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ACCESS TO XR

Exploring the Potential of Immersive Experiences in Virtual Reality for Low Vision and Blind Users

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ACCESS TO XR

Exploring the Potential of Immersive Experiences in Virtual Reality for Low Vision and Blind Users

Dissertation in the context of the Master's Degree in Industrial and Product Design from the Faculties of Fine Arts and Engineering of the University of Porto, supervised by Professor Bruno Giesteira (PhD) and co-supervised by Researcher Filippo Talami.

Carla Sofia Madeira Gomes

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“Adoramos a perfeição, porque a não podemos ter; repugná-la-íamos, se a tivéssemos. O perfeito é o desumano, porque o humano é imperfeito.”

“We adore perfection because we cannot attain it; we would despise it if we had it. The perfect is inhuman, because the human is imperfect.”

Bernardo Soares (Fernando Pessoa), in Livro do Desassossego

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ABSTRACT

Vision impairments vary in their causes and degrees of severity, affecting people of all ages at different stages of life. According to the World Health Organization, about 2.2 billion people globally experience some form of eye condition. Virtual Reality (VR) is a versatile technology with applications in diverse areas such as entertainment, education, healthcare, rehabilitation and accessibility. As vision is the primary sense engaged in VR, this technology is generally not associated with blind and low vision users. However, by leveraging other senses, VR can be made accessible and beneficial for these individuals.

Therefore, the main purpose of this investigation is to explore how an enjoyable immersive experience in VR can be designed for users with low vision or blindness. The work begins by examining current best practices of accessibility within Human-Computer Interaction and VR, followed by the application of user research methods through a human-centered approach. The project ends with the prototyping and user experience assessment of an immersive experience. The study also provides insights on how to conduct and adapt user research, as well as enhance the overall accessibility of the technology for these users.

The outcome of this project is a set of guidelines for designers and developers to consider in their work, based on the gathered knowledge, to enhance the user experience. These guidelines focus on several key categories: improving the device; considerations for conducting user research with blind and low vision users; important factors for designing audio and visual content; appropriate application of haptic feedback; and enhancing overall accessibility for the entire VR experience, which can also be applied to other technologies and disabilities.

KEYWORDS

Human-Centered Design, Human-Computer Interaction, Accessibility, Virtual Reality,
Vision Impairments, Disability.

RESUMO

As deficiências visuais variam nas suas causas e graus de severidade, afetando pessoas de todas as idades em diferentes fases da vida. Segundo a Organização Mundial da Saúde, cerca de 2,2 mil milhões de pessoas em todo o mundo sofrem de alguma condição visual. A Realidade Virtual (RV) é uma tecnologia versátil, aplicada em diversas áreas, sendo utilizada para entretenimento, educação, saúde, reabilitação e acessibilidade. A visão é o sentido principal utilizado na RV, o que leva a que esta tecnologia não seja geralmente associada a utilizadores invisuais ou com baixa visão. No entanto, através da exploração de outros sentidos, a RV pode tornar-se acessível e benéfica para estes utilizadores.

Assim, o objetivo principal desta investigação consiste em explorar de que forma podemos desenvolver uma experiência imersiva agradável em RV, para utilizadores invisuais ou com baixa visão. O projeto começa com uma análise das melhores práticas atuais de acessibilidade, no âmbito da Interação Humano-Computador e da RV, seguida pela aplicação de métodos de *user research*, através de uma abordagem centrada no ser humano. O projeto termina com a prototipagem e avaliação da experiência do utilizador de uma experiência imersiva. O estudo também fornece conhecimentos sobre como realizar e adaptar a *user research*, assim como melhorar a acessibilidade em geral desta tecnologia, para estes utilizadores.

O resultado deste projeto é um conjunto de diretrizes, baseadas no conhecimento adquirido, para os *designers* e *developers* considerarem no seu trabalho, de modo a melhorar a experiência do utilizador. Estas diretrizes centram-se em várias áreas-chave: melhorar o dispositivo; considerações para a realização de *user research* com utilizadores cegos e com baixa visão; fatores importantes a ter em consideração no desenvolvimento de conteúdos visuais e áudio; aplicação adequada de feedback háptico; e, por fim, aspetos para melhorar a acessibilidade em geral de experiências em RV, que também podem ser aplicados a outras tecnologias e deficiências.

PALAVRAS-CHAVE

Design Centrado no Humano, Interação-Humano Computador, Acessibilidade, Realidade Virtual, Deficiência Visual, Deficiência.

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ACRONYMS

AR Augmented Reality

HCD Human-Centred Design

HCI Human-Computer Interaction

HMD Head-Mounted Display

MR Mixed Reality

VI Visual Impairments

VR Virtual Reality

XR Extended Reality

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CHAPTER 1
INTRODUCTION

Virtual reality (VR) is a term that refers to a computer-generated simulation of the real world in which the user is immersed. (Dix et al., 2004). This technology is applied to diverse areas such as health care, rehabilitation, entertainment, education and accessibility often offering multi-sensory experiences (XR Accessibility User Requirements, 2021; Zhao et al., 2019).

Vision Impairments (VI) are very common. According to the World Health Organization, around 2.2 billion people suffer from an eye condition (World Report on Vision, n.d.). Despite being more common in people over 50 years old, vision impairments can affect people of all ages, at any time of their lives (Eye Care, Vision Impairment and Blindness, n.d.).

As vision is the main sense used in VR, this technology is not generally associated with visually impaired users. Despite this, Vision Impaired people can also be included in the use of VR, by considering other senses, like audio sonification or haptic feedback, in the development of new VR experiences. The exploration of touchable and walkable VR for individuals who are blind or visually impaired began in the literature in 1997, with Max and Gonzales's work on "Navigable Virtual Reality Worlds for Blind Users, using Spatialized Audio". Throughout the late 1990s and early 2000s, significant research was carried out, aiming to make, for example, simple 3D geometric objects understandable. However, from a contemporary perspective, the technology available at that time was quite limited (Kreimeier & Götzelmann, 2020).

This dissertation aims to understand the difficulties of vision impaired users (more specifically blind or low vision) when using a VR headset, to then explore how an immersive experience for individuals with these needs could be designed. The aim is to reflect upon the topic and document some guidelines for designers and developers to consider in their future work, when designing and developing a new immersive VR experience.

1.1 Project Background

This dissertation was developed in collaboration with Fraunhofer Portugal AICOS, in the Human-Centred Design group, as part of the Master's Degree in Industrial and Product Design at the Faculties of Fine Arts and Engineering of the University of Porto (FBAUP/FEUP).

Associação Fraunhofer Portugal Research

The **Associação Fraunhofer Portugal Research** (Fraunhofer Portugal), is a non-profit private association founded in 2008 by **Câmara de Comércio e Indústria Luso-Alemã** and **Fraunhofer-Gesellschaft**, the largest organisation for applied research in Europe (Fraunhofer Portugal - About Fraunhofer Portugal, n.d.).

Focusing on the creation of scientific knowledge that generates added value for clients and partners, Fraunhofer Portugal explores technology innovations geared towards economic growth, social well-being and the enhancement of end-users' quality of life. By promoting and coordinating cooperation between its research centres, other research institutions and industry partners, Fraunhofer Portugal aims to undertake applied research directly beneficial to private and public enterprises, while also contributing to broader societal advancement (Fraunhofer Portugal - About Fraunhofer Portugal, n.d.). Fraunhofer Portugal is divided into two research centres, **AICOS** and **AWAM**.

The **Research Center for Assistive Information and Communication Solutions – AICOS** (Fraunhofer Portugal AICOS) is located in Porto and was born in 2009, following a partnership between the Fraunhofer Society (Fraunhofer-Gesellschaft), the Foundation for Science and Technology and the University of Porto (UP). Fraunhofer Portugal AICOS focuses its activity in a broad range of sectors, such as Health, Information and communications technology (ICT) & Electronics, Manufacturing and Public Administration. AICOS has consolidated competence in Human-Centred Design, Artificial Intelligence and Cyber-Physical Systems, therefore, the **Human-Centred Design Group** is part of Fraunhofer Portugal AICOS (Fraunhofer Portugal - Research Centers, n.d.).

The **Research Center for Advanced Water, Energy and Resource Management – AWAM** (Fraunhofer Portugal AWAM), has branches in Évora and Vila Real. AWAM was created in 2019 from a partnership between the Fraunhofer Society (Fraunhofer-Gesellschaft), the Foundation for Science and Technology (FCT), the University of Évora (UÉ) and the University of Trás-os-Montes and Alto Douro (UTAD). This research centre conducts applied research and development with a clear customer focus to provide cutting-edge solutions for a sustainable circular economy for a wide range of sectors such as agriculture, food and beverages production, (waste) water treatment, pulp and paper, (bio)energy and (bio)chemical industries (Fraunhofer Portugal - Research Centers, n.d.).

Fig.1.1. Fraunhofer Portugal Structure (Fraunhofer Portugal - About Fraunhofer Portugal, n.d.).

The **Human-Centred Design group** is a multidisciplinary group with researchers from various design fields (industrial, graphic, service), informatics and healthcare. The group is focused on guaranteeing that the voices of users are included in the design of digital technology, especially of those who are traditionally unheard, such as older and disabled adults, people with chronic illnesses, or shop floor operators, ranging from screen user interfaces to tangible objects, using participatory methods. This ensures that the proposed designs are appropriate, meaningful, efficient, inclusive and ethically sound. The HCD group specialises in designing for health and wellbeing at home, work and in clinical settings, regularly teaching these participatory methods to researchers and practitioners through the 'Learning from Users' course. (Fraunhofer Portugal AICOS - Human-Centred Design, n.d.)

1.2 Research Purpose and Motivation

The main purpose of this investigation is to explore how an immersive experience for people with Vision Impairments (VI) in Virtual Reality (VR) could be designed. Considering ableism (prejudice against people with disabilities), we were motivated to explore how VR could be enjoyable for these individuals. By investigating what could be incorporated to enhance accessibility, while raising awareness to the needs of these disabled individuals, we aim to develop guidelines for designers and developers to consider in their work, based on the gathered knowledge.

The investigation begins by a review of the existing literature and by examining current best practices. Following this, the project was carried out by using user research methods, to explore how and if an immersive experience could be designed for people with these characteristics. This promotes inclusivity by improving accessibility, challenging the idea that the number of people who benefit from accessibility in VR is not significant, as described by Heilemann et al., 2021.

How can an enjoyable immersive experience in VR be designed for Vision Impaired people? How can we enhance accessibility inside of VR for people with these impairments? How can user research be adapted to these individuals? - are the main questions to be addressed in this research.

1.3 Document Structure

The document is divided into seven chapters: Introduction; Literature Review; Methodology and Work Plan; Working with users; Prototyping and Testing; Results, Guidelines and Best Practices; Conclusions, Limitations and Future Work.

In Chapter One, **Introduction**, the context of the project, the research purpose, the work's motivation and the document structure are outlined.

Chapter Two, **Literature Review**, examines existing work in this field, along with key issues and essential concepts for understanding the project's problems and development.

Chapter Three, **Methodology and Work Plan**, explains the human-centered approach of this research, the methods contemplated and used to carry out the research, the work plan followed and the project phases.

Chapter Four, **Working with Users**, details the process and findings from the investigation conducted with users, prior to the prototyping phase.

In Chapter Five, **Prototyping and Testing**, the development of prototypes is detailed and explained, along with documentation of the findings from prototype's user experience evaluation with users.

Chapter Six, **Results, Guidelines and Best Practices**, summarises all investigation findings, translating them into learned lessons and guidelines on how to design immersive experiences, enhance comfort and accessibility for blind and low vision users in VR.

Finally, Chapter Seven, **Conclusions, Limitations and Future Work**, discusses the limitations of the work done, along with conclusions and suggestions for future research.

CHAPTER 2
LITERATURE REVIEW

In this chapter, the main topics and concepts are explored and researched, in order to understand how to meet the needs of the project (according to the investigation purpose). This includes an overview of the universe of Extended Reality (XR) and Virtual Reality (VR), an overview of the causes and consequences of Vision Impairments, the accessibility needs of these individuals, the current solutions within Human-Computer Interaction (HCI) and within VR. The chapter ends with a section about sound feedback and storytelling, introducing important concepts for the project development phase.

2.1 The XR universe: AR, MR and VR

2.1.1 What is Extended Reality (XR)

The term XR stands for Extended Reality, an umbrella term that encompasses all the immersive technologies, such as Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR) and the technology (hardware, software) used to create immersive environments. All three types of technology, AR, VR and MR, incorporate some level of spatial tracking to simulate a view of the virtual content and a way to navigate and interact with objects inside these environments (XR Accessibility User Requirements, 2021).

The term XR first appeared in the sixties, to designate Charles Wyckoff's silver-halide "XR" film, a project developed to photograph extremely bright light events, such as nuclear explosions. This term then migrated to designate a large spectrum of technology, being considered an "umbrella" term, as all devices with AR, VR and MR technology are considered XR devices (fig 2.1A) (What Is Extended Reality (XR) and How Is It Changing the Future?, n.d.). This results, to this day, in an unclear definition of the term XR (Rauschnabel et al., 2022).

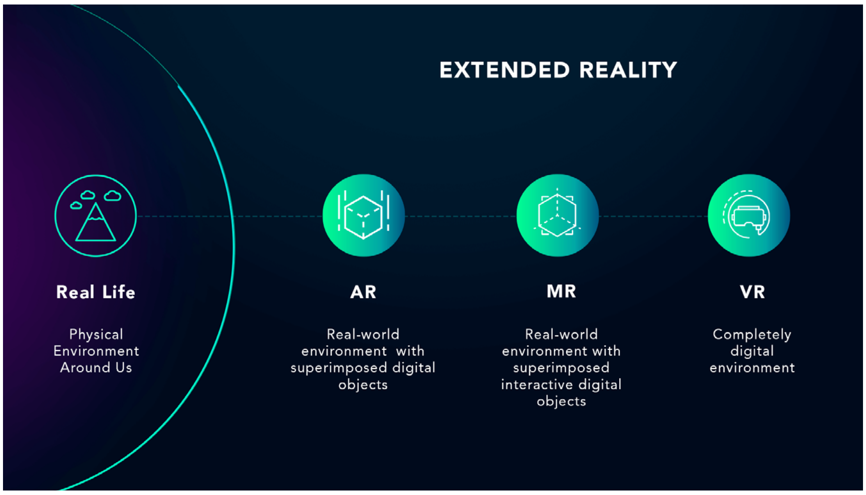

Fig 2.1A. The differences between AR, MR and VR (The Future of Community Media Is Extended Reality | Softengi.Com, n.d.).

Virtual reality (VR) refers to a computer-generated simulation of a real world in which the user is fully immersed (Dix et al., 2004). This technology is applied to diverse areas, from health care and rehabilitation to entertainment, offering multi-sensory experiences through visual, sound and haptic inputs (Zhao et al., 2019, XR Accessibility User Requirements, 2021).

Augmented Reality (AR) has been defined in various ways. In a broad and general way, it is a combination of digital information with the real world, presented in real-time through a device, such as a smartphone (Rauschnabel et al., 2022).

Mixed Reality (MR) results from the combination of AR and VR. VR is about immersion, using a headset to fully immerse the user in a game or experience. AR is about augmentation, using an app and a device to place a digital object, for example, in the user's living room, like it happens in the games Pokemon Go and Invizimals for PSP (What Is Extended Reality (XR) and How Is It Changing the Future?, n.d.). If the user is wearing a headset and the content they are viewing is in 3D and integrated into their surroundings, they are experiencing mixed reality (L'Italien, n.d.; qianw211, 2023).

All XR technology has a wide range of purposes, from work to entertainment or health and keeps evolving as hardware becomes financially more accessible and the experience more user-friendly (XR Accessibility User Requirements, 2021).

2.1.2 The History of VR into Today's World

Virtual Reality (VR) is a technology applied to diverse areas such as entertainment, education and accessibility, in constant growth and development (Zhao et al., 2019). To make VR a technology involved in everyday life, understanding how users interact with the virtual environment and how it enhances their sense of presence is crucial. Studying the user interface and haptic feedback is also important, as these features enable users to interact with the virtual environment, controlling objects as if they were in the real world (Kim, 2020).

Analysing human-centered psychology and social science is also becoming a common practice when designing and developing for VR (Kim, 2020). With further study and development, VR might transition from a niche product to a mainly used technology, enabling people to work, socialise and play from anywhere in the world. This versatility can be especially beneficial for people with certain disabilities or health conditions (Mott et al., 2020).

The idea of Virtual Reality was first experimented through panoramic paintings during the 19th century. These paintings were designed to fill the entire field of vision of the viewer, creating a sense of complete immersion in a historical event or scene ("History Of Virtual Reality," n.d.; Rauschnabel et al., 2022).

In 1840, Sir Charles Wheatstone was awarded the Royal Medal of the Royal Society for his research on binocular vision, which led him to invent the **Stereoscope** (fig. 2.1B). Through his research, he demonstrated that the brain combines two photographs of the same object, taken from different points of view, to create the illusion of depth and immersion (three-dimensional) ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

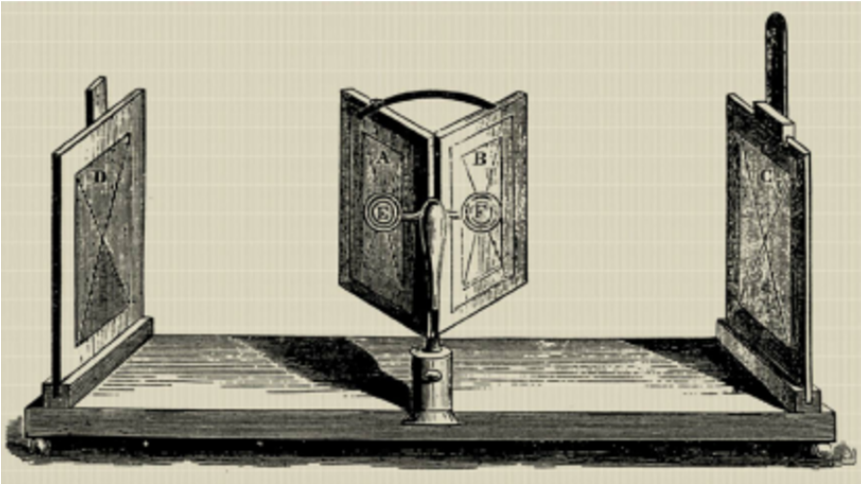

Fig 2.1B. "Charles Wheatstone-mirror stereoscope (XIX century)" (Figure 1. Charles Wheatstone-Mirror Stereoscope (XIX Century) [1]...., n.d.).

In 1929, Edward Link invented the **Link Trainer**, also known as **Blue Box** (fig 2.1C), which is considered to be one of the first commercial flight simulators, entirely electromechanical, simulating turbulence and other disturbances. Due to the need for safer pilot training methods, during World War II, more than 10 000 Link Trainers were used to train over 500 000 pilots ("History Of Virtual Reality," n.d.).

Fig 2.1C "Link Trainer Flight Simulator on Exhibit © NAS Fort Lauderdale Museum" (McElhiney, n.d.).

In 1956, Morton Heilig, a cinematographer, invented **Sensorama** (fig 2.1D), the world's first Virtual Reality machine, patented in 1962. The Sensorama was a large booth that could accommodate up to four people at once. It used a combination of various technologies to stimulate all senses. It included a full-colour 3D video, audio, vibrations, smell and atmospheric effects like wind ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

Fig 2.1D "Virtual Reality Machine, Sensorama, created by Morton Heilig in the 50s" (Figura 1. Máquina de Realidade Virtual, Sensorama, Criada Por Morton..., n.d.).

In 1960, Morton Heilig invented the **Telesphere Mask** (fig 2.1E), which was the first example of a head-mounted display (HMD). The headset offered stereoscopic 3D and wide vision with stereo sound, however, it was not interactive and lacked motion tracking ("History Of Virtual Reality," n.d.).

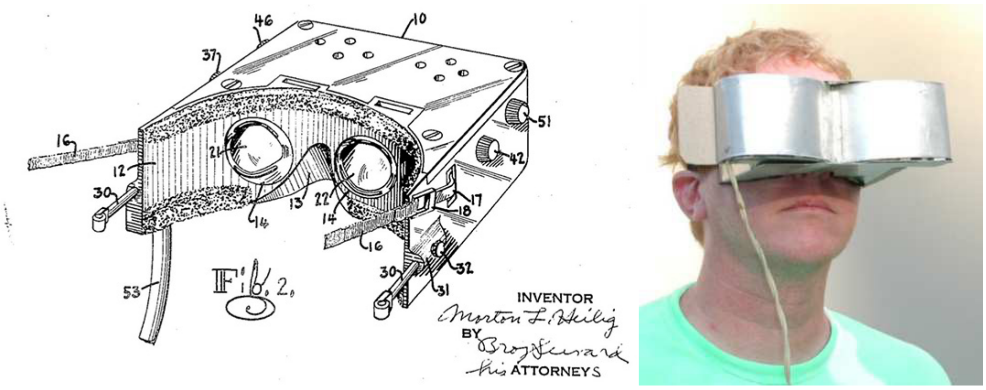

Fig 2.1E "Drawing from Telesphere Mask Patent" and "Telesphere Mask Demonstration" (neeru, 2017).

In 1965, Ivan Sutherland introduced the concept of the **Ultimate Display**, envisioning a virtual world experienced through a head-mounted display (HMD) so immersive that users could not distinguish it from reality. This idea included interactive elements, facilitated by computer hardware to generate and sustain the virtual environment in real-time. Sutherland proposed that the ultimate display would be a room where the computer could control the objects' existence, enabling users to interact with virtual objects in a lifelike manner. In his vision, everyday objects displayed in this room would function as they would in reality, offering users an immersive and realistic experience. This paper set the foundation for today's VR. In 1968, Ivan Sutherland and his student Bob Sproull developed the **Sword of Damocles** (fig 2.1F), the first head-mounted display (HMD) connected to a computer (instead of a camera). It was bulky and hung from the ceiling, requiring users to be strapped into the device. This HMD displayed primitive wireframe graphics of rooms and objects. However, despite its innovative tracking system, which adjusted the perspective of 3D models as users moved their heads, the Sword of Damocles remained a lab project due to its heavy design causing discomfort to users ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

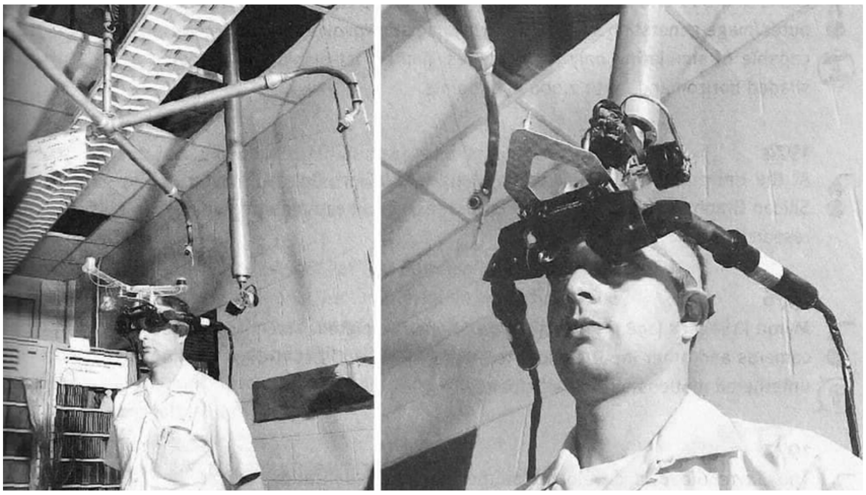

Fig 2.1F "Ivan Sutherland's head-mounted 3D display Sword of Damocles" (Figure 1, n.d.).

Even with significant advancements in Virtual Reality technology, there was still no single term to embrace the entire field. In 1985 Jaron Lanier and Thomas Zimmerman founded the **Visual Programming Lab - VPL Research, Inc.** and in 1987, Lanier came up with the term "Virtual Reality," giving the field a clear name. VPL Research developed a range of VR equipment, including the DataGlove, EyePhone HMD and the Audio Sphere. They were the first to sell VR goggles and gloves, marking a significant advancement in Virtual Reality technology, especially in haptics ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

In 1997, Georgia Tech and Emory University teamed up to use VR for treating PTSD in war veterans, which remains important to this day. Controlled exposure to traumatic triggers is key to managing PTSD symptoms. VR technology allowed therapists to control what patients see and experience. The researchers created war zone scenarios in VR to help veterans undergoing exposure therapy for PTSD. This was known as Virtual Vietnam ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

In 2010, Palmer Lucky created a "do it yourself" (DIY) VR headset kit that was accessible to everyone. Later, he met computer icon John Carmack, which boosted him to develop the groundbreaking "Oculus Rift". By 2012, Lucky launched a Kickstarter campaign to fund both the product and the advancement of his prototype headset, the Rift ("History Of Virtual Reality," n.d.).

In 2014, Facebook (now Meta) recognized the potential of Oculus technology and acquired the company from Lucky. Meanwhile, Sony revealed Project Morpheus, a VR headset in development for the PlayStation 4 (PS4). Around the same time, Google introduced Cardboard (fig 2.1G), an affordable DIY stereoscopic viewer for smartphones. Additionally, Samsung announced the Samsung Gear VR, which utilises a Samsung Galaxy smartphone as its display ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

Fig 2.1G Google Cardboard (Figure 2, n.d.).

In 2015, VR technology became increasingly accessible to the public, with various innovative experiences emerging, for example, the Wall Street Journal introduced a VR roller coaster tracking the Nasdaq Stock Market's fluctuations, while the BBC produced a 360-degree video offering a glimpse into a Syrian migrant camp. By 2016, numerous companies were developing VR products, many featuring dynamic binaural audio. Haptic interfaces remained underdeveloped, which means that handsets were typically button-operated. In 2017 multiple VR products were released, like the Rift and HTC Vive ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

By 2018, Virtual Reality technology had made significant progress and was being used in various fields. Apart from providing immersive gaming experiences, it was also being utilised for treating psychological disorders, imparting new skills and creating virtual journeys for terminally ill patients ("History Of Virtual Reality," n.d.; History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.). In 2019 standalone VR headsets already include Mixed Reality features. Advanced tech and smartphone-based VR projects started to decline as VR headset prices dropped and the necessary computer hardware became more readily available ("History Of Virtual Reality," n.d.).

In September 2020, Facebook (now Meta) introduced the Oculus Quest 2 during the Facebook Connect 7 event, receiving positive reviews. In 2021, Pico launched the Pico Neo 3 headset to compete with the Meta Quest 2. In June 2023, Apple announced its entry into the VR market with the Apple Vision Pro (fig 2.1I), a mixed-reality headset unveiled at the 2023 Worldwide Developers Conference (WWDC). In February 2024, the Apple Vision Pro officially launched in the US. Meanwhile, on June 1st, 2023, Meta introduced the Meta Quest 3 (fig 2.1H) featuring improvements in display quality, processing power and tracking capabilities compared to the Quest 2. (History of VR – Timeline of Events and Tech Development – VirtualSpeech, n.d.).

Fig 2.1H Meta Quest 3 (Meta Quest 3 128GB + Active Straps : Amazon.Co.Uk: PC & Video Games, n.d.).

Fig 2.1I Apple Vision Pro (Editor, 2024).

While gaming has made VR popular, its uses go beyond gaming. Many industries like healthcare, education, architecture and engineering find VR valuable. Surgeons use it for practice, students explore history and architects plan buildings virtually. Today, using VR is easier for consumers, although the hardware still needs improvement. Big companies like Meta, Sony and Samsung are investing in consumer VR and Apple, with its focus on user experience, can bring significant advancements to this technology (Cross, n.d.).

2.1.3 Developing for VR: The Software

There are many software that developers and designers use to develop for Virtual Reality (VR). The best option depends on the purpose of the work, the need to maximise compatibility with software and devices, etc.

According to Zhao et al., 2019, the major platform for VR app development is **Unity**. In addition, Unity is mentioned on all websites dedicated to the rating and description of VR development software. The software uses high-fidelity graphics, allowing the creation of advanced VR system applications. This makes it a widely used software to build games (like Pokemon Go). As it is a cross-platform tool, it also allows the creation of content compatible with multiple platforms and devices (PC, console, mobile and web)(PM, 2023). Unity also offers a learning portal, with courses on Unity development and a portal for support & services, enabling developers to access documentation and help (Davies, 2023).

Despite this, these other programs and software development kits (SDK) are also frequently mentioned: Unreal Engine, Blender, Maya, A-Frame, VRTK (SDK), OpenVR (SDK) and Eyeware Beam's software development kit (SDK) (Davies, 2023, p. 101010; L'Italien, n.d.; PM, 2023; Talentverse, n.d.; Top 10 Virtual Reality Software Development Tools, 2022).

Unreal Engine is a game engine available in a free, open-source version, also having a premium professional version, developed by Epic Games. This is a powerful tool for creating high-quality, interactive 3D content, mainly utilised by game developers, film studios and architectural visualisation companies. The engine is well known for its real-time rendering capabilities that allow highly detailed realistic environments and characters, supporting a variety of platforms, including Windows, Mac, iOS android and Linux (Talentverse, n.d.).

Blender is a free and open-source 3D creation program that supports the complete 3D pipeline - modelling, rigging, animation, simulation, rendering, compositing and motion tracking - and can even be used for video editing and game creation (Foundation, n.d.).

Maya and Blender are similar software. While Blender is open-sourced, Maya belongs to Autodesk and requires the acquisition of a licence, being one of the most used software, for example, in the film industry. This software is a professional 3D software for creating realistic characters and effects (from explosions to cloth simulations), also supporting the complete 3D pipeline. It also comes with a dedicated VR toolset, like VR cameras and VR animation, letting developers test and create VR content (Maya Software | Get Prices & Buy Official Maya 2024 | Autodesk, n.d.; Talentverse, n.d.).

A-Frame is a web framework based on top of HTML, for building VR experiences. A-Frame supports most VR headsets such as Vive, Rift, Windows Mixed Reality, Cardboard and Oculus Go and can also be used to develop augmented reality (Introduction, n.d.).

VRTK is a collection of scripts and concepts to aid in building VR solutions rapidly and easily in Unity3d 5+. These scripts help in a various number of solutions such as: locomotion and body physics in the virtual space; interactions with objects; and with Unity3d UI elements (among other features) (Welcome to VRTK, n.d.)

OpenVR is an API and runtime that enables access to VR hardware from various vendors, without applications needing specific knowledge about the targeted hardware. It's considered useful to develop in Unity (L'Italien, n.d.; ValveSoftware/Openvr, 2015/2024).

Beam's eye-tracking software development kit tracks the user's head and eyes, allowing developers to incorporate gaze-based interactions into their apps. The software uses computer vision and machine learning algorithms, providing precise and accurate gaze data in real time (PM, 2023).

2.2 Accessibility, Virtual Reality, Vision Impairments and Other Disabilities

2.2.1 Disability and The Impact of Ableism

Being disabled is part of being human. About 1 in every 6 people worldwide experience significant disability. This number is rising due to the increase of noncommunicable diseases. Disability is the result of health conditions such as dementia, blindness or spinal cord injury, which makes this a diverse group (Disability, n.d.).

Living with disabilities is different for each individual, according to their economic situation and health needs, which depend on sex, age, gender identity, sexual orientation, religion, race and ethnicity (Disability, n.d.). Two people with the same disability can be affected in a different way. Some disabilities may be hidden or unable to be seen (CDC, 2020). Generally this population has a decreased life expectancy, poorer health and more day to day limitations (Disability, n.d.).

Ableism is a concept that perpetuates a negative view of disabilities, created to describe the social prejudice and the discrimination against disabled people, similarly to racism or sexism, for example (Ableism, 2021). This type of prejudice is associated with a sense of superiority, harmful stereotypes, misconceptions and generalisations, considering disabled people as less capable, dependent, defected and/or inferior (Ableism, 2021; APA Dictionary of Psychology, n.d.; Eisenmenger, 2019). Caregivers can also be affected by this type of prejudice (Ableism, 2021). Ableism can manifest in many ways and on different levels, from simple day to day comments and interactions (as microaggressions, for example), to open hostility (Eisenmenger, 2019).

Being “normal” is considered to be non-disable. This shapes how we perceive physical or mental differences, which can be acquired by anyone throughout their life, but also leads to a lack of investment in accessibility (Ableism, 2021). Disabled people have a reduced access to transport, education, technology, culture, often suffering from unemployment and an increased risk of poverty (Ableism, 2021; Ableism, n.d.). However, ableism can also be present in the most subtle/common aspects, as choosing an inaccessible venue for a meeting, referring to disabilities as tragic or inspirational, asking invasive questions about someone’s condition, using the accessible bathroom leaving it unavailable, treating a person with a disability as a child, speaking for them or talking to someone about them instead of directly addressing the disabled person, assuming a disability is a visible condition, questioning the veracity of the condition and so on (Eisenmenger, 2019).

Understanding others’ limitations, capacities and emotions and having empathy towards others’ condition is essential for living in society and interacting with each other. However, understanding the challenges faced by individuals with impairments can be especially difficult for those who don’t experience such conditions (Maeda et al., 2022).

2.2.2 Diverse Disabilities, Different Needs

When talking about accessibility in Extended Reality (XR), there is a lack of implemented features such as screen readers for people with visual impairments or customised input devices for people with motor impairments, which leads to an exclusion of a large group of the population (Ji et al., 2023). Virtual Reality (VR) is a relatively new technology, with no accessibility framework or guidelines defined (Zhao et al., 2019). The idea that the number of people who benefit from accessibility in VR is not significant and the lack of training of developers in this topic, may be some of the reasons for poor accessibility. In addition, it can be challenging to develop for accessibility, as it is difficult to find the right balance between challenge and accessibility, due to the unique nature of impairments or the need to make fundamental changes in a game structure (Heilemann et al., 2021). Disabilities can be categorised into auditory, cognitive, neurological, physical, visual and speech. The term “Modality” relates to modes of sense perception such as hearing and touch. Modality has some inputs that help people with disabilities make the best of their senses in XR: speech, keyboard, switch, gesture and eye tracking (XR Accessibility User Requirements, 2021).

People with **Intellectual Disabilities** can benefit from the use of VR, as this type of technology helps with the acquisition of new skills, can improve learning and reduce the impact of the disability in the patient’s daily life. However, it is important to understand that in these types of disabilities, cognitive capacities, emotions and behaviour can vary throughout the experience and must be taken into consideration. Negative disturbances can occur when the user leaves the immersive environment into the real world, being important to explore the risk of XR technology to these users (Maran et al., 2022).

People with **Physical Disabilities** may encounter various challenges, such as configuring computer peripherals for traditional desktop systems, managing hand controllers if lacking a limb, or performing specific movements. Even the headset itself presents some problems with design. Besides being bulky and heavy, people who only have one hand may find it difficult to adjust it and for those who need a headrest in a wheelchair, the strap/the way it is attached to the head can make the glasses move, making the experience unpleasant[1] (Mott et al., 2020).

In terms of software, **WalkinVR Driver** is a software tool designed to make Virtual Reality Games and Applications more accessible to those with physical and neurological limitations. It allows players to interact in the virtual world in a variety of adaptive ways and provides a set of features to assist players with disabilities in adapting VR games to their needs[2] (*How WalkinVR Software for the Disabled Works*, n.d.).

When thinking of **Hearing Impairments**, stereo sound, mono audio channels and the need for subtitles must be features to consider (Heilemann et al., 2021).

Vision Impairments (VI), as previously described, can vary from different ranges of severity and can affect people in many different ways. Despite the complexity of vision conditions, the user experience problems start with people with near normal visual impairment, caused by common issues such as myopia and astigmatism. These users, who don’t require any special accessibility features in their daily lives, **can struggle with the discomfort of wearing glasses under a headset**, even with the accessory specifically designed for this purpose integrated into the device (Heilemann et al., 2021).

Some common interactions like teleportation in VR or fast movements may represent a trigger for users with **vestibular disorders**, **epilepsy** and **photosensitivity** (XR Accessibility User Requirements, 2021).

Users may experience one type of disability or multiple types concurrently. For instance, an individual with cerebral palsy might deal with both physical impairment and vision issues. Alternatively, another user might have good vision but struggle due to additional physical and/or intellectual disabilities (Cerebral Palsy - Symptoms and Causes, n.d.).

In Literature, it is considered good practice to enable users to adjust their input preferences, remap interaction keys and customise accessibility features, according to their **preferences** and **needs**. Designers should also understand how to **categorise**, **group** and **position** different accessibility features to maximise their use and potential (XR Accessibility User Requirements, 2021).

[1] https://youtu.be/14e0pZ8QyMA

[2] https://youtu.be/FHeVIJib-mk

2.2.3 Blindness and Low Vision

Eye conditions are very common, according to the World Health Organization around 2.2 billion people have vision problems. Out of this number, at least 1 billion people have vision problems that could have been prevented or still need to be addressed (World Report on Vision, n.d.). The rise in global population, longer life expectancy and the lack of adequate ophthalmological care, are the primary factors contributing to the increase of these numbers. The prevalence of blindness increases after the age of 60, with 90% of cases occurring in the poorest countries. Childhood blindness remains a significant issue in underdeveloped regions, where approximately 1.4 million children are affected, 90% of whom live in areas with the greatest need (Cegueira | CUF, n.d.). Children who experience severe visual impairment from an early age may face difficulties in educational achievement. In adults, lower levels of productivity, reduced participation and inclusion at work and higher rates of depression can negatively impact their quality of life. Families with lower and middle incomes may face fewer opportunities to access crucial eye care services (Eye Care, Vision Impairment and Blindness, n.d.).

Blindness is a general term used to describe people with low vision and legal blindness, having many types and causes, from injuries and infections to neurological or congenital conditions. Blindness can be categorised based on its cause or according to the level of blindness, that can be either complete or partial (Types of Blindness, 2023). Legally, blindness is defined as having a visual acuity of less than 1/10 in the better eye and/or a visual field of less than 10º (Cegueira | CUF, n.d.). **Total blindness** refers to individuals who have a complete absence of vision, without light perception, often documented as no light perception (NLP) (Lee & Mesfin, 2023). Despite this, some blind individuals, even with no visual potential, may be able to perceive light or luminous projections. In the first case, there is only the distinction between light and dark; in the second, the individual is able to identify the direction from which the light is coming (Cegueira | CUF, n.d.). **Low vision**, on the other hand, describes individuals whose vision cannot be fully corrected by conventional methods such as glasses, contact lenses, medication, surgery, or assistive devices. **Visual impairment** is a functional term used to describe individuals whose reduced visual function affects their ability to perform daily activities such as reading or driving, also including low vision and blind individuals (Lee & Mesfin, 2023). To be **congenitally blind** (since birth) or **adventitiously blind** (developed later in life as a result of accident, trauma, disease, medication, etc), is significantly different. It can be more difficult making sense of tactile maps for congenitally blind individuals than for adventitiously blind ones, as they have never acquired spatial perception by visually interacting with their environment (Ghali et al., 2012).

Colour blindness is the inability to see colours as most people, being hard to tell the difference between certain colours. Colour vision deficiency runs in families and has no cure, but most people with the condition can perform everyday activities with no problems. Despite this, special glasses and contact lenses can help differentiate between colours (Color Blindness | National Eye Institute, n.d.). People with low vision may find it easier to see solid and bright colours as these reflect the most light, but may struggle with the perception of subtle colours and patterns. If blindness was a consequence of an event later in life, the patient may remember what colours look like and recall them when listening to a description. If someone has been blind for their entire life, they may be able to understand colours as concepts, but they're unable to imagine them. Colour blindness is a different condition from blindness, despite the name. (Color Blindness | National Eye Institute, n.d.; Types of Blindness, 2023; What Do Blind People See?, 2023).

The World Health Organization classifies visual impairment based on visual acuity or visual field of the better seeing eye:

- **Normal**: 20/10-20/25;
- **Near Normal visual impairment**: 20/30-20/60;
- **Moderate visual impairment**: 20/70-20/160;
- **Severe visual impairment**: 20/200-20/400, or 11-20 degrees on visual field;

- **Profound visual impairment**: 20/500-20/1000 visual acuity, or 6- 10 degrees on visual field;
- **Near total visual impairment**: Counting fingers, Hand motion, Light perception, or 5 degrees or less on visual field;
- **Total visual impairment**: No light perception (Lee & Mesfin, 2023).

As mentioned before, there can be many different causes of blindness in newborns, children and adults (Types of Blindness, 2023). Worldwide, the leading causes for these conditions are cataracts, age-related macular degeneration, glaucoma, diabetic retinopathy and trachoma (Lee & Mesfin, 2023). However, users with vision impairments have a very big range of problems, from easily correctable issues, to more serious conditions (Ghali et al., 2012):

Both **Astigmatism** and **Myopia** are common vision conditions. In Astigmatism, some parts of the eye (either the cornea or lens) are more curved than they should, resulting in blurry vision at any distance (Astigmatism, n.d.). In Myopia near objects can be clearly perceived and farther away objects look blurry, due to the shape of the eye (or the shape of some parts of the eye) (Nearsightedness - Symptoms and Causes, n.d.). Most cases of astigmatism and myopia can be easily treated with eyeglasses, contact lenses and even refractive surgery (Astigmatism, n.d.; Nearsightedness - Symptoms and Causes, n.d.).

Nyctalopia commonly known as night blindness, results from the eyes' inability to adjust rapidly from lightness to darkness. Individuals with Nyctalopia experience challenges in seeing clearly under dim light and at nighttime. Daytime vision, however, is unimpaired (Mehra & Le, 2023).

Presbyopia is the gradual decline in the eyes' ability to focus on nearby objects, typically occurring as a natural aspect of ageing, usually noticeable in early to mid-40s, progressing until around the age of 65. It can be corrected with glasses, contact lenses and even surgery (Presbyopia - Symptoms and Causes, n.d.).

Diabetic Retinopathy is a condition that occurs in patients with diabetes that can cause blurry vision, the appearance of floating spots and blindness. In a more advanced stage, the blood vessels in the retina start to bleed into the vitreous (gel-like fluid that fills the eye), being crucial to get proper treatment instantly, as scars can form in the back of the eye, the blood vessels can start to bleed again, or the current bleeding can became worse. This condition can also lead to **diabetic macular edema** causing blurry vision, as the blood vessels leak fluid into the macula (a part of the retina responsible for sharp central vision); **neovascular glaucoma** occurs when abnormal blood vessels extend from the retina, obstructing fluid drainage from the eye. This can lead to a form of glaucoma, as it can result in the formation of scars in the back of the eye. These scars, when they pull the retina away from the back of the eye, are referred to as **tractional retinal detachment** (Diabetic Retinopathy | National Eye Institute, n.d.).

Glaucoma is a group of eye diseases where the optic nerve (a nerve behind the eye) is damaged, leading to the loss of peripheral vision, blind spots and ultimately blindness. There can be various types of glaucoma: open-angle-glaucoma, angle-closure glaucoma and congenital glaucoma. Early treatment is crucial and can often stop the damage and preserve the vision. However this condition has no cure (Glaucoma | National Eye Institute, n.d.).
Retinal detachment is a medical emergency that can lead to permanent vision loss. It's an emergency situation in which the retina (a thin layer of tissue in the back of the eye) pulls away from its normal position. Despite being painless, it can cause some early symptoms such as the sudden appearance of many floaters, flashes of light in one or both eyes (photopsia), a curtain-like shadow over the field of view, gradually reduced peripheral vision and blurred vision (Retinal Detachment - Symptoms and Causes, n.d.).

A **Cataract** is a cloudy area in the lens of the eye that makes the vision blurry, hazy, decreases the perception of colour and the ability to see at night and increases the sensitivity to light, leading to vision loss. This condition is very common at an older age and can be easily treated with surgery. It can be a result of ageing, can occur after an eye injury or surgery for another eye problem like glaucoma (Cataracts | National Eye Institute, n.d.).

A **Coloboma** is a missing tissue area in the eye, present since birth, affecting one or both eyes. People with Colobomas may experience light sensitivity, a keyhole or cat-eye-shaped pupil, nystagmus, low vision with reduced peripheral vision, a larger blind spot and difficulties with depth perception, partial vision loss or blindness (Coloboma, n.d.).

Nystagmus is a condition that usually happens in both eyes, where the eyes move generally fast, but varying between a slow and fast movement uncontrollably in three directions possible: side to side (horizontal), up and down (vertical) and in a circle (rotary). There can be congenital nystagmus (appearing between 3 and 6 months of age) or acquired nystagmus (appearing later in life). Other symptoms besides the rapid eye movement are sensitivity to light, dizziness, difficulty seeing in the dark and vision problems (What Is Nystagmus?, 2022).

Scotoma is the term used to refer to a visual field abnormality or blind spot, associated with other problems and diseases. These blind spots typically occur in one eye, however they can also affect both eyes. A scotoma may be an area on the retina where the nerves are not functioning correctly, therefore not sending the correct signals to the brain, resulting in a temporary or permanent impairment in a specific location. Signs and symptoms of a scotoma may include a blocked or disturbed spot in your vision, difficulty perceiving certain colours, the need for bright light to see well, eye floaters and flashes (What Is a Scotoma?, n.d.).

Anisocoria refers to the different sized pupils. The pupil allows light to enter the eye, which makes us able to see. Anyone can have pupils with different sizes with no associated problems. However it can signal other conditions like nervous system problems, eye damage history, increased stroke risk, viral infections, or a different light response in each pupil, called Adie's tonic pupil (What Is Anisocoria?, 2023).

Cone Dystrophy is a term used to classify a group of rare eye disorders which affect the cone cells in the retina, leading to various symptoms, including decreased visual clarity (acuity), reduced colour perception (dyschromatopsia) and higher sensitivity to light (photophobia) (Cone Dystrophy - an Overview | ScienceDirect Topics, n.d.; Cone Dystrophy - Symptoms, Causes, Treatment | NORD, n.d.).

Retinitis Pigmentosa is a term used to refer to a group of rare genetic eye diseases (occurring since birth) with no cure, that affect the retina by slowly breaking down the cells in the retina over time, causing the loss of peripheral vision, leading to tunnel vision and ultimately to vision loss. During this process people with this disease also experience sensitivity to bright light and loss of colour perception (Retinitis Pigmentosa | National Eye Institute, n.d.).

Keratoconus is an eye condition where the cornea, the clear front part of the eye, becomes thinner and gradually bulges outward into a cone shape, causing blurred vision and increased sensitivity to light and glare, usually affecting both eyes. This condition can progress slowly over 10 years or more and occurs between the late teens and 30 years of age. In the early stages, vision problems can often be corrected with glasses or soft contact lenses. As the condition advances, rigid gas permeable contact lenses or other specialised lenses, such as scleral lenses, may be required. In severe cases, a cornea transplant might become necessary (Keratoconus - Symptoms and Causes, n.d.).

Trachoma is caused by an obligate intracellular bacterium called Chlamydia trachomatis and is responsible for the blindness or visual impairment of about 1.9 million people, causing about 1.4% of all blindness worldwide, being, therefore, the leading infectious cause of blindness worldwide. It is an hyperendemic disease in many of the poorest and most rural areas of Africa, Central and South America, Asia, Australia and the Middle East (Trachoma, n.d.).

2.2.4 Current Accessibility Practices within HCI for People with Vision Impairments

Devices to assist individuals with vision impairments have been around for a long time. Glasses, contact lenses, braille code and white canes are well-known examples. Technology has evolved significantly, making it nearly impossible to carry out daily tasks without it. As a result, the necessity for assistive technology adapted to people with disabilities has become a reality. To assist visually impaired users in performing their daily tasks, software and hardware has been developed:

Screen readers are digital tools that use synthetic speech to read aloud computer screen content. They help users navigate through applications and websites and are commonly used by the blind. Screen readers repeat user keystrokes for constant feedback and work well with braille displays. Popular screen readers include **JAWS**, **NVDA** and **VoiceOver** (fig 2.2A; fig 2.2B) (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.; Wambolt, 2021).

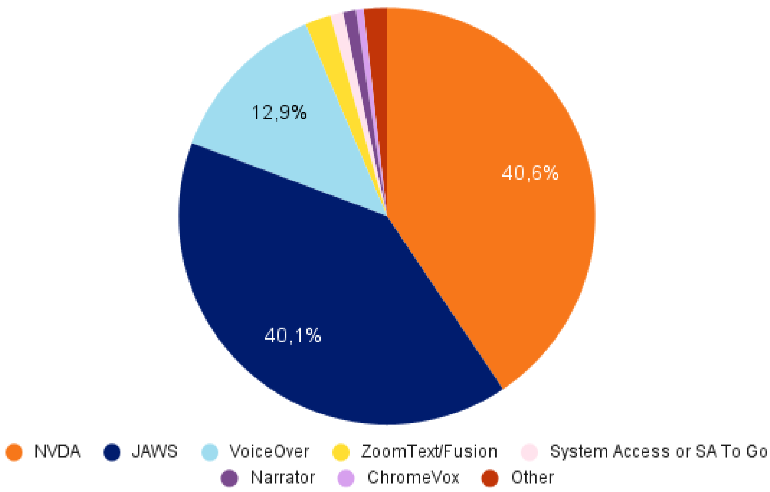

Fig 2.2A "Most common screen readers used for computers": percentage of use from the most common screen readers for computers - adapted (Wambolt, 2021).

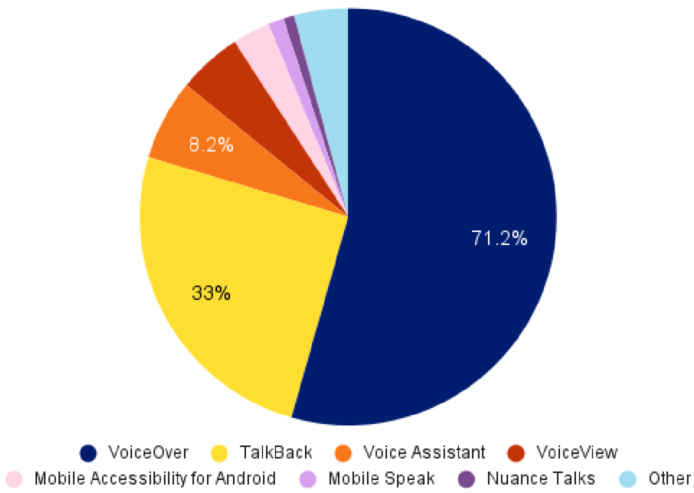

Fig 2.2B "Most common screen readers for mobile platforms": percentage of use from the most common screen readers for mobile platforms - adapted (Wambolt, 2021).

Virtual Assistants like **Google Assistant**, **Amazon Alexa** and **Siri**, can be incredibly useful for individuals who are visually impaired. These systems enable users to give voice commands that can be used to carry out a variety of tasks, such as obtaining information, sending messages and setting reminders (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.).

Apps powered by AI, such as **Microsoft's Seeing AI**, utilise computer vision for identifying and describing objects, individuals and surroundings in real-time. The technology proves to be especially useful in recognizing and comprehending the environment of the user (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.).

E-books that have accessibility features like **adjustable text size** and **screen reading compatibility** are also beneficial tools, as users can access a variety of reading materials. **Audiobooks** and **podcasts** are also alternative formats that can be used for consuming information. Developers and organisations are **making customizable** apps to meet the needs of individuals with blindness. These apps perform various functions like identifying colours and describing images (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.).

Braille displays (fig 2.2C) are electronic devices that convert digital text into Braille, enabling users to read content through touch. They can be directly connected to a computer or connected wirelessly, are silent and can be used in quiet environments. These devices also enable users to get a more accurate representation of what is being presented on the screen by allowing the identification of spelling, spacing and punctuation marks (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.; Wambolt, 2021).

Fig 2.2C Braille display (Rodriquez, 2019).

Navigation systems use mobile devices with GPS data and audio to provide directions and information about nearby points of interest. They are accurate outdoors but not indoors. **BlindSquare** and **Lazarillo** are GPS-based navigation apps that provide audible directions and information about nearby points of interest, helping individuals with blindness navigate their surroundings independently (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.; Wambolt, 2021).

Optical Character Recognition (OCR) allows printed or handwritten text to be converted into digital text. Those who are visually impaired can use OCR apps like **Abbyy Finereader**, or tools like S**canmarker Air pen** (fig 2.2D), to capture and transform text from digital PDF's or printed materials into speech or digital text (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.; Deals, 2022).

Fig 2.2D Scanmarker Air smart pen (Deals, 2022).

Tongue Interfaces help blind or low vision individuals to see using their tongue. The **BrainPort Vision Pro** (fig 2.2E) is an example of these devices. It captures images through a camera and transmits the data onto an array of electrodes placed on the user's tongue. With practice, users can interpret the object's motion, size, shape and location. It's a non-invasive method of providing visual stimulation (Wambolt, 2021).

Fig 2.2E BrainPort Vision Pro Tongue interface device (BrainPort Vision Pro | United States | BrainPort Technologies, n.d.).

The **Bionic Eye** is a device that requires surgical implantation into a patient's eye. During the procedure, the device's electrical components are placed discreetly within the eye, while the electrode array is carefully placed on the retina. Once the system is installed, the user can put on glasses with an attached camera. In a resumed way, the camera attached to the glasses sends wireless signals to the electrode array, which then sends electrical signals to the optic nerve. The **Argus II System** (fig 2.2F) is an example of these devices. Users have reported seeing flashes of light, reading large print and crossing streets. However, the device's 60 electrodes are insufficient to replicate real vision, as 1 million would be required (Wambolt, 2021).

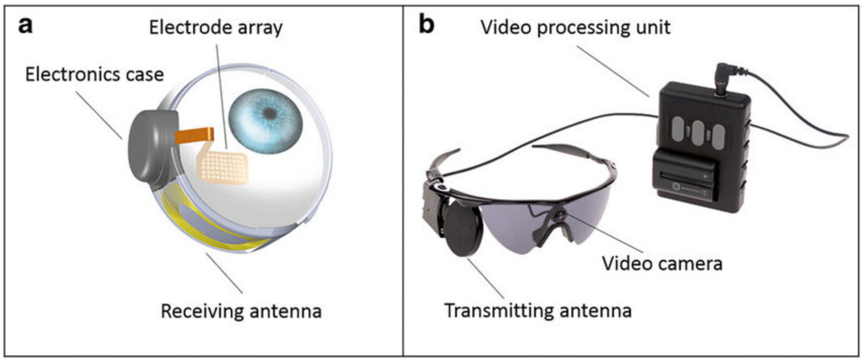

Fig 2.2F "The Argus II System. (a) Implanted components of the system. (b) External components of the system." (Figure 1. The Argus II System. (a) Implanted Components of the System...., n.d.).

Smart Glasses (fig 2.2G) combine augmented reality (AR) or mixed reality (MR) functionalities with a pair of eyeglasses, integrating a compact computer display and cameras. These glasses overlay digital data onto the physical environment, enabling users to interact with digital content hands-free. Despite not being developed particularly for disabled users, smart glasses may have the potential to assist those with visual impairments by offering real-time visual descriptions or reading assistance. Additionally, they can offer navigational support, object recognition and facial recognition thereby enhancing accessibility[3] (Ray-Ban Meta Smart Glasses | Meta Store, n.d.; What Are Smart Glasses and How Do They Work? | Nsflow, n.d.).

Fig 2.2G Ray-Ban Meta Smart Glasses (Ray-Ban Meta Smart Glasses | Meta Store, n.d.)

Blind and low visioned individuals use a variety of tools to meet their needs and preferences. As the effectiveness of these tools vary, they tend to use a combination of technologies (Can a person with visual impairment use Assistive Tech and AI tools in their daily life., n.d.).

[3] To further understand how a blind user could benefit from the use of the Smart Glasses, some feedback from a user with these needs can be viewed in https://youtu.be/HJdFWs7_YEs

2.2.5 Enhancing Accessibility: Virtual Reality Solutions for the Visually Impaired

When considering Virtual Reality (VR) and Visual Impairment (VI), it may not be immediately clear how the two are related. While vision is the primary sense used in VR, individuals with visual impairments can also benefit from VR technology (Kreimeier & Götzelmann, 2020). Although non-visual VR options exist for blind individuals through the use of auditory VR, this technology remains inaccessible for many people with visual impairments (Zhao et al., 2019).

To make this technology more accessible to people, several efforts have been made over the years. The following studies focus on very different dimensions of Virtual Reality, from social VR improvement and white cane controllers to sound based experiences.

Wielandm et al., 2023, focus their study in **social interaction through VR** (fig 2.2H). As social VR evolves, avatars are built in the most realistic way possible, incorporating non-verbal cues like eye contact (also referred as gaze). As these are non verbal cues, it can become hard for people with VI to perceive this type of interaction in a conversation. The eleven participants of this study had the following vision impairments: Cone dystrophy; Myopia and Nyctalopia; High Myopia; Nystagmus; Nystagmus since birth; Coloboma; Anisocoria, Retinal detachment; Keratokonus; Retinitis pigmentosa; Blind on left eye (Wieland et al., 2023).

To help participants perceive gaze, a total of five different cues, two visual (Visual Ray and Visual Flash), two auditory (Auditory Earcons and Auditory Icons) and one tactile, are implemented in a VR scene. This scene consists of an avatar engaging a conversation with the user. The goal is to explore how the presented cues are perceived and then evaluate their potential to improve the quality of a conversation (and consequently of the experience) in social VR (Wieland et al., 2023).

Fig 2.2H "SVR scene and visual cues. (a) shows the VR scene with an animated avatar sitting across from the participants. (b) Visual Ray cue that starts from the avatar's eyes and ends below the participant's head in VR. If the ray were to pass from eye to eye, it would obscure the entire scene for the participant. (c) Visual Flash cue briefly illuminates the scene with white light, while retaining the outline of the avatar's hair." (Wieland et al., 2023)

Zhao et al., 2019 developed a tool with a set of fourteen features to help low vision users surf a VR scene, called **SeeingVR** (fig 2.2I). Most of these tools were inspired by low vision technologies already implemented in the real world, allowing users to select, combine and adjust the different features, to suit their preferences and needs.

SeeingVR can be applied to an existing VR system via development or via post hoc modification approaches. The nine tools that augment VR apps through a post hoc plugin (without developers action) are: Magnification Lens, Bifocal Lens, Brightness Lens, Contrast Lens, Edge Enhancement, Peripheral Remapping, Text Augmentation, Text to Speech and Depth Measurement. The five tools presented in a Unity toolkit that require a developer's intervention are: Object Recognition, Highlight, Guideline, Recoloring and Assistive Apps (Zhao et al., 2019).

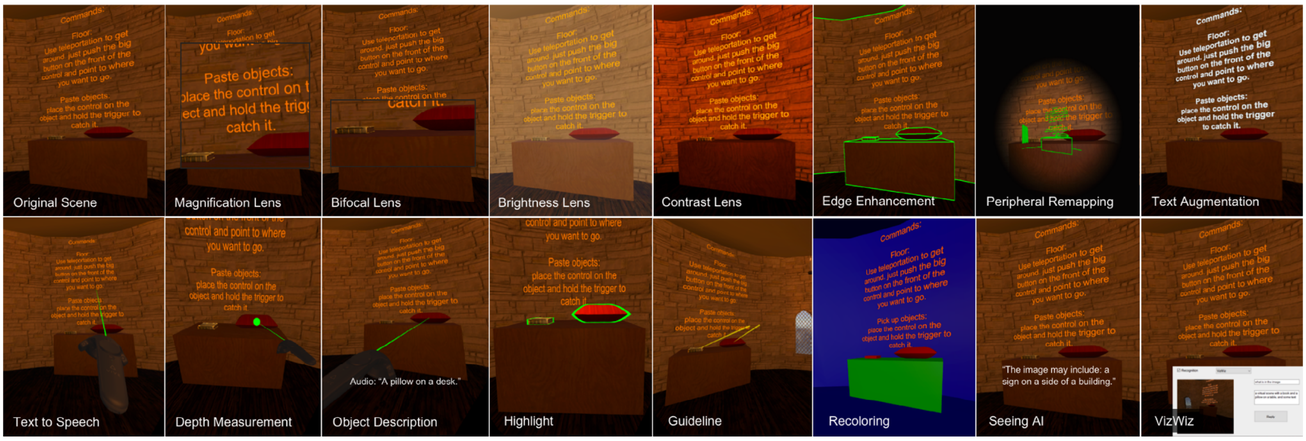

Fig. 2.2I "SeeingVR's 14 low vision tools. Tunnel vision in 'Peripheral Remapping' is simulated. The quote in 'Object Description' shows the read-aloud audio description. The quote in 'Seeing AI' shows the read-aloud audio description from the recognition API. The inset in 'VizWiz' shows a screenshot of the question received and the response provided by the human worker." (Zhao et al., 2019)

Zhao et al., 2018 designed **Canetroller** (fig 2.2J), a haptic cane controller coupled with spatial audio feedback, that allows Vision Impaired users to explore a VR scene using their real world cane knowledge. The controller provides three types of feedback to the user: Braking, Vibrotactile and Auditory.

Braking feedback occurs when the virtual cane hits a virtual object horizontally in the left-right direction. This mechanism generates physical resistance, preventing the controller from moving towards the object, thereby providing feedback regarding the boundaries of virtual objects. Vibrotactile feedback occurs when the cane hits an object or sweeps on a surface, simulating the corresponding impact, or texture vibration, that the user would experience in the real world. Auditory feedback occurs as the result of the interaction of the cane with the virtual world, simulating the sound from a real life interaction, depending, for example, from the type of surface, or the speed of collision with the object. The system supports different cane strategies: Shorelining, Two-point Touch and Constant Contact (Zhao et al., 2018).

The physical controller itself is short. However, It is possible to adjust its height in the virtual world, according to the user's needs: height adjustment; and how the cane is held (Zhao et al., 2018).

Fig. 2.2J "(A) A blind user wearing the gear for our VR evaluation, including a VR headset and Canetroller, our haptic VR controller. (B) The mechanical elements of Canetroller. (C) Overlays of the virtual scene atop the real scene show how the virtual cane extends past the tip of the Canetroller device and can interact with the virtual trash bin. (D) The use of Canetroller to navigate a virtual street crossing: the inset shows the physical environment, while the rendered image shows the corresponding virtual scene. Note that users did not have any visual feedback when using our VR system. The renderings are shown here for clarity." (Zhao et al., 2018)

Jinmo Kim 2020 developed **Visual Impairment Virtual Reality (VIVR)** (fig 2.2K), an immersive VR experience that consists of an outdoor walking experience environment with high immersion for Visually Impaired people, where the users walk along a road by recognizing braille blocks. The goal is for the user to classify the sidewalks and roadways where braille blocks are installed, finding an appropriate walking route. Having the controller attached to a white cane, both in real life and in the 3D scene, allows the user to surf the virtual scene in the most familiar way possible: through a white cane interaction as it would happen in the real world. The participants from this study have impairments such as glaucoma (resulting in a reduced visual field) and cataracts (gradually blurry vision that leads to total vision loss) (Kim, 2020).

Fig. 2.2K "Immersive walking experience environment and application system structure of the proposed VIVR." (Kim, 2020)

Torres Gil et al.,2010 created **Virtual Reality Simulator for Sonification Studies (VRS3)** (fig 2.2L) an acoustic based walking through environment experience. The goal is for users to navigate the scene by receiving audio information, while using a 3D tracking system to locate their head orientation and position. The idea is to collect the information relative to the distance between the user and the virtual objects, transforming this data into sound (sonification process) and was also inspired by a previous project called "Virtual Acoustic Space". Instead of a "traditional" Head-Mounted Display (HMD) device, for this study a set of other devices were used: a magnetic field based tracker, for tracking (the Polhemus Fastrak); an antenna (the LongRanger), to cover the full simulator room; a 3d distance sensor (glasses), a pair of headphones, with one small probe attached to the diadem for the auditory rendering; and the control and sound generation hardware.

The previous research and literature stated in this study reference various devices that provide auditory spatial information to assist blind users with orientation and mobility. Some of these studies also investigate the user's ability to recognize the shape of an object through sound information (Torres Gil et al., 2010).

Fig. 2.2L "Picture of a user performing a training task, moving around fake walls and columns and trying to identify the whole environment; The final prototype was composed by a 3d distance sensor (glasses), the control and sound generation hardware and a pair of headphones." (Torres Gil et al., 2010)

2.3 Sound and Storytelling

2.3.1 Sonification and Audio Feedback - Introducing Concepts

Sonification and visualisation by sound have been the subjects of research for several years and have been implemented in software for visually impaired individuals. The fundamental concept is to represent graphics, line graphs, or even photographs through non-speech sound. By adjusting various sound attributes such as pitch, volume and waveform, the sound is modified to match its visual equivalent. Over the course of a decade, more than 400 audio games have been developed, which is a relatively small number compared to video games (Ghali et al., 2012)

Derived from the domain of sonification came two types of auditory cues, **earcons** and **icons**. Earcons are sounds that don't have any association with real-world sounds, while icons are sounds that have real-world equivalents (Wieland et al., 2023). These cues enhance usability of the system or device they're applied to ("Earcon - Explore the World of Earcon on Sonic Minds," n.d.).

Auditory **icons** are brief sounds that represent an event, object, function, or action. These cues use everyday sounds that people recognize and link to specific events, being easy to understand. For example, when you empty the trash on your Mac or lock your iPhone, you hear a sound that mirrors the action in the real world ("Earcon - Explore the World of Earcon on Sonic Minds," n.d.). **Earcons** are structured sounds that represent an event or giving information/feedback to the user. These are generally synthesised tones or sound patterns that have no direct relationship to the event, but instead are a representation of the event. For instance, you hear an earcon when you type a message, when you get an error message or send an email (table 2.3A).

	Function	
Type of Alert	**Driving Headway Closing**	**Driving Low Tire Pressure**
Auditory Icons	Sound of a vehicle crashing	Air release blast sound
Earcon	Three ascending notes	Low rate, low pitch warbling tone
Speech	Spoken phrase "headway closing"	Spoken phrase "tire pressure low"
Spearcon	Accelerated spoken phrase "headway closing"	Accelerated spoken phrase "tire pressure low"
Other/Hybrid	Earcon + speech combined	Earcon + speech combined

Table 2.3A "Examples of Each Type of Alerting Approach in a Driving Application" - adapted (Nees & Liebman, 2023)

2.3.2 Ambisonics

The concept of Ambisonic sound was first developed in the mid-1970s by a small group of British researchers, including Michael Gerzon from Oxford's Mathematical Institute and Professor Peter Fellgett from the University of Reading. They designed a system to reproduce recordings made with a specialised 'Soundfield' microphone or mixed in 3D surround, reproduced over a minimum of four speakers. This technology allowed for an immersive sound experience, capturing the direction, distance and height of the recorded sound (What Is Ambisonics?, n.d.).

Ambisonics is a multichannel spatial audio format that captures and reproduces a full three-dimensional sound field. Unlike traditional surround sound systems that create a 2D sound circle around the listener, Ambisonics can render sounds from above and below the listener as well. This format is particularly effective for creating a detailed and immersive soundscape with higher spatial resolution than typical surround sound formats. Ambisonic audio is not limited to field recordings: by using mixing tools, It is possible to create custom 3D soundscapes by positioning and moving mono, stereo and surround tracks within the sound field (Fumo, n.d.).

Recording Ambisonics content typically involves using sound field microphones, known as A-format recordings. Because recording in A-format can be expensive and technically complex, B-format can be synthesised from regular audio recordings, such as mono, stereo, or multi-channel (5.1 or 7.1). This synthesis can be done using plugins that allow precise positioning of each sound element in the sound field (Fumo, n.d.; IMMERSIVE AUDIO: AMBISONICS AND DAW PLUGINS, n.d.).

The basic form of Ambisonics, known as "first order," uses four channels: W, X, Y and Z. The W channel contains the total sound from all directions, while the Y, X and Z channels represent the left/right, front/back and up/down spatial information, respectively. Combining these channels creates a full 3D sound field. This four-channel B-format can be extended to higher spatial resolutions (Higher Order Ambisonics - HOA), requiring 10, 16, or more channels for greater spatial detail (table 2.3B). Playing a 7th-Order mix, for example, means more control of the atmospheric sound and would require a system of 64 units, which is rarely found in studios but can be enjoyed with headphones when decoded to a binaural 3D format (Fumo, n.d.; IMMERSIVE AUDIO: AMBISONICS AND DAW PLUGINS, n.d.).

High Order	Speakers (output channels needed)
1st	4
2nd	9
3rd	16
4th	25
5th	36
6th	49
7th	64

Table 2.3B Output channels needed for every High Order (IMMERSIVE AUDIO: AMBISONICS AND DAW PLUGINS, n.d.)

Encoding involves processing A-format recordings into B-format. If the original recordings are not in Ambisonics (A-format), encoding refers to converting mono or stereo audio using a program or plugin that enables the audio to mimic the effect of having been recorded with Ambisonics microphones. Decoding, on the other hand, involves converting B-format audio into signals for loudspeakers or binaural 3D audio for headphones. This allows the audio to be transformed into standard surround and 3D surround formats used in film and television, such as Dolby Atmos, IMAX, or Auro 3D, as well as binaural stereo or Higher-order AmbiX for VR and AR applications (IMMERSIVE AUDIO: AMBISONICS AND DAW PLUGINS, n.d.).

2.3.3 Storytelling

Storytelling, by definition of the Oxford Languages Dictionary, is "the activity of telling or writing stories". The act of storytelling serves as a way to connect and build a sense of community. Overtime and across different societies, the purpose and parameters of storytelling have evolved, but its importance in fulfilling social and individual needs remains constant. Research has shown that exposure to stories and the structure of storytelling can improve comprehension, increase content recall and enhance vocabulary, language fluency, as well as reading and writing skills (Negro, 2021). Stories also have the power to help people understand and relate to others, building empathy towards different situations and realities (Literacy, 2020).

"Oral storytelling is the original immersive technology", according to Sherry Norfolk and Lyn Ford (Negro, 2021). For many people, reading or listening to stories is the preferable way of entertainment, especially nowadays, with audiobooks and podcasts, It is even possible to listen to stories while exercising, commuting or travelling (Literacy, 2020). For effective storytelling, entertainment is essential (Spaulding, 2011).

"Voici ce que j'ai pensé : pour que l'événement le plus banal devienne une aventure, il faut et il suffit qu'on se mette à le raconter. C'est ce qui dupe les gens : un homme, c'est toujours un conteur d'histoire, il vit entouré de ses histoires et des histoires d'autrui, il voit tout ce qui lui arrive à travers elles ; et il cherche à vivre sa vie comme s'il la racontait."

"Here's what I thought: for the most banal event to become an adventure, you have to start telling it. That's what fools people: a man is always a storyteller, he lives surrounded by his stories and the stories of others, he sees everything that happens to him through them; and he tries to live his life as if he were telling it."

Jean-Paul Sartre, in La Nausée

2.4 Discussion

Virtual Reality (VR) is a versatile technology that can be engaging for both adults with and without impairments. It offers a unique way of gaming, enables social experiences in virtual spaces and allows users to enjoy digital content with an enhanced sense of presence. VR is also valuable for professional applications such as medical training, rehabilitation and 3D visualisation and modelling. Furthermore, it has the potential to provide different experiences to hospitalised patients, individuals with certain disabilities and elderly people with reduced mobility. However, the technology still requires further development, especially in terms of accessibility.

Research on VR began in the 20th century as technology became more widespread and advanced. Nowadays, there are various devices with different price ranges and purposes, from VR to MR headsets. In developing for VR, there is a diverse set of software that can be used and even combined to achieve the desired results. Despite this, Unity is widely used for development, as it has a great set of available assets and extensive documentation and support for project implementation.

Being disabled is often viewed negatively, but it is as normal as being non-disabled. In fact, as we get older or as a consequence of accidents at any stage of life, one can become disabled. Additionally, not all disabilities are visible. A disabled person simply has a different reality from a non-disabled person. In an ideal world adapted for every individual, or in a society properly educated and informed on all types of disabilities, would we still think of disabled individuals as inferior?

There are various types of disabilities that can be categorised into auditory, cognitive, neurological, physical, visual and speech impairments. An individual may experience one or multiple types of disabilities simultaneously. The same disability can also affect two individuals in different ways, while two different disabilities in two different individuals can affect them in similar ways. Vision Impairments are relatively common and can vary in degree of visual capacity. They can be congenital or adventitious, with a wide range of possible causes. Fortunately, there are devices and apps available to enable visually impaired users to perform daily activities in a similar way to non-disabled individuals.

In Virtual Reality, to enhance accessibility, interesting studies have been conducted in different VR areas such as: social VR interactions with incorporated non-visual gaze cues; complementary features to help low vision users surf a 3D environment; white cane controllers; training environments; and the use of sound to represent data.

Storytelling is consciously and unconsciously used by people, from marketing campaigns to the latest personal incident shared to friends. Incorporating storytelling while planning for VR can be an approach worth exploring, especially when looking to emphasise senses other than sight.

CHAPTER 3
METHODOLOGY AND WORK PLAN

In this chapter, a contextualization of the human-centered approach is presented, along with the methods contemplated to conduct the research and the project's schedule plan. The work started on the 11th of September 2023 and ended on the 5th of July 2024. For this study, as a project integrated in the Human-Centered Design Group of Fraunhofer Portugal AICOS, user research methods were applied.

3.1 Human-Centered Design and Human-Computer Interaction

Human-Centered Design

Early computers were notoriously difficult to operate and required specialists to manage them in controlled settings. However, by the 1980s, smaller computers became more accessible to the general public, nonetheless the people lacked specialised knowledge. This shift highlighted usability issues and the necessity for designers to consider the users needs, eliminating ambiguity. Rather than focusing solely on interface aesthetics, designers needed to prioritise human needs, to predict and accommodate human behaviour through intuitive system design and align with circular economy principles to maximise resource efficiency and sustainability. With this, a human- or people-centered design approach arised (What Is Human-Centered Design (HCD)?, 2024).

According to Don Norman, **Human-Centered Design (HCD)** is an approach that focuses on prioritising human needs, capabilities and behaviours in the design process. It starts with understanding psychology and technology and emphasises clear communication from machine to user indicating possible actions, current events and upcoming changes. HCD is a design philosophy that begins with a deep understanding of people and the needs the design aims to fulfil. This understanding is primarily gained through observation, as people are often unaware of their true needs and the challenges they face. Defining the specifications of the product's needs is one of the most challenging aspects, so the HCD principle is to avoid specifying the problem at an early stage and instead to iterate through rapid testing and refining ideas, modifying both the approach and the problem definition after each test (Norman, 2013).

HCD is a philosophy and a set of procedures, while **Experience design**, **Industrial design** and I**nteraction design** are specific areas of focus. To Norman, **Experience design** involves creating products, processes, services, events and environments with an emphasis on the quality and enjoyment of the overall experience (Norman, 2013). Victor Papanek described **Industrial Design** as the practice of analysing, creating and developing products for mass production. To the author, this discipline's goal is to ensure product forms are accepted, before significant capital investment is made and so these products can be manufactured cost-effectively for wide distribution with reasonable profits. During World War II, industries like automobile manufacturing shifted to war production, facing stringent performance requirements imposed by combat conditions. This led industrial designers to prioritise functionality over sales (Papanek, 1985). Nowadays, Don Norman defines industrial design as the professional service of creating and developing concepts and specifications that optimise the function, value and appearance of products and systems for the mutual benefit of both users and manufacturers (Norman, 2013). **Interaction design**, according to Jennifer Preece, Yvonne Rogers and Helen Sharp, involves crafting interactive products that support people in their daily and professional lives, creating user experiences that enhance and extend how they work, communicate and interact (Preece et al., 2002). Don Norman emphasises that interaction design focuses on how people engage with technology, aiming to improve their understanding of "what can be done, what is happening and what has just occurred". This field combines principles from psychology, design, art and emotion to create a positive and enjoyable user experience (Norman, 2013). Alan Cooper highlights that interaction design focuses on understanding what the user wants. With this knowledge designers can create more effective and user-friendly products that outperform feature-heavy but poorly designed alternatives. To this author, anticipating user behaviour before the initial release of the product helps avoid committing to non-optimal strategies (Cooper et al., 2007).

Human-centered design (HCD) is guided by four principles:

1. **People-centered**: Focus on individuals and their context to create appropriate solutions, incorporating participatory design to involve users in the process.
2. **Understand and solve the right problems, the root problems**: Identify and address the root causes and fundamental issues, so the symptoms don't keep returning.
3. **Everything is a system**: View everything as a system of interconnected parts.
4. **Small and simple interventions**: Implement iterative work, not rushing the solution. Making small and simple changes while learning from each new iteration will slowly lead to bigger and better results. The iterative process of prototyping, testing and refinement ensures that the small solutions effectively meet user needs (What Is Human-Centered Design (HCD)?, 2024).

As previously discussed , HCD is an approach that ensures solutions are tailored to human needs, cultures and societies, emphasising a people-centric approach, with the goal to create inclusive solutions. **Inclusive design** is a design process that acknowledges and values individuals' diverse backgrounds and abilities. This means creating products usable by people with hearing, visual, motor or cognitive impairments, thus fostering a more inclusive community (What Is Human-Centered Design (HCD)?, 2024; NNgroup, 2019).

Human-Computer Interaction

Technology has the capacity to simplify life and make it more enjoyable as every emerging technology brings new and greater benefits. Nevertheless, the more complex the technology becomes, the more difficult and frustrating it can be to use (Norman, 2013). Through the rapid development of technology and the emergence of computers, researchers began studying the interaction between people and computers. This research originally went under the name of man-machine interaction, which later became known as **Human-Computer Interaction (HCI)** (Dix et al., 2004). HCI "involves the design, implementation and evaluation of interactive systems in the context of the user's task and work" (Dix et al., 2004).

The study of human performance dates back to the early 80s, with its beginning in the 19th century, with an emphasis on manual tasks in factories. During World War II, the interaction between each side's weapons systems led to a wave of interest in ergonomics research. This led to the formation of the Ergonomics Research Society in 1949 (Dix et al., 2004).

HCI is a wide-ranging and interdisciplinary field that "involves the design, implementation and evaluation of interactive systems in the context of the user's task and work" (Dix et al., 2004). In other words, it concentrates on designing and using computer technology, with a focus on the interactions between users and computers. This extensive area combines various disciplines, including user-centered design (UCD), user interface design (UI) and user experience design (UX). While HCI initially focused on computers, it now encompasses nearly all types of information technology design (What Is Human-Computer Interaction (HCI)?, n.d.)

3.2 User Research Methods

The field of User Experience offers a broad spectrum of research methods, which can be categorised into a three-dimensional framework:

1. Attitudinal vs. Behavioral:

This axis distinguishes between what people say versus what they do, which often differs significantly. Attitudinal research aims to understand or measure people's stated beliefs, but is limited by participants' self-awareness and willingness to report accurately (Experience, n.d.-c, n.d.-a).

2. Qualitative vs. Quantitative:

Qualitative studies generate data about behaviours or attitudes based on direct observation or listening, (with data analysis typically being non-mathematical), while quantitative studies gather data indirectly through tools like surveys or analytics (which are analysed mathematically). Qualitative methods are better in answering questions like "why" or "how", while quantitative methods are better suited for questions like "how many" or "how much". This data helps prioritise resources, as focusing on issues with the biggest impact (Experience, n.d.-c, n.d.-a).

3. Context of Product Use:

This axis considers the context (how and whether) in which participants use the product and can be described as:

- Natural or near-natural use of the product;
- Scripted use of the product;
- Limited in which a limited form of the product is used to study a specific aspect of the user experience;
- Not using the product during the study (decontextualized) (Experience, n.d.-c, n.d.-a).

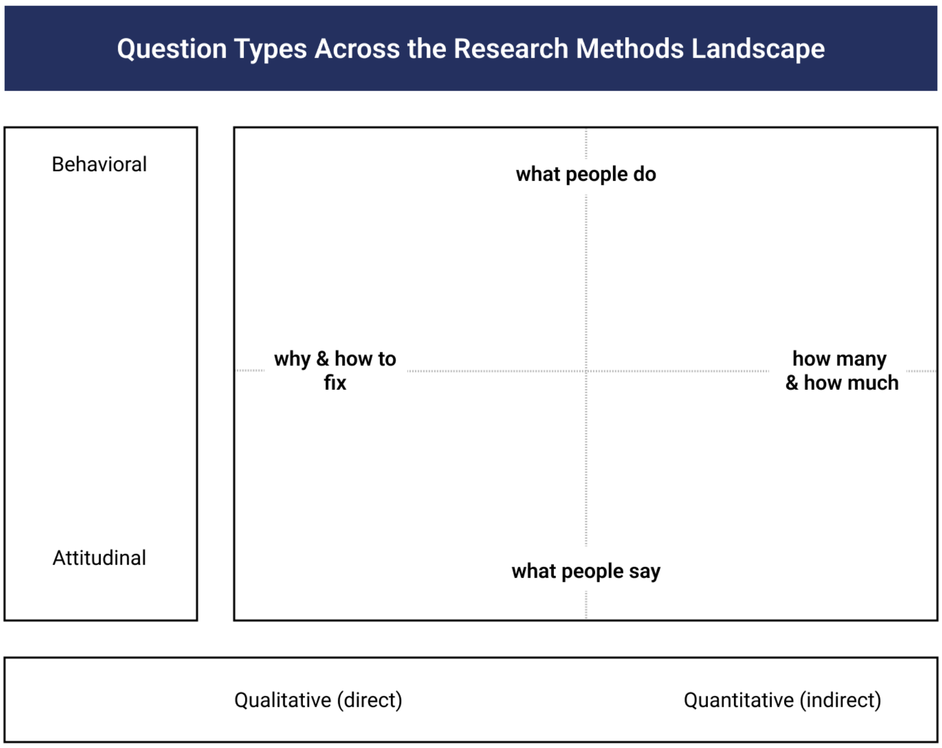

Fig. 3.2A "Question types across the Research methods landscape" - adapted (Experience, n.d.-c)

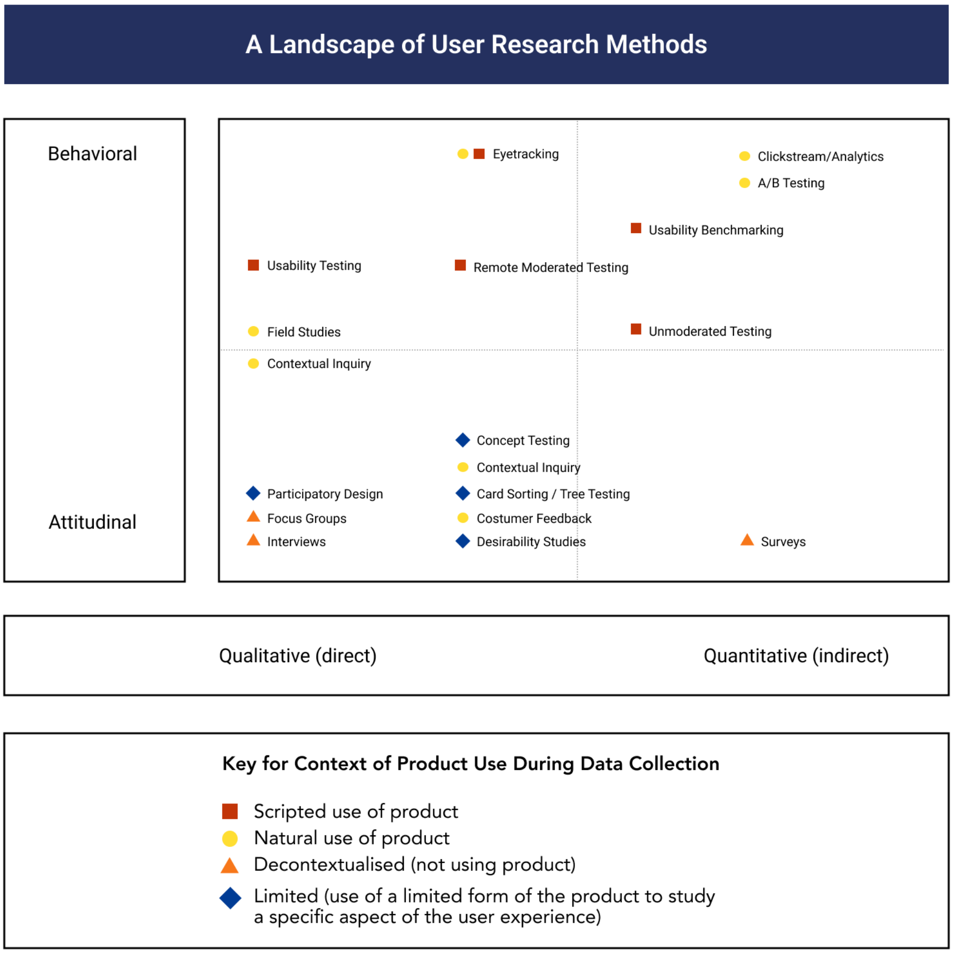

Fig. 3.2B "A Landscape of User Research Methods: Each dimension provides a way to distinguish among studies in terms of the questions they answer and the purposes they are most suited for. The methods placed in the middle of the quantitative–qualitative axis can be used to gather both qualitative and quantitative data." - adapted (Experience, n.d.-c)

These methods are also integrated differently depending on the phase of the project. According to Bella Martin and Bruce Hanington in "Universal Methods of Design", a project can be divided into the following phases:

1. **Planning, Scoping and Definition:** in this phase, project parameters are explored and defined;
2. **Exploration, Synthesis and Design Implications:** this phase is characterised by immersive research and design ethnography, which leads to design implications;
3. **Concept Generation and Early Prototype Iteration:** involves participatory and generative design activities;
4. **Evaluation, Refinement and Production:** is based on iterative testing and feedback;
5. **Launch and Monitor:** involves quality assurance testing, to ensure readiness for market and public use, as well as ongoing review and analysis to make necessary adjustments (Martin & Hanington, 2012).

The following methods were some of the methods considered/used for this investigation.

Literature Review

Project Phases 1 and 2
Behavioural; Attitudinal; Qualitative

The purpose of the literature review is to extract information from prior research or projects (published sources) that may inform the current project. Instead of summarising each source in detail, the review should synthesise the information, highlighting connections between references while maintaining a clear focus on the design project at hand (Martin & Hanington, 2012).

This investigation began by reviewing the existing literature, in order to understand previous work carried out in the same field and, thereby, enable consistent decision-making during the project's development.

Interviews

Project Phases 2, 3 and 4
Attitudinal; Qualitative

Interviews are a research method for directly engaging with participants to gather firsthand information on their experiences, opinions, attitudes and perceptions. As one of the primary survey research methods alongside **questionnaires**, interviews are best conducted in person to best perceive personal expressions and body language, although they can also be conducted remotely. Interviews can be either structured, following a set script of questions, or relatively unstructured, allowing for a more conversational and flexible approach. Even in unstructured interviews, the researcher usually has a set of topics to address. Unstructured interviews tend to be more conversational and comfortable for participants but require the researcher to effectively guide the session and gather the necessary information within the given time. Structured interviews can become more formal and impersonal, but offer better control over the questions and timing, being easier to analyse (Martin & Hanington, 2012).

For this research, semi-structured interviews were conducted. Participants were given the possibility to choose the modality of the interview (in person or remotely), according to their preference. Four interviews took place remotely and two interviews in person.

Participatory Design

Project Phases 2, 3 and 4
Behavioural; Attitudinal; Qualitative

Participatory Design is a human-centered approach that emphasises the active involvement of users and stakeholders throughout all stages of the research and design process, including co-design activities (Martin & Hanington, 2012). While the terms “Co-Design” and “Participatory Design” are often used interchangeably in the design industry, there are subtle differences between them. Both approaches involve stakeholder collaboration in the design process, but they differ slightly in their emphasis and origins (What Is Codesign?, n.d.).

Codesign is a method where designers serve as facilitators, collaborating with non-designers and guiding participants through the stages of design, to develop solutions. The goal of codesign is to leverage the combined knowledge and insights of all the stakeholders involved, especially the end-users, to encourage innovation and effectively tackle problems (What Is Codesign?, n.d.).

Participatory design emphasises collaboration, co-creation and empowerment, involving users directly in the design process to provide feedback, suggest ideas and participate in decision-making. This approach aims to create products and services that meet users' needs and help them achieve their goals (What Is Participatory Design?, n.d.). It involves active consultation with users, clients and other stakeholders, ideally through face-to-face, activity-based co-design engagements. Methods commonly used in participatory design include cultural probes, diary studies, photo studies, collage, flexible modelling, creative toolkits and design workshops (Martin & Hanington, 2012).

The origins of participatory design can be traced back to Scandinavian researchers in the 1970s and 1980s, particularly in the field of human-computer interaction (HCI). Initially, computer professionals in Norway collaborated with ironworker and metalworker union leaders and members to integrate new technologies into the workplace. Subsequent projects across Scandinavia involved interdisciplinary research teams from various fields such as computer science, sociology, economics and engineering working with union members in various industries to address computer integration and its impact on workplace production and processes. Notably, the UTOPIA project of the late 1980s, involving graphics workers in the newspaper industry, introduced innovative, experience-based methods such as role-playing scenarios using low-fidelity prototypes. Over time, participatory design has expanded in scope and methods, gaining widespread acceptance across industrial design, architecture, urban design, interaction design and communication design (Martin & Hanington, 2012; What Is Participatory Design?, n.d.).

The second sessions performed with participants were considered participatory design sessions, despite not having them directly designing an artefact (co-design activities), as participants were mostly blind or low vision users and the sessions had to be adapted to this reality. Participants were given the Head-Mounted Display (HMD) Meta Quest 2, to try a set of experiences and asked to **think-aloud** their actions, feelings and thoughts. The goal was to understand participants' interaction with the device, what they felt and what they would change/add, in order to make the device and the experiences it encompasses more accessible to them. At the end of the session a set of **questions** were asked, to further encourage the dialogue and collect feedback to take into the next stage of the project. All sessions took place in person.

Think-aloud Protocol

Project Phases 3 and 4
Behavioural; Quantitative; Qualitative

Think-aloud protocol is a method where participants verbalise their thoughts, actions and feelings allowing researchers to observe the task completion process and identify areas that need improvement. There are two main procedures for the think-aloud protocol: Concurrent Think-aloud (the most used) where participants are supposed to verbalise their thoughts and actions in real-time while completing tasks and Retrospective Think-aloud, where participants complete tasks silently while being recorded, then comment on their process while watching a replay. This method is more commonly used in both low- and high-fidelity prototypes, but it can also be used to evaluate products already in the public domain (Martin & Hanington, 2012).

Personas

Project phase 3
Behavioural; Attitudinal; Qualitative

Personas consolidate archetypal descriptions of user behaviour patterns into representative profiles to humanise design focus, test scenarios and aid design communication. Understanding people is one of the foundations of user-centered design, but attempting to design for everyone can result in unfocused or incoherent solutions. Personas, crafted from real user data through sound field research, provide a solution by capturing common behaviours in meaningful and relatable profiles. A project should have a limited number of personas, varying from three to five, to maintain a manageable design focus and avoid targeting extreme outliers. Personas are presented in concise descriptions, including a name, photograph (stock photos are used to avoid real identity connections) or sketch and a narrative story detailing the individual's life situation, goals and behaviours relevant to the design inquiry (Martin & Hanington, 2012).

For this study we could only gather six participants, with different vision impairments, different technology use and needs. As their reality is very different from our own, it was also a challenge to understand what they could perceive in order to prototype the best experience possible. So, for these reasons, to categorise these users into personas ended up not making sense, as we considered a larger group of participants would be required, in order for the personas to actually be representative.

Prototyping

Project Phases 3 and 4
Behavioural; Attitudinal; Qualitative

Prototyping involves creating tangible artefacts at various levels of resolution to develop and test ideas within design teams and with clients and users. They vary in terms of fidelity. Low-fidelity prototypes such as paper prototyping, are used in the early ideation processes and are interesting for testing ideas in generative research, so that the product is seen as a concept proposed for constructive revision with the aim of making iterative changes. High-fidelity prototypes represent the final product's appearance and functionality for later-phase evaluation testing. High-fidelity prototypes, include CAD models or working models with interactive functionality, which provide realistic user experiences for feedback on aesthetics, form, interaction and usability (Martin & Hanington, 2012).

The prototypes created for this project intend to test concepts and ideas and focus on users' senses, (mostly audition, but also, in some cases, vision). They are not the exact desirable final solutions, as only free tools and assets were used, so they are considered Lo-Fi prototypes. Despite this, they still represent the best experience possible with the resources and time available, in order to gather participants' insights on a solution, developed based on their feedback.

Usability Testing vs User Experience Assessment

Project Phases 3, 4 and 5
Behavioural; Quantitative; Qualitative

Usability is a quality attribute that measures how easy user interfaces are to use.Its value depends on how well the product's features meet users' needs and fit their contexts. Once it is established that the product can solve users' problems, addressing its usability becomes essential. Usability also encompasses methods for enhancing ease-of-use during the design process. It follows utility and precedes desirability and brand experience, being defined by the following five quality components:

1. **Learnability:** How easy do users complete basic tasks the first time they use the design?
2. **Efficiency:** After learning the design, how quickly can users perform tasks?
3. **Memorability:** When users return to the design after a break, how easily can proficiency be recovered?
4. **Errors:** How many errors are made, how severe are they and how easily can users recover from them?
5. **Satisfaction:** How enjoyable is the design to use? (Experience, n.d.-b; What Is Usability - The Ultimate Guide, n.d.)

In addition to **usability**, another important quality attribute is **utility**, which refers to the design's functionality - whether it provides the features users need. Both usability and utility are equally important and together determine the overall usefulness of a product: Utility - whether the design offers the necessary features; Usability - How easy and pleasant it is to use these features; Useful - the combination of usability and utility (Experience, n.d.-b; What Is Usability - The Ultimate Guide, n.d.).

The **ISO 9241-11:2018** standard, titled "Ergonomics of human-system interaction, part 11: Usability: Definitions and concepts," offers a framework for understanding usability. It helps designers and researchers grasp how to apply usability to various interactive or other types of systems, products and services. The standard defines usability as an outcome of use, explains key terms and concepts, outlines the fundamentals of usability and elaborates on the application of the concept. However, it does not provide specific processes or methods for integrating usability into design development or assessment (14:00-17:00, n.d.).

Usability testing Is an evaluative method that allows teams to observe an individual's experience with a digital application as they complete specific tasks, seeking empirical evidence to improve an interface's usability. This method identifies frustrating or confusing aspects of an interface so they can be prioritised, fixed and retested before launch. As they are designed around tasks and scenarios representing typical end-user goals, they ensure validity, empiricism and avoid bias (Martin & Hanington, 2012).

For this research, the test of the prototype is not task-based. Therefore, the process of gathering participants feedback on the developed work is called "User Experience Assessment", instead of "Usability Testing". We could've specifically tested the usability of the HMD, but it lacked basic accessibility features for vision impaired users, so they would not be able to perform tasks. For this research and its prototypes, also according to participant's feedback from prior sessions and the found constraints, we've decided to focus on exploring the user's senses, rather than which and how specific features should be incorporated. However, we did contemplate, during the prior Participatory Design Session, ways to collect participants feedback on how they would enhance accessibility in the device, by incorporating already existing accessibility tools for computers and smartphones in virtual environments. It could be interesting to consider doing usability testing of the full experience with the device, if accessibility features became incorporated. As the prototypes are of a contemplative experience, it made no sense to evaluate its usability bur rather evaluate the user experience.

For the User Experience Assessment sessions, we seeked to understand which prototype moments were frustrating or confusing and how they could be fixed, incorporating the **short version of the User Experience Questionnaire (UEQ-S)** at the end of each session, to gather qualitative data on the overall experience.

Questionnaires

Project phases 2 and 4
Behavioural; Attitudinal; Quantitative; Qualitative

Questionnaires are survey instruments used to collect self-reported information from people about their characteristics, thoughts, feelings, perceptions, behaviours, or attitudes, typically in written form. As one of the primary tools for survey research alongside interviews, questionnaires are simple to produce and administer, but require careful attention to question wording, response options, sequencing, length, layout and design. The construction of questions significantly impacts the type of response and analysis. Open-ended questions allow for depth, while closed-ended questions are easier to analyse numerically. Techniques like ranking choices provide better indications of preferences than a single checked response. It is recommended to use Likert scale questions to maintain the neutrality of the question and at the same time assess the strength of the answers. Questionnaires are often combined with other methods, such as observation, to supplement the data with personal information and verify or challenge self-reported behaviours. They can be used at various stages of research for different purposes, such as diary studies or product evaluations (Martin & Hanington, 2012).

As most participants can't read text without it being written in braille or without the use of an external device/app, the best considered approach to incorporate the UEQ[4] was for the researcher to ask out loud the questions to participants. For this reason, also because the developed prototype did not involve tasks and we aimed to gather qualitative insights by understanding the overall impression of the product, the short version (eight items) was preferred to the long version (twenty-six items).

Focus Groups

Project phases 1 and 5
Attitudinal; Qualitative

Focus groups are a qualitative method used by market researchers to assess the opinions, feelings and attitudes of a group of carefully recruited participants about a product, service, marketing campaign or brand. The strength of this method lies in the group dynamic. When properly recruited and moderated, participants quickly accept each other as peers, creating a non-threatening environment where they are more likely to share experiences, stories, perceptions and needs. Focus groups should be supplemented with other quantitative and qualitative methods to further investigate attitudes and behaviours in real-use contexts. Results from focus groups should not be generalised to an entire population. Being one of this method's criticism, researchers must be aware of the bias introduced by the formal setting of focus groups and how it may influence participant responses and therefore, data analysis.

Focus groups were considered to put into practice after the prototyping and testing phase, to have participants sharing ideas about the project so far. However, as four of the six participants are low vision or blind, it would

[4] https://www.ueq-online.org/

be a challenge to gather them in the same physical space. This could be solutioned by scheduling a video call, but given participants' different schedules and availability, the delivery date of the project and also the bias that could result from the session, we decided to skip this method, having the possibility to consider it in future work.

3.3 Work Plan

The work plan (fig 3.3A) consists of five main stages, as shown in figure 3.3.A. After the **Literature Review**, firstly, **interviews** were conducted to understand the participants' conditions, realities and daily technology use. This was followed by **participatory design sessions**, during which participants were asked to identify their difficulties and suggest improvements to make the experience more enjoyable and accessible for them. After **prototyping**, the final stage of user research involved **testing** the prototype, which was developed based on the insights from the previous sessions. Finally, the results, difficulties and guidelines were documented according to the acquired knowledge.

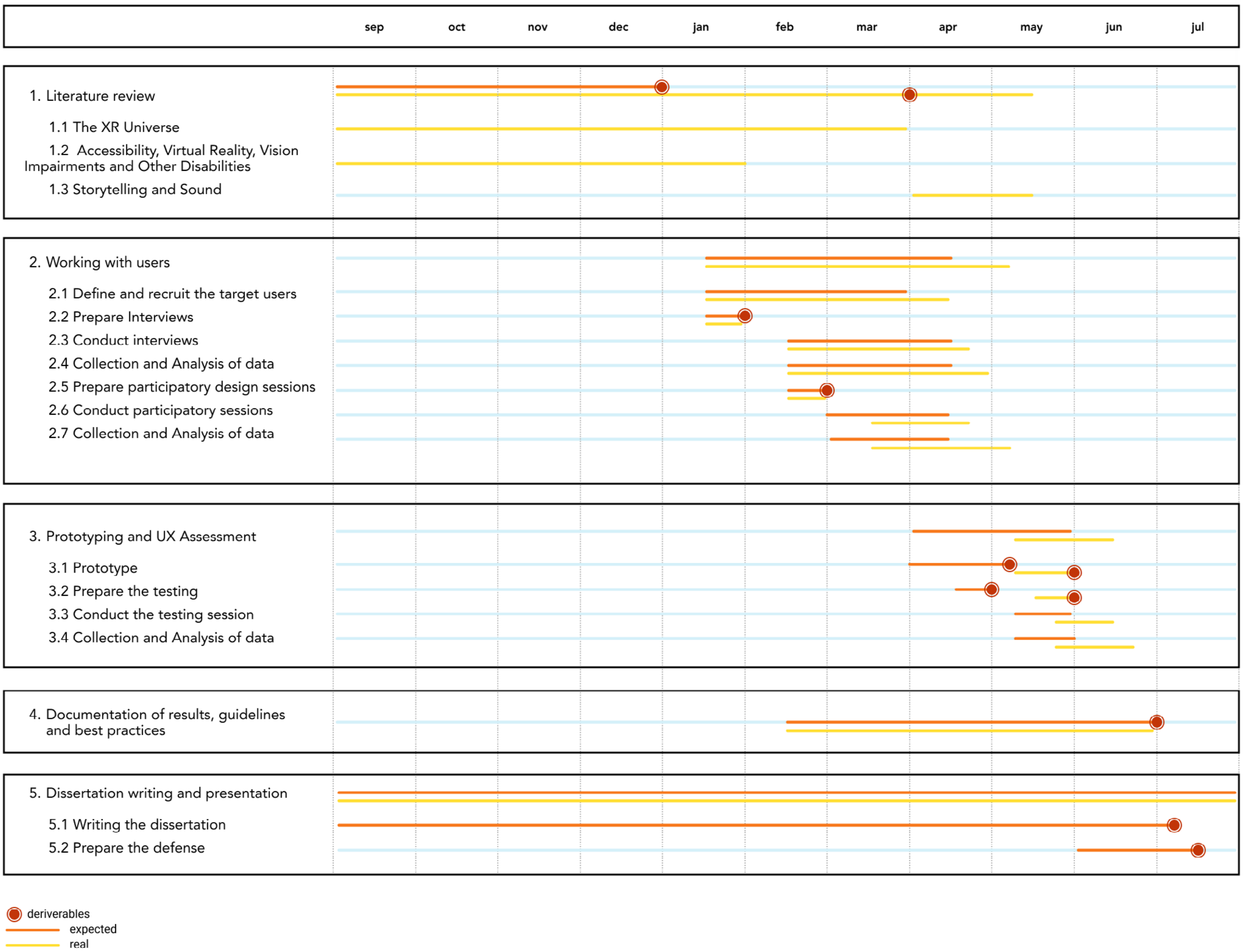

Fig. 3.3A Gantt Chart for the Dissertation

3.4 Discussion

In today's consumer-driven world, with a diverse spectrum of rapidly evolving technology, a Human-centered design (HCD) approach is crucial to ensure a product, physical or digital, is produced targeting its consumer's needs. This approach emphasises ergonomics, interaction and functionality, focusing on human-computer interaction (HCI). By prioritising the user and hers/his experience, a better user-friendly product can be achieved. The better the product, the harder it is to replace.

Given the fact that the target users of this investigation are individuals with low vision or blindness, the way some of the methods considered were applied had to be adapted to the reality of these users. There are numerous methods available for human-centered research. The chosen methods were considered the ones that best suited the investigation's goals, motivation and constraints, including project deadlines and available resources.

CHAPTER 4
WORKING WITH USERS

In this chapter the work developed with users before the prototyping phase is described. Besides the description and results from the interviews and participatory design sessions, the specifications of the Virtual Reality (VR) headset used are also detailed.

4.1 The Equipment - Meta Quest 2

The VR equipment used in this study is the Meta Quest 2 headset (fig 4.1A to F). This device allows users to immerse themselves in the VR world using just the headset and controllers. It can also be connected to a computer via the USB-C port. The headset tracks the user's head and body movements, translating them into VR without the need for external sensors. For audio, the Meta Quest 2 features built-in 3D positional sound and a microphone for communication in social apps, with the option to connect external headphones if desired. The touch controllers offer precise motion tracking. Users can define their play area on the floor, ensuring a safe and immersive VR experience. (Meta Quest 2, n.d.).

Specifications:

- 224mm x 450mm (headset);
- Fast-Switch LCD Display;
- Qualcomm Snapdragon XR2 processor;
- 1832 x 1920 Resolution Per Eye;
- 60, 72, 90 Hz Refresh Rate Supported;
- Glasses Compatible;
- Meta Quest Store;
- Storage of 128GB | 256GB (Meta Quest 2, n.d.).

Fig 4.1A, B Meta Quest 2 (pictures taken by the author)

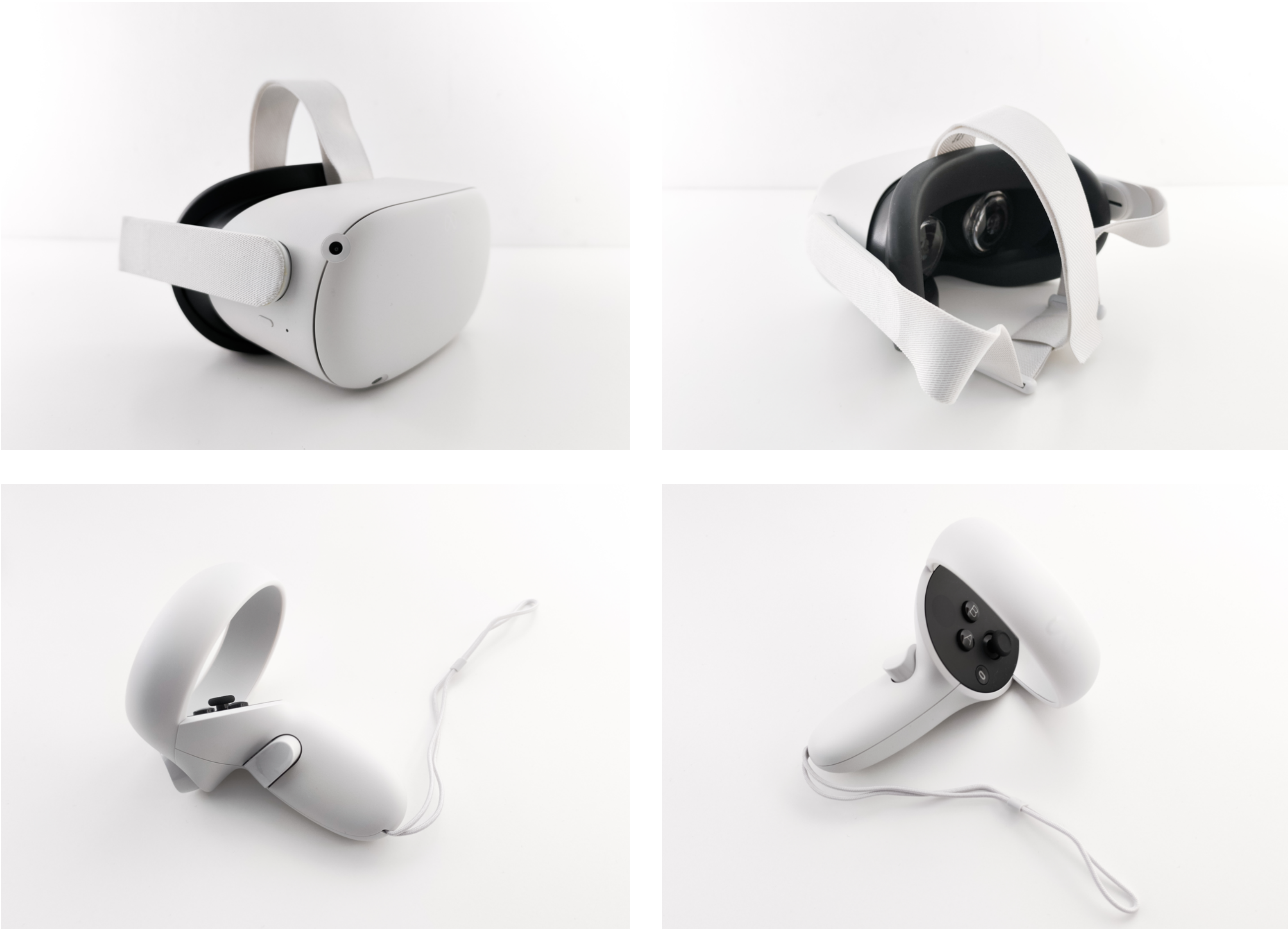

Fig 4.1C, D, E, F Meta Quest 2 (pictures taken by the author)

4.2 Participants and Recruitment

For this study, we gathered six participants: two male and four female, aged between 18 and 55 years old (table 4.2A). Recruitment was conducted via the Inclusion Support Center of the University of Porto (Núcleo de Apoio à Inclusão da Universidade do Porto - NAI) and we also gathered external volunteers. Participants were free to withdraw from the study at any stage and signed informed consent statements for every session conducted.

4.2.1 Núcleo de Apoio à Inclusão da Universidade do Porto

António Silva has been a member of the Inclusion Support Center of the University of Porto (Núcleo de Apoio à Inclusão da Universidade do Porto, in Portuguese, referred to as NAI from now on) for about 26 years. António helped us get to know the organisation better and to recruit participants. In a conversation, António explained how NAI was born and how it has evolved ever since. According to António, NAI was created in the Faculty of Letters to address the needs of the students with Vision Impairments (VI). This faculty was chosen as it was the most prepared to receive students with this type of needs, having degrees that only required to work with text (no need to use mathematical formulas, for example), it was more achievable for students with VI to pursue a career, therefore preferable degrees among the students with these conditions. Although the majority of the target students were from the Faculty of Letters, some students from the Faculty of Psychology also benefited from these resources. Students with VI had a hard time taking notes during classes, finding study materials and even executing the evaluation tests.

In 1997, with the initiative of Phd Alice Ribeiro, student at the time, financing from Calouste Gulbenkian Foundation and the support of the faculty's direction, the support office, later NAI, for students with VI was created. With the computer resources available at that time, using the MS-DOS operating system, a keyboard, a screen reader via USB and a synthesiser, it was possible for students to write their essays and make scans through the use of a word processor and to print in the end. However, as it was not accessible as it is nowadays, these students weren't familiar with the technology, which required training before they could become independent users.

With the modernization of the different faculties and the investment in accessibility, more students with other needs started to be a part of the university's community. Mostly from the 2000, students with hearing impairments, physical impairments as limb loss, reduced mobility, cerebral palsy and neurodivergent started to increase, bringing new needs and new challenges to NAI, as there was no prior experience with these various types of disabilities.

Nowadays the number of Vision Impaired students has decreased, being about 6, in a universe of around 300 students with disabilities. On the other hand, neurodivergent, psychological or psychiatric conditions such as OCD (Obsessive-Compulsive Disorder), dyslexia and others have increased (especially students with autism). There is currently available research and literature on these new disabilities that help the professionals better understand the needs, in order to help these students in their academic journey. However this was not always the case, as technology did not used to be as developed and accessible as it is nowadays. NAI has been a national pioneer in the pursuit of accessibility in the Portuguese academic world, with 26 years of continuous growth and learning.

As time went by, other public universities started to have their own support services. This allowed, in 2004, to create GTAEDES (Working Group for the Support of Students with Disabilities in Higher Education, in Portuguese, Grupo de Trabalho para o Apoio a Estudantes com Deficiências no Ensino Superior), enabling mutual support and knowledge sharing on the topic (O GTAEDES – GTAEDES, n.d.). Despite all the evolution and constant efforts, there are still challenges and investigation areas that cause doubts in which is the best course of action when helping a student. This made NAI's experience become far beyond Vision Impairments.

4.2.2 Participants

Participant one, referred as **P1** from now on, aged between 55 and 64 years old, totally blind (with no light perception), condition acquired adventitiously. P1 was born with (congenital) Glaucoma which, at 27, due to a detached retina, resulted in total blindness.

Participant two, referred as **P2** from now on, is a male, aged between 18 and 24 years old, is blind in his left eye and has low vision in his right eye, due to a sequelae of a Glioma, which destroyed the optic nerve in his left eye and affected the vision in his right eye, at birth (congenital). P2 can see out of his right eye depending on proximity and detail, can perceive all colours but has difficulty distinguishing similar ones (colour blindness). So, in general, P2 can perceive forms, fingers, light and colours in a short distance and uses a white cane to help him in his daily routine.

Participant three, referred as **P3** from now on, is a female, aged between 18 and 24 years old, blind (with light perception). P3 was congenitally low visioned, due to a genetic error and got blind around the age of 18. Currently P3 can only perceive light when the light focus is strong and the contrast high.

Participant four, referred as **P4** from now on, is a female, aged between 18 and 24 years old, with advanced myopia in both eyes, anisometropia and congenital amblyopia in the left eye (also known as lazy eye). This progressive condition has led to P4 currently having 40% and 70% visual acuity in the left and right eye respectively, with contact lenses. Without lenses, P4's visual acuity does not reach 10%. Due to the conditions described above, P4's left eye does not contribute to sharpness, but rather to depth of field.

Participant five, referred as **P5** from now on, is a female, aged between 25 and 34 years old, with mild myopia in the right eye and blind in her left eye. This condition was a consequence of a surgical complication that resulted from a congenital cataract surgery at the age of 8. Fibrosis developed in the lens of the left eye, leading to vision loss in one eye, also affecting general depth perception.

Due to her high myopia, without the use of contact lenses, P4 would be considered a low vision user. P5 sees well from the right eye, but is blind from the left eye. Despite their conditions, **both participants P4 and P5 perform their daily tasks similar to a non-vision impaired individual**, only requiring the use of glasses or contact lenses.

Participant six, referred as **P6** from now on, is a female, aged between 25 and 34 years old, totally blind (with no light perception), condition acquired adventitiously, as a consequence of Wolfram's Syndrome, a rare genetic disease. P6 progressively lost her vision and got blind at 17. P6 also has a hearing impairment.

Participant (PN)	Age	Gender	Condition
P1	55 to 64	Masculine	Totally blind (no light perception)
P2	18 to 24	Masculine	Low vision (blind in the left eye; 1/10 visual acuity on the right eye)
P3	18 to 24	Feminine	Totally blind (with some light perception)
P4	18 to 24	Feminine	Vision Impaired (High Myopia)
P5	25 to 34	Feminine	Vision Impaired (blind in the left eye)
P6	25 to 34	Feminine	Totally blind (no light perception); Hearing impaired

Table. 4.2A Participants

4.3 Interviews

The main goal with the interviews was to understand the characteristics of the participants: their demographic data (age and gender), their visual impairment and their daily technology use and knowledge. The interview script can be accessed in the **Appendix A - Interview Script**.

Gathered Knowledge

Regarding the use of technology, participants are very different from each other, so their technology knowledge and use also differs. For **P4** and **P5**, as they perform their daily tasks as a non-vision impaired user (not requiring accessibility), most questions were not applicable.

When questioned about the use of technology and most used devices, all participants responded that they use technology in their daily lives. The participants with severe visual impairment (**P1**, **P2**, **P3** and **P6**) all use a computer and/or tablet and a smartphone. **P2** does not have a tablet and **P1** uses technology in a more diversified way, also through the use of smart devices (Alexa), household appliances and gadgets for a smart home.

Participants were questioned about their device use, activities for entertainment, content preference and the respective relation with storytelling/audio quality. To these questions all participants with profound visual impairment responded that they use a computer or tablet for work. However, for entertainment, despite the use of the computer, or occasionally, the tablet, the smartphone was the most used device. They all access at least one social network (whatsapp, facebook, tiktok and/or instagram), they all listen to music and they all watch videos on youtube or films/series on streaming platforms. Three of the four also play games. Only **P6** mentioned the preference for books, instead of watching films/series, in digital format, as, according to her, **"the book has more detail allowing me to be in my world"**. For this user, the music and noise of films/series makes the content less appealing. Only **P1** mentioned using a smartphone to read the news, highlighting the use of RSS apps for content personalization, which television content does not allow. The consumption of visual content (videos, series or films) varies according to users' personal interests, with no particular preference for a type of storytelling or audio due to their visual impairment.

When questioned about their brand preference and the reason for that preference, three out of the four participants who require technology with accessibility features consider Apple to be the best brand in terms of accessibility. **P1** mentions the ease of communication between Apple devices. **P2**, although agreeing that Apple is the most accessible brand, prefers a Microsoft computer, due to software incompatibility issues with some programs and less free options of software for the IOS computers. **P6** mentions feeling uncomfortable with the voice of the Android accessibility system (Talkback), so the iPhone is essential for her. Despite agreeing that Apple is the most accessible brand, **P6** has an ASUS computer, which the family already had. Only **P3** mentioned acquiring a MacBook and iPad due to accessibility advice but owns a Xiaomi phone that she considers to meet all her needs.

When questioned about the most used accessibility features in their devices, all four participants mentioned **OCR apps** and **screen readers** (**VoiceOver, TalkBack**). Three participants mentioned the use of audio description for streaming apps and/o some video content. **P2** considered audio description an imposition over the content, as he has some degree of vision and **P1** considered audio description to be unpleasant if it becomes an imposition over the content (which is, according to the user, a "bad example of audio description"). Some of the mentioned accessibility apps (for different uses) were Lazarillo, **TApTAPSEE**, **Seeing AI** and **Be My Eyes**. Regarding streaming apps, **Netflix** and **Apple TV** were mentioned as the most accessibility-friendly apps, as Netflix offers the option between audio description (for all content) or traditional subtitles read out loud and Apple TV the same as Netflix, but with more languages available.

When questioned about their Virtual Reality technology knowledge all six participants mentioned knowing what the technology is, but two participants did not understand how it worked. Five of the six participants never had the opportunity to try a VR headset and one tried it due to a Master's Degree Investigation. **Two participants mentioned the technology's cost as an obstacle.**

P1 and **P2** described other potential uses for virtual/mixed reality glasses as a **follow up answer to the question above**. Using **Apple Vision Pro** as an example, these users consider that the technology could be interesting for helping blind users. If accessibility features were implemented in these devices (screen readers, voice commands), MR/VR headsets' use could become similar to the smartphone/iphone use. The two participants have a similar view and consider that the technology could help with outdoor routes, with the use of a GPS that could describe the environment (traffic lights, obstacles) in real time, also allowing the user to move around with their hands free; for reading printed text in a restaurant menu, giving audio feedback and recognizing images, for example.

All six participants showed interest in experimenting with the technology in a future session.

4.4 Participatory Design Sessions

With the participatory design sessions, our main goal was to understand how participants interacted with the device, gather their feedback on the shown immersive experiences and identify the technology's limitations. With this knowledge, we intended to co-create a better solution, to meet these users' needs. The script of the participatory design session can be accessed in the **Appendix B Participatory Design Session Script**.

4.4.1 Plan and Goals

The Participatory Design Sessions (fig 4.4A to E) all began with the description of the equipment (headset and commands) and of the stages of the session. To participants **P1**, **P3** and **P6** the equipment description was more detailed and the initial environment was also described.

The sessions were divided in four stages: the immersive experience “First Steps for Quest 2”, YouTube Vídeos “Underwater Life, Marsa Alam, Egypt. 360 video in 8K”[5] and “Lions 360° | National Geographic”[6]; the 3D audio “The Tucker Zone (A 3D Sound Experience)”[7] and lastly a questionnaire about the different moments of the session.

“First Steps for Quest 2” is the immersive experience available in the Meta Quest 2, to help a beginner user understand the commands, how to interact with the virtual environment and to experiment two short games (a shooting game and a dance moment). The goal with this experience was to understand how far participants could go through the experience, what their thoughts and feelings towards the sound and feedback about the use of the commands.

The youtube videos consisted of two short 360º documentaries, an underwater experience about sea life in Marsa Alam and a savannah experience through Lions natural habitat. Our goal with these experiences was to understand participants’ audio feedback and in the case of blind (if not totally blind) and low vision users, which visual stimuli they could perceive.

The youtube audio had, in general, no visual content associated. It consisted of a man randomly placing and exposing the listener to various scenarios and objects through sound. This utilised a 360º field around the user’s head, to create the illusion of movement and immersion. Participants were asked to listen to the audio both

[5] https://youtu.be/eKumVFvGHFA
[6] https://youtu.be/sPyAQQklc1s
[7] https://youtu.be/3txhT2ncNOU

through the headset and their own earphones to compare audio quality and the feeling of immersion. Despite using the same headset, each participant used their own pair of earphones (except P6, who uses hearing aids as earphones). This aspect should be taken into consideration, as different earphones have different sound quality.

The sessions were performed standing or sitting, depending on what worked best for each participant, but always within a stationary boundary.

Before starting performing the tasks, participants were asked to state out loud their actions, the environment they were in and their difficulties.

As **P6** required a caregiver to accompany her, the session had to be shortened. Therefore, the video "Underwater Life, Marsa Alam, Egypt. 360 video in 8K" was not shown, as previous feedback from other users between videos did not differ significantly. As in the previous session, although **P4** and **P5** completed all planned stages, their use of the headset was identical to that of a fully sighted user. Out of the six participants, as native Portuguese speakers, three (**P2**, **P3** and **P6**) considered English content to be a language barrier, so translation was required.

Fig 4.4A, B, C, D First Participatory Design Sessions with users

Fig 4.4 E First Participatory Design Sessions with users

4.4.2 Participant's Feedback

Although **P4** and **P5** completed all planned stages, their use of the headset was identical to that of a fully sighted user.

Commands

After getting comfortable with commands and the placement of buttons, all participants considered it easy to learn:

- **P6** could not understand what happened when she touched the different buttons and mentioned different vibrations or audio feedback would help;
- **P3** thought it would be nice to have some form of button distinction, but it was not essential;
- **P2** touched the joystick instead of other buttons after a break in the session.

Headset

One user considered it necessary and two users considered it interesting but not essential, for the headset to provide some feedback so they could understand if it was well placed. Most participants felt a little bit tired and they all considered the headset to be more on the heavier side:

- **P2** would like feedback on whether the glasses are centered or not, as it took him a little while to understand that he needed to adjust the headset to see better;
- **P4** mentioned the sound button in the headset could have the "+" and the "-" more perceptible to touch, even for sighted individuals, as she could only understand which side turned the volume up via attempt error;
- **P3** had a slight headache.

General Navigation

Fig 4.4F Meta Quest 2 home environment (Facebook's Oculus Quest 2 Takes Wireless VR to the next Level, 2020)

P1 was able to navigate through the virtual environment, to some extent, despite the absence of implemented accessibility features, due to the haptic feedback. **P3** and **P6** needed help to perform all tasks, due to the lack of accessibility features.

Instead of describing the initial environment to **P2**, to understand the extent of detail he can see, P2 was asked to describe what he saw and his difficulties, which allowed gathering the following feedback:

- He described that he was under a wall or bridge with several arches that he could pass over to access various places. Slightly on his left there was a view that looked like a beach, with mountains in the background and palm trees. Then he proceeded to describe the first seated area (on the right), the living area, the kitchen and the last seating area in a general way.
- Everything was described with only a few mistakes;
- He could not perceive the garden part as it was too dark;
- In terms of colours he described the sky as cloudy, he said he could see the blue of the sea (which was the further part in the horizon), the brown from the mountains, trees, rocks and furniture, the green from the leaves, white and the reflection of light in the walls;
- He was able to navigate autonomously through the virtual environment, despite experiencing some difficulties in distinguishing characters or icons and despite the absence of implemented accessibility features;
- He managed to find the applications menu and the First Steps experience with some help and directions, as he could not see what was written.

First Steps for Quest 2

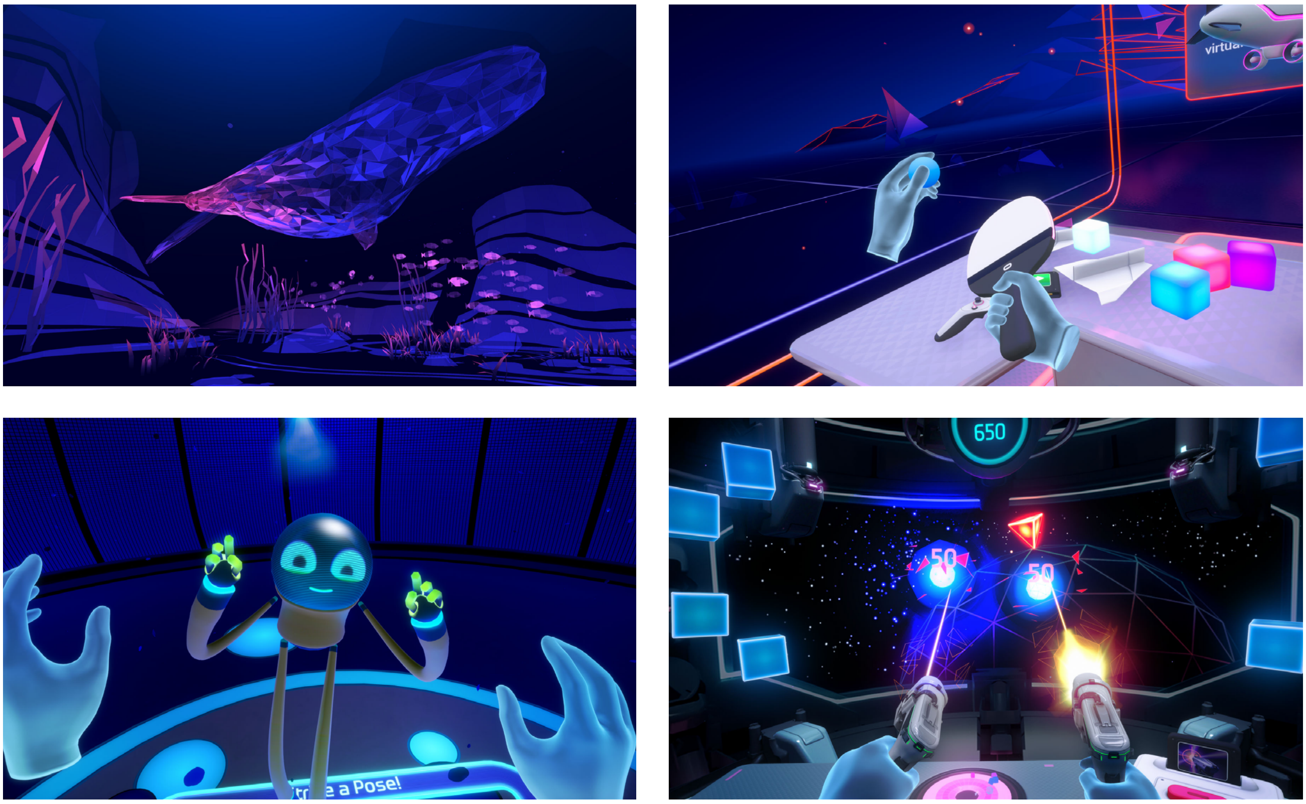

Fig 4.4G First Steps for Quest 2 (VR, n.d.)

All three blind users (**P1**, **P3** and **P6**) associated "First Steps" initial animation to the **beginning of a movie**. All three participants considered the **audio to be confusing**, as it had **too much sound information**, making it hard to understand what visuals the sound was associated with. Despite this, **P3** highlighted the existence of water and soil animations during the initial animation.

P2 could perceive more detail than previously anticipated, describing the initial animation in the following order:

1. He saw a flash;
2. After a waterfall;
3. Followed undersea life with fishes and seaweed;
4. Could not perceive well but described it as something similar to a wall;
5. Lastly the sea further away.

Regarding the tutorial:

- He mistook the light blue cube colour, considering it to be white;
- Saw all the objects and interacted with them with some help, as he could not read the labels (both because the words were small and in English);
- He danced with the robot and said he particularly enjoyed it;
- While playing the gun game, compared to the general navigation ray (the pointer ray from the controller) in the main menu, he highlighted that the yellow ray from the gun in the black background (the pointer ray from the controller), as it had a **bigger contrast**, it allowed him to **understand better where he was pointing at**.

360° Videos

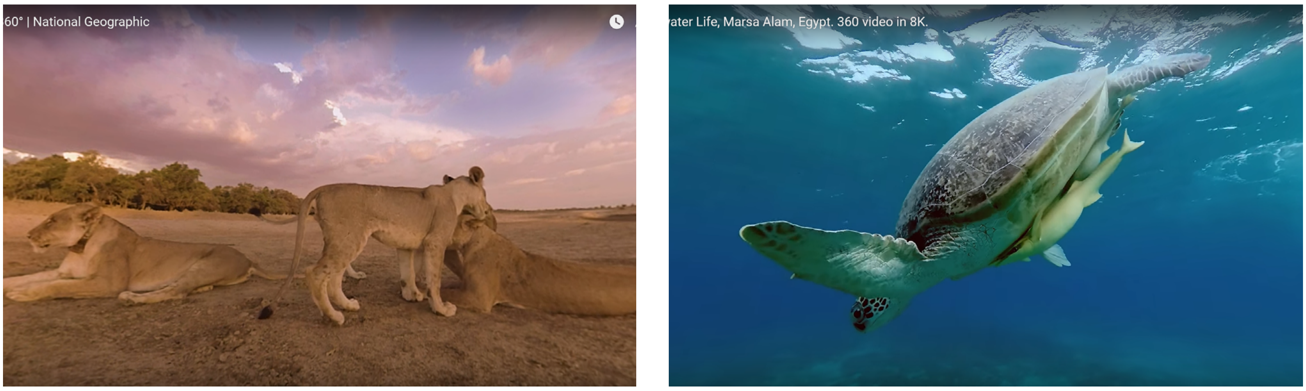

Fig 4.4H "Lions 360 | National Geographic" and "Underwater Life, Marsa Alam, Egypt. 360 video in 8K"

P1 described the "Underwater Life" audio as "free movement under water", stating the music took him to a documentary about nature and wildlife. Regarding the "Lions 360º" through sound, he could perceive he was in a jungle.

P2 described the scenes of both videos accurately:

In the "Underwater life" video:
- He saw he was on a bridge;
- Then went under the sea;
- Saw corals, the colour of sand, the green of the seaweed and the sea waves;
- Identified the turtle and a swimmer above him.

In the "Lions 360º" video:
- He saw the lions, the trees, the elephant and the water;
- He particularly enjoyed the proximity of the animals (in both videos), because it allowed him to see some details, as **"in VR everything is closer and bigger, it becomes easier to see"**.

P2 also mentioned both audios to give him perception of the environment, but preferred the "Lions 360º" audio, as it had more sounds of nature.

P3, regarding:

The "Underwater Life" video:
- Understood the video starts above water, identifying the moment it goes inside the ocean;
- She considered the music overlaid the content.

The "Lions 360º" experience:
- She felt like she was in a forest, due to the sound of animals and insects;
- Was able to identify the changes of scenario due to the change of nature sounds;
- Could understand she was surrounded by animals through the sound distance;
- Could not perceive any visual stimuli, but she pointed out the following **- "As it had bird sounds, the scene occurred during the day. I would imagine the sky to be above me. So for me, that I can only perceive high contrast, maybe it would make a difference to have a high contrast light focus to reference the sky"**.

P5, when questioned about the sound of the videos:

- Mentioned **the more natural the sound was, the easier it was for her to feel immersed**, so she preferred the “Lions 360º” video, as it had detail according to the visual scene;
- In the “Underwater life” video, “the music overlaid the content a bit” and she would like “more ocean sounds, to make the experience more realistic.”

P6, referring to the “Lions 360º” experience:

- She described the scene as “being in the woods, somewhere near a river” and considered both music and nature sounds to be interesting;
- To her, the experience did not feel real as it “has nature and animals sounds and to be inside a room feels limiting, maybe if we were outside it would feel as if we were in the middle of this [the video’s] environment”;
- She added that the headset’s audio made her feel as if “things are happening inside my head”.

When referring to the audio from the videos, **all participants** (including **P4**) preferred the “Lions 360º” experience to the “Underwater Life”. While both videos have music in the background, the participants considered that in the first one they could perceive **the environment through sound better than in the second one, where the music overlaid the nature sounds**.

Both **P1** and **P6** mentioned that they would appreciate having audio description, so they could understand what was actually happening. P1 added the following feedback:

- He had “to imagine what is being showed, with the help of the narration”;
- Regarding video production, **“to enhance accessibility, having audio description in a scene where the sound by itself hasn’t information enough, having this resource is essential”**, for example **“in a scene with only water sounds, It is impossible to understand we’re seeing the Nilo”**;
- He considered this a problem of content production and not of the platform itself.

3D Sound Experience

In the 3D Sound experience, the feedback differed among users:

- In terms of audio quality, from the **six** participants, **three** preferred the headset audio (P2, P5 and P6) and **three** (P1, P3 and P4) preferred their earphones audio. **P4** felt more immersed in the headset, enjoying the experience better, despite the audio quality. **P1** and **P3** preferred the earphones, as sound quality was better, therefore enhancing their sound perception and distinction;
- **Three** out of **six** users thought a phone was ringing in the actual room, when it was the audio from the experience;
- **All** participants could perceive the main character performing actions around them;
- To this particular experience **no user** considered adding haptic feedback as a beneficial feature to enhance the immersion experience, as all information comes through sound. **One user** pointed out that haptic feedback would only justify if it would be something very important that otherwise would go as unseen.

P1 preferred the earphones audio as he could perceive the sounds, the surrounding effect and distance better, when comparing with the headset. According to him “as the headset has open sound, not isolated from the exterior, maybe that interferes with the experience”.

P2 preferred the headset sound as he felt the sense of depth (the main character being closer or further away).

P3 felt she could understand and distinguish sounds better in her earphones and could perceive the scenario changes. **She enjoyed the audio not having too many stimuli at once, but mentioned the scissors sound being too close gave her a slight discomfort**.

P4 said the experience was similar. She liked the audio better in the earphones, but preferred the experience in the headset as the feeling of immersion is better. "When the main character asks the user to open their eyes to see the game, it is better to be inside the environment than to be looking at a phone screen". **She mentioned the main character's whispering voice gave her a slight discomfort as she considered it too close**.

P5 liked the sound and experience better in the glasses, as she felt the sense of presence faster, as she had her eyes covered and there was no light from the outside, it felt like the person was really there. **She got startled when the balloon popped because it felt like it was too close.**

P6 said that in the hearing aids (that she uses also as earphones) it did not give the sense of movement, as it happened in the headset, so she preferred the headset. She added the following:
- When the main character spoke lower, it felt as if he was outside of the room she was in;
- If anyone actually in the room would have spoken, she would have difficulty in distinguishing if it was us inside the room or something in the video;
- She asked what happened when the balloon popped, but as the video had no visuals associated, her question could not be answered;
- She had a hard time identifying some of the sounds.

Difficulties with Interaction and Accessibility Suggestions

To enhance accessibility, **P1** suggested the following:
- In order for the user to move across the screen, instead of moving the controller and pointing to icons and objects the user could use the joystick only;
- If the interaction had to be through moving the command, haptic feedback should continue to exist, complemented with earcons (sounds that indicated the beginning and the end of an icon, for example). The user can have feedback on whether he is inside or outside of a clickable icon, as current haptic feedback is always the same, he could not understand that aspect;
- As an example of a good accessibility practice an good audio feedback, he showed the iphone camera app, that provides haptic and audio feedback via earcons and speech, on whether the camera is in the right angle, if It is too inclined and how the user can improve in order to take the best picture;
- **"As the interaction level in the virtual environment will never be the same for a vision impaired user, compared with a fully sighted individual, not having the movement of controllers could help the interaction"**.

P2 had some difficulties:
- He could not perceive where he was pointing at with the pointing white ray and circle, in the initial environment, in the icons and in YoutubeVR. However if the background was of one colour only and the ray in a high contrast colour, he could see it with no problem, has it happened with the black background and yellow ray, in the "First Steps' ' gun game;
- He had a hard time distinguishing icons and reading text, as they were too small.

P5 had some difficulties in finding the search icon inside of "YoutubeVR", as the icon's background was overlaid with some images.

For **all four** participants with severe Visual Impairment the major problem with interacting with the device was the lack of accessibility features. They would add **screen readers** and/or **voice commands**. Two participants mentioned they would add **audio description** to the content, when the sound by itself does not provide enough information to describe the scene.

Personal Feedback Overview

Despite the difficulties, **all** participants considered the experience to be pleasant.

P1 would like to have content about nature, rich in detail, but mentions that this is a personal liking and that the preferred content will vary from person to person.

P2 felt more immersed inside the First Steps robot game, but enjoyed the 360º sensation from the audio experience. He liked the sound and quality of the videos. **He mentioned he enjoyed VR, as the image is bigger and closer, the colours are more vivid and because he has no outside light reflection interfering with his sight, he felt that VR "might be good to watch series and movies"**.

P3 felt more immersed in the "Lion 360º" video and in the 3D audio experience. About visual stimuli she can perceive, mentioned that a **stronger point of light would be better for her to see** (gave as an example the room light that she could perceive, despite being in a lower contrast then she would like), as generally she can't perceive or see the light from a regular screen.

P4 liked the videos, but according to her, the image "always had a little blur, pixelated" (even adjusting the lens distance (positions 1, 2 and 3) and the proximity of content made her feel like she had her face too close to a screen.

P5 liked the graphics and visuals, but **would change the commands for gloves, as the interaction with the virtual objects would feel more close to reality**. She found VR to be particularly interesting for gaming, as she felt really inside of the game. She felt immersed in all the experiences. However, she said the audio experience was more immersing as, according to her, **"in the video my brain knows this is not real, there's no lion here, but if I close my eyes and imagine, I can imagine a person talking to me, even without the visual part"**.

P6 felt more immersed in the 3D audio experience then in the youtube videos, because in the videos, the sounds of nature she was hearing while being inside of a room did not feel real, while in the audio, as it was voices inside a room, it felt more real.

As a follow up question to the interviews, participants **P1**, **P2**, **P3** and **P6** were asked if they felt as if their other senses were more sharp. Three participants made the correction from **sharp** to **attentive**. Therefore, **all four users considered some of their senses to be more attentive with the loss of vision, because they learnt to pay attention to things fully sighted individuals don't need to**.

4.5 Discussion

After performing all the sessions, with the feedback from participants and the knowledge from the literature review, we've decided to develop a stationary immersive experience for blind and low vision users.

After the interviews, given the fact P2 uses a white cane and has a high degree of impairment, the idea was to develop one experience focusing on P1, P2, P3 and P6's needs. However, during the participatory design sessions it became clear that P2 could perceive more visual content than previously anticipated. With this, two things became needed: to target P3's light perception **- "I would imagine the sky to be above me. So for me, that I can only perceive high contrast, maybe it would make a difference to have a high contrast light focus to reference the sky" -** in VR and to explore P2's need for objects' proximity to the lens and the use of bright colours, in addition to an immersive audio. As P1 and P6 mentioned, audio descriptions when the sound was not sufficient to describe the scene, were considered important and missing. P4 and P5 can enjoy the already existing experiences like any user without a disability. However P5 gave an interesting insight on the audio experience: she felt it was more immersing because **"in the video my brain knows this is not real, there's no lion here, but if I close my eyes and imagine, I can imagine a person talking to me, even without the visual part"**.

Regarding content the feedback is very personal and depends on each participant's taste. Some prefer movies and series, others documentaries or youtube videos on a subject of interest. As P2, P3 and P6 don't understand English, the production of content in Portuguese, participants's native language, is also an aspect to take into consideration.

CHAPTER 5
PROTOTYPING AND TESTING

In this chapter, the prototyping process is outlined, along with a step-by-step description of how the prototype was developed. The second part of the chapter is dedicated to presenting the feedback from the last sessions conducted with participants - the User Experience Assessment - where the developed work was evaluated.

5.1 Prototyping

5.1.1 Conceptualisation and Planning

Concept

To collect new feedback from participants, we chose to create an experience based on a children's story. This experience includes scene descriptions narrated within the story, spatial audio and visual stimuli. As highlighted in the literature review, stories play a crucial role in our development since childhood. Childhood stories are designed to impart moral lessons, however, in this case, we aim to transport users to an imaginative field. Therefore, we have selected and adapted an excerpt from the story of "Little Red Riding Hood"(Capuchinho Vermelho) (Capuchinho Vermelho - Histórias e contos infantis, n.d.).

The story selection as main subject for the experience was influenced by feedback from P6, to see if altering the context of the experience (imaginative field) would result in similar feedback, particularly regarding the unnatural feeling of outdoor sounds experienced indoors. Additionally, opting for an outdoor setting in an imaginative space, aimed to visually simulate sunlight for P3's perception, which was considered a natural way to incorporate a light focus. As three participants don't speak or understand English, the prototype was developed in Portuguese.

Having as inspiration and example some of the Virtual Reality (VR) animations - like "Beyond the Fence" (fig 5.1.1A) - in the "Animation VR" app, from the Meta Quest 2, the planning began.

Fig 5.1.1A Beyond the Fence by Goro Fujita (Quill, n.d.)

Plan

The planning began by selecting an excerpt from the story. After, a draw of the scene where all the action takes place was drafted, to simplify the creation and placement of visual content. Next, proceeded the adaptation of the script (orange text) to suit the requirements, focusing on describing the environment. The sounds (blue text) and visual stimuli (red text) to incorporate into the experience are also identified:

SCRIPT (IN PORTUGUESE)

(Narração em posição central neutra; pássaros à esquerda, uma abelha à direita; música suave)

C1

Era uma vez uma linda menina, que vivia na clareira de um bosque com a sua mãe e a quem todos chamavam, carinhosamente, de capuchinho vermelho. A Capuchinho vermelho é muito parecida com a sua mãe. É uma menina pequena, com longos cabelos morenos, pele clara com faces muito rosadas, uns grandes olhos castanhos e nunca sai de casa sem o seu capuz vermelho, que lhe foi oferecido pela sua avó.

C2

O bosque é denso, cheio de árvores e de vida. Os caminhos estão trilhados e a caminhada até à aldeia faz-se em poucos minutos. A sua pequena casa tem as paredes brancas e o telhado ladrilhado em tons de tijolo, mas o que mais sobressai nesta pequena construção no meio da natureza, é a sua grande e imponente porta vermelha. O céu está azul. O sol no alto - **SOL, FOCO LUZ** - doura os tons verdes vívidos das árvores e das flores rasteiras. A brisa de verão toca suavemente (som de vento suave da direita para a esquerda) a pele. Capuchinho brinca lá fora, quando a mãe a chama:

- Capuchinho! (som longe dentro de casa à esquerda)

C3

Sai à rua (som porta à esquerda) e diz-lhe:

(som de frente)
- Coloquei neste cesto um bolo e um pote de mel. Leva-o à avozinha, que tem andado adoentada. Mas Capuchinho, tem cuidado! Não te desvies do teu caminho e não fales com desconhecidos.
- Sim mãe! - prometeu Capuchinho Vermelho.

A mãe deu-lhe um beijo na face (som de beijinho direita + baixinho - vai com cuidado) e [...]

C4

[...] Capuchinho pôs se a caminho (som de passos esquerda para direita). A avó mora longe, no meio do bosque, o caminho é longo e nunca se sabe quem pode aparecer... (música sinistra)

Little Red Riding Hood - adapted excerpt

After this step, needed visual elements and sounds were listed (table 5.1A).

Sounds	Visual Elements
Narration Mum's lines Little Red Riding Hood's lines Music (soft) Sounds of nature (birds, bees) Cooking sounds Wind breeze Door A kiss Footsteps	Sun - Light focus Trees House Mum Little red riding hood Basket Path General scene

Table. 5.1A Needed elements for the prototype

Finally, using C1, C2, C3 and C4 (representing different scenes), both a general scene overview drawing (fig 5.1.1B) and a storyboard (fig 5.1.1C) were developed. The objective behind the various scenes is to introduce changes in camera angles and perspectives, as well as to outline the placement of content.

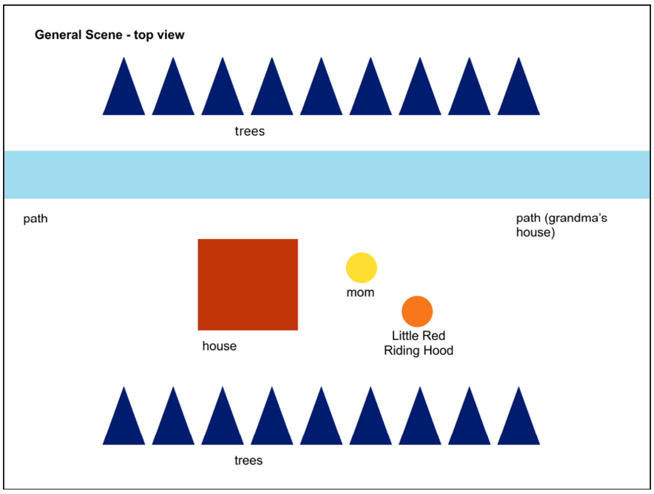

Fig 5.1.1B General Scenario (viewed from above) - content placement

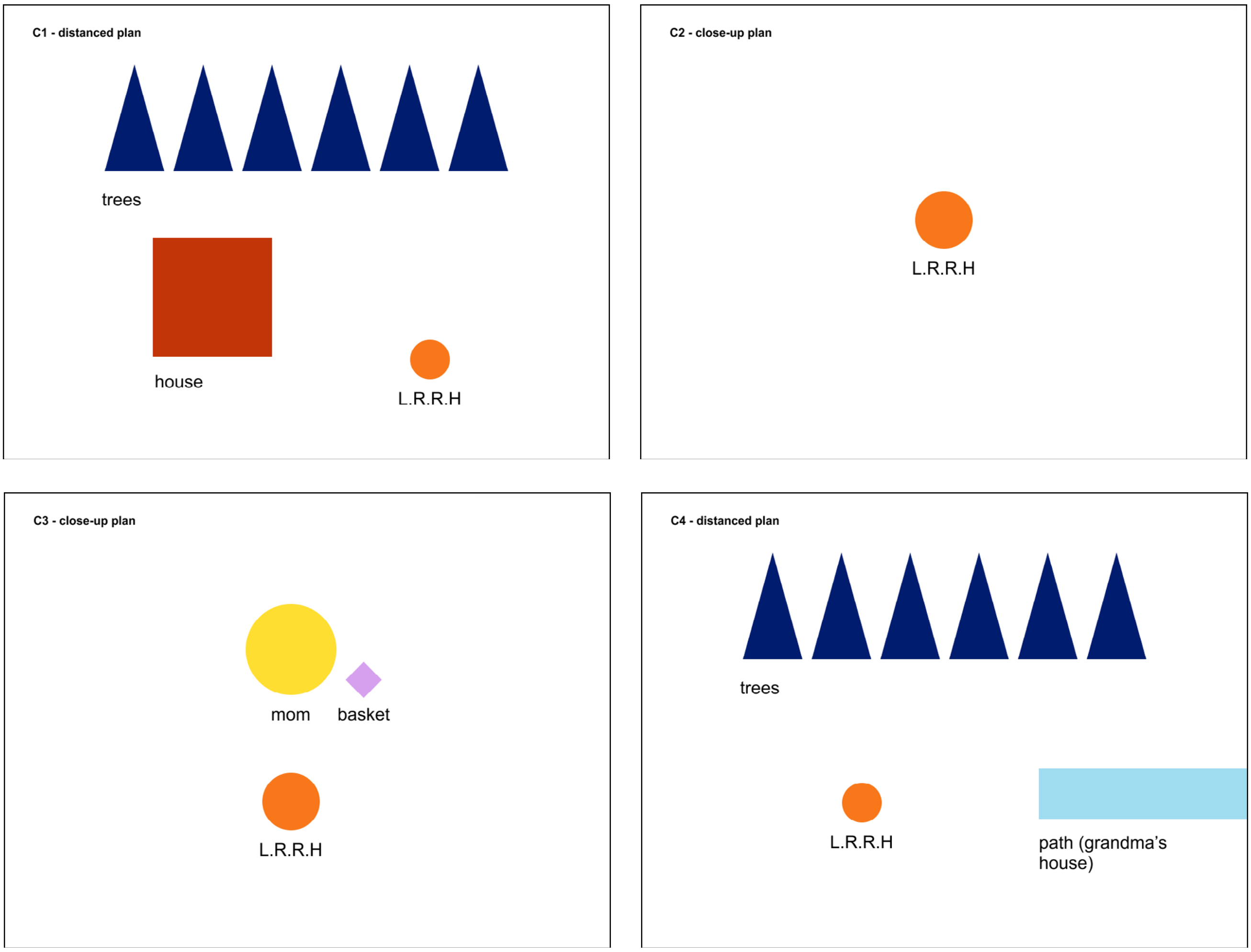

Fig 5.1.1C Storyboard

Finally, over the storyboard and in order to create the sounds in the desired position, an Ambisonics sound plan was created (fig 5.1.1D). The user is positioned at the origin of the reference frame.

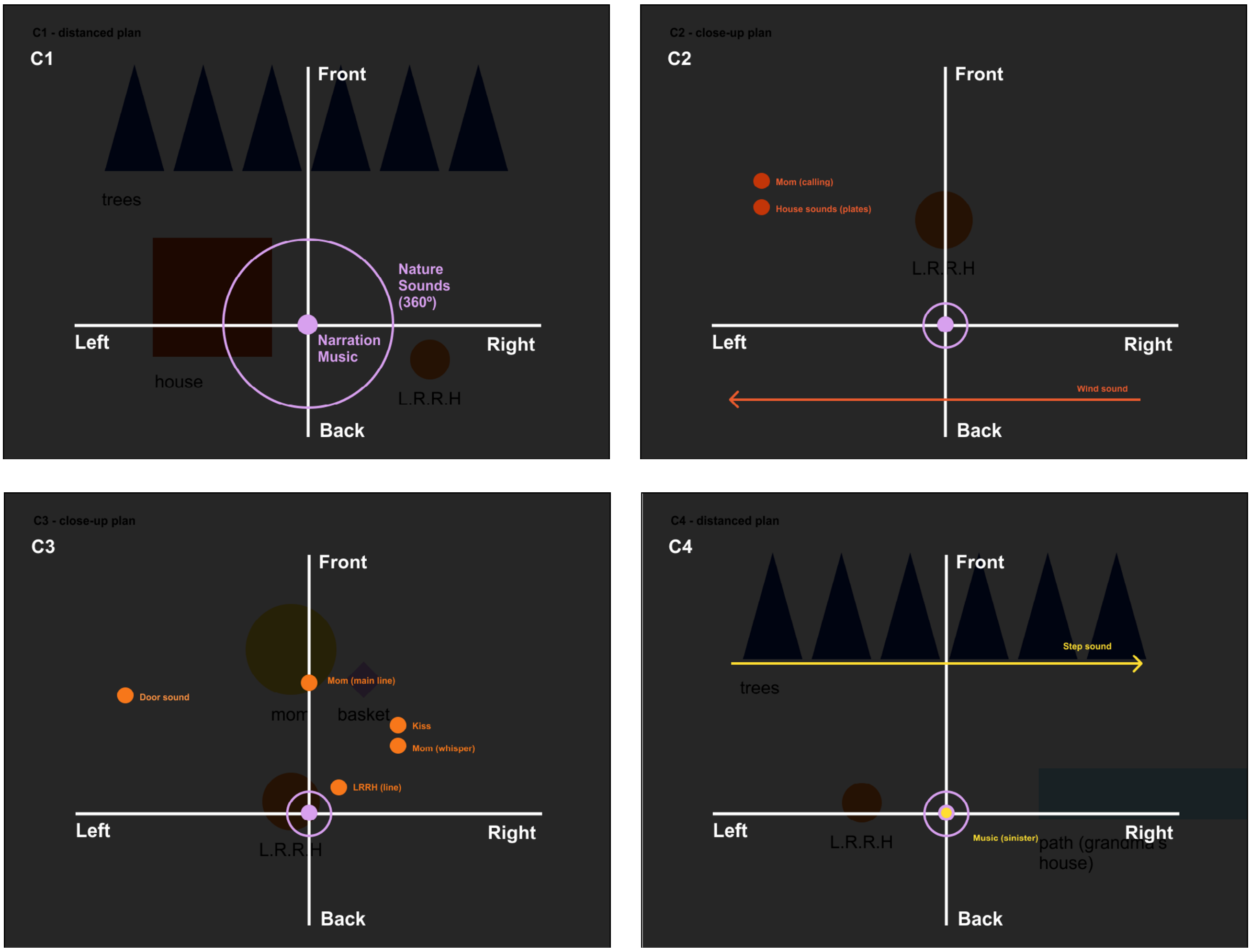

Fig 5.1.1D Ambisonics horizontal audio plan

The English version of the script, the storyboard, the general scene overview drawing and the ambisonics sound plan can be accessed in the **Appendix C - Prototyping related content**.

5.1.2 Used Software

After defining the concept and completing the planning phase, we decided to prioritise the exploration and development of spatial audio, as our primary target users are individuals with low vision to blindness. Afterwards, we invested in the visual content. Therefore, the visual content was created for the sound and not the other way around.

Voices and Sounds

To generate the various voices as if they were recorded in a studio, we used **VEED.IO's AI text-to-speech** technology, an Artificial Intelligence (AI)-based software. This platform enables the user to use text to generate audio in three different voices as needed. We opted for this solution because the sound quality recorded by the available resources (smartphone or pc microphones) contained background noise, which could interfere with the immersive experience. However, as the audio was created with AI, the narration and intonation did not sound as natural as if they were recorded by a human, which also interfered with the quality of the experience. For this reason a second version was recorded with human voices, enhanced in **Adobe's Enhanced Speech**, an AI tool to remove background noise and turn the audio the most similar to a studio recording. The rest of the sounds are royalty free and were downloaded from Pixabay. Despite this, all sounds, music and voices are credited in the **Annex A - Sound Credits**.

To develop the spatial sound, we used Reaper with IEM plug-ins ("**VST: StereoEncoder (IEM) (64ch)**" to encode and "**VST: BinauralDecoder (IEM) (64ch)**" to decode) to create the desired 3D effects, according to the plan described in **Fig 5.1.2A**. Reaper is a computer audio production software that provides a comprehensive set of tools for multitrack audio, recording, editing, processing, mixing and mastering. (REAPER | Audio Production Without Limits, n.d.).

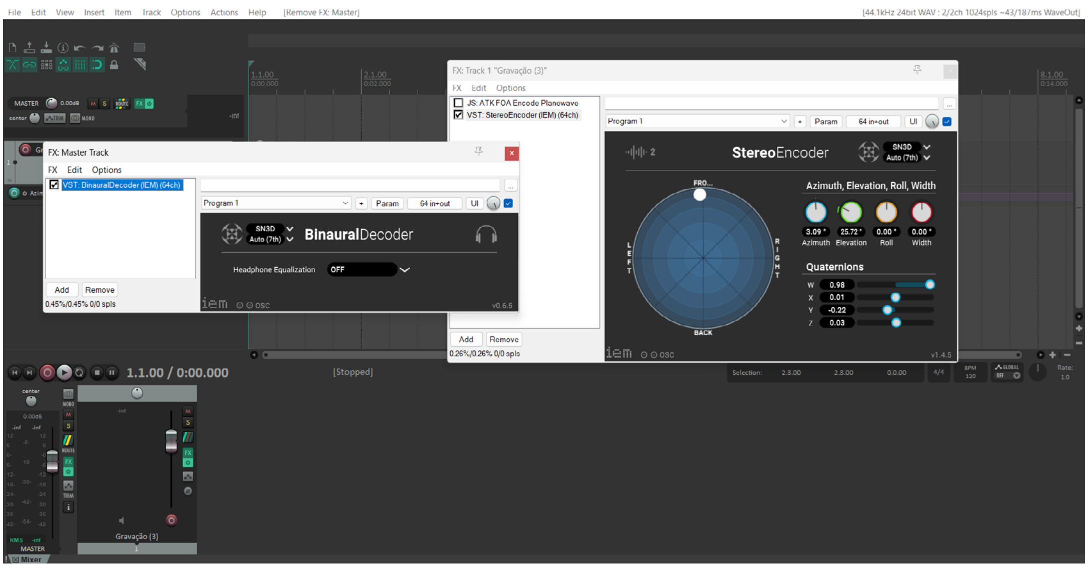

Fig 5.1.2A Reaper Ambisonic audio creation with IEM plug-ins (encoder and decoder, on the right and left, respectively)

Visuals

The prototype is divided into two: Prot_V1 and Prot_V2, different visuals with the same audio experience.

The visuals were combined in Unity, using **free only** Assets from the Unity Asset Store and from SketchFab. To animate the characters body movement, Adobe's Mixamo online tool was used. All the visual content used to produce the final prototype experience is credited in the **Annex B - Visual Assets Credits**. The rendering was made using the built-in Recorder from Unity, in both experiences.

Final Experience

The rendered Video from Prot_V2 needed to be turned into a 360º video. For that the Spatial Media Metadata Injector v2.1[8] was used. Finally, to broadcast the prototypes to the Meta Quest 2 for testing, the videos were uploaded to youtube. They can be accessed through the following links: Prot_V1[9] and Prot_V2 [10].

5.1.3 The Prototype

Ambisonic Audio - Reaper

In order to create the 7th order ambisonics audio the following was done:

1. Changing the number of channels to 64 in each track (fig 5.1.3A);

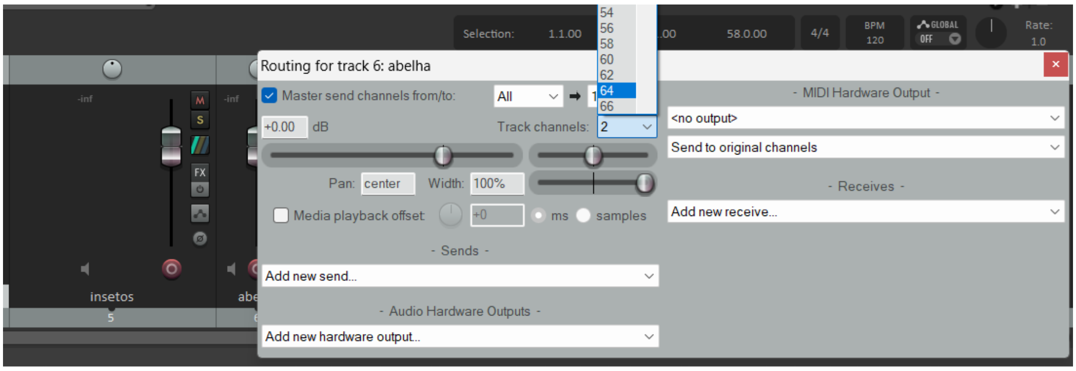

Fig 5.1.3A Changing the number of channels in each track

2. Creating a new track, called "E to D", to be the parent of all the tracks with mixed audio, so then only one track has to be sent (with all the applied effects) to the decoder (fig 5.1.3B); The "VST: EnergyVisualizer (IEM) (64ch)" plug-in was added to this track, in order to understand the sound position in the 360º space;

[8] https://github.com/google/spatial-media/releases/tag/v2.1
[9] https://youtu.be/IqVCHaga8fQ
[10] https://youtu.be/xuSX5LkHsPc

Fig 5.1.3B "E to D" track and children

3. Creating a track to apply the binaural decoder, called "Binaural Decoder" (fig 5.1.3C), receiving the information from the track "E to D", which contained all the information from It is track children with all applied effects;

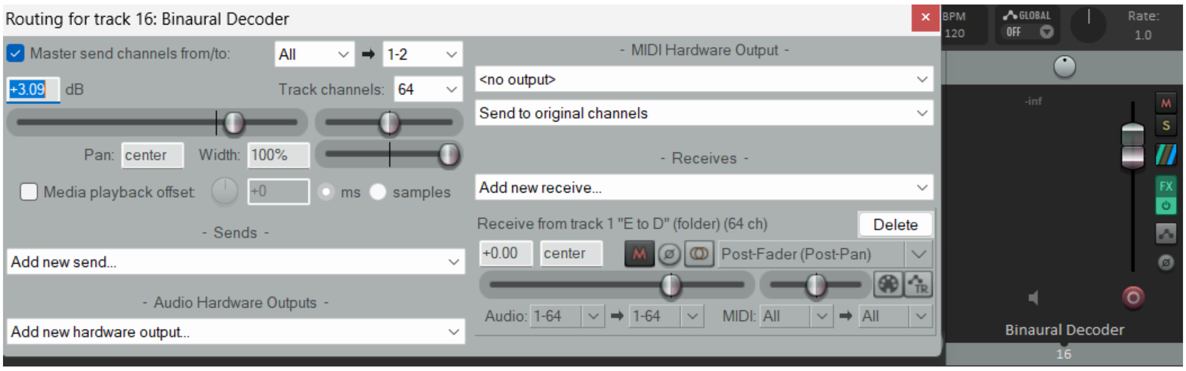

Fig 5.1.3C "Binaural Decoder" track

4. Adding the encoder to each track (narration, dialogue, nature sounds, etc) in order to position the audio around the user's head (using the **Azimuth** and **Elevation** attributes and also the **Volume** for proximity). A Reverber ("**VST: FdnReverb (IEM) (64ch)**") (fig 5.1.3D) was added to the nature sounds and the final walk. The ReaFir plug-in ("**VST: ReaFir (FFT EQ+Dynamics Processor) (Cockos)**") (fig 5.1.3E) was used to enhance speech and remove the remaining background noise. Finally, an energy visualizer was added to help understand the position of sounds within the user's sound field (fig 5.1.3F).

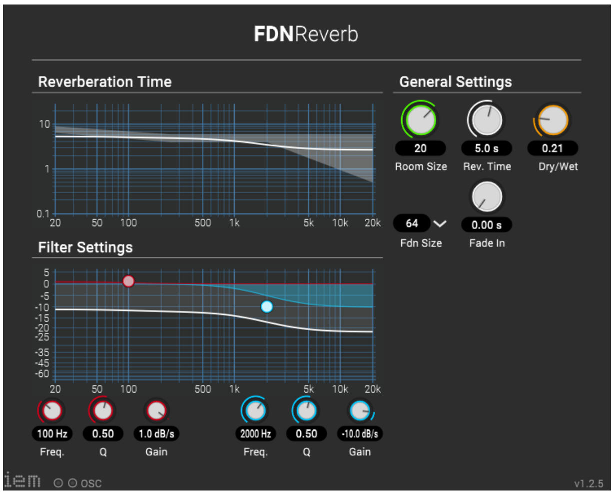

Fig 5.1.3D Reverb plug-in in birds's sound

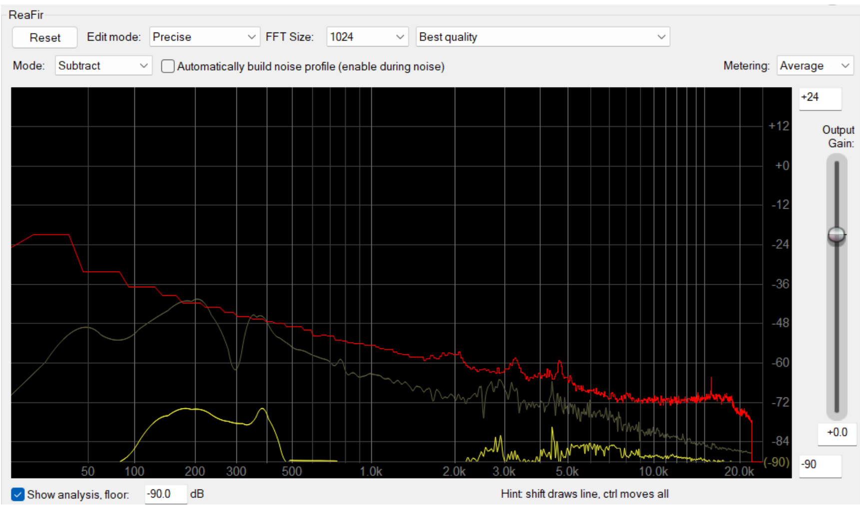

Fig 5.1.3E Reafir plug-in in Mom's main line

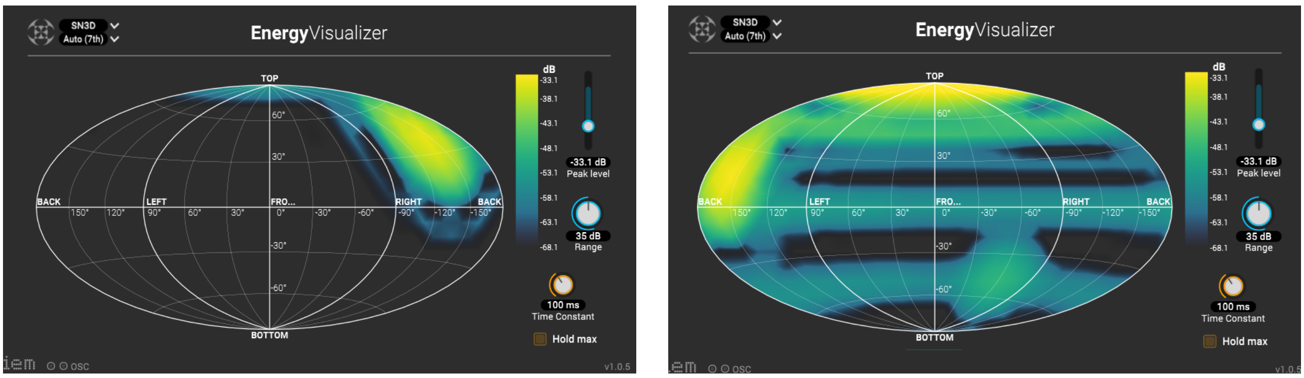

Fig 5.1.3F Energy Visualizer in two different moments

Finally, the mix was ready to render (fig 5.1.3G).

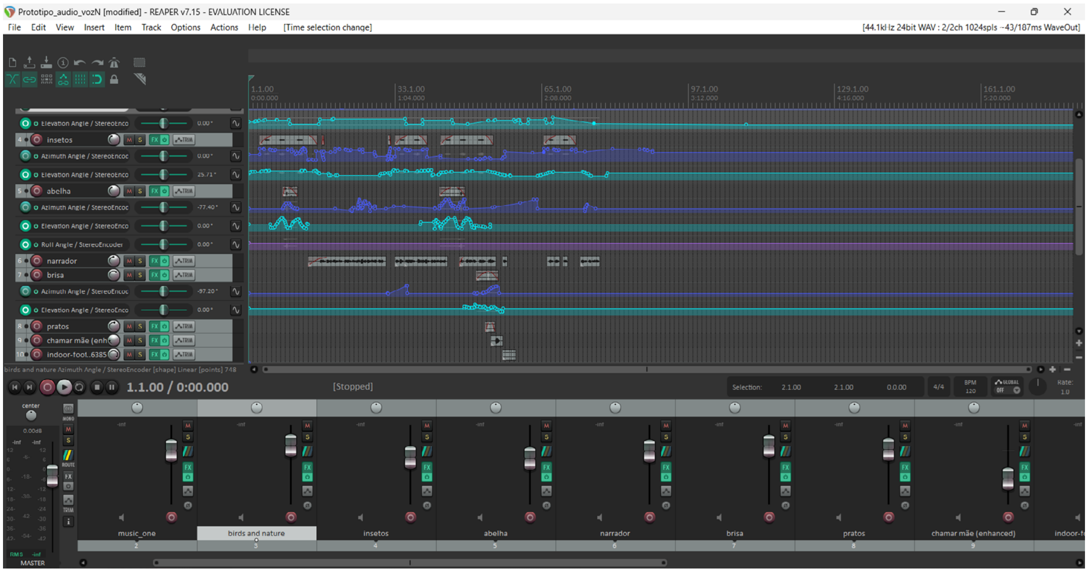

Fig 5.1.3G Reaper Ambisonic final audio

Visuals - Unity

As mentioned before, all individuals are different, which means their needs differ. Because of this, the prototype is divided into: Prot_V1 and Prot_V2, different visuals with the same audio experience.

PROT_V1

The first prototype (Prot_V1, fig 5.1.3H) was developed to test with the blind participants that can perceive light (P3), as the visual characteristics are not the same. This prototype consists of one light focus when the Sun is mentioned, developed according to P3's feedback, as she is the only blind user with light perception.

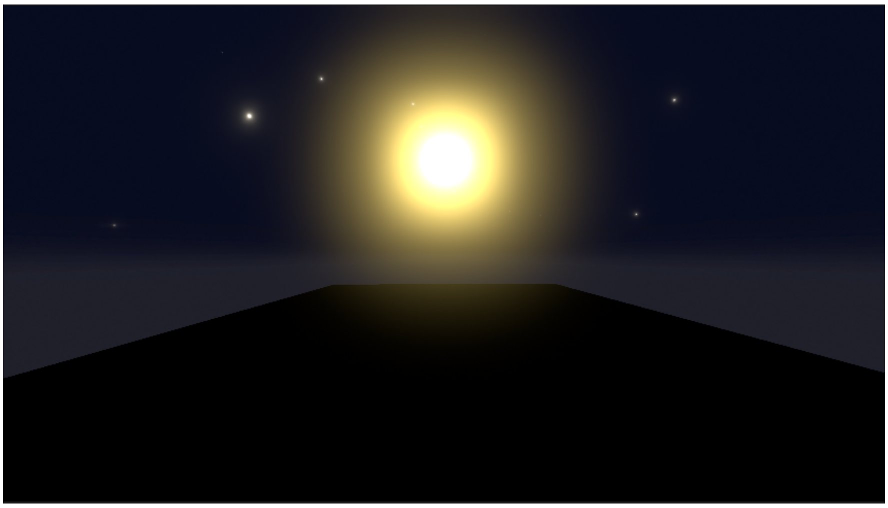

Fig 5.1.3H Prot_V1 Final Visual Effect

To do the light focus a dark Skybox was chosen, so the background contrast was higher. After that, a plane was created for reference and a black material applied. The Light Focus, from now on referred to as The Sun, was created from a 3D Game Object of a Sphere and by following the next steps:

1. Besides having an already default existing Directional Light, a new emissive material was needed to emit that light; this material was created, the “Emissive” property activated and the colour chosen (fig 5.1.3I);

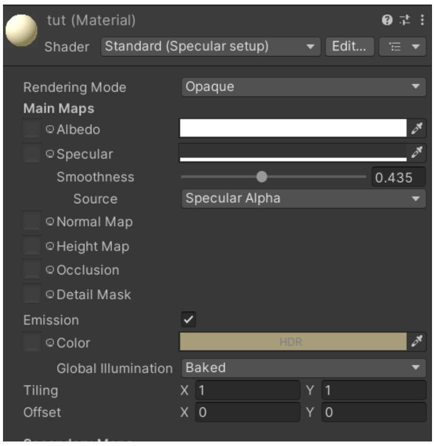

Fig 5.1.3I Emissive Material

2. After, the Post Processing Package was installed using Unity’s Package Manager (fig 5.1.3J). The idea is to put a filter over the camera, to obtain the desired glowing effect;

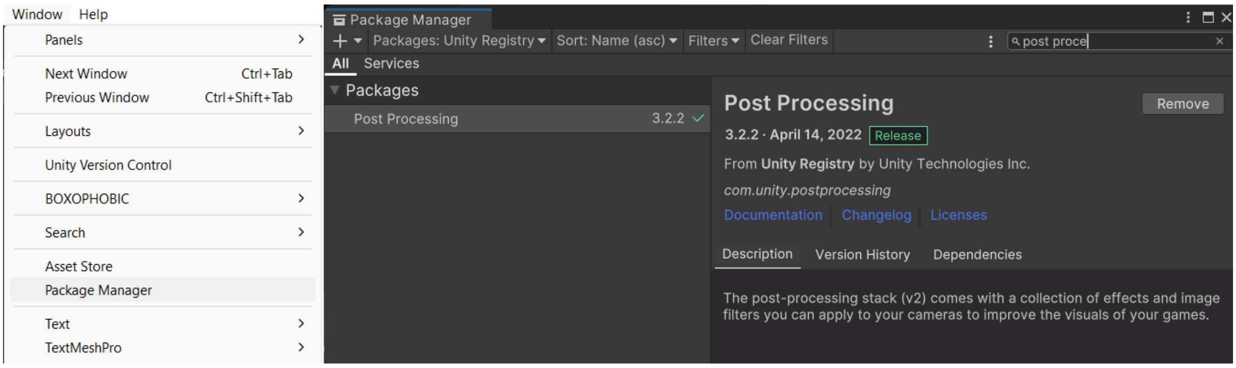

Fig 5.1.3J Post Processing

3. Afterwards, a new layer called "camera" was created and added to the Main Camera so the effects can became visible (fig 5.1.3K);

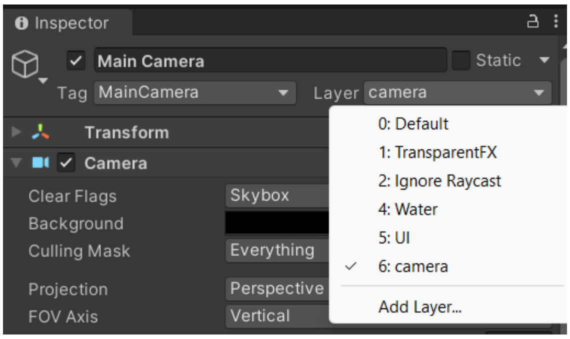

Fig 5.1.3K Adding "camera" layer to the Main Camera

4. Then it was time to also add to the main camera the Post-process Layer (fig 5.1.3L) and Post-process Volume, so we can, respectively, set the layer to which the effects will be applied and then manipulate it;

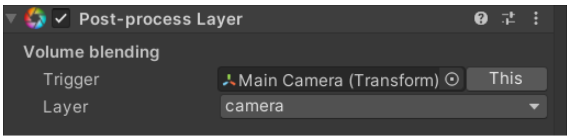

Fig 5.1.3L Adding Post-process layer to affect the layer "camera"

5. In the Post Processing Volume (fig 5.1.3M) we selected "Is Global" so the effects are applied to the whole scene and then added the "Bloom" effect (to expand the borderlines and light from the Sphere); after the properties"Intensity", "Threshold", "Soft Knee", "Diffusion", "Anamorphic Ratio" and "Color" were activated/manipulated, in order to achieve the glowing Sun.

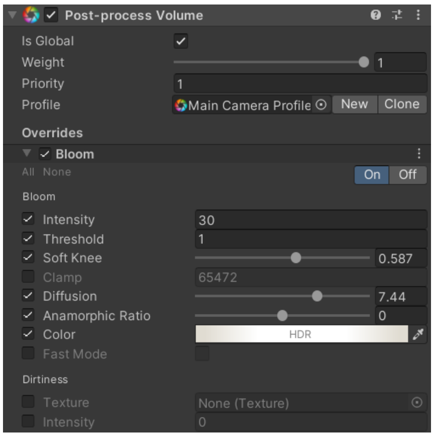

Fig 5.1.3M Post-process Volume with Bloom effect

At the end, the camera was animated (fig 5.1.3N), so The Sun was only present in the user's field of view in the moment of the story that it is mentioned. Finally the video was recorded (fig 5.1.3O).

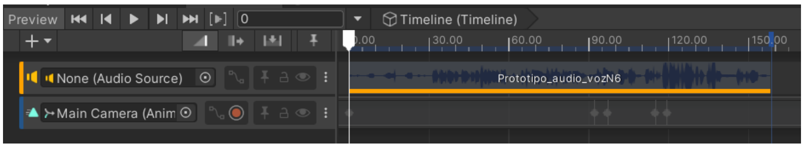

Fig 5.1.3N Prot_V1 Timeline

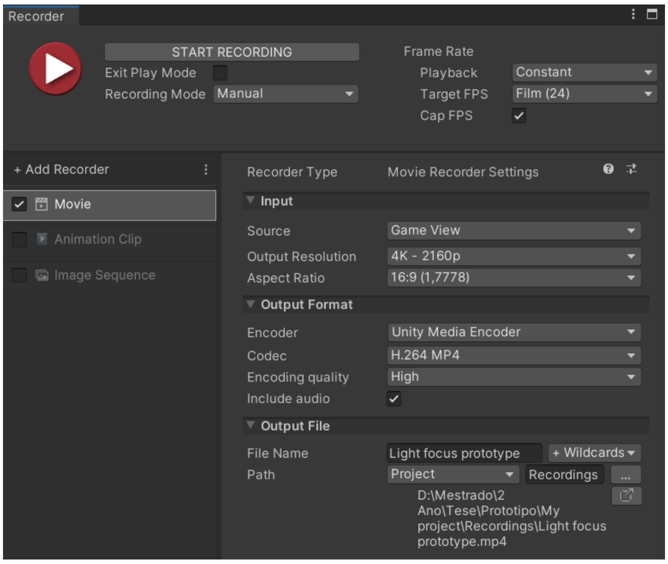

Fig 5.1.3O Prot_V1 Recording Settings

PROT_V2

The second prototype (Prot_V2) was developed to test with sighted participants (P2, P4 and P5). This prototype consists of the full animated scene, with different camera angles, always close to the characters when the action is focused on them (fig 5.1.3P to T). The added light was also intentional to illuminate the scene from all angles and give bright colours. This prototype was developed according to **mainly P2's feedback**, as he is the only user with Low Vision, using the storyboard previously presented. The planning stayed pretty much untouched. In the audio, the Mom's and Little Red Riding Hood's Lines changed position (from right to left), to go according to the camera animation.

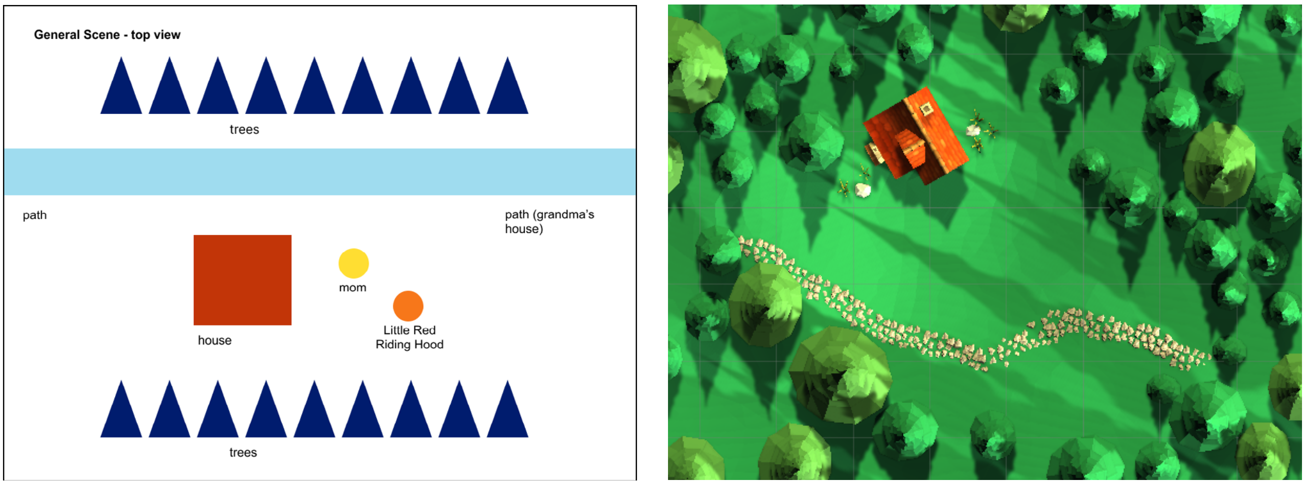

Fig 5.1.3P Top View, General Scene, Real vs Plan

Fig 5.1.3Q Scene C1, Real vs Plan

Fig 5.1.3R Scene C2, Real vs Plan

Fig 5.1.3S Scene C3, Real vs Plan

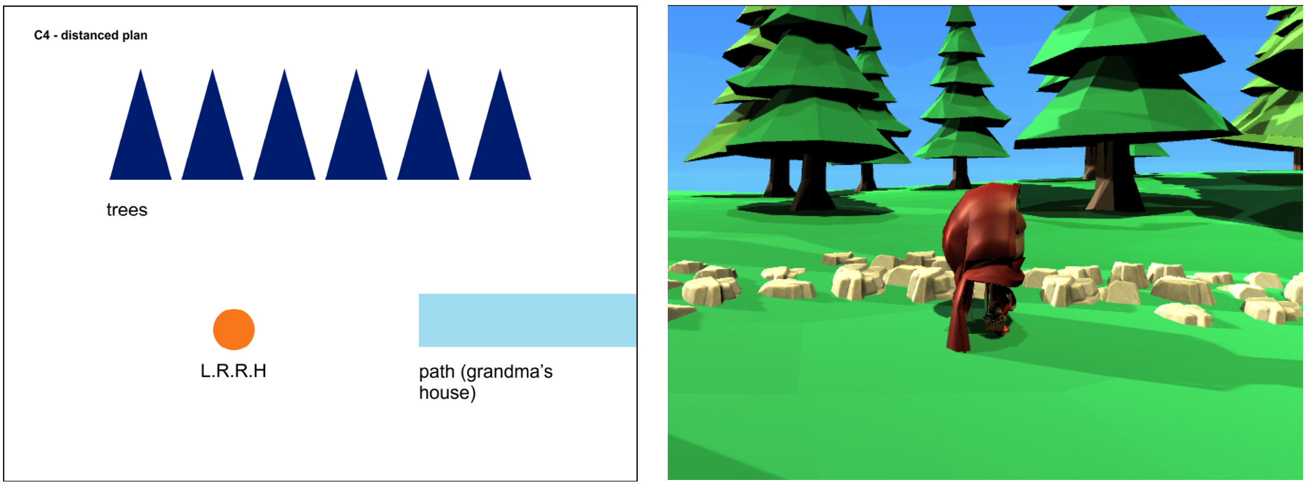

Fig 5.1.3T Scene C4, Real vs Plan

To animate the camera and the characters position, the movement was recorded in the timeline (fig 5.1.3U) and edited in Unity's built-in animator tool (fig 5.1.3U) (in the characters case, additionally to Mixamo's body movements - fig 5.1.3V).

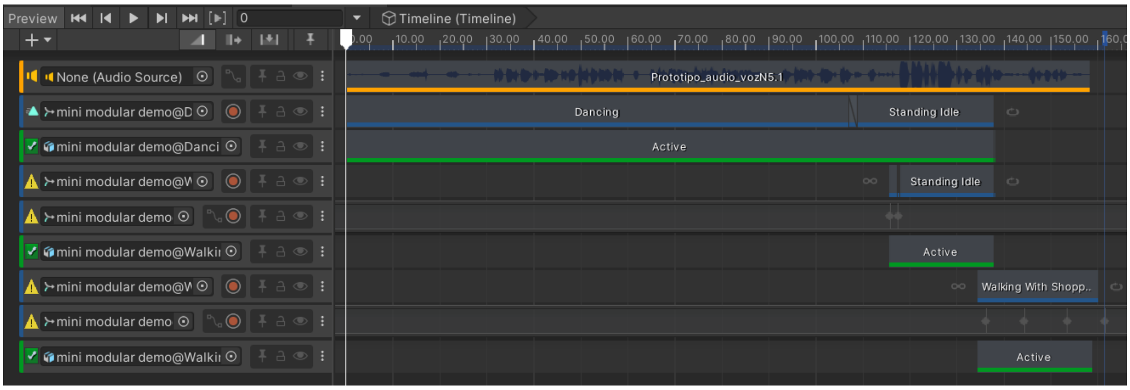

Fig 5.1.3U Timeline

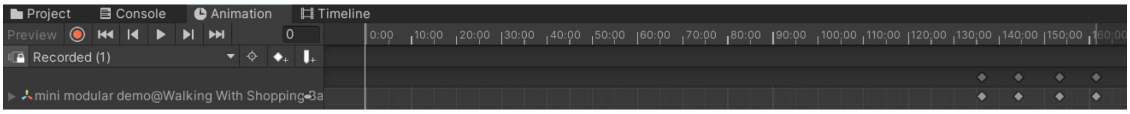

Fig 5.1.3V Unity's Animator - Little Red Riding Wood final walk

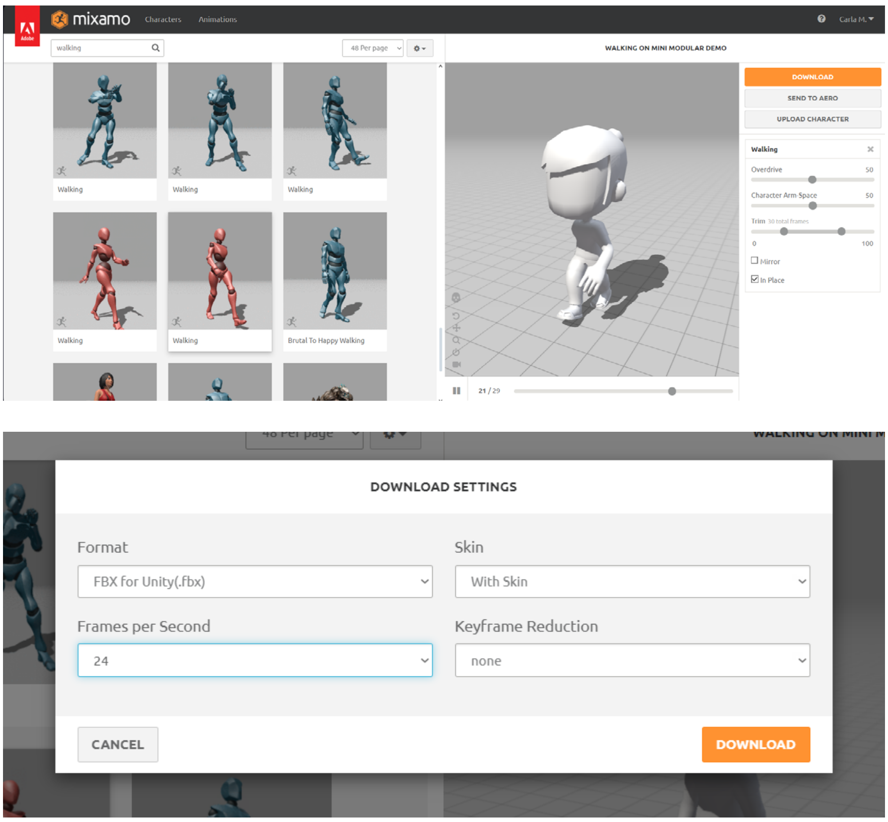

Fig 5.1.3W Mixamo Animation

After all these steps, the final experience was ready to record and render (fig 5.1.3X).

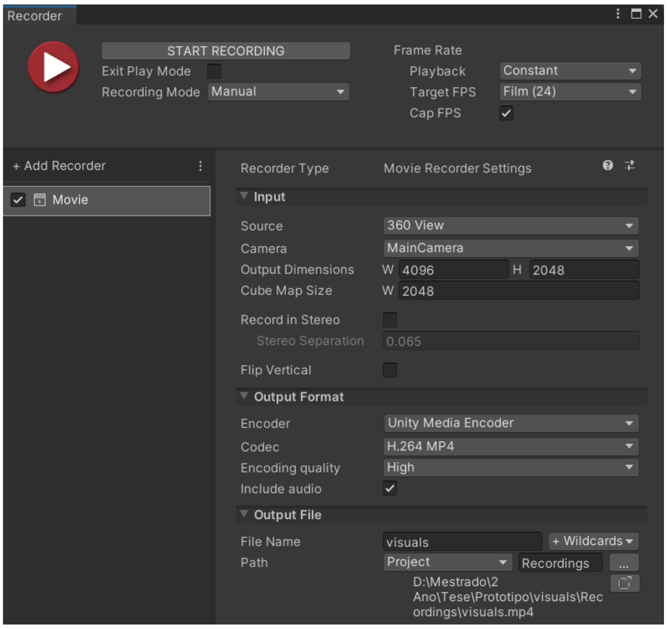

Fig 5.1.3X Prot_V2 Recording Settings

5.2 User Experience Assessment

5.2.1 Audio's Evaluation

To get the best audio experience, the prototype was sent to two participants at a time, in order to prevent learnability and bias in their feedback. Each participant listened to the audio in their own earphones.

Firstly, we sent the audio to P1 and P6, both blind users with no light perception. After that, the audio was sent to P2 and P3, a blind user and a low vision user, respectively, and lastly to P5, a user who performs her daily activities requiring only the use of contact lenses or glasses. P4's feedback is not included at this stage of the study, as the participant was no longer available. The order was influenced by the fact that P1 and P6 would only be evaluating the audio, as they have no visual perception, so the final version they test in the headset is different from the version they evaluate using their own earphones.

We asked participants to answer the following questions:

1. Do you feel the 360º effect?
2. What do you think about the level of immersion?
3. What do you think about the descriptions provided?
4. What do you think worked well and what would you change?

Prototype version one (V1):

Participant one (**P1**):

- Did not feel the 360º effect;
- He enjoyed the narration, as it was slow and with good intonation;
- The distinction between right/left is clear, but not behind/front, top/down;
- He liked the soundscape of the forest - "**It gives the feeling that I'm Little Red Riding Hood and that I'm in the middle of the forest"** - but pointed out that he would like to have an enhanced 360º effect, especially the flying animals and insects, instead of just being clearly perceivable on the left and right ear channels.

Participant six (**P6**):

- Like P1, she did not feel the 360º;
- She thinks the experience is very accessible, as it describes the space well, giving a sense of how the scene is like;
- Enjoyed the sound of the door, the sound of Little Red Riding Hood's footsteps at the end (which gave the impression Little Red Riding Hood was walking away), the sounds of nature and the description of the weather;
- In general considered the experience pleasant;
- The description of the mum is missing:
- It could be interesting to specify what Little Red Riding Hood was playing and if at the end of the story, the mum was watching Little Red Riding Hood leave.

Alterations:

Based on participants feedback it was imperative to enhance the 360º effect. Regarding the descriptions, as one participant considered them insufficient and the other enjoyed them, no alterations were made in order to collect other participants feedback on the current solution.

Prototype version two (V2):

Participant two (**P2**):

- Felt the 360º effect,considered the feeling of immersion good and the description was clear;
- Mentioned that the insect's noise was a little bit too loud while going through his ears.

Participant three (**P3**):

- Felt the 360º effect, especially in the sounds of nature, birds and flying insects;
- Perceived that the story took place inside, not outside
- Pointed out that when she thought Little Red Riding Hood left the house, the sound was the same as when she was inside;
- Mentioned it was possible to understand when Little Red Riding Hood leaves by the footsteps and the sound of the door. Even though she can perceive the characters moving apart or closer together, through their speech and the sound of their footsteps, the voices always remain at the same distance not following the footsteps or the movement of the characters.

Alterations:

After clarifying to P3 that the story was always outside, she said the voice's volume did not need to change. However, we tried to accentuate the difference of speech of the mother from when she is inside and outside of the house. Regarding P2 feedback, the insect volume was toned down.

Prototype version three (V3) and final:

Participant five (**P5**):

- Felt the 360º effect - **"you really feel like you're immersed in history"**;
- Enjoyed the nature sounds, as she considered it helped her feel inside the environment and to have a more real perception of the story;
- Considered that the descriptions were clear and allowed the imagination to run free;
- Felt like the background music and the sounds of nature fitted in well with the story, not adding negative feedback.

For this reason, no changes were made.

5.2.2 Final Prototype's Evaluation

Regarding the Final Prototype evaluation (fig 5.2.2A to E), Prot_V1 was tested with participant P3 and Prot_V2 with participants P2 and P5. To participants P1 and P6, as they are totally blind, either prototype could be used, as the audio was the same (V3). The Script for this session is present in the **Appendix D - Testing Script**.

Fig 5.2.2A Testing Sessions with users

Fig 5.2.2B, C, D, E Testing Sessions with users

Participant's Feedback

Participant one (**P1**):

- Felt that the 360º effect was improved compared to the V1 version of the audio, but noted that the mother's voice was a bit distorted and preferred the voices in the V1 version of the audio (despite the voices recording remained the same, but in a different soundfield position);
- Liked the sound environment of the final version (V3) and felt that the level of immersion in the experience was good;
- Believes that incorporating **audio description into the narration** of the story is a **more natural way to include audio description**;
- **Felt that the YouTube experiences from the previous session had a higher degree of immersion due to a greater profusion of sounds**, creating a more complex sound environment. Despite this, he believes that **this experience does not benefit from greater sound complexity**;

- Felt present in the scene, as if he were inside the story. It was possible to perceive the space, the narration and the movement of the characters;
- Found the experience pleasant and, given its context, would not change any aspect, as the work developed meets his expectations, considering the research proposal;
- Emphasised the quality of the narration and the clear differentiation of voices (consequently, of characters), as a positive aspect;
- Considered that the way the story was worked on was original in terms of sound, but that the story itself is identical to the already existing one;
- Perceiving nature sounds indoors is natural and inherent to the concept of Virtual Reality: **"the better the immersion, the more the experience makes us forget the space we are in."**

Participant two (**P2**):

- Felt immersed in the environment, found the experience interesting and well-characterised, both in terms of sound and visuals;
- Felt the 360º effect of the sound in the nature sounds and character movements;
- Overall liked the audio, but noted that the mother's voice was a bit low;
- Liked the narration of the story and the description of the environment, **not considering it exhaustive**. However, he felt that the description did not match the visual content regarding the colour of the walls;
- Regarding the scenario: enjoyed the animation, the initial distant shot zoomed in on the house; found the characters simple and easy to understand; liked the colours, except for the walls of the house, for the reason described earlier;
- Considered the YouTube experiences from the previous session to be more realistic and detailed, as they were real recordings. In the developed experience the shapes of objects were more geometric and less detailed, like a cartoon, but with a 360º setting;
- Would've liked a more detailed scene to enhance the feeling of immersion and similarity to reality;
- Though this experience had **more vivid colours** than the ones from the previous session, **making it easier to see and distinguish the elements**. However, at first, he could not tell that Little Red Riding Hood was present in the scene, **as the character was far away**, only noticing it after the scene zoomed in, whereas in the other videos he could always see the animals without any problem;
- Felt comfortable, in a calm environment, where it was easy to understand everything that was happening;
- Found the experience pleasant and would like to experience more similar experiences in VR;
- Perceiving nature sounds within the headset felt natural;

Participant three (**P3**):

- It was difficult to assess the participant's perception of the presence of light as, initially, she could perceive when the light was present and when it disappeared, but after a few minutes of effort, she could no longer perceive the light even when it was there;
- She believes that if the **light focus were stronger**, it would have been easier for her to see, but for people with more visual perception, a stronger light might be unpleasant;
- The participant **naturally directs her head downward**, while the visual content in the headset is positioned higher up, so it was necessary to ask her to raise her head to keep the light focus within her visual field;
- She mentioned that she can only perceive light with her left eye and that **the visual effort causes her fatigue**, even for a short period;
- Initially, she did not focus on the light (only when asked) because when she watches a movie or listens to audio, she usually **imagines the story and does not use her vision**;
- The experience in the headphones and in the headset is similar;
- She had the feeling that the story took place inside the house due to the noise of dishes, but she would not remove it because she considers it makes sense in the context of the story. However, she would make it more muffled or distant;

- Since she was unsure about the setting of the story, she would add more exterior sounds to the sound environment, like birds and wind;
- She felt the 360 effect, especially with insects and nature sounds and liked the level of immersion;
- She **considered audio description essential for understanding the context and setting of the experience** and thinks it is a **more natural and pleasant way to incorporate audio description**;
- Compared to the videos from the previous session, especially the video "Underwater Life" she felt that the music in the developed experience was more appropriate because it was minimal and present at key moments. She thought the sound environment was similar to the video "Lions 360";
- She found the experience pleasant and thought it was natural to hear nature sounds in an indoor space;
- She finds using **the headset somewhat tiring**;
- She found the way the story was explored to be an original and new way to explore and experience stories or games.

Participant five (**P5**):

- Regarding the level of immersion and audio in the experience, she believes that the nature sounds help her feel in the story;
- She considers the description of the environment to be **natural and not exhaustive**;
- Overall, she liked the visual content, but because the shapes were very geometric and the characters lacked detail, she did not feel the setting was real, but more like a cartoon;
- She would like to have the same setting but with **more detail**;
- She would prefer an ending where Little Red Riding Hood does not disappear suddenly;
- She would enhance the sounds of the characters' movements, like footsteps;
- Compared to the videos from the previous session, she felt that the "Lions 360" video, because it featured real settings, gave a more real sense of presence than this animated story;
- She preferred the audio "The Tucker Zone" from the previous session, as she felt the 360º effect more easily in more elements (in this experience, she felt this only with the nature sounds);
- Perceiving nature sounds within the headset felt natural;
- She would like a more exciting story with a more complex and engaging plot, which would allow to incorporate more sounds and achieve a more complex soundscape.

Participant six (**P6**):

- Preferred the experience with the headset because it allowed her to perceive the 360º movement, **which was not possible with her hearing aid** (which she uses as headphones);
- Liked the overall experience, highlighting the movement of the characters and the description which allowed her to create a mental image of the space;
- Considers incorporating audio description into the story's narration to be a **more natural way of including audio description**;
- Compared to the previous experience, because it was in Portuguese, she could understand everything that was happening, but felt that the soundscape was similar;
- Would like a more detailed description of the mother;
- Felt that experiencing the audio through the headset was like **"things were happening right in my head,"** which did not happen with earphones;
- She found the experience enjoyable;
- It felt more natural than the first time to experience nature sounds indoors, although she would still prefer being outdoors;
- Liked that it was a familiar story, allowing her to better evaluate the experience, as she already knew what to expect of it.

UEQ-S Results

The main goal with this method was to gather qualitative insights. The following graphs are the result of the responses collected from the Short User Experience Questionnaire (UEQ-S) and were generated using the Short UEQ Data Analysis Tool.

The UEQ-S focuses on measuring two meta-dimensions: pragmatic (task-related) and hedonic (non-task-related) quality. Each of these dimensions is assessed using four specific items, making a total of eight items divided into two scales. Additionally, an overall UX score is derived from the mean value of these eight items. All items have the same polarity, with the left side representing negative terms and the right side representing positive terms. Furthermore, the order is fixed, with the first four items assessing pragmatic quality and the last four evaluating hedonic quality (Schrepp et al., 2017).

The scales used range between -3 and 3, varying from "horribly bad" to "extremely good." Values below 0.8 represent a negative evaluation, while values above 0.8 represent a positive evaluation. Values between -0.8 and 0.8 represent a neutral evaluation. Regarding scale consistency, values should not be lower than 0.7. Values below this threshold may indicate that participants did not interpret the same item in a consistent manner.

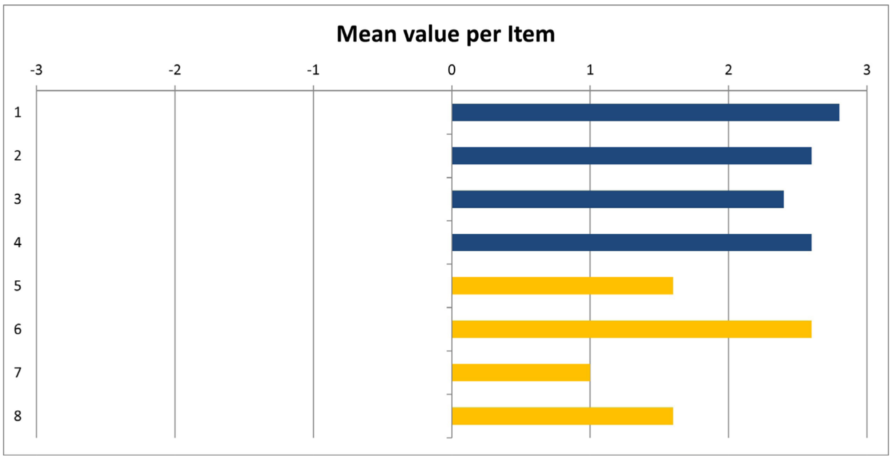

Fig 5.2.2F Mean value per Item

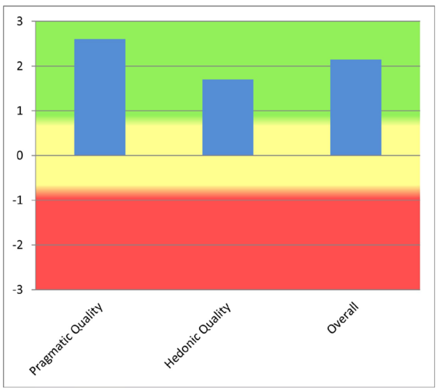

Fig 5.2.2G Short UEQ Scales

From this data (fig 5.2.2F and G) we can conclude that the overall evaluation of the experience was positive, as all the values are above 0.8.

Confidence interval (p=0.05) per item						
Item	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence Interval**	
1	2,800	0,447	5	0,392	2,408	3,192
2	2,600	0,894	5	0,784	1,816	3,384
3	2,400	0,894	5	0,784	1,616	3,184
4	2,600	0,894	5	0,784	1,816	3,384
5	1,600	1,140	5	0,999	0,601	2,599
6	2,600	0,548	5	0,480	2,120	3,080
7	1,000	2,345	5	2,056	-1,056	3,056
8	1,600	1,673	5	1,467	0,133	3,067

Table 5.2A Confidence interval (p=0.05) per item

Confidence interval (p=0.05) per scale						
Scale	**Mean**	**Std. Dev.**	**N**	**Confidence**	**Confidence Interval**	
Pragmatic Quality	2,600	0,518	5	0,454	2,146	3,054
Hedonic Quality	1,700	1,362	5	1,194	0,506	2,894
Overall	2,150	0,693	5	0,607	1,543	2,757

Table 5.2B Confidence interval (p=0.05) per scale

From these data (table 5.2A and B), we verified one inconsistency in the Hedonic Quality items, with severity 1. Despite the mean being positive, this scale presents an inferior interval lower than 0.8, with item 7 (conventional/original) scoring below -0.8. When asked for feedback on their answers, two participants mentioned rating this parameter highly due to the way the experience was explored. In contrast, one participant gave a low score because the story was a traditional, already existing children's tale. This discrepancy may explain the inconsistency.

Pragmatic Quality	
Average	0,31
Alpha	**0,65**

Hedonic Quality	
Average	0,86
Alpha	**0,96**

Tables 5.2C, D Correlations of the items per scale and Cronbachs Alpha-Coefficient: (A) Pragmatic Quality; (B) Hedonic Quality

The Pragmatic Quality value (table 5.2C) is slightly below 0.7, which may mean participants answered to the same item with different perspectives.

As mentioned above, after having participants score on each item, to further encourage the discussion, we invited participants to justify or explain the punctuation given in each item. Only with this approach became possible to understand the difference between the interpretation of original and conventional, from the different participants, for example.

Conclusions of the session

P1:
- Noted that the mother's voice was a bit distorted;

P2:
- Noted that the mother's voice was a bit low;
- Felt that the description did not match the colour of the walls;

P3:
- Finds using the headset somewhat tiring;
- Had the feeling that the story took place inside, so she would make the plate sound more muffled or distant;
- Would add more exterior sounds to the sound environment, like birds and wind;
- Considered having a stronger light focus would have been easier to see, as the visual effort causes her fatigue, even for a short period of time;
- Did not focus on the light (only when asked) as she usually imagines the visual content, not using her vision;

P5:
- Would change the ending where Little Red Riding Hood disappears suddenly;
- Would enhance the sounds of the characters' movements, like footsteps;

P6:

- Would like a more detailed description of the mother.

General

- Blind participants naturally have the tendency to **direct their heads downward**, while the **visual content in the headset is positioned higher up**, which sometimes makes the content nor present in the visual field;
- All participants felt the 360º sound effect especially in the nature sounds;
- **All blind participants enjoyed incorporating the audio description into the narration of the story;**
- All participants liked the narration of the story and the general sound environment;
- Both participants with vision perception would have liked a **more detailed scene to enhance the feeling of immersion and similarity to reality;**
- Two participants would have enjoyed a more captivating, complex and engaging plot, with **higher profusion of sounds;**
- One participant liked that it was a familiar story, as it allowed her to better evaluate the experience, knowing what to expect.
- Two participants found the way the story was explored to be original and new;
- Four participants felt that perceiving nature sounds within the headset felt natural while one participant would prefer to be outdoors;
- All participants considered the experience to be pleasant;

5.3 Discussion

Participants appreciated the 360º sound effect, feeling it especially in nature sounds. However, there were some mixed reactions regarding the complexity and clarity of the produced content: one participant could not understand the scenario of the story; some participants preferred a simpler soundscape and story while others favoured the more detailed audio from previous sessions; some would enjoy a story with a more complex and engaging plot while others enjoyed the simplicity provided in this experience. Incorporating audio description into the narration was seen as a positive aspect by all the blind participants (P1, P3 and P6), making the experience easier to follow.

Both P2 and P5 mentioned the visual scene would benefit from having more detail, therefore enhancing the feeling of realism and immersion. P3's suggested having a stronger light focus for her to perceive with less effort, as it can become tiring for her to use her vision. Blind participants naturally direct their heads more downwards while having the headset on, which makes the visual content not always present in their field of view.

Compared to previous YouTube experiences, participants P2 and P5 felt the previous videos provided a stronger sense of presence as they were of real life scenes. Regarding the audio, overall participants enjoyed the developed solution, but some pointed out that the videos previously shown had a more complex soundscape, which could be interesting to have, if the story was more engaging and complex, as it enhances the feeling of immersion.

Despite the suggestions for improvement, all participants found the experience to be pleasant and enjoyable. Most participants also appreciated the approach to incorporate audio description into the narration and were interested in experiencing more VR content similar to this.

CHAPTER 6
RESULTS, GUIDELINES AND BEST PRACTICES

In this chapter, the results, lessons learned and guidelines gathered from the prior work are presented. This includes insights gained from the adversities encountered during the work with users and the prototyping phase, as well as the knowledge and best practices for designers and developers to apply in their work. These insights are relevant not only to take into consideration while developing immersive experiences and Virtual Reality (VR) environments, but also while conducting user research with low vision and blind users.

6.1 Lessons Learned

Interviews, Participatory Design Session and Testing

All users are distinct from one another. None of their causes of deficiency are the same, even if they share similar issues (P1 and P6 are both totally blind, but have different causes of blindness). Therefore, their vision capacity and perception of visual stimuli are very different from each other, which means that personalization is key, as anticipated during the literature review phase.

Even after interviewing participants, it was only during the participatory design sessions that it was possible to gain a better understanding of the extent of their vision and limitations, especially for P2 and P3. Despite the efforts, it was not possible to fully comprehend their reality. Even when they described their experience, it was challenging to visualise what they perceived. This resulted into two different prototypes in terms of visual content, which was not planned, as in the beginning of the research, we believed the same prototype could suit both impairments (Low Vision and Blindness). However, this difficulty of understanding participants' reality was expected, as the literature review revealed studies focusing solely on simulating vision impairments in Virtual Reality (VR), to conduct diary studies, or sensitise non-visually impaired individuals, highlighting the challenge of understanding a reality very different from our own. "Simulating Cataracts in Virtual Reality" (Krösl, 2021), "Evaluating Virtual Reality as a Tool for Empathic Modelling of Vision Impairment: Insights from a simulated public interactive display experience" (Yao et al., 2022) and "VisionPainter: Authoring Experience of Visual Impairment in Virtual Reality" (Maeda et al., 2022) are three examples of this.

Aside from differences in vision impairment, audio perception also varied among participants. Some preferred using the same audio in a headset, while others preferred earphones. Additionally, feedback from users on the developed audio prototype differed across versions, even when certain aspects remained unchanged.

As the headset lacked accessibility features for non-sighted individuals (such as screen readers or voice commands), blind users were unable to perform tasks autonomously. Assistance was required to transition between experiences or interact with the interface. By broadcasting the sessions to a computer, it was possible to see what participants were experiencing, which allowed them to keep the headset on (unless they wished otherwise) and it was possible for a sighted individual (the researcher) to select buttons and change experiences without having the headset on. However, selecting the necessary buttons was challenging because users had to face the correct direction and remain still, despite not being able to see the interface. This made the sessions longer. P2, who has some degree of vision, asked to perform tasks independently, which extended his session further and required him considerable effort. This was due to the text and elements being too small for his needs and the main pointer ray having a colour and a final pointer hard to perceive (the elements lacked contrast with the icons and the background). Despite the progress of the sessions, no better solution was found for transitioning between experiences.

To make the setup faster, after the first sessions, the whole setup was made to be adequate to the position the user was going to be (the boundary, which is the feature that ensures the user can move freely in the physical space, and the broadcast of the session to the computer). Only after this process and after cleaning the headset, the device was given to the participant. This process was easier and faster than trying to set up everything with the user already seated and ready.

Recruitment was also a challenge, as it is not easy to gather participants with these conditions and institutions that support these individuals often take time to respond. Fortunately, we were able to recruit participants from the “Núcleo de Apoio à Inclusão” at the University of Porto and two external volunteers.

All participants work/study in different places and have different schedules/availability. As four of the six participants are blind or have really low vision the sessions were conducted in places they were comfortable with. Additionally, one participant required a caregiver, which also had their own schedule and availability. Despite this, as we’re not from their faculties/workplace, it was difficult to reserve the resources (a room) to conduct the sessions, needing participants' help. It was also difficult for participants to go to Fraunhofer AICOS or FBAUP, where it was possible to set up the session in advance (only one session was conducted in FBAUP).

Prototyping

Although it was not necessarily a difficulty, creating the prototypes required time to learn how to achieve the desired results, for both the visual and audio components, as well as the software being used for the first time. Additionally, new concepts such as ambisonic audio and its basic principles needed to be understood.

The audio recording conditions for the prototype were not ideal, as only smartphone microphones were available. To achieve the best possible quality, the narration—the longest piece of audio—was recorded inside a wardrobe at 1 a.m. to avoid street and neighbour noise. Other voices were recorded by friends in various environments. The mother's voice was recorded with the same microphone as the narrator’s, while Little Red Riding Hood's voice was recorded with a different microphone. To mitigate background noise and improve the audio quality given the available equipment and circumstances, Adobe’s Enhanced Speech and the ReaFir plug-in (“VST: ReaFir (FFT EQ+Dynamics Processor) (Cockos)”) were used. This resulted in a satisfactory, though not ideal, solution.

Regarding the visual part of the prototype, the software compatibility was an issue. As the available PC is from 2018, the graphics card was no longer compatible with the software of Meta, which made it impossible to directly broadcast the experience from Unity to the Meta Quest. To solve this issue, the recorder from Unity was used. However, it did not properly render the light focus from Prot_V1 and the camera movement from Prot_V2 for a reason we were unable to identify.

To address this, the recording of Prot_V1 was made by using the “Game View” in Unity instead of the “Main Camera”, which resulted into a 2D video, where the user could only see the light focus (the Sun) at the specific moment it was mentioned in the story, rather than being able to look at it at any time. For Prot_V2, the recording was shown in 3D, but participants were asked to turn around to enjoy the final moment of the scene. Since the primary goal was to understand whether the light focus could be perceived in Prot_V1 and to evaluate the perception of graphics in Prot_V2, besides the audio and story, these solutions were considered reasonable despite not being ideal.

6.2 Guidelines and Best Practices

Improving the Meta Quest 2

Regarding the physical product, the Meta Quest 2 headset, we gathered feedback to improve the experience of using both the headset and the commands. To enhance accessibility when using the controller, as previously mentioned, **earcons and/or icons should be added to the haptic feedback** to assist with interface interaction. Additionally, incorporating some form of **button distinction** similar to computer keyboards could help users recognize commands instead of having to remember which buttons perform which functions, especially if the functionality differs between the right and left controllers. **The headset was considered somewhat heavy, making its use tiring**, especially during longer sessions. It would also be beneficial to have a feature that helps participants **understand if the headset is correctly positioned** (centered) and to have the volume button with **more perceptible "+" and "-" markers through touch**, despite the user.

User Research with Blind and Low Vision Users

Blind Participants don't move their heads (exploring) during the experience, as sighted users do (even low vision users). Blind users naturally have the tendency to direct their heads downward, while the visual content in the headset is positioned higher up, which sometimes makes the content not present in the visual field.

Blind participants with light perception:
- May **not focus** their attention **on visual stimuli** even if it is present;
- May find the **effort to use visual perception tiring**;

It is a **challenge to understand and visualise** what blind or low vision participants can perceive, even when they describe their experience, as their reality is very different. This makes it **harder to design according to the user's needs**, being important to **develop and test, several times**.

Currently, the **headset lacks accessibility features for non-sighted individuals**, which **prevents users from performing tasks autonomously**. Assistance is required to transition between experiences or to interact with the interface, which is only possible by broadcasting the sessions to a computer, to see what the headset is displaying. However, selecting the necessary buttons is challenging as users may not face the correct direction or have a natural head movement, making the elements not visible. This can be time consuming and frustrating for both the participants and the researcher.

It is **faster and easier** to set up the headset boundaries, the experience and the broadcast into the computer, in the position the users will be, **before starting the sessions with the participants**, even if they are already present in the room.

In addition to the availability of the researcher and the participants, it may be necessary to take into consideration the availability of a caregiver (if needed), which makes **combining agendas more challenging**. **Finding a suitable location for the session can also be a difficulty.** Besides the availability, it may be **extremely difficult**, or even not possible, to bring **all the participants together in the same place**, for example, for a Focus Group session.

Recruiting the target users can also become challenging and it may take time, as it is not easy to gather participants with these conditions.

Audio

Developing **immersive audio** (for example ambisonics, dolby atmos) should be considered, despite the user (for **both Blind/Low vision users and Vision Impaired/fully sighted individuals**) as immersive audio received positive feedback from all users, including those who can perform their daily activities with only the use of glasses or contact lenses.
For **Blind Participants**, audio with **too much sound information** makes it hard to understand what visuals the sound is associated with, which **interferes with the quality of the experience**. However, **a higher profusion of sounds enhances the feeling of immersion**.

The **more natural the sound is**, the **easier it is to feel immersed** in the environment.

The **background music should not overlay the nature sounds** from the videos, as it can interfere with the perception of the environment and therefore with the quality of the experience.

Sounds **too close to the ear may cause discomfort**.

Haptic Feedback

For this particular experience, adding **haptic feedback was not beneficial to enhance immersion**, as **all information was conveyed through sound**. Haptic feedback would only be justified **to highlight very important information** that might otherwise be overlooked or if it would **relate to touch feedback**.

Visual Content

For Low Vision users, **having bigger elements**, or **closer scene plans** is beneficial for them to perceive the elements in the scene. Also, the **bigger/closer the object**, the **easier it is to perceive the details**.

Colours play an important role in making the **scene more appealing**. However, they are especially important when designing the components and objects of the interface. **Colours should be bright and distinct from one another**, not only for interaction purposes, but to allow for a **clear understanding of the scene and distinction of elements**, as fully sighted **colour blind** user would also require. A **high contrast colour should be chosen for the pointer, like a black background and a yellow ray**, as it is easier to see and understand, helping with the interaction.

VR scenes may represent an optimal visual environment to Low Vision users, as the image is bigger, the objects are closer and the colours are more vivid than in real life, allowing for more detailed perception. This may be due to the user having no outside light reflection interfering with sight, which may turn VR into an “ideal” visual setting.

Scenarios with a **higher level of detail** and **closeness to reality**, allow for a **higher feeling of immersion**.

General Accessibility

As disabled users have diverse needs, **personalization is key**, despite the disability, technology (used devices) and experience to develop (immersive stationary or walking experiences, games, social VR setups, etc).

It is important to take into consideration the **language barrier users might face**, incorporating **multiple languages** or the **possibility for translation**.

Adding **screen readers** and/or **voice commands** to the software is crucial to allow users for autonomous navigation.

Having **audio description** in a scene, when the sound by itself does not provide enough information about the scenario or action, is essential. Also incorporating audio description of the scene **into the story narration** is a **more natural/pleasant way to incorporate audio description**.

Eliminating the need to **move controllers** could enhance interaction, even for individuals with other disabilities. Instead of moving the controller and pointing to icons and objects, it could be interesting if the user could **use only the joystick**, with a similar effect to the use of a smartphone/iphone assistant (example: Talkback/VoiceOver). In case of the free use of controllers, **adding earcons** and **icons** to the **haptic feedback of buttons** would help **blind users get feedback of their actions**.

6.3 Discussion

Throughout the project, numerous unplanned difficulties were encountered. Ranging from the lack of accessibility features in the headset and recruitment challenges to software compatibility issues. These obstacles influenced the project's development, sometimes resulting in outcomes that were not as intended. The recruitment was not easy. Users had different vision impairments and understanding their experiences was difficult. The headset's lacked accessibility features for this type of users, which made the sessions more challenging. Creating prototypes required learning new concepts and software, the audio recording conditions were not ideal and during the visual prototypes development we had some software compatibility issues that could not be predicted. Nevertheless, solutions were found to test concepts and features, even if they did not fully align with the desired goals, offering valuable insights for future work.

The gathered knowledge was compiled into several guidelines divided into six categories: Improving the Meta Quest 2; User Research with Blind and Low Vision Users; Audio; Haptic Feedback; Visual Content; and General Accessibility. The first section, Improving the Meta Quest 2 discusses feedback on the physical product, focusing on how to enhance the user experience. The second section, User Research with Blind and Low Vision Users highlights some of the aspects to take into consideration when doing user research with this type of users. The third, fourth and fifth sections, Audio, Haptic Feedback and Visual content describe the aspects to take into consideration when designing audio and visual content and when haptic feedback should be applied. The sixth and last section describe some aspects to consider to enhance accessibility for the whole VR experience, that can also be applied for other technologies or disabilities.

CHAPTER 7
CONCLUSIONS, LIMITATIONS AND FUTURE WORK

In this chapter, the final conclusions are presented, along with a discussion on how the project's limitations and the insights from these conclusions can be addressed in future work.

7.1 Conclusions

Through the development of this Dissertation, we found some studies about different ways to make VR accessible for people with Vision Impairments. However, they are all independent studies that have not been gathered into one device. If we put together the **Social VR visual cues**, **Seeing VR**, **Canetroller**, **VIVR** and **VRS3** (studies stated in chapter 2.2.5) with accessibility features already used in smartphones and computers, such as **screen readers**, **voice commands** and **audio description**, would we be that far from an accessible device for people with vision impairments?

For this study, we always had as a goal to understand how the technology could be overall improved to suit these users' needs, besides the development of an immersive experience, especially because the headset had no accessibility for blind or low vision users. Despite this, the primary goal was to explore how VR can be entertaining, instead of focusing on how the technology can help these users perform their daily activities. That's the reason why an immersive experience was designed. However, two participants mentioned the potential uses of virtual/mixed reality glasses to help Low Vision and Blind users. If accessibility features like screen readers and voice commands were integrated into MR/VR headsets, their use could become similar to the use of smartphones: by assisting with outdoor navigation using GPS with real-time environmental data descriptions (such as traffic lights and obstacles), allowing users to move hands-free; to read printed text on restaurant menus and receive audio feedback; to recognize images, for example. Nevertheless, currently, Smart glasses (such as Ray-Ban Meta Smart glasses) already offer some of the features described to help these users, also being lighter and more cost-effective (more feedback on these glasses on chapter 2.2.4). Despite this, since they are not VR glasses, they do not fully replace the capabilities of a VR headset, especially regarding entertainment.

The developed work is different from the work presented in the Literature Review, therefore it does not aim to replace or improve the already existent work in this field, but rather offer more and different insights on how to conduct or adapt user research, enhance accessibility and develop experiences specifically for Low Vision and Blind users. However, when comparing with the existing experiences in the Meta Quest 2 or youtube, despite some already having spatial audio, our goal was to incorporate immersive audio with the description of the environment and the action in the most natural way possible (in this case we took advantage of the narration). Also, having a balanced audio environment was found crucial, as too much sound information prevented blind users from recognizing sounds and creating a mental image of the scenario.

Due to the fact most participants have a significant vision impairment, Participatory Design and User Experience Assessment sessions had to be adapted. In the Participatory Design sessions, we didn't perform co-design activities. Instead participants were given the Head-Mounted Display (HMD) Meta Quest 2, to try a set of experiences and asked to think-aloud their actions, feelings and thoughts, to gather their feedback on the experience. For the User Experience Assessment sessions, the short version of the User Experience Questionnaire (UEQ-S) was preferred to the longer version. Besides being more adequate to the assessment of the developed prototype, as the questionnaire was performed out loud (the researcher read the items and the participant said the punctuation) a longer version might have been tiring. The headset lacked accessibility for non-sighted individuals and for this reason the usability was not evaluated.

Regarding the visual part, directed to Low Vision users, it became important to use vivid colours, distinct from one another (as a colour blind user would also require), as similar colours were misunderstood and dark scenes harder to perceive. Another aspect that was not always present in already existing experiences was the proximity of objects to the user, as closer and therefore larger objects were easier to see and allowed for some detail perception. When targeting blind users with light perception, it was unclear if having visual stimuli was an advantage, because as these users are not accustomed to relying on their sight, trying to perceive visual stimuli can become tiring.

Finally, testing with a larger sample of users would be important to consolidate the findings.

7.2 Limitations and Future Work

To the existing version of the prototype, there are some basic changes to be made, according to the last user experience assessment session:

- Enhance the mother's voice and voluming it up;
- Change the colours of the walls;
- Make the plate sound more distant;
- Add more sounds (from nature, steps, doors) to the sound environment;
- Experiment with a stronger light focus;
- Change the ending where Little Red Riding Hood, for her to disappear in the horizon;
- Add the description of the mother;
- Develop the visual scene to a more detailed one.

However, there are many more aspects that can be worked upon and improved.

The developed prototypes faced some challenges regarding software compatibility, so, to render the final products to test, the recorder from Unity was used. However, it did not properly render the light focus from Prot_V1 and the camera movement from Prot_V2. Another feature that was not incorporated was the personalization of the environment. It was not possible to augment or reduce the brightness of the light focus in Prot_V1 and it was not possible to choose the brightness of colours and proximity to the objects in Prot_V2, for example. The visual assets used were all free and created by professionals and enthusiasts, which meant that the house prefab was a solid block, preventing the animation of the door. Also, the experience was stationary.

To target these limitations, it would be interesting to directly broadcast the experiences from Unity to the Meta Quest 2 and allow for some degree of personalization. It would also be interesting to explore this type of experience in a non-stationary way, allowing the user to walk through the environment and experience the sounds changing according to the user's head position in real-time. The development of customised assets would also be worth considering. With this, in future works, we would like to further develop the audio experience, until the end of the story, while also enhancing the sound profusion of the environment (in a balanced way). Changing the traditional story of Little Red Riding Hood to a more engaging plot and circumstances (for example the mother being the father) could also be a path to explore. Regarding the visual prototype, it would be interesting to have a more realistic and detailed environment.

Regarding the overall experience, if possible, it would be interesting to apply Seeing VR to the initial environment and add a controller like Canetroller. After, an improved version of the developed prototype would be shown. Finally, the idea would be to test and evaluate the full interaction (especially with low vision users, but also with blind people), from the moment users put on the headset, until the final moment of the developed prototype. To enhance accessibility, especially for blind users, besides the addition of voice controls, screen readers and earcons/icons, instead of moving the controller and pointing at icons and objects, the user could use only the joystick. It would be interesting to evaluate the usability, especially because some of the tools we suggested to incorporate were developed for smartphones, tablets and computers and not for a virtual environment, some incompatibilities may arise.

Despite being challenging to gather participants in the same place, it could be interesting to perform a Focus Group session, to share ideas, feedback and insights.

Finally and as stated in the conclusion, to assess the user experience of the already existing prototype, to improve the user research and mitigate the found constraints, having a larger sample of users would be important to consolidate the findings and gather more diversified feedback.

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Zhao, Y., Cutrell, E., Holz, C., Morris, M. R., Ofek, E., & Wilson, A. D. (2019). SeeingVR: A Set of Tools to Make Virtual Reality More Accessible to People with Low Vision. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 1–14. https://doi.org/10.1145/3290605.3300341

ANNEX A
SOUND CREDITS

Voices

Narration - Carla Gomes (the author)
Mom - Beatriz Moreira
Little Red Riding Hood - Francisca Laureano

VEED.IO AI Voice Generator

Narration - Duarte (PT/PT)
Mom - Fernanda (PT/PT)
Little Red Riding Hood - Leticia (PT/BR)

Pixabay Sounds and Music

• Acoustic Guitar Loop F# 91bpm - Sound Effect by Kammerin Hunt from Pixabay (https://pixabay.com/users/kamhunt-27612606/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=132687; https://pixabay.com//?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=132687)

• Bird Chirp - Sound Effect by herkesicinbisikletpodcast from Pixabay (https://pixabay.com/users/herkesicinbisikletpodcast-31487391/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=126647; https://pixabay.com//?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=126647)

• Bumblebee Flying Around - Sound Effect by Alexander Jauk from Pixabay (https://pixabay.com/users/alex_jauk-16800354/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=199838; https://pixabay.com//?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=199838)

• Buzzing Bee - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=91887)

• Cheerful Chirping Of Birds_Nature Sound - Sound Effect by Nicky from Pixabay (https://pixabay.com/users/nickype-10327513/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=201697; https://pixabay.com//?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=201697)

• Dishes Clink - Sound Effect by Mary S. from Pixabay (https://pixabay.com/users/irhouen-40320452/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=189725);

• Door - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=43633)

• Footsepts_Grass_1 - Sound Effect from Pixabay (https://pixabay.com/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=6810)

• Footsteps on Gravel - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=61337)

• Indoor Footsteps - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=6385)

• Kissing - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=6174)

• Wings of insects - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=45540)

• Winter Winds - Sound Effect from Pixabay (https://pixabay.com/sound-effects/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=7077)

• Suspense Piano Theme - Sound Effect by TheoJT from Pixabay (https://pixabay.com/users/theojt-11288480/?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=131357; https://pixabay.com/sound-effects//?utm_source=link-attribution&utm_medium=referral&utm_campaign=music&utm_content=131357)

ANNEX B
VISUAL ASSETS CREDITS

Unity Asset Store

• Environment Prot_V1 (Skybox) and Prot_V2 (Skybox, Trees, Ground, Rocks): FREE Skybox Extended Shader - BOXOPHOBIC
(https://assetstore.unity.com/packages/vfx/shaders/free-skybox-extended-shader-107400)

• House: Lowpoly Baker's House - Evgenia
(https://assetstore.unity.com/packages/3d/environments/fantasy/lowpoly-baker-s-house-26443)

• Walkroad (Rocks): Stylized Rocks FREE Sample - Meanwhile On The Moon
(https://assetstore.unity.com/packages/3d/environments/stylized-rocks-free-sample-283215)

• Basket: Stylized bread serving - Yodah_the_cat
(https://assetstore.unity.com/packages/3d/props/food/stylized-bread-serving-279531)

• Mum and Little Red Riding Hood: Mini Modular Character | Free Demo - João Baltieri
(https://assetstore.unity.com/packages/3d/characters/humanoids/mini-modular-character-free-demo-256389#reviews)

Sketchfab

• Red cloak: Cloack_Game ready - farvardin.fashion3d
(https://sketchfab.com/3d-models/cloack-game-ready-0f682a0ab7414fd3be29948ff0029871)

APPENDIX A
INTERVIEW SCRIPT (PT)

Introdução

Este estudo pretende compreender a realidade e características da deficiência visual dos participantes e o seu uso da tecnologia no quotidiano, de modo a desenvolver posteriormente uma experiência imersiva a testar nos óculos de realidade virtual Meta Quest 2.

A dissertação "ACCESS TO XR: Exploring the Potential of Immersive Experiences in Virtual Reality for Low Vision and Blind Users", tem como principal objetivo explorar de que forma pode ser concebida uma experiência imersiva em Realidade Virtual (RV) (recorrendo aos óculos de realidade virtual, os Meta Quest 2) para pessoas com deficiência visual, mais especificamente invisuais ou pessoas com visão reduzida. Tendo em conta o capacitismo (preconceito contra pessoas com deficiência), fomos motivados a explorar a forma como a RV pode ser agradável para estes indivíduos. Ao investigar o que poderia ser incorporado para melhorar a acessibilidade, ao mesmo tempo que se sensibiliza para as necessidades destas pessoas com deficiência, pretendemos desenvolver diretrizes para os designers e programadores considerarem no seu trabalho, com base no conhecimento adquirido.

Esta dissertação foi desenvolvida em colaboração com a Fraunhofer Portugal AICOS, no âmbito do Mestrado em Design Industrial e de Produto, das Faculdades de Belas Artes e Engenharia da Universidade do Porto (FBAUP/FEUP).

Secção 1 - Dados Demográficos

1.1. Idade:

a)18 a 24;
b)25 a 34;
c)35 a 44;
d) 45 a 54;
e) 55 a 64;
f) 65 ou mais.

1.2 Género:

a) Feminino;
b) Masculino;
c) Outro. Qual?

Secção 2 - Deficiência Visual

2.1 Qual é a sua condição visual? (ex: glaucoma)

2.1.1 Se o(a) participante for cego:
Cegueira congénita ou adquirida?

2.2 O seu grau de deficiência visual é considerado:

- Perda de visão leve - 20/30 a 20/60
- Incapacidade moderada - 20/70 e 20/160
- Incapacidade Grave 20/200 a 20/400 grave
- Incapacidade visual profunda - 20/500-20/1000
- Incapacidade visual quase total - contagem de dedos, movimento da mão, perceção da luz
- Incapacidade total - Sem perceção de luz

2.2.1 Para incapacidade moderada, grave, visual profunda ou quase total:
Que estímulos visuais é capaz de percecionar? (ex: Luz, cor)

Secção 3 - Interação com a Tecnologia no Quotidiano

3.1 Costuma utilizar tecnologia no seu dia-a-dia? Se sim, que dispositivos utiliza habitualmente?

Questão de seguimento 1: Dentro desses gadgets, que atividades costuma fazer habitualmente, para além do trabalho?

Questão de seguimento 2: Relativamente ao lazer, quando por ex vê videos no youtube ou conteúdo televisivo, tem alguma preferência por algum tipo de programa?

Questão de seguimento 3: Relativamente aos documentários ou à tipologia de vídeos que prefere, existe alguma característica sonora ou a nível do storytelling que lhe seja apelativo e que não exista noutros programas?

3.2 Quais as marcas que utiliza e porquê (vantagens, relação qualidade-preço)? (ex: Apple, Samsung, Xiaomi)

3.3 Nos dispositivos que utiliza, que sistemas de acessibilidade estão implementados, aos quais recorre para desempenhar as suas tarefas?

3.4 Está familiarizado(a) com o que são Óculos de Realidade Virtual?
a) Se sim, já experimentou? Que opinião tem acerca destes dispositivos?
b) Se não, porquê?

3.5 Teria interesse em experimentar uma experiência imersiva nuns Óculos de Realidade Virtual?

APPENDIX B
PARTICIPATORY DESIGN SESSION SCRIPT (PT)

Introdução

Este estudo pretende analisar as dificuldades encontradas na utilização dos óculos de realidade virtual Meta Quest 2, compreender de que forma a experiência de utilização é percepcionada pelos participantes e de que forma a tornariam mais acessível. Pretende-se assim traduzir a paisagem, interações e/ou efeitos visuais em som, música e/ou feedback háptico, para, posteriormente, desenvolver um protótipo.

A dissertação "ACCESS TO XR: Exploring the Potential of Immersive Experiences in Virtual Reality for Low Vision and Blind Users", tem como principal objetivo explorar de que forma pode ser concebida uma experiência imersiva em Realidade Virtual (RV) (recorrendo aos óculos de realidade virtual, os Meta Quest 2) para pessoas com deficiência visual, mais especificamente invisuais ou pessoas com visão reduzida. Tendo em conta o capacitismo (preconceito contra pessoas com deficiência), fomos motivados a explorar a forma como a RV pode ser agradável para estes indivíduos. Ao investigar o que poderia ser incorporado para melhorar a acessibilidade, ao mesmo tempo que se sensibiliza para as necessidades destas pessoas com deficiência, pretendemos desenvolver diretrizes para os designers e programadores considerarem no seu trabalho, com base no conhecimento adquirido.

Esta dissertação foi desenvolvida em colaboração com a Fraunhofer Portugal AICOS, no âmbito do Mestrado em Design Industrial e de Produto, das Faculdades de Belas Artes e Engenharia da Universidade do Porto (FBAUP/FEUP).

O Headset

O Headset, para além das fitas de ajuste, tem um botão na lateral direita, que serve para ligar e desligar; tem uma ranhura na lateral esquerda, para se carregar a bateria; tem um botão na parte inferior direita para aumentar e diminuir o volume do som.

Os Comandos

Os comandos são simétricos. Para interagir com o dedo polegar, ambos os comandos têm um thumbstick, dois botões com relevo e um botão plano. No comando da esquerda, o botão superior corresponde à letra "Y", o inferior à letra "X" e o botão plano tem três traços. No comando direito, o botão superior corresponde à letra "B", o inferior à letra "A" e o botão plano tem um retângulo inscrito.

Os botões dos dedos indicador e "do meio", servem para agarrar, afastar, lançar, ou seja, interagir com os objetos do meio, em ambos os comandos.

Cada vez que o cursor passa por um botão ou ícone com os quais pode interagir, o comando irá vibrar, isto ajudará a compreender a passagem entre ícones ou elementos, por exemplo ao navegar o menu “App Library”.

Com o botão plano do lado direito com o retângulo inscrito, o utilizador poderá esconder ou mostrar a barra de tarefas do ambiente inicial Dentro de um jogo ou experiência imersiva, o utilizador poderá abrir o menu para sair, as definições de jogo, etc.

O Ambiente

Ao colocar os óculos de realidade virtual, o utilizador irá encontrar-se dentro do ambiente inicial dos óculos VR Meta Quest 2:

O utilizador encontra-se no pátio exterior de uma casa na montanha ao pôr-do-sol. No campo visual do utilizador encontra-se em frente um pilar e uma montanha, ligeiramente à esquerda duas palmeiras e ligeiramente à direita um banco/sofá em meia lua branco com almofadas de cores escuras. Continuando para a direita, mas já a sair do campo visual, está a montanha vizinha, mais elevada, com uma casa semelhante à qual o utilizador se encontra. À medida que roda o seu corpo para o lado esquerdo, irá primeiramente encontrar um espelho, que reflete o reflexo do avatar. Em seguida uma pequena sala exterior com a porta de entrada para a casa, um banco/sofá em meia lua com uma mesa de centro, uma ventoinha e um candeeiro de teto redondo e achatado. A continuar, agora a cerca de 180º do ponto inicial, encontra-se uma cozinha/sala de jantar exterior, com uma mesa retangular comprida de refeições e cinco candeeiros de teto pendurados de diferentes formatos. A continuar a rotação encontra-se um jardim. Após o jardim está uma zona de lazer com dois sofás, mesa de centro, candeeiro de pé, prateleiras, mantas e almofadas. Na parede lateral desta última sala estão duas cadeiras de baloiço. Neste momento volta a estar no campo de visão do utilizador o banco em meia lua branco e a casa na montanha vizinha. A casa tem alguns degraus. No céu há balões de ar. A florestação consiste apenas em catos e palmeiras. As cores do ambiente são maioritariamente cores quentes características de um pôr do sol: predominam o amarelo, o laranja, os roxos e os rosas. O sol reflete na cena, ao fim da tarde, tipicamente caracterizado como “Golden Hour”.

Ao regressar à posição inicial, voltará a encontrar a barra de tarefas, com os seguintes ícones, ordenados da esquerda para a direita: “Profile”, “Quick Settings” - indicação da hora, ligação à wi-fi e bateria, “Notifications”, “Switch Distance” - onde se pode aproximar ou afastar a barra de tarefas da posição do utilizador, “Horizon Feed”, “Store”, “People”, “Camera”, “Browser”, “Settings”, “First Steps for Quest 2” e “App Library”.

Tarefas

****Descreva em voz alta, as ações que pretende realizar e as dúvidas que possa estar a sentir. Poderá partilhar sugestões ao nível do design da interação (numa perspetiva multimodal/multisensorial) para contornar ou mitigar este(s) constrangimento(s).****

FIRST STEPS

No início da experiência, um conjunto de animações irão anteceder o tutorial. Descreva, em voz alta, para que tipo de gráficos lhe remetem os sons desta animação inicial e dos objetos com os quais irá interagir.

Tarefa 1: Abra o menu das aplicações chamado “App Library”. (Será o ícone mais à direita).

Tarefa 2: Encontre a aplicação “First Steps for Quest 2” (Será o primeiro ícone da segunda fila a contar da esquerda).

Tarefa 3: Entre na experiência imersiva.

Tarefa 4: Interaja com os comandos: apontar o dedo; fechar o punho; agarrar um objeto.

Tarefa Final: Saia da aplicação e regresse ao menu inicial.

VÍDEO YOUTUBE

Descreva, em voz alta, para que tipo de gráficos e ação lhe remetem os sons deste áudio.

Youtube videos - Underwater Life, Marsa Alam, Egypt. 360 video in 8K; Lions 360° | National Geographic

Tarefa 1: Abra o menu das aplicações chamado “App Library”. (Será o ícone mais à direita);

Tarefa 2: Encontre a aplicação “Youtube”;

Tarefa 3: Pesquise o vídeo “Underwater Life, Marsa Alam, Egypt. 360 video in 8K”;

Tarefa 4: Explore o vídeo;

Tarefa 5: Pesquise o vídeo “Lions 360° | National Geographic”;

Tarefa 6: Explore o vídeo;

ÁUDIO YOUTUBE

Descreva, em voz alta, para que tipo de gráficos e ação lhe remetem os sons deste áudio.

Youtube video - The Tucker Zone

Tarefa 1: Pesquise o vídeo “The Tucker Zone”;

Tarefa 2: Explore o vídeo;

Tarefa Final: Saia da aplicação e regresse ao menu inicial.

QUESTIONÁRIO FINAL

First Steps

1. O que sentiu depois da animação inicial?

2. Os gestos para realizar ações com os comandos são fáceis de aprender?

3. Existe alguma característica ou feedback que gostaria que os comandos fornecessem, de modo a ajudá-lo a realizar as tarefas (ex: distinção dos botões através do tato, feedback háptico)? - se comandos fossem luvas iria melhorar a experiência

Youtube Video

1. Que estímulos visuais foi capaz de percecionar?

2. Para que imagem visual lhe remeteram os sons do vídeo?

Youtube Áudio

1. O que achou do grau de imersividade da experiência?

2. Se adicionássemos feedback háptico aos comandos ao longo da experiência, considera que poderia melhorar a experiência?

Interação Geral

1. Quais foram as maiores dificuldades na interação com o dispositivo?

2. O que considera que funcionou bem? (ex interação com os comandos)

3. Baseado nas dificuldades que teve ao interagir com o dispositivo, aplicativo e comandos, que considera que poderia ajudar a ultrapassar estas dificuldades? Que ferramentas adicionava, de modo a tornar esta experiência acessível?

5. Existe alguma característica ou feedback que gostaria que o headset fornecesse, de modo a ajudá-lo a realizar as ações necessárias (ex: colocar o headset, aumentar e diminuir o volume)?

6. Como avalia a experiência? Por ex. agradável, desinteressante e porquê?

Outras Questões

Sente que com a perda de visão outros sentidos ficaram mais apurados? Se sim, quais e porquê?

APPENDIX C
PROTOTYPING RELATED CONTENT

(Narration in a neutral central position; birds on the left, a bee on the right; soft music)

C1

Once upon a time, there was a beautiful girl who lived in a clearing in the forest with her mother and whom everyone affectionately called Little Red Riding Hood. Little Red Riding Hood is very much like her mother. She is a small girl with long brown hair, fair skin with very rosy cheeks, large brown eyes and she never leaves the house without her red hood, which was given to her by her grandmother.

C2

The forest is dense, full of trees and life. The paths are well-trodden and the walk to the village takes only a few minutes. Her small house has white walls and a tiled roof in brick tones, but what stands out the most in this small construction in the middle of nature is its large and imposing red door. The sky is blue. The sun is high - SUN, FOCUS LIGHT - gilding the vivid green tones of the trees and the undergrowth flowers. The summer breeze gently touches the skin (sound of soft wind from right to left). Little Red Riding Hood is playing outside when her mother calls her:

Little Red Riding Hood! (sound far away inside the house on the left)

C3

She goes outside (sound of door on the left) and says to her:

(sound from the front)

- I have placed a cake and a pot of honey in this basket. Take it to your grandmother, who has been unwell. But Little Red Riding Hood, be careful! Do not stray from your path and do not talk to strangers.
- Yes, mom! - promised Little Red Riding Hood.

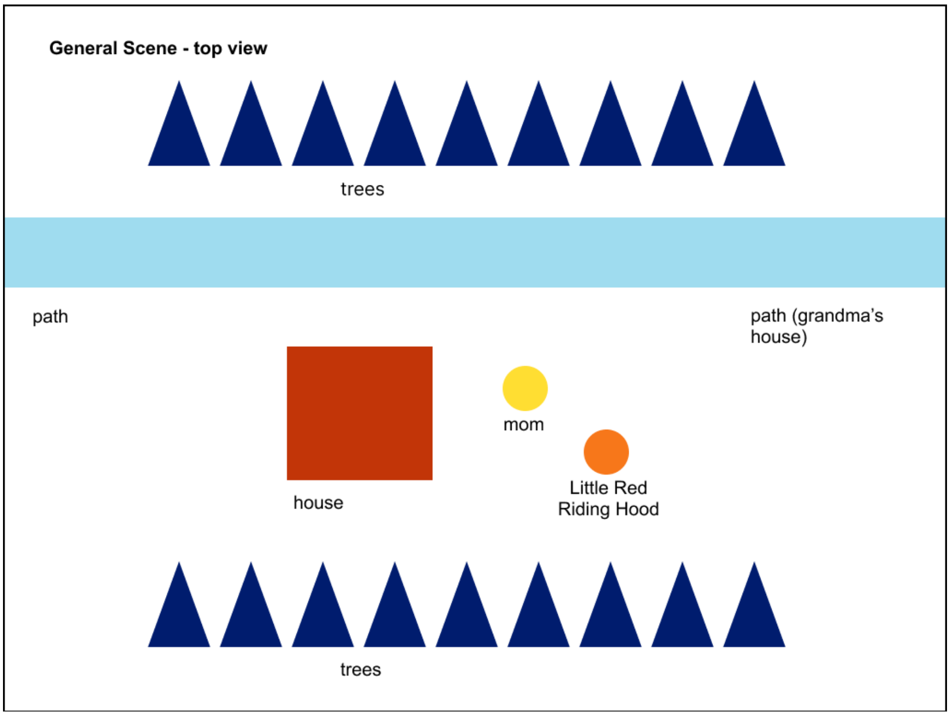
Her mother gave her a kiss on the cheek (sound of kiss on the right + softly - be careful) and [...]

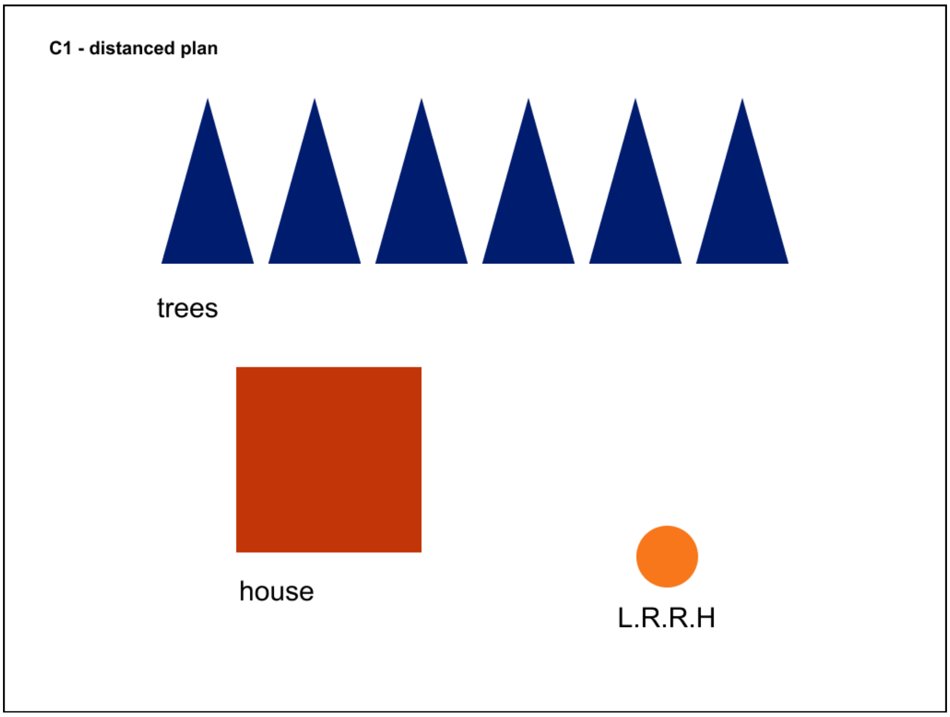
C4

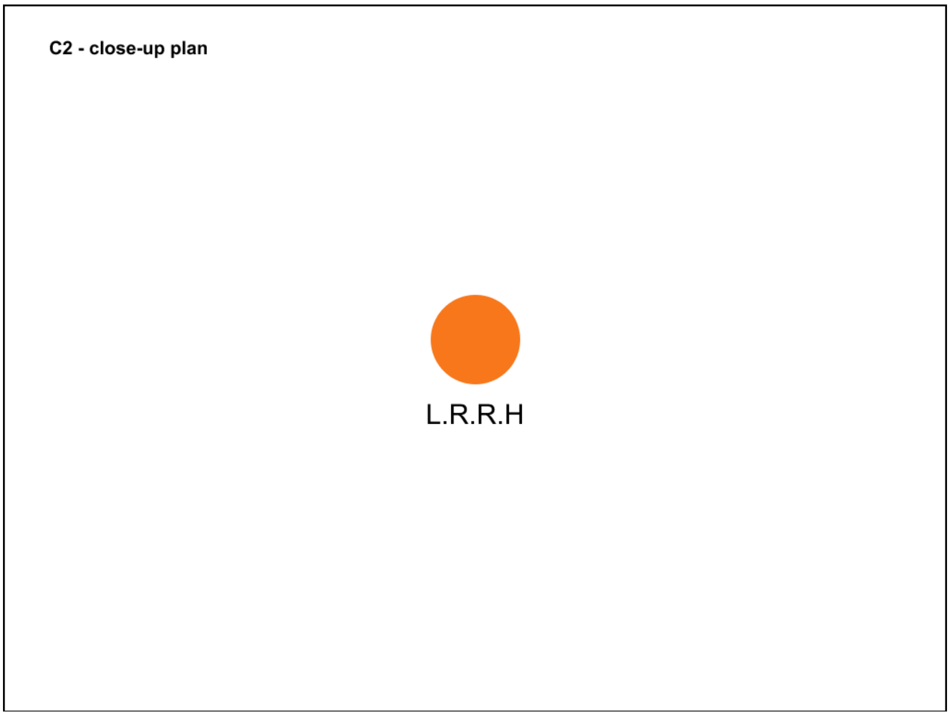
[...] Little Red Riding Hood set off (sound of footsteps from left to right). Her grandmother lives far away, in the middle of the forest; the path is long and you never know who might appear... (sinister music)

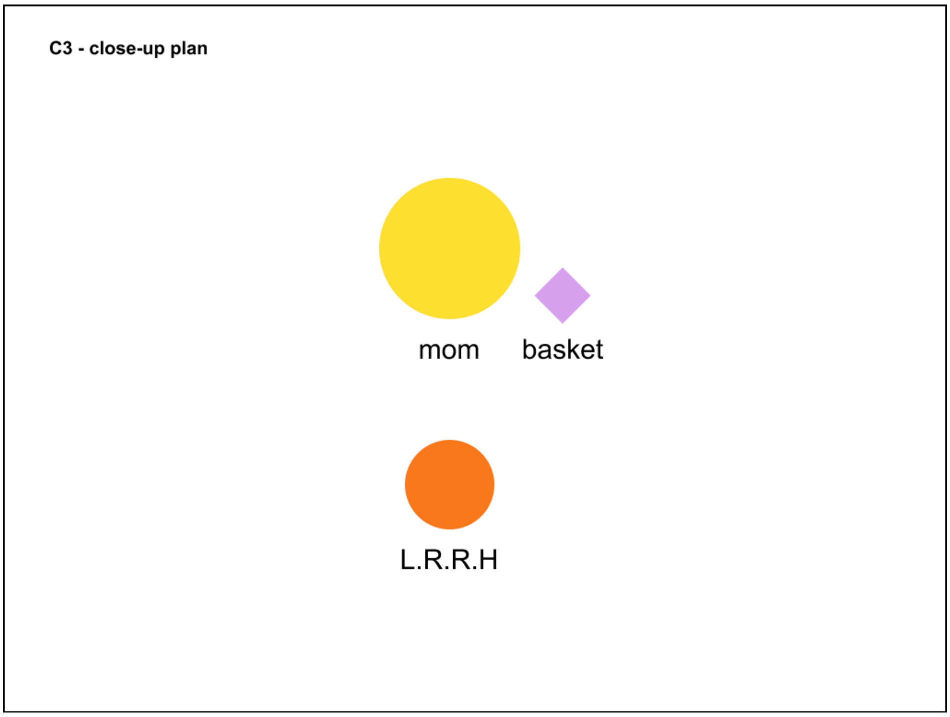
Little Red Riding Hood - adapted excerpt

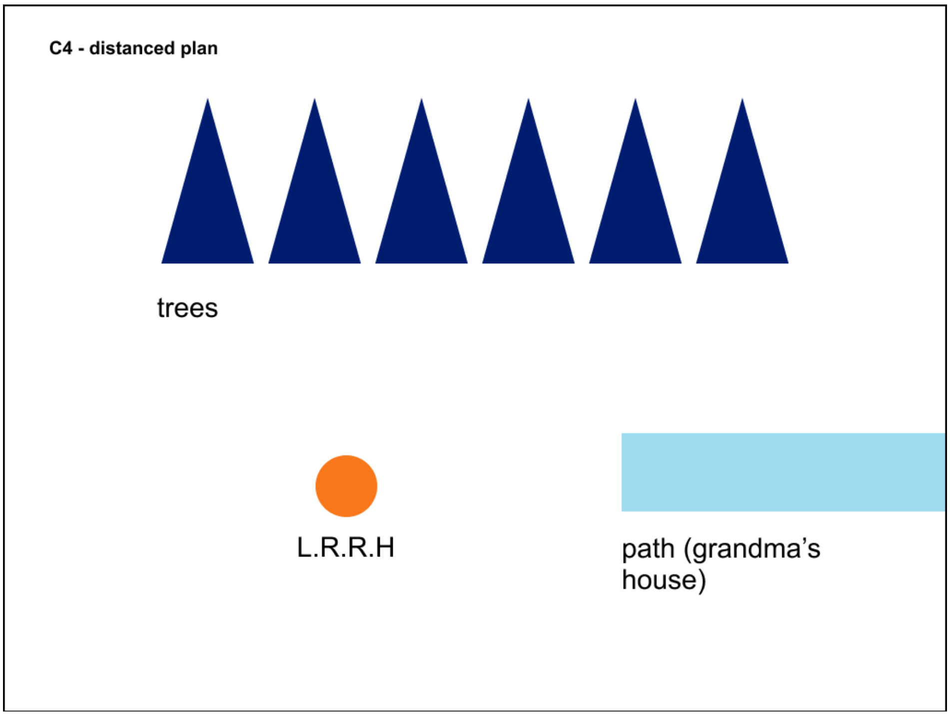
Link to Prot_V1 https://youtu.be/IqVCHaga8fQ
Link to Prot_V2 https://youtu.be/xuSX5LkHsPc

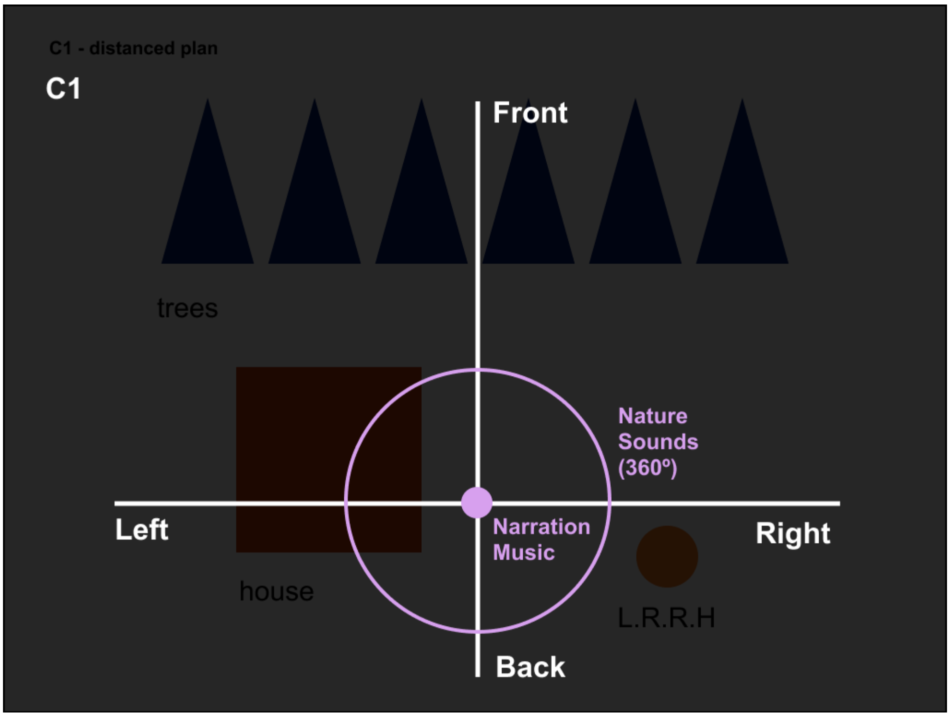

General Scene - top view
trees
path
path (grandma's house)
house
mom
Little Red Riding Hood
trees

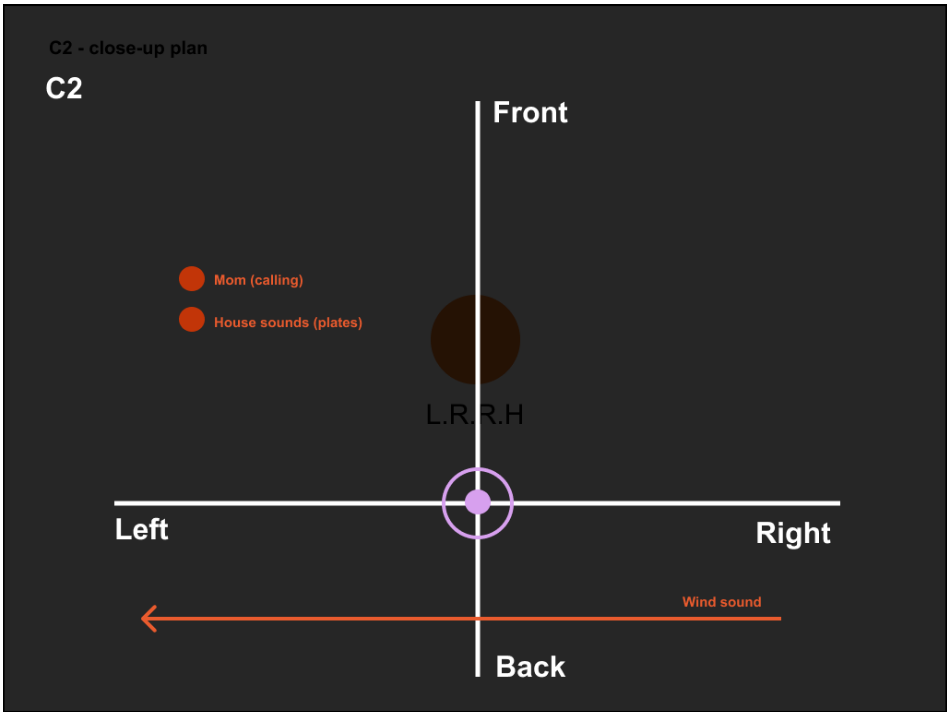

C1 - distanced plan
trees
house
L.R.R.H

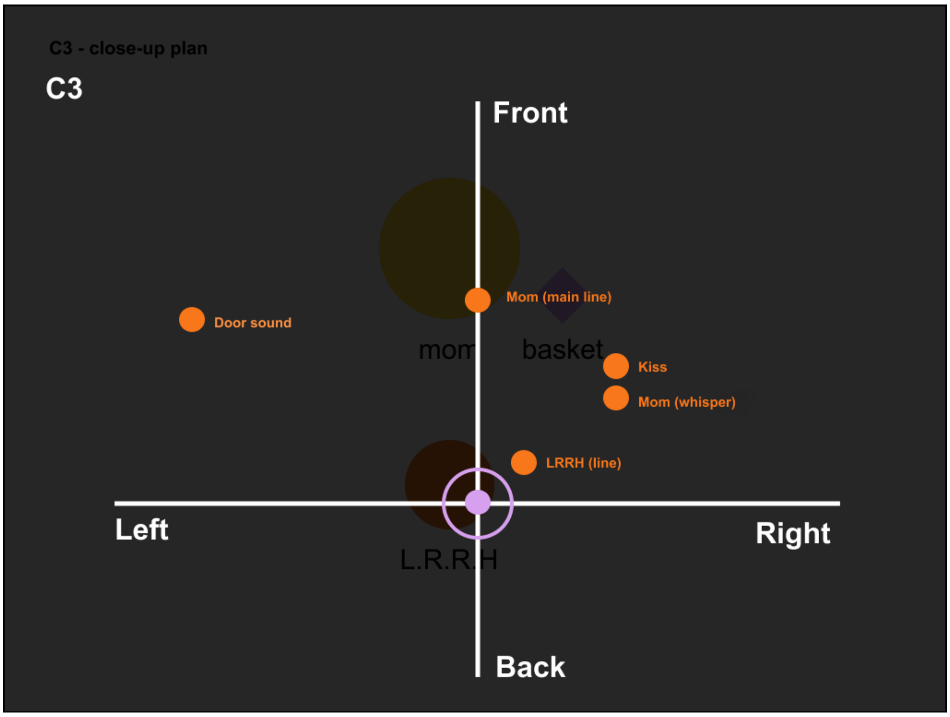

C2 - close-up plan
L.R.R.H

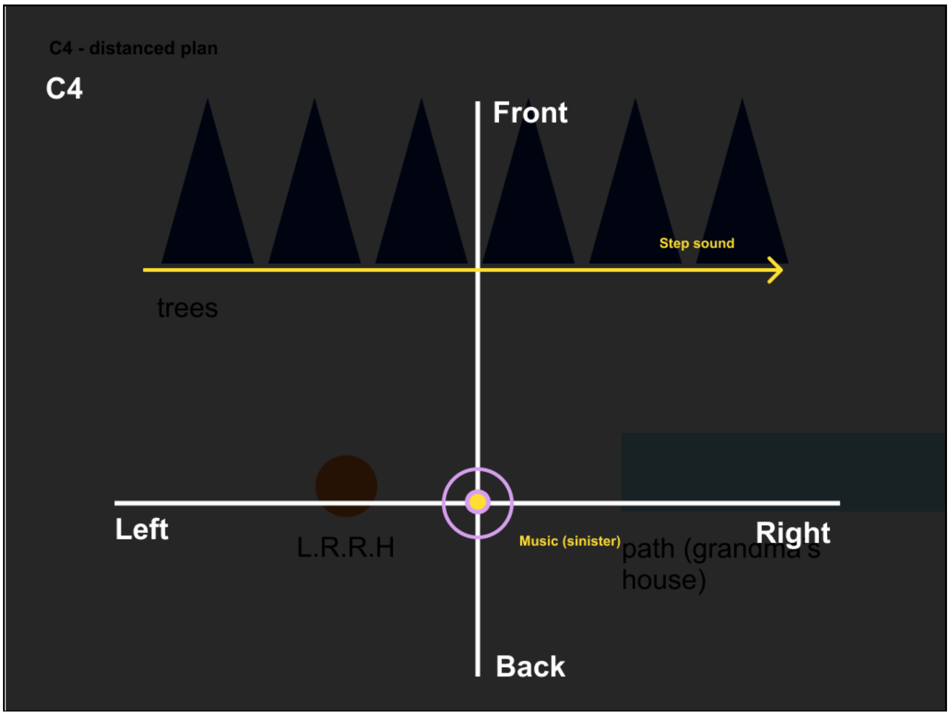

C3 - close-up plan
mom
basket
L.R.R.H


C4 - distanced plan
trees
L.R.R.H
path (grandma's
house)


C1 - distanced plan
C1
Front
trees
Nature
Sounds
(360º)
Left
Narration
Music
Right
house
L.R.R.H
Back


C2 - close-up plan
C2
Front
Mom (calling)
House sounds (plates)
L.R.R.H
Left
Right
Wind sound
Back


C3 - close-up plan
C3
Front
Mom (main line)
Door sound
mom
basket
Kiss
Mom (whisper)
LRRH (line)
Left
Right
L.R.R.H
Back


C4 - distanced plan
C4
Front
Step sound
trees
Left
L.R.R.H
Music (sinister)
path (grandma's house)
Right
Back

APPENDIX D
USER EXPERIENCE ASSESSMENT SCRIPT (PT)

Introdução

Este estudo pretende compreender a perceção dos participantes acerca da experiência imersiva prototipada, a testar nos óculos de realidade virtual Meta Quest 2.

A dissertação "ACCESS TO XR: Exploring the Potential of Immersive Experiences in Virtual Reality for Low Vision and Blind Users", tem como principal objetivo explorar de que forma pode ser concebida uma experiência imersiva em Realidade Virtual (RV) (recorrendo aos óculos de realidade virtual, os Meta Quest 2) para pessoas com deficiência visual, mais especificamente invisuais ou pessoas com visão reduzida. Tendo em conta o capacitismo (preconceito contra pessoas com deficiência), fomos motivados a explorar a forma como a RV pode ser agradável para estes indivíduos. Ao investigar o que poderia ser incorporado para melhorar a acessibilidade, ao mesmo tempo que se sensibiliza para as necessidades destas pessoas com deficiência, pretendemos desenvolver diretrizes para os designers e programadores considerarem no seu trabalho, com base no conhecimento adquirido.

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ÁUDIO

Questionário

1. Sente o efeito 360º?
2. O que acha do grau de imersividade?
3. O que acha das descrições feitas?
4. O que acha que funcionou bem e o que mudaria?

VISUAL

Questionário

1. Como avalia o grau de imersividade da experiência?
2. O que acha do áudio, na sua globalidade?
3. Considera que incorporar a descrição da cena na narração da história é uma forma mais natural/agradável de incorporar a áudio descrição?
4. Relativamente ao conteúdo visual?
    a) Conseguiu perceber algum estímulo?
    b)O que achou do cenário, da animação, das cores, da proximidade dos objetos, dos objetos em si?
5. O que mudaria de modo a que a experiência fosse de encontro às suas expectativas ou preferências?

6. O que sentiu ao longo da experiência?
7. Em comparação com a sessão anterior, quais foram as maiores diferenças, o que gostou mais ou menos?
8. Como avalia a experiência?
9. O utilizador encontra-se dentro de uma sala. A experiência nos óculos de realidade virtual sons da natureza, parece-lhe estranho ou pouco natural?

USER EXPERIENCE QUESTIONNAIRE (UEQ-S) - VERSÃO CURTA

Portuguese version

Obstrutivo	o o o o o o o	Condutor
Complicado	o o o o o o o	Fácil
Ineficiente	o o o o o o o	Eficiente
Confuso	o o o o o o o	Evidente
Aborrecido	o o o o o o o	Excitante
Desinteressante	o o o o o o o	Interessante
Convencional	o o o o o o o	Original
Comum	o o o o o o o	Vanguardista