwanted accidents. The sports mat on the floor is a further

[1]The inner parts of the wall need to be oiled regularly to keep the noise at desired levels.

Figure 5.1: The Vreeclimber wall.

measure to prevent or reduce the effect of possible injuries in case of a participant's fall. Participants also had to wear climbing shoes that are designed for bouldering.

Because of the worn HTC VIVE Headset during the climb, various adjustments had to be made to the safety ropes without compromising safety. In a regular climbing scenario, a safety suite has carabiners to attach the safety rope to which then goes up at the front of the climber (Figure 5.2). If the same concept was kept for climbing in VR, the front ropes would interfere with the VR headset. That would be undesired because of safety, immersion, and tracking reasons. To prevent this from happening a robust bar is attached between the two ropes coming from the front side of the carabiners. (Figure 5.4) These adjustments kept the ropes from touching the VR headset.

As mentioned before in Section 3.1, the success rate of tracking has a direct and immense effect on immersion. Placing the VR equipment based on needs was another important part of the setup. 4 lighthouses and 8 VIVE Trackers are used for this matter to minimize any possible tracking issues. The lighthouses are used to track the position of the headset, controllers, and trackers inside the Chaperon area [155]. For the best possible tracking experience, VIVE Trackers and the VR headset should be visible to multiple lighthouses simultaneously. To enable this scenario, 2 of the VIVE Trackers are placed on the dorsal side of hands, and 2 on the dorsal side of feet. Although these placements of VIVE Trackers are on point in terms of tracking limbs accordingly, the tracking of these VIVE Trackers becomes difficult if the lighthouses are placed improperly. Figures 5.5 and 5.6 show possible positions of the VIVE Trackers on the limbs during the climb. In these cases, the VIVE Trackers find themselves in-between two solid objects, hands/feet, and

Figure 5.2: Operator holding the climber.

Figure 5.3: Carabiners with the safety ropes.

the wall. To always keep these trackers trackable, various room setups with different positioning of lighthouses are tested. After comparing the results of these tests, two of the lighthouses are placed at the low and middle levels of the wall and close to the wall. The other 2 lighthouses are positioned far back from the climbing wall at upper levels which are mainly responsible for tracking the 4 trackers on the wall. These placements also got approved by Prof. Kaufmann who specializes in the Augmented and Virtual Reality research area.

Figure 5.4: Extra safety measures with ropes and a robust bar.

There are two reasons behind using 4 VIVE Trackers for the climbing wall:

Calibration process: The application starts with a calibration process where two VIVE Trackers must be present on the front side of the wall simultaneously. With the help of the calibration process, the physical climbing holds on the wall align with their virtual representations in the application.

Figure 5.5: Tracker is hidden between the body and the wall.

Figure 5.6: Tracker is hidden between the hand and the wall.

Ongoing aligning process: As the wall rotates, the climbing holds stay aligned with the help of an algorithm that needs at least a VIVE Tracker getting tracked in the Chaperon area.

Because of the number of grip blocks, the use of at least 4 VIVE Trackers on the climbing wall is required to be able to achieve these goals. Besides the overall aligning processes, further in-game measures are taken in order to keep the climber safe and the tracking as smooth as possible, and increase the feeling of immersion:

In-game tracker covers: As tracker covers, spheres with dangerously looking electrical circuits are placed where the VIVE Trackers on the physical wall are supposed to be. The pure purpose of making these virtual representations look alarming is to discourage the climber from touching or holding onto the VIVE Trackers because applying force on this fragile equipment or covering these trackers at any point during the runtime of the application may result in reducing the quality of tracking and as well as the level of immersion drastically.

Warning text: The climber is kept at a so-called climbing window during the climb which means that the climber is restricted to not climb too high up on the physical wall because of safety reasons. Exceeding this high threshold results in giving the climber visual feedback with a warning sound to make them pause climbing for a little bit.

Skipping to end: It is possible for the climber to not want to continue with the content or with the climb itself because of various reasons. For that matter, a UI button is added to the game that is only available for the operator present at the PC. Pressing this button will finish the simulation and jump to the end screen of the game.

Shoe and glove size: 3 different virtual gloves and shoe sizes are available for the climber to pick from at the start of the game so their real hand and shoe sizes can match with the virtual representations as closely as possible.

All the points mentioned above created the setup for a safe and immersive experience.

5.2 Covid-19 measures

Since the testing requires the use of the rotating wall, operators and participants had to be present at the workshop. A Covid-19 procedure is prepared to minimize the risk of infection during the time spent in the workshop. Below is the list of taken measures:

- Participants and operators must be tested for Covid-19 and the results must be negative.
- A maximum of 4 people can be present in the workshop at the same time.
- Participants and operators must wear FFP2-masks to be able to enter the workshop. Since the test sessions will take place inside of TU Wien campus, all campus rules apply during entering and leaving the building. A full list of additional measures can be read on the official pages [182].
- Participants must keep their FFP2-masks during the climb.
- Participants must use the provided hand sanitizers before and after the climb and the test session.
- The provided climbing shoes must get disinfected after use.
- The VR equipment must get disinfected before each climb by the operators. Operators will wear plastic gloves during the sanitization process and a new pair of gloves will be used between each climb.

All the measures listed above were followed strictly.

5.3 Testing

The current situation the world is in because of the Covid-19 pandemic and the requirement of being present in the workshop to be able to participate in the study caused a low participation rate than expected. Furthermore, it also affected the diversity of the participants in a negative way. All participants were males, but they had a diverse climbing, VR, and gaming experience, and age spectrum. For detailed background information about the participants, the following table is provided.

Age	Sex	VR Experience	Climbing Experience	Gaming hours per week	Gaming hours for VR per week
22	male	3	2	3-6	1
27	male	5	2	3-6	0
32	male	4	3	0	0
47	male	3	5	1-3	<1
31	male	2	3	3-6	0

Table 5.1: Background information about participants

The test begins with following the Covid-19 measures. After filling the pre-questionnaire, the participant gets ready for the game by wearing the necessary equipment and listening to the briefing. Once the calibration for the wall, hands, and feet is done, the participant is ready to play the game. After the game, the participant removes the VR equipment, fills out the after-questionnaire, and has a small interview with the tester. For a more detailed step-by-step walkthrough of this procedure please read *Step-by-step Test Procedure* in the appendix.

Approximately 30-40 minutes got reserved for each session and the planned time was enough for every test person. The test sessions went mostly smooth in terms of timing apart from the first participant. There were some technical problems regarding the wall calibration process, but the issue got resolved in a short time.

Besides this small delay, there were a couple of further problems with the comfort of some of the climbers. The assembled hand-straps that were designed for holding the VIVE Trackers on the hands got uncomfortable towards the end of the climbing. One of the test persons also reported that there was a slight offset between their left hand and its virtual representation which made reaching the grips not as precise as planned.

5.4 Results

The questionnaires answered by the participants created a mix of qualitative and quantitative data. Since most of the questions that grade different aspects of the game are followed up by personal comments, the answers to most of the questions will be handled separately and include citations from the participants about their thoughts towards their experience. Figure 5.7 shows the effect of various elements used in the game to increase the immersion levels.

5.4.1 Immersion, Aesthetics, and Story

Aesthetics are one of the core game design elements that have the most direct relationship to a player's experience. They must make sense to players so they can relate events and objects to the environment they find themselves in. If these elements seem logical

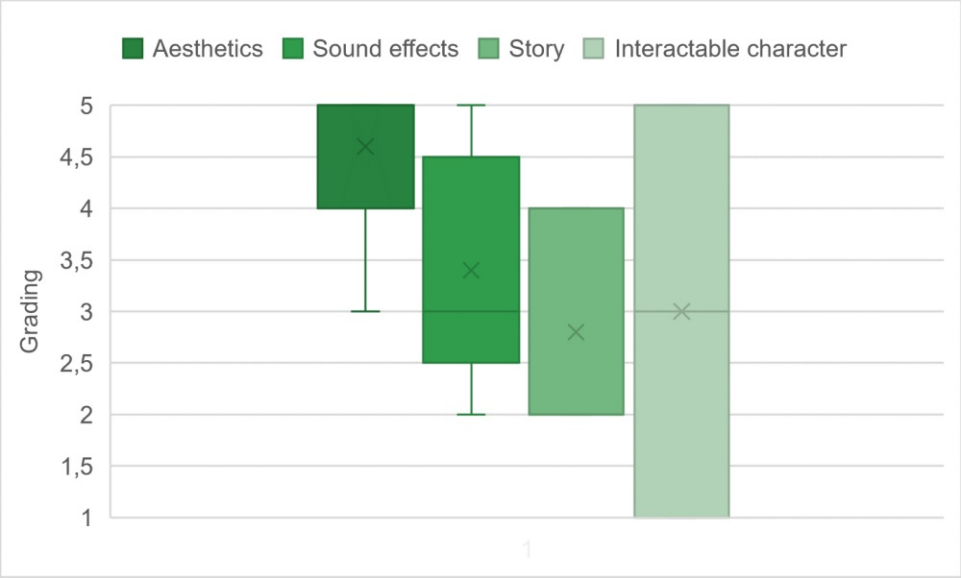

Figure 5.7: Effects of different game design elements on immersion.

to them for the environment, players can immerse themselves easily. Figure 5.7 states that the use of aesthetics was successful (See Section 5.4 for evaluation results), and this game design aspect was well applied. The design of the environment helped the players a great deal with immersing themselves and feel like a part of the environment. One of the participants mentioned in his comments: “In the beginning, the door and the interior of the space station were realistically designed. This gave me a strong feeling of immersion right away.” Another participant mentioned that the launching of the spaceship, the surroundings in general, the background music, and the transition from the spaceship to the wall were particularly immersing. Sound effects are also counted as a part of aesthetics. Maybe not as successful as the objects included in the environment but the sound effects aided to enhance immersion.

In comparison to environmental elements and sound effects, the story had a lesser impact to increase the immersion, however, as the graph states, it still contributed to giving a more immersive experience. The story was a prelude to the main event in the game and tried to set the stage for the player before experiencing the VR environment. Feeling immersed with both of these game design aspects also means that the connection between aesthetics and story was successful. The story shortly states that the player is in a space odyssey and makes a pit-stop to climb an anomaly wall. This small piece of information gives the player what kind of environment to expect once he wears the VR glasses. The starting point which is the hanger of an enormous spaceship confirms the story for the player and then seeing the climbing wall for the first time supports this story further. These elements should complement each other to make players feel more immersed in the scene.

The existence of a non-playable but interactable character in the game gave controversial feelings regarding adding more immersion to the experience. Almost half of the participants stated that the owl did not help with increasing immersion levels at all while the other half felt the effects of it to a great extent. One of the participants that did not find the owl immersive reported that it was lacking realism because an owl is unnatural both in climbing and space. Another one acknowledged that he recognized the owl late because it was kind of behind him and pointed out that a climber almost always looks towards the wall instead of checking the front view. The high experience of these participants in climbing and their low to none gaming habits can be the reasons behind their interpretations. It is possible that the expectations from a game can differ on an individual level. However, none of these participants reported that the existence of the owl was immersion breaking. This result can be explained with Cheng and Cairns study [22]. They examine in their study how a game should behave and what would happen if that behaviour was deliberately made to be incoherent. The results suggest that immersion within an application can overcome effects that are completely against user expectations. Other participants reported that the interaction with the owl was greatly immersive and one of the most memorable events throughout the game.

The occasionally appearing vertical offset between the hands and the virtual gloves, the need for rearranging of headphones during the climb, the wait to continue climbing because of the previously mentioned safety reasons were reported as immersion-breaking parts during the climb.

5.4.2 Fun, Tiredness, and Motion Sickness

Fun is one of the most iconic game design elements a game needs to possess. Figure 5.8 shows how engaging the participants find the game. It affirms that all participants enjoyed their experience greatly. However, this is just a general statement from the participants which does not inform the game designer about the specifics of the parts that made the game enjoyable, hence the participants were also asked about why they find the game engaging. One of the participants reported that the game was unique while another one found the general idea and the design behind the game neat. Another participant found the idea of being able to climb infinitely appealing. The combination of physical climbing with a space-themed VR environment that offers different levels and being able to explore the environment to an extent were the aspects for a participant that made the game fun.

As explained previously in Section 4.3.1, the player is given a choice through the middle of the game which affects the rest of the climb remarkably. As seen in Figure 5.9, participants found that change in the flow of the game (more) challenging or/and engaging. One participant reported that he misinterpreted the goal.

Furthermore, most of the participants reported that they would not be interested in playing a similar game on a PC. One of the participants believes that physical climbing

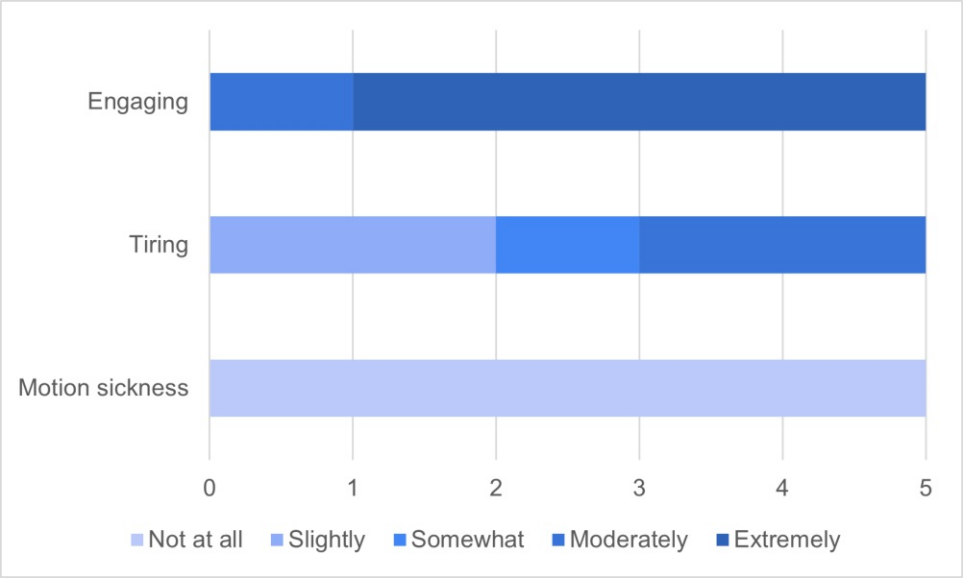

Figure 5.8: Effectiveness of some of the in-game experiences.

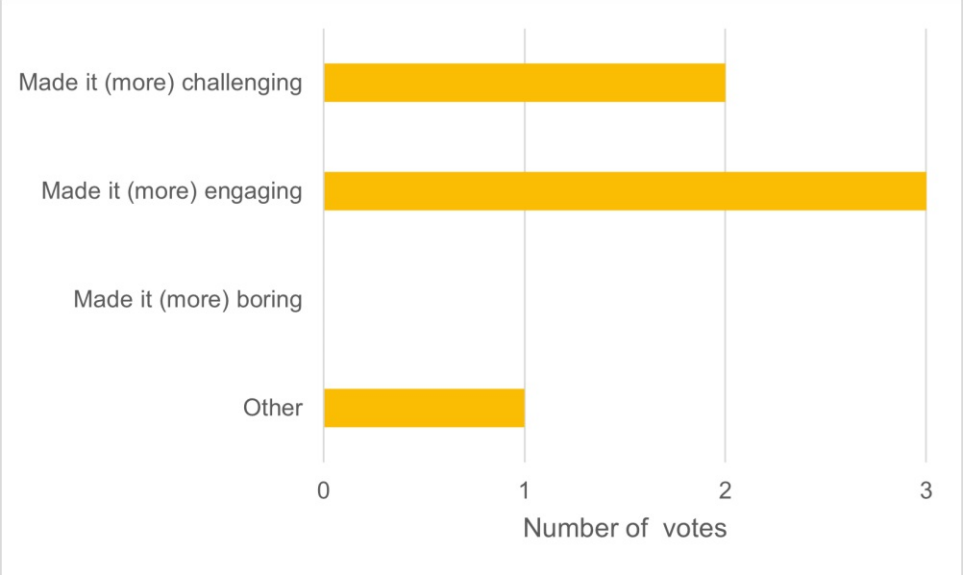

Figure 5.9: Effects of the chosen orb on the game experience.

is essential in such a setup and the controls on a PC game would make the game boring. Another participant thinks that experiencing such an environment in VR is the most interesting aspect of it and the way you can immerse yourself when physical activity is at present is unique. These comments indicate that it is more desirable and makes more sense to participants to play a game that involves physical activity in a VR environment.

A mention-worthy find is that the participants described the game as relatively tiring as seen in Figure 5.8. This was mentioned multiple times during the short interviews after the climbs as well. When the specific part asked about the tiring part of the climb, participants pointed out the time towards the end. Towards the end of the climb, an asteroid crashes the top side of the wall which triggers the physical wall to tilt forward. This means that the participants climbed at least a quarter of the wall while it was tilted which required more force to hold onto climbing holds. Considering no one quit climbing during the test, this tells that the enjoyment the players received took over the tiredness.

Figure 5.8 shows that there were not any motion sickness complaints from the participants during or after the game which is a good sign. This piece of information indicates that the decisions made while designing the game helped with preventing possible motion sickness cases. This can also be explained that all of the participants had VR experience before and are used to the situation. As Alex Riviere mentions in his blog [133], some game developers intend to say that with experience of hours playing in VR, people eventually get used to it, and the problem of motion sickness will be resolved on its own with time.

5.4.3 Problem Solving, Critical Thinking, and Replayability

As previously explained in Section 4.3.1, the player has to make a choice between three presented orbs to be able to continue climbing. Although the orbs are animated and each of them gives hints about how the gloves get enchanted, the situation was still not perfectly clear to the player. The purpose of this section of the game is to force players to think critically and guess the changes that will be applied once the climb continues. On one hand, as seen in Figure 5.10, the participants found the idea of these enchantments fairly interesting. On the other hand, figuring out the changes that will be applied for the rest of the game was fairly difficult. Two of the participants reported that they did not think about the outcome and randomly chose one of the orbs. One of the participants stated that he chose the middle orb because he was sure what was going to happen if that orb would be chosen. Another participant figured out the possible outcomes of every choice and chose the one that seemed the most challenging amongst them. Moreover, a participant addressed that one of the animations was misleading because no one would expect the gloves to get duplicated. Another participant reported that he misinterpreted the same animation and thought picking that orb would specify which grips to hold as next.

Making participants misinterpret things in the game can be seen as a design issue, however, misinterpretations build the path to solve puzzles. The main goal is actually achieved here by making some of the participants guess things wrong.

Although the choices were generally unclear and relatively hard to understand all participants managed to understand that they had to pick an orb to be able to continue climbing. This behaviour states that they were able to solve the problem that was thrown at them.

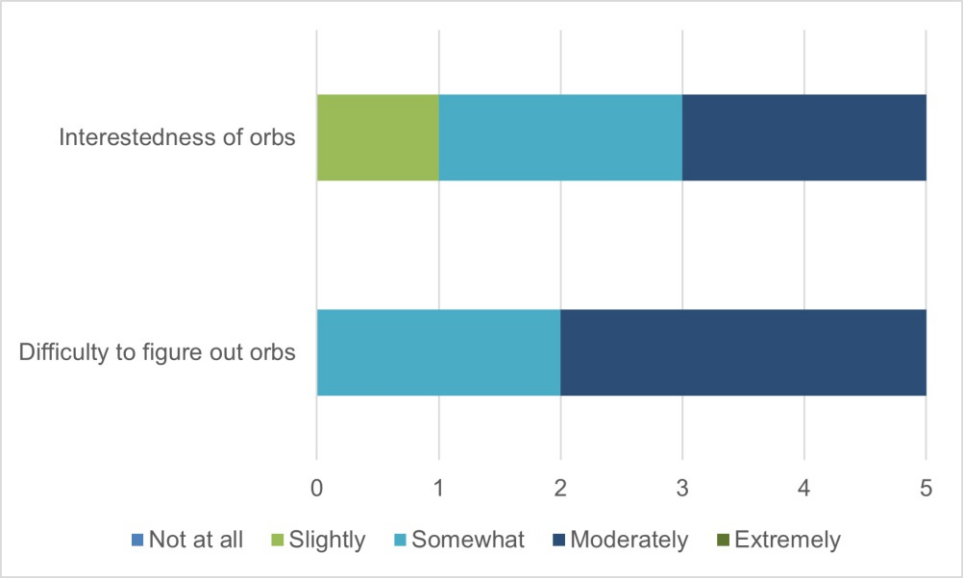

Figure 5.10: Participants' thoughts on orbs.

After the climbing session ended for one of the participants, he was curious about what would happen if he picked one of the two other orbs. Explaining the outcomes made him interested enough to play the game again and this time he picked another orb once that stage is reached in the game. He reported after his second climb that he enjoyed how differently picking another orb affected the outcome of the climb. This behaviour shows curiosity leads to the replayability of the game which is another important game design element. Figure 5.11 shows how likely it is for the participants to play again to see the other presented options would affect their experiences. Besides curiosity, there are other aspects such as challenging other players that can lead players to replay the game. All participants agree with this statement and as seen in Figure 5.11, everyone is eager to play the game again to beat their own or another player's score or time.

5.4.4 Element of Surprise, Curiosity, and Progression

One way to keep players interested in the game they are playing is by creating surprises and unexpected events. All participants experienced at least a moment where they were surprised. Three of the participants found the appearance of the owl and the options it presents surprising. Another participant reported that the asteroid hitting the wall which makes a part of the glass wall shatter caught him off guard. The hangar door's opening and seeing the space environment for the first time was surprising for another participant. One of the participants reported further that noticing how high he climbed after looking down surprised him.

After the climb, the participants were also asked whether they felt the physical wall getting tilted at one point during the game. Most of the participants were baffled by

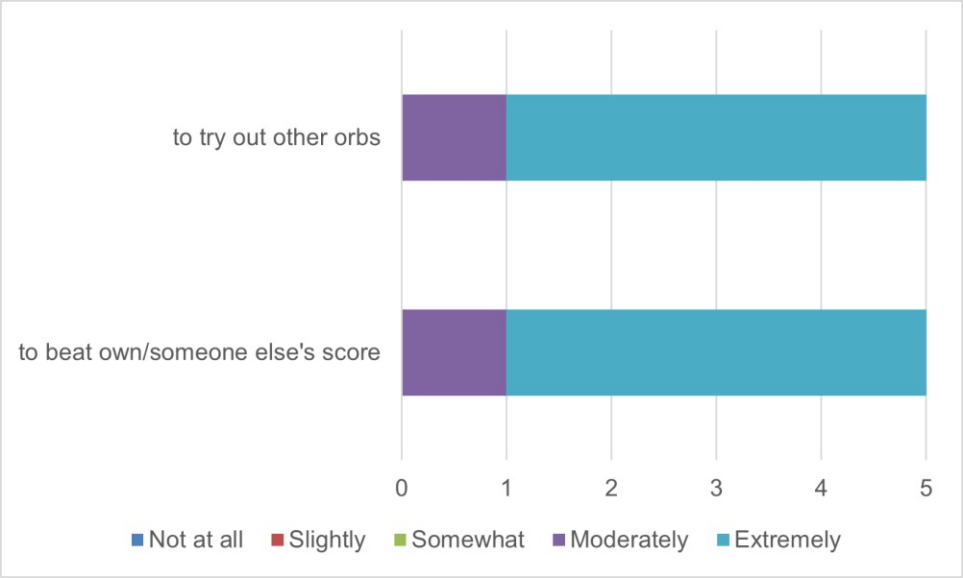

Figure 5.11: Likeliness to play the game again.

the question because none of them noticed that the wall they were attached to actually tilted forward. Another important acknowledgment was that none of them felt the wall was rotating although they knew that is how the wall operates. These observations can be explained by how highly immersed the participants were in the game.

Curiosity is another way to make a game appealing. A participant reported that the very beginning of the game where he waited for the door to open made him curious about what is behind the door. Another source of curiosity was the owl and the possible outcomes of picking an orb which made two of the participants curious.

The UFO ship that arrives on top of the climber at the end was another element of the game that triggered curiosity for one of the participants. He stated that he expected the enormous spaceship to come back and pick him up. The arrival of the UFO left him with questions in the end. Although the game ends at that point, it still gives the players things to think about even after the game.

One of the participants reported that none of the aspects in the game awakened curiosity in him because he was too focused on climbing.

The pause created during the game where the player has to make a choice to continue climbing gave all of the participants except one a sense of progression. Giving players a milestone to reach makes them curious about what is to unfold next and creates expectations. These aspects prevent the game from becoming stale. The participants are further questioned about the motivation level reaching a milestone gives to progress further. As seen in Figure 5.12, all participants except one felt relatively motivated to

continue with the game after the interaction with the owl.

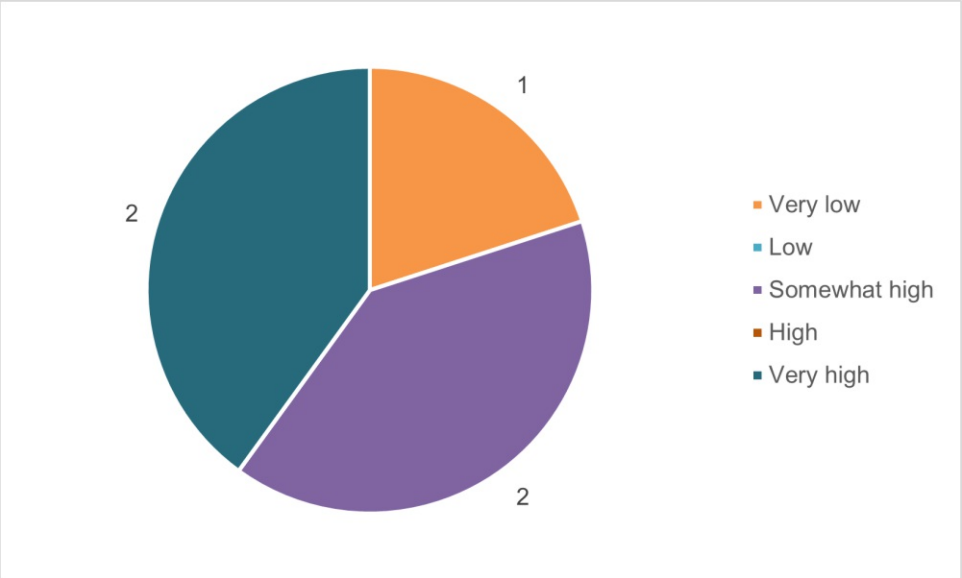

Figure 5.12: Motivation level to continue climbing after the milestone.

5.4.5 Overall Results of Applying Game Design Element

The purpose of the data collected from the participant was to find out how likely it is to apply generally accepted game design practices and methods to the virtual reality platform. The core game design elements aesthetics, story, mechanics, and technology are all present in Astroclimb and they complement each other. Although the use of these elements can get transitioned to virtual reality platforms successfully, there are other core concepts such as immersion, usability and game feel that need to be looked into because they mean differently for VR games.

Immersion is the most important aspect of virtual reality. Every other element used in a game should try to add to the overall immersion level to increase the satisfaction rate of players. The importance of immersion increases further if the physical play area needs to be in harmony with the world created in the virtual reality environment. In this case, the alignment of the physical wall, the climbing holds on them, the virtual gloves and shoes should match positioning-wise as perfectly as possible with their virtual representations, otherwise playing this game would not be possible at all. This is done by the calibration processes at the start of the application and the (almost) perfect alignment carried on throughout the game. If other physical objects are involved in the game design besides the VR equipment, further measures have to be taken to keep the immersion at a high level. Besides the calibration process and providing a core concept of being able to climb in a virtual environment, in-game elements should make

players immersed in the scenario. The data gathered from the climbing sessions that are discussed in this section previously clearly states that the participants were immersed in the game. Creating the environment for players in virtual reality should take "presence" into account. Presence also called "telepresence" is a phenomenon that makes people be able to become connected with a world outside of their bodies with the help of technology. Since players become physically a part of the game they are playing, the experience with VR glasses produces a visceral feeling of being in a simulated environment. Creating this simulated environment successfully adds more to the immersion levels of the game.

Usability refers to maximizing the effectiveness and efficiency of the game elements used in a game while keeping the players satisfied. It is about delivering an enjoyable experience while keeping away the unnecessary interruptions or challenges that have not been designed by the developers [85]. As mentioned before, Astroclimb is built upon Vreeclimber which makes the climbing experience possible but also brings limitations with it. As already stated, the climbing experience became stale because of the pauses players had to encounter. A possible solution to this issue would be providing higher rotation speed for the physical wall. However, the game design could also find an in-game solutions which are discussed in the next subsection. The low participation rate also did not help with testing the game with people that have no climbing experience at all. This low diversity of players prevented gathering data about the challenge level of Astroclimb for non-climbers. A high rate challenge level would also affect usability in a negative way. The overall gathered data, however, made it clear that unlike in non-VR digital game design, usability has additional pit-holes if physical activity is involved in a game.

Game feel for traditional video games is described as the intangible, tactile sensation experienced when the player interacts with video games [158]. This definition changes for VR games because virtual reality enables the possibility of making the interactions tangible. Astroclimb is a perfect example where it makes some of the core elements such as the wall and the climbing holds in the game tangible which enhances the game feel and immersion directly.

Astroclimb tries to use a decent amount of traditional game design elements in itself such as story, game mechanics, replayability, challenge, and critical thinking while keeping in mind that the VR and physical activity aspects of it can influence these game design elements and require adaptations of these elements.

As the data states all of these game design elements were successfully applied with different satisfactory levels for the players. The results also show that these applied game design elements improved immersion for the participants which enabled a higher quality of user experience. Additionally, the absence of motion sickness helped with giving this level of quality experience. There were, however, some issues such as occasional imperfect object alignments and long pauses during the game which affected immersion negatively.

5.5 Discussion

The evaluation showed that various game design elements can be applied to the VR platform, although some of them may need adjustments to make more sense for the circumstances in the game. The limitations and additional benefits VR platform can provide should be taken into account to enhance gameplay and increase player satisfaction.

Experienced climbers were less aware of their environment during the climb and noticed some of the crucial objects in the environment such as the owl extremely late because of that. As stated in Section 2.3.1, climbers tend to focus on looking forward where the wall stands and do not pay much attention to their environments. To keep the climbers' focus on what is important, some of the objects in the environment could be re-allocated to draw more attention from the players. The used material for the virtual climbing wall, glass, can be used further for this implementation. The owl could have appeared behind the wall and the interaction could be designed differently.

One of the issues addressed by the fast climbers was the wait time that had to experience because of the rolling speed of the climbing wall. An in-game design solution for that would be forcing the climber to traverse horizontally with some different difficulty levels so that the rolling speed would stop being an issue to continue climbing. For that particular solution, a strict and challenging grip path could be made visible to the climber by changing the grip colors. Moving horizontally would give enough time for the physical wall to roll down which would eliminate the pauses.

Although the owl was not interpreted realistically, it is clear that the lack of realism does not have any negative effects on immersion. This idea can be supported further when the created virtual environment is observed. A hanging climbing wall in the middle of the space, spaceships warping in and out, the audible sound effects in space, wearing sports shoes, or change of the nebula in the blink of an eye do not add any realism to the game, however, the players accept this simulation as it is and the environment makes sense for them.

Combining physical activity and training with a VR game creates another challenge from a game design perspective. The game length can easily become an issue if the physical activity is tiring to an uncomfortable extent. Participants with less climbing experience stated that the game was tiring but it was not tiring enough to stop playing it. The tiredness level of the game is also directly proportional to the player's overall physical training and condition at that point in time which determines the outcome of the gaming experience.

Finally, it is also interesting that the players with higher weekly gaming time had fewer problems with identifying the outcome of the choices that were represented to them by the owl. It can also be explained with other skills participants possess. The low participation makes it difficult to make claims about this observation, hence, further

studies should be conducted in this area to judge the results fairly.

CHAPTER 6

Conclusion and Future Work

As part of this master's thesis, a VR game called Astroclimb based on the project Vreeclimber was developed and a selection of various game design elements such as aesthetics, challenge, and replayability that are used for video games were applied. During the development process, the game went through modifications and adaptations based on testers' feedback. In the end, a space-themed game that focuses on climbing with a unique gameplay was developed.

The literature research has shown that there are already similar approaches to overlay a real existing climbing wall with virtual content. The applications built upon these approaches, however, are lacking content and focus on only aligning the digital scene with the real world. Another limitation of these approaches is the limited climbable area which is dictated by the height of a real boulder wall. In comparison to these approaches, successful climbing-based VR games on the market focus on creating VR experiences with rich content and ignore the real climbing aspect since providing players with a real climbable terrain or structure would be too expensive or non-profitable. In Astroclimb, however, the rotation mechanism of the climbing wall enables endless climbing which creates opportunities to develop games with advanced gameplay logic.

During the development stage of Astroclimb, various game design elements are added to make the game more compelling to players while keeping them immersed at all stages. The evaluation results showed that the players found the game aesthetically pleasing, the gameplay fun due to the application of aforementioned game design elements. The use of these aspects in harmony increased the level of immersion in the game and the quality of user experience. Of course, the game is not perfect and needs improvement especially in terms of gameplay for fast climbers so they do not have to pause climbing because of reaching the top of the physical wall too quickly. Furthermore, some objects can be placed better in the virtual environment in order to not create discomfort for the players.

The length of the game is also still problematic although it was shortened once already. The visible exhaustion of players towards the end of the game shows the game's overall difficulty due to its physical activity aspect.

APPENDIX A

Step-by-step Test Procedure

1. Operators make sure that the test person followed the Covid-19 procedure until they entered the workshop.
2. The test person disinfects his hands with the provided hand sanitizer.
3. The test person reads and fills out the declaration of consent, the information papers, and the pre-climb questionnaire. If they have any questions regarding any paper, they get answered.
4. VR headset and trackers get disinfected by one of the operators.
5. The test person is asked about their shoe size to provide them with a fitting pair of climbing shoes.
6. The test person wears the safety suit.
7. Test person sits on a chair and wears climbing shoes. At the same time, the person gets a briefing about what to expect during the climb. Further questions get answered if there are any.
8. The VIVE Trackers get attached to climbing shoes by one of the operators.
9. The test person gets informed about how to wear the VIVE Trackers on their hands, and they follow the instructions.
10. The test person wears the VR headset and stands away from the climbing wall at a certain point.
11. Safety ropes get attached to the carabiners of the safety suit.

12. The test person gets informed about holding their feet and hands with palms parallel to the ground and fingertips facing straight towards the climbing wall. (picture)
13. The application starts.
14. Hand and feet calibration commences. After this, the test person gets informed to move their hands and feet freely again.
15. Wall calibration commences.
16. Once the door of the hanger in the game opens, the test person can start climbing whenever they want and/or keep observing their surroundings.
17. The test person plays the climbing game which lasts approximately 4 minutes.
18. In the end, the test person can get their hands and feet off the grips.
19. The operator that is responsible for holding the safety ropes of the climber lowers the climber slowly to the ground.
20. The safety rope gets removed from the carabiners once the test person is on their feet.
21. The VR headset, VIVE Trackers get removed.
22. The test person gets freed from the safety suit.
23. The test person takes off the climbing shoes.
24. Once the test person is ready, he is asked to fill out the post-climb questionnaire.
25. If the test person has additional remarks towards their current experience a short interview is conducted.

List of Figures

Bibliography

[1] 360VirtualTour. The White House Virtual Tour. https://www.360virtualtour.co/portfolio/the-white-house-google-virtual-tour/, 2017. Online; accessed 18-June-2021.

[2] ADVRTAS. 360 VR is Interactive and Immersive. https://advrtas.com/360-vr/, 2021. Online; accessed 18-June-2021.

[3] M. Ahmad. *Categorizing Game Design Elements into Educational Game Design Fundamentals*. 11 2019.

[4] A. Alexiou and M. Schippers. Digital game elements, user experience and learning: A conceptual framework. *Education and Information Technologies*, 23:2545–2567, 2018.

[5] M. Alger. Visual Design Methods for Virtual Reality. 2015.

[6] Alice. VR Locomotion On Rails. https://www.alice.org/resources/how-tos/vr-locomotion-on-rails/, 1999–2020. Online; accessed 18-June-2021.

[7] Apple. App store. https://www.apple.com/app-store/. Online; accessed 18-June-2021.

[8] V. A. Art. VR for Galleries: Grow from a local to a global gallery. https://vrallart.com/vr-for-galleries/, 2021. Online; accessed 18-June-2021.

[9] B. Bahnke. Simple top rope problem. http://ffden-2.phys.uaf.edu/webproj/211_fall_2020/Brayden_Bahnke/brayden_bahnke/Slide6.htm. Online; accessed 18-June-2021.

[10] M. I. Berkman and E. Akan. *Presence and Immersion in Virtual Reality*, pages 1–10. Springer International Publishing, 2019.

[11] T. Bezmalinovic. Half-Life: Alyx - So trikste valve bei der VR-Fortbewegung. https://mixed.de/half-life-alyx-so-trickste-valve-bei-der-vr-fortbewegung/, 2020. Online; accessed 18-June-2021.

[12] S. Bjork and J. Holopainen. Patterns in game design. IT Faculty, Göteborgs universitet, 2004. Page 206.

[13] S. Björk, S. Lundgren, and J. Holopainen. Game Design Patterns. January 2003.

[14] R. Black. Virtual Reality Programs Now Target Pain, Stress, and Depression. Practical Pain Management - https://www.practicalpainmanagement.com/patient/virtual-reality-for-pain-depression, 2020. Online; accessed 18-June-2021.

[15] Blender. Blender - free and open source 3D creation suite. https://www.blender.org/, 2021. Online; accessed 04-July-2021.

[16] Blunty. Beat Saber Developer Interview. https://www.youtube.com/watch?v=oTmQQVfwOt8, 2018. Online; accessed 18-June-2021.

[17] S. Boiler. Learning Game Design: Game Mechanics. http://www.theknowledgeguru.com/learning-game-design-mechanics/, 2013. Online; accessed 18-June-2021.

[18] D. R. Boyd, D. Gould, M. Hutson, M. Klawunn, D. Laidlaw, J. Chan-Norris, J. Potter, and H. Rohde. Depth Cues in Virtual Reality and Real World : Understanding. 2000.

[19] W.-P. Brinkman, A. Hoekstra, and R. Vanegmond. The Effect of 3D Audio and Other Audio Techniques on Virtual Reality Experience. volume 219, January 2015.

[20] E. Chang, H.-T. Kim, and B. Yoo. Virtual reality sickness: A review of causes and measurements. *International Journal of Human-Computer Interaction*, 36:1–25, 07 2020.

[21] E. Chang, H. T. Kim, and B. Yoo. Predicting cybersickness based on user's gaze behaviors in HMD-based virtual reality. *Journal of Computational Design and Engineering*, 8(2):728–739, 2021.

[22] K. Cheng and P. Cairns. Behaviour, realism and immersion in games. pages 1272–1275, 2005.

[23] K. Choi, Y.-J. Yoon, O.-Y. Song, and S.-M. Choi. Interactive and Immersive Learning Using 360° Virtual Reality Contents on Mobile Platforms. *Mobile Information Systems*, 2018:1–12, 10 2018. doi: 10.1155/2018/2306031.

[24] ConcernedApe. Stardew valley. https://www.stardewvalley.net/. Online; accessed 18-June-2021.

[25] Crytek. The climb 2. https://www.theclimbgame.com/. Online; accessed 18-June-2021.

[26] A. Dancu. The Ultimate Display. Technical report, Chalmers University of Technology, 2014.

[27] David. How Virtual and Augmented Reality Help to Cut Costs. Vection - https://www.vection.com.au/news/post/how-virtual-and-augmented-reality-help-cut-costs, 2021. Online; accessed 18-June-2021.

[28] H. Desurvire and M. Kreminski. *Are Game Design and User Research Guidelines Specific to Virtual Reality Effective in Creating a More Optimal Player Experience? Yes, VR PLAY*, pages 40–59. 2018.

[29] N. Didehbani, T. Allen, M. Kandalaft, D. Krawczyk, and S. Chapman. Virtual Reality Social Cognition Training for children with high functioning autism. volume 62, pages 703–711, 2016. URL https://www.sciencedirect.com/science/article/pii/S0747563216303089.

[30] M. Domenech Lopez. How can i get there? Disorientation and motion sickness effects depending on the virtual reality navigation technique. 2020.

[31] S. Dredge. Facebook closes its $2bn Oculus Rift acquisition. What next? The Guardian - https://www.theguardian.com/technology/2014/jul/22/facebook-oculus-rift-acquisition-virtual-reality, July 2014. Online; accessed 18-June-2021.

[32] A. Dublin. 23 museums, attractions, and theme parks you can visit virtually including the Louvre, San Diego Zoo, Great Wall of China, and The Wizarding World of Harry Potter. https://www.businessinsider.com/virtual-museums-theme-parks-activities?r=DE&IR=T, 2020. Online; accessed 18-June-2021.

[33] E3. E3 expo. https://e3expo.com/, 2012. Online; accessed 18-June-2021.

[34] H. Eidenberger. Jumpcube Project - Technical University of Vienna. http://www.jumpcu.be/, 2015. Online; accessed 18-June-2021.

[35] H. Eidenberger. VreeClimber Project - Technical University of Vienna. http://www.vreeclimber.at/, 2020. Online; accessed 18-June-2021.

[36] Eurogamer. What Remains of Edith Finch. http://edithfinch.com/. Online; accessed 18-June-2021.

[37] C. Fabricatore. Gameplay and game mechanics design: a key to quality in videogames. 10 2007.

[38] G. Falloon. Using avatars and virtual environments in learning: What do they have to offer? *British Journal of Educational Technology*, 41(1):108–122, 2010. doi: https://doi.org/10.1111/j.1467-8535.2009.00991.x. URL https://bera-journals.onlinelibrary.wiley.com/doi/abs/10.1111/j.1467-8535.2009.00991.x.

[39] M. Fitzsimmons. Sony reveals PS4 VR headset at GDC 2014. techradar - https://www.techradar.com/news/gaming/sony-reveals-it-s-been-developing-vr-at-gdc-2014-1234976, March 2014. Online; accessed 18-June-2021.

[40] O. for Developers. Understanding Gameplay Latency for Oculus Quest, Oculus Go and Gear VR. https://developer.oculus.com/blog/understanding-gameplay-latency-for-oculus-quest-oculus-go-and-gear-vr/. Online; accessed 18-June-2021.

[41] J. Fu. The Influence of Background Music of Video Games on Immersion. *Journal of Psychology & Psychotherapy*, 05, 2015.

[42] Gamereactor. E3 12: John Carmac's VR Presentation. https://www.youtube.com/watch?v=kw-DlWwlXHo, July 2012. Online; accessed 18-June-2021.

[43] B. Games. Beat saber. https://store.steampowered.com/app/620980/Beat_Saber/, 2018. Online; accessed 18-June-2021.

[44] E. Games. Unreal Engine. https://www.unrealengine.com/, . Online; accessed 18-June-2021.

[45] F. Games. The Room. https://www.fireproofgames.com/games/the-room, . Online; accessed 18-June-2021.

[46] F. Games. The Room VR: A Dark Matter. https://store.steampowered.com/app/1104380/The_Room_VR_A_Dark_Matter/, 2020. Online; accessed 18-June-2021.

[47] N. P. Gerald Lynch. Best VR headset 2021: Oculus Quest 2, PSVR, Valve Index and more. techradar - https://www.techradar.com/news/the-best-vr-headset, 2021. Online; accessed 18-June-2021.

[48] A. Giddens. Notes on the Concepts of Play and Leisure. *The Sociological Review*, 12(1), 1964. Page: 75.

[49] L. K. Goode. Synesthesia : a sixth sense or a sensation : a research project based upon interviewing persons with color synesthesia. 2010.

[50] Google. Daydream. https://vr.google.com/daydream. Online; accessed 18-June-2021.

[51] Google. Google earth. https://www.google.com/earth/, 2001. Online; accessed 18-June-2021.

[52] Google. Google maps. https://www.google.com/maps, 2005. Online; accessed 18-June-2021.

[53] Google. Google street view. https://www.google.com/streetview/, 2007. Online; accessed 18-June-2021.

[54] Google. Get your Cardboard. https://arvr.google.com/cardboard/get-cardboard/, 2014. Online; accessed 18-June-2021.

[55] Google. Google cardboard. https://arvr.google.com/cardboard/, June 2014. Online; accessed 18-June-2021.

[56] Google. Google Earth VR. https://arvr.google.com/earth/, 2021. Online; accessed 18-June-2021.

[57] I. Granic, A. Lobel, and R. Engels. The benefits of playing video games. *The American psychologist*, 69 1:66–78, 2014.

[58] C. Greg. I Have No Words & I Must Design: Toward a Critical Vocabulary for Games. In *Computer Games and Digital Cultures Conference Proceedings*. Tampere University Press, June 2002. Page 22.

[59] B. Halliwell. Understanding Auto Belays. https://www.theclimbingguy.com/understanding-auto-belays/, 2020. Online; accessed 18-June-2021.

[60] S. T. Help. Future of Virtual Reality - Market Trends And Challenges. https://www.softwaretestinghelp.com/future-of-virtual-reality/, 2021. Online; accessed 18-June-2021.

[61] S.-F. Henrik. The Player Engagement Process - An Exploration of Continuation Desire in Digital Games. In *DiGRA &#3911 - Proceedings of the 2011 DiGRA International Conference: Think Design Play*. DiGRA/Utrecht School of the Arts, 2011.

[62] H. Hermann. Oculus kauft Beat-Saber-Entwickler. https://www.gamersglobal.de/news/167437/oculus-kauft-beat-saber-entwickler, 2019. Online; accessed 18-June-2021.

[63] U. S. Hollywood. Jurassic Park - The Ride. https://www.universalstudioshollywood.com/web/en/us/things-to-do/rides-and-attractions/jurassic-world, 2021. Online; accessed 18-June-2021.

[64] IMDb. Battlestar Galactica. https://www.imdb.com/title/tt0407362/, 2021. Online; accessed 04-July-2021.

[65] IMDb. Back to the Future. https://www.imdb.com/title/tt0088763/, 2021. Online; accessed 04-July-2021.

[66] IMDb. Dark Star. https://www.imdb.com/title/tt0069945/, 2021. Online; accessed 07-July-2021.

[67] IMDb. Star wars. https://www.imdb.com/star-wars/, 2021. Online; accessed 04-July-2021.

[68] V. Inc. Omni by virtuix. https://www.virtuix.com/accessories/. Online; accessed 18-June-2021.

[69] J. Incao. How VR is Transforming the Way We Train Associates. Walmart - https://corporate.walmart.com/newsroom/innovation/20180920/how-vr-is-transforming-the-way-we-train-associates, September 2018. Online; accessed 18-June-2021.

[70] V. Index. Controllers. https://www.valvesoftware.com/en/index/controllers, 2019. Online; accessed 18-June-2021.

[71] V. Index. Valve index headset. https://www.valvesoftware.com/en/index/headset, 2019. Online; accessed 18-June-2021.

[72] F. B. Insights. Market research report. https://www.fortunebusinessinsights.com/industry-reports/virtual-reality-in-education-market-101696, November 2019. Online; accessed 18-June-2021.

[73] F. B. Insights. *Virtual Reality in Gaming Market Size, Share & Covid-19 Impact Analysis, By Component (Hardware, Software and Content), By Device (Mobile, Console/PC and Standalone), and Regional Forecast, 2020-2027*. 2020.

[74] D. Jagneaux. Developers Test Running in Place To Solve VR's Movement Problem. https://uploadvr.com/running-in-place-movement-locomotion-vr-developers/, 2016. Online; accessed 18-June-2021.

[75] Jay. Field of View for Virtual Reality Headsets Explained. VR Lens Lab: Virtual Reality Knowledge - https://vr-lens-lab.com/field-of-view-for-virtual-reality-headsets/, March 2016. Online; accessed 18-June-2021.

[76] H. Kaufmann and T. Cacmak. The Virtualizer - A New Locomotion Device. https://www.ims.tuwien.ac.at/projects/virtualizer, 2013–2015. Online; accessed 18-June-2021.

[77] Kickstarter. Oculus Rift: Step Into the Game. https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game, 2012. Online; accessed 18-June-2021.

[78] E. Kidwell. How to avoid motion sickness caused by VR headsets while gaming. Windows Central - https://www.windowscentral.com/how-avoid-motion-sickness-caused-by-vr-headsets-while-gaming, April 2018. Online; accessed 18-June-2021.

[79] J. Kim. Get a closer look with Street View in Google Earth VR. https://blog.google/products/google-ar-vr/get-closer-look-street-view-google-earth-vr/, September 2017. Online; accessed 18-June-2021.

[80] M. Kleffmann. The Room VR: A Dark Matter - VR-Rätsel-Abenteuer erscheint Ende März. https://www.4players.de/4players.php/spielinfonews/Allgemein/41596/2188451/The_Room_VR_A_Dark_Matter-VR-Raetsel-Abenteuer_erscheint_Ende_Maerz.html, 2020. Online; accessed 18-June-2021.

[81] F. Kosmalla, A. Zenner, M. Speicher, F. Daiber, N. Herbig, and A. Krüger. Exploring Rock Climbing in Mixed Reality Environments. pages 1787–1793, 2017.

[82] B. Kuchera. The Room VR: A Dark Matter fulfills the promise of VR puzzle games. https://www.polygon.com/reviews/2020/3/27/21196839/the-room-vr-review-oculus-quest-rift-playstation-vr-vive-valve-index, 2020. Online; accessed 18-June-2021.

[83] G. Kumparak. A Brief History of Oculus. https://techcrunch.com/2014/03/26/a-brief-history-of-oculus/, March 2014. Online; accessed 18-June-2021.

[84] C. Lai, X. Hu, A. Segismundo, A. Phadke, and R. P. McMahan. The Comfort Benefits of Gaze-Directed Steering. In *2020 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, pages 102–103, 2020.

[85] S. Laitinen. Better Games Through Usability Evaluation and Testing. https://www.gamasutra.com/view/feature/130745/better_games_through_usability_.php?print=1, 2005. Online; accessed 12-July-2021.

[86] A. LaMeyer. An Update on Concerts in VR - Progress, But Not Perfection. https://amylameyer.medium.com/an-update-on-concerts-in-vr-progress-but-not-perfection-e3fc6772a7a7, September 2019. Online; accessed 18-June-2021.

[87] B. Lang. GDC 2014: Oculus Rift Developer Kit 2 (dk2) Pre-orders Start Today for $350, Ships in July. Road to VR https://www.roadtovr.com/oculus-rift-developer-kit-2-dk2-pre-order-release-date-specs-gdc-2014/, 2014. Online; accessed 18-June-2021.

[88] B. Lang. Social VR App 'VRChat' is Seeing Record Usage Amidst the Pandemic. Road To VR - https://www.roadtovr.com/vrchat-record-users-coronavirus/, 2020. Online; accessed 18-June-2021.

[89] B. Lang. Half-Life: Alyx Has Become Steam's Best & Most Rated VR Game Less Than a Year After Launch. https://www.roadtovr.com/half-life-alyx-steam-best-most-rated-game/, 2020. Online; accessed 18-June-2021.

[90] E. Langbehn, P. Lubos, G. Bruder, and F. Steinicke. Application of redirected walking in room-scale vr. In *2017 IEEE Virtual Reality (VR)*, pages 449–450, 2017.

[91] S. M. LaValle. Virtual Reality. In *Chapter 10 Interaction*, pages 283–312. Cambridge University Press, 2015.

[92] S. M. LaValle. Virtual Reality. In *Chapter 9 Tracking*, pages 245–282. Cambridge University Press, 2015.

[93] R. Lavoie, K. Main, and C. King. Virtual experience, real consequences: the potential negative emotional consequences of virtual reality gameplay. In *Virtual Reality*, 2021.

[94] F. Learn. Interaction techniques in VR. https://www.futurelearn.com/info/courses/construct-a-virtual-reality-experience/0/steps/96390, 2020. Online; accessed 18-June-2021.

[95] C.-C. Lee, K.-L. Hsiao, and C.-C. Chen. Exploring the benefit and sacrifice factors of virtual reality gameplay. *Frontiers in Psychology*, 11:251, 2020. ISSN 1664-1078. doi: 10.3389/fpsyg.2020.00251. URL https://www.frontiersin.org/article/10.3389/fpsyg.2020.00251.

[96] A. Lund. Norn. https://www.alexanderlund.se/norn/. Online; accessed 18-June-2021.

[97] A. Lund. Is Seeing Believing? A Study in Virtual Realities, Immersion and Game Design. 2017.

[98] P. Machine. Rules vs Mechanics. https://problemmachine.wordpress.com/2013/05/27/rules-vs-mechanics/, 2013. Online; accessed 18-June-2021.

[99] N. Machner. Virtual Climbing Application. *Master's Thesis - Vienna University of Technology*, 2018.

[100] S. Macy. Microsoft Flight Simulator Review. https://www.ign.com/articles/microsoft-flight-simulator-review, 2021. Online; accessed 18-June-2021.

[101] Manus. Prime II Motion Capture Gloves. https://www.manus-vr.com/mocap-gloves, 2020. Online; accessed 18-June-2021.

[102] D. Mason. What is motion sickness in video games and how can you prevent it? KITGURU - https://www.kitguru.net/gaming/damien-cox/what-is-motion-sickness-in-video-games-and-how-can-you-prevent-it/, July 2018. Online; accessed 18-June-2021.

[103] M. Matamala-Gomez, T. Donegan, S. Bottiroli, G. Sandrini, M. V. Sanchez-Vives, and C. Tassorelli. Immersive Virtual Reality and Virtual Embodiment for Pain Relief. *Frontiers in Human Neuroscience*, 13:279, 2019.

[104] S. Matovina and E. Johns. World's First Virtual Reality Department Store. https://www.ebayinc.com/stories/press-room/au/worlds-first-virtual-reality-department-store/, 2006. Online; accessed 18-June-2021.

[105] MDB. TRON: Legacy. https://www.imdb.com/title/tt1104001/?ref_=nv_sr_srsg_0, 2010. Online; accessed 18-June-2021.

[106] A. Meban. Immersive storytelling placing viewers beside refugees in boats, camps & detention centres. focus on refugees - https://focusonrefugees.org/immersive-storytelling-placing-viewers-beside-refugees-in-boats-camps-detention-centres/, June 2016. Online; accessed 18-June-2021.

[107] E. Mellou. Play Theories: A contemporary review. *Early Child Development and Care*, 102(1):91–100, 1994.

[108] Microsoft. Flight simulator. https://www.flightsimulator.com/, 2020. Online; accessed 18-June-2021.

[109] S. Miklaucic. John Carmack. Encyclopedia Britannica - https://www.britannica.com/biography/John-Carmack, August 2020. Online; accessed 18-June-2021.

[110] L. Nacke. Acagamic. In *The formal systems of games and game design atoms*, 2014. Retrieved from https://acagamic.com/courses/intro-to-game-design/the-formal-systems-of-games-and-game-design-atoms/.

[111] NASA. 3D resources. https://nasa3d.arc.nasa.gov/models, 2021. Online; accessed 04-July-2021.

[112] T. Nemeth. English Knight. In *Gamifying the EFL Classroom (Unpublished master's thesis)*, 2015. Retrieved from https://ludus.hu/en/gamification/.

[113] J. Nguyen, C. Smith, Z. Magoz, and J. Sears. Screen door effect reduction using mechanical shifting for virtual reality displays. In B. C. Kress and C. Peroz, editors, *Optical Architectures for Displays and Sensing in Augmented, Virtual, and Mixed Reality (AR, VR, MR)*, pages 200 – 210. International Society for Optics and Photonics, SPIE, 2020.

[114] J. Nolan, D. Harley, A. Walsh, and E. McQuiggan. Emerging Trends in Virtual Reality for Gaming: an assessment of best practices from research and development in the gaming industry.

[115] Oculus. Oculus store. https://www.oculus.com/experiences/rift/. Online; accessed 18-June-2021.

[116] Oculus. Oculus Guardian System. https://developer.oculus.com/documentation/native/pc/dg-guardian-system/, 2016. Online; accessed 18-June-2021.

[117] Oculus. Experience the next level of wireless vr. https://www.oculus.com/go/, May 2018. Online; accessed 18-June-2021.

[118] Oculus. Accessorie & Parts. https://www.oculus.com/quest/accessories/, 2019. Online; accessed 18-June-2021.

[119] Oculus. Explore oculus quest. https://www.oculus.com/quest/features/, 2019. Online; accessed 18-June-2021.

[120] P. A. Pallavicini F. Virtual Reality Games and the Role of Body Involvement in Enhancing Positive Emotions and Decreasing Anxiety: Within-Subjects Pilot Study. In *JMIR serious games*, 2020.

[121] M. Pavlovich. The Role of Playtesting in Game Design. https://www.gamesprecipice.com/role-of-playtesting/, 2014. Online; accessed 18-June-2021.

[122] C. Petrov. 43 virtual reality statistics that will rock the market in 2021. techjury - https://techjury.net/blog/virtual-reality-statistics/, May 2021. Online; accessed 18-June-2021.

[123] M. Phan, J. Keebler, and B. Chaparro. The Development and Validation of the Game User Experience Satisfaction Scale (guess). *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 58, 2016.

[124] D. Pickell. The 7 Stages of Game Development. https://www.g2.com/articles/stages-of-game-development, 2019. Online; accessed 18-June-2021.

[125] G. Play. Google Store. https://play.google.com/store. Online; accessed 18-June-2021.

[126] PlayStation. PS VR accessories. https://www.playstation.com/en-us/ps-vr/accessories/, 2016. Online; accessed 18-June-2021.

[127] S. Pradeep, A. Alexander, S. Narayanan, and N. Polys. Immersion and Engagement in a VR Game. *Virginia Tech*, 2016.

[128] X. qin Chang, D. hua Zhang, and X. xin Jin. Application of virtual reality technology in distance learning. *International Journal of Emerging Technologies in Learning (iJET)*, 11(11):76–79, 2016. ISSN 1863-0383. URL https://online-journals.org/index.php/i-jet/article/view/6257.

[129] P. Raut. Analysis of immersive virtual reality vs. desktop 3D games. Boston, Massachusetts : Northeastern University, 2018.

[130] V. R. M. Report. *Virtual Reality Headset Market Size, Share & Trends Analysis Report By End-device (Low-end, High-end), By Product Type (Standalone, Smartphone-enabled), By Application (Gaming, Education), And Segments Forecasts, 2021 - 2028*. Grand View Research, 2021.

[131] S. D. Resort. TRON Lightcycle Power Run - Presented by Chevrolet. https://www.shanghaidisneyresort.com/en/attractions/tron-lightcycle-power-run/, 2021. Online; accessed 18-June-2021.

[132] H. Reynolds. Three simple (but not obvious) tips on playtesting. https://mojo-nation.com/three-simple-not-obvious-tips-playtesting/, 2019. Online; accessed 18-June-2021.

[133] A. Riviere. How do you design your VR game around motion sickness constraints. *Gamasutra*, 2017.

[134] A. Robertson. HTC VIVE Review. The Verge - https://www.theverge.com/2016/4/5/11358618/htc-vive-vr-review, 2016. Online; accessed 18-June-2021.

[135] K. Rogers, G. Ribeiro, R. Wehbe, M. Weber, and L. Nacke. Vanishing Importance: Studying Immersive Effects of Game Audio Perception on Player Experiences in Virtual Reality. pages 1–13, 2018.

[136] A. Romano. Stuck at Home? These 12 Famous Museums Offer Virtual Tours You Can Take on Your Couch. Travel Leisure - https://www.travelandleisure.com/attractions/museums-galleries/museums-with-virtual-tours, 2020. Online; accessed 18-June-2021.

[137] D. Rudin. The stock market's roller coaster metaphor becomes literal thanks to VR. Kill Screen - https://killscreen.com/previously/articles/stock-markets-roller-coaster-metaphor-becomes-literal-thanks-vr/, April 2015. Online; accessed 18-June-2021.

[138] RYOT. Solitary confinement in 360 virtual reality. https://www.youtube.com/watch?v=nDwulYcboDU, September 2015. Online; accessed 18-June-2021.

[139] Samsung. Gear VR. https://www.samsung.com/global/galaxy/gear-vr/, 2015. Online; accessed 18-June-2021.

[140] A. Savage. Inside Valve: Making Half-Life: Alyx for Virtual Reality. https://www.youtube.com/watch?v=cRVXhA0-TI4, 2020. Online; accessed 18-June-2021.

[141] J. Schell. *The Art of Game Design: A book of lenses*. Taylor & Francis, 2008. Page 30.

[142] J. Schell. *The Art of Game Design: A book of lenses*. Taylor & Francis, 2008. Page 37.

[143] J. Schell. *The Art of Game Design: A book of lenses*. Taylor & Francis, 2008.

[144] ScienceDaily. Human Brain Loves Surprises, Research Reveals. Emory University Health Sciences Center - https://www.sciencedaily.com/releases/2001/04/010415224316.htm, 2021. Online; accessed 18-June-2021.

[145] V. Sense. VIVE Pro Specs & User Guide. https://developer.vive.com/resources/vive-sense/hardware-guide/vive-pro-specs-user-guide/. Online; accessed 18-June-2021.

[146] W. Shelstad, D. Smith, and B. Chaparro. Gaming on the Rift: How Virtual Reality Affects Game User Satisfaction. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, pages 2072–2076, 2017.

[147] D. Shin and S.-i. Kim. Homo Curious: Curious or Interested? *Educational Psychology Review*, 2019.

[148] N. Simon. What We Talk About When We Talk About Game Aesthetics. In *Proceedings of the 2009 DiGRA International Conference: Breaking New Ground: Innovation in Games, Play, Practice and Theory*. Brunel University, September 2009.

[149] A. Skandalis. Virtual reality has been boosted by coronavirus - here's how to avoid it leading us to dystopia. The Conversation - https://theconversation.com/virtual-reality-has-been-boosted-by-coronavirus-heres-how-to-avoid-it-leading-us-to-dystopia-141073, 2020. Online; accessed 18-June-2021.

[150] I. Staff. Inspire News and Articles. https://inspirerock.com/blog/inspiring-gear-scarpa-helix-shoes-black-diamond-solution-harnesses/. Online; accessed 18-June-2021.

[151] Steam. Half-Life: Alyx. https://store.steampowered.com/app/546560/HalfLife_Alyx/. Online; accessed 18-June-2021.

[152] Steam. Games with Space-Tag. https://store.steampowered.com/search/?term=space, 2021. Online; accessed 24-June-2021.

[153] S. Store. Lucid Trips. https://store.steampowered.com/app/389260/Lucid_Trips/, 2017. Online; accessed 18-June-2021.

[154] S. Store. To The Top. https://store.steampowered.com/app/509250/TO_THE_TOP/, 2017. Online; accessed 18-June-2021.

[155] S. Support. SteamVR Chaperone FAQ. https://support.steampowered.com/kb_article.php?ref=6281-TOKV-4722, 2021. Online; accessed 12-July-2021.

[156] D. Swinhart. Virtual reality has real problems. Here's how game developers seek to delete them. https://www.washingtonpost.com/video-games/2021/01/21/virtual-reality-2021/, 2021. Online; accessed 18-June-2021.

[157] S. Swink. Game Feel: The Secret Ingredient. https://www.gamasutra.com/view/feature/130734/game_feel_the_secret_ingredient.php, 2007. Online; accessed 20-June-2021.

[158] S. Swink. *Game Feel: A Game Designer's Guide to Virtual Sensation*. Amsterdam, Boston: Morgan Kaufmann Publishers/Elsevier, 2008.

[159] Y. Takahashi and A. Murata. Change of equilibrium under the influence of VR experience. In *Proceedings 10th IEEE International Workshop on Robot and Human Interactive Communication*, pages 642–647, 2001.

[160] J. Taylor. Virtual reality and the changing face of surgery. https://www.standard.co.uk/futurelondon/health/virtual-reality-in-surgery-a3998166.html, 2018. Online; accessed 18-June-2021.

[161] U. Technologies. Unity Game Engine. https://unity.com/. Online; accessed 18-June-2021.

[162] A. Thompson. The Importance of Video Game Narrative. https://sbanimation.com/the-importance-of-video-game-narrative/, 2021. Online; accessed 18-June-2021.

[163] S. Thompson. Motion Sickness in VR: Why it happens and how to minimise it. https://virtualspeech.com/blog/motion-sickness-vr, 2020. Online; accessed 18-June-2021.

[164] P. Thurrott. Over 2 Million People Have Played Microsoft Flight Simulator. https://www.thurrott.com/games/245159/over-2-million-people-have-played-microsoft-flight-simulator, 2020. Online; accessed 18-June-2021.

[165] O. Tiilikainen. The Pros & Cons of Virtual Reality in L&D. Valamis - https://www.valamis.com/blog/pros-and-cons-of-virtual-reality, 2021. Online; accessed 18-June-2021.

[166] ultraleap. Leap Motion Controller. https://www.ultraleap.com/product/leap-motion-controller/, 2013. Online; accessed 18-June-2021.

[167] T. Unige. Game Design Patterns. https://tecfa.unige.ch/tecfa/maltt/VIP/Ressources/Articles/Game%20Design%20Patterns/collection/Alphabetical_Patterns/CognitiveImmersion.htm, . Online; accessed 18-June-2021.

[168] T. Unige. Game Design Patterns. https://tecfa.unige.ch/tecfa/maltt/VIP/Ressources/Articles/Game%20Design%20Patterns/collection/Alphabetical_Patterns/ConsistentRealityLogic.htm, . Online; accessed 18-June-2021.

[169] T. Unige. Game Design Patterns. https://tecfa.unige.ch/tecfa/maltt/VIP/Ressources/Articles/Game%20Design%20Patterns/collection/Alphabetical_Patterns/Downtime.htm, . Online; accessed 18-June-2021.

[170] T. Unige. Game Design Patterns. https://tecfa.unige.ch/tecfa/maltt/VIP/Ressources/Articles/Game%20Design%20Patterns/collection/Alphabetical_Patterns/Downtime.htm, . Online; accessed 18-June-2021.

[171] Unity. Unity Manual: Coroutines. https://docs.unity3d.com/Manual/Coroutines.html, 2021. Online; accessed 08-July-2021.

[172] Valve. Steam store. https://store.steampowered.com/. Online; accessed 18-June-2021.

[173] L. Vanacken, T. Grossman, and K. Coninx. Multimodal selection techniques for dense and occluded 3d virtual environments. *Int. J. Hum.-Comput. Stud.*, 67(3): 237–255, Mar. 2009. ISSN 1071-5819. doi: 10.1016/j.ijhcs.2008.09.001. URL https://doi.org/10.1016/j.ijhcs.2008.09.001.

[174] E. Vasina. 7 Steps You Must Take to Succeed in VR Game Development. IT Craft - https://itechcraft.com/blog/vr-game-development/, 2021. Online; accessed 18-June-2021.

[175] VIVE. VIVE Tracker Developer Guidelines. https://developer.vive.com/resources/vive-sense/hardware-guide/vive-tracker-developer-guidelines/, . Online; accessed 18-June-2021.

[176] VIVE. VIVE Products. https://www.vive.com/us/product/, . Online; accessed 18-June-2021.

[177] VIVE. Viveport. https://www.viveport.com/, . Online; accessed 18-June-2021.

[178] VIVE. Vive Controller. https://www.vive.com/eu/accessory/controller/, 2016. Online; accessed 18-June-2021.

[179] VIVE. Vive Tracker. https://www.vive.com/eu/accessory/vive-tracker/, 2017. Online; accessed 18-June-2021.

[180] C. VR. Curriculum-aligned Virtual, Augmented & Mixed Reality Content. https://www.classvr.com/school-curriculum-content-subjects/, 2021. Online; accessed 18-June-2021.

[181] O. VR. The Leading Virtual Reality Surgical Training & Assessment Platform. https://ossovr.com/, 2021. Online; accessed 18-June-2021.

[182] T. Wien. Coronavirus: Rules of conduct at TU Wien. https://www.tuwien.at/en/tu-wien/corona, 2021. Online; accessed 12-July-2021.

[183] P.-M. Wiki. Pac-man. https://pacman.fandom.com/wiki/Pac-Man. Online; accessed 18-June-2021.

[184] A. M. Winderl. Indoor Rock Climbing 101; Everything You Need to Know Before Your First Visit to the Climbing Gym. SELF - https://www.self.com/story/indoor-rock-climbing-101, 2019. Online; accessed 18-June-2021.

[185] Youtube. Benson Arizona - John Yager. https://www.youtube.com/watch?v=WCoqOCvhSR0, 2014. Online; accessed 07-July-2021.

[186] Youtube. Echoes - Pink Floyd. https://www.youtube.com/watch?v=KBca3xf-j3o, 2015. Online; accessed 07-July-2021.

[187] Youtube. Mr. Spaceman - The Byrds. https://www.youtube.com/watch?v=3KFTm9vmZDI, 2021. Online; accessed 07-July-2021.