POLYTECHNIC OF TURIN

Master's Degree in cinema and media engineering

Master's Degree Thesis

Pedal Project: Virtual Assistants for Rehabilitation

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Academic Year 2021-2022

"To my grandmother Nella"

Summary

Alzheimer's disease is the most common form of dementia, is a generic term that refers to the loss of memory and other intellectual abilities so severe that it interferes with daily life. People with Alzheimer's disease are generally elderly and account for 60-70% of dementia cases. Some of the scientific research involved in the study of this disorder focuses on finding methods to slow down the course of the disease by training the patient through the method of cognitive rehabilitation in order to slow down the course of the disease and thus reduce the difficulties that can arise in many aspects of daily life. This project aims to design an an immersive virtual reality experience for patients with this disease to train them and try to reduce the possible effects that this disease can have on the patient. This project is based on the studies conducted by Vito De Feo, who identified possible alternatives to cognitive rehabilitation thus creating the PEDAL project. In this field, he introduces an alternative to classical rehabilitation by trying to stimulate, through immersive environments, neuronal plasticity. Neuroplasticity allows neurons to regenerate anatomically and functionally and thus form new synaptic connections. The goal of this thesis project is to create a virtual assistant that can assist the user during treatment and to improve the UI of the project itself. The novelty of the project lies in stimulating neuronal plasticity in an interactive and immersive 3D application in which the patient can both train and do cognitive rehabilitation. The interactive application will be path-based that can be explored using a virtual reality headset and a bicycle suitably modified to make it an input device within the experience. Within the experience will be coached through the technique of memory travel and accompanied by a virtual assistant along the way to help him in moments of disorientation. The application is designed to be the most as usable as possible, as it is aimed at older people with early dementia and will hopefully help in the prevention and perhaps even treatment of the disease.

Acknowledgements

After this long, albeit intense academic journey, it seems only right to say a few words for those who have been close to me in these long years. First of all, I thank Professor Sanna and Professor De Feo for following me in these months, for always being present throughout the writing of the thesis and for giving me the opportunity to work on such an ambitious project. Special thanks go to my family.

To my mother who has always been a point of reference and a model to follow.

To my father, who despite not being aware of it, passed on his passion for cinema and animation thanks to the evenings spent playing video games when I was little, without this I probably wouldn't dream so much.

To my sister Roberta who acted as my second mother, always present in times of need.

To my grandfather, my number one fan who always believed in me.

To my brother Marco who is also my best friend and my half, without him my journey in Turin would not have been the same.

I thank my friends at the Polytechnic who have made the days of lessons more carefree and light, for always being by my side even after all these years and also staying outside the university.

I thank the children of the theater who taught me that "I can do it" and for accompanying me in the warm Turin nights.

Finally, I thank all the people I have met over the years, the friends of Liborio and Paoli, and the people who, even if briefly, have spent time with me, each of them has left me something and the person I am today, I owe it to them too.

Last but not least, I thank Viviana for walking by my side in the last year, supporting me even in the most difficult moments and believing in me more than I can. My days would have been grayer without you.

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Chapter 1

Introduction

The following thesis was born with the aim of the PEDAL project to design and build a prototype to improve the rehabilitation experience of patients with cognitive deficits through the use of immersive virtual reality technologies. The project aims to develop a phygital[1] experience that combines physical and cognitive exercise. Virtual rehabilitation has made its way over the years as a valid tool to assist the therapist, this is made possible thanks to immersive and interactive environments that help the patient stay motivated during the treatments. Generally this type of treatment is dedicated to patients with musculo-skeletal problems and cognitively-impaired. This first chapter intends to introduce the topic of virtual rehabilitation, above all by making a distinction between cognitive and motor rehabilitation, then ending up trying to motivate the choice of a virtual reality project for rehabilitation and what the PEDAL project proposes to do.

1.1 Virtual Reality as a tool for analysis and rehabilitation

Today virtual reality branches out into many technical-scientific fields, in fact it is used both as a teaching support and as a diagnostic tool and as a rehabilitation therapy. Before going into the various rehabilitation techniques it seems only right to have an introduction to the disease, followed subsequently by a description of what congitive stimulation is and how it is applied.

[1] term that derives from the crasis between physical and digital

1.1.1 Why Virtual Reality on rehabilitation?

Recent studies have highlighted the potential of virtual reality as a prevention tool and in some cases also as a tool for rehabilitation (motor and / or cognitive). It turns out to be a promising ally as it offers patients an immersive and often fun approach, it can be considered as a virtual environment in steroscopy (therefore with three-dimensional images). Virtual reality has been used in various rehabilitation areas, in particular there is a trend in the use of the latter on people suffering from stroke, cerebral palsy and Parkinson's disease. The use of VR as an assistance tool can be very useful for having real-time feedback, for having greater flexibility and a safer and more customizable rehabilitation environment. In fact, VR allows you to customize the treatment according to your needs and to better adapt the patient's assessment procedures. Some characteristics of VR that make rehabilitation interventions virtual compared to the classic one are the ability to include immersive environments and involve the patient with interactive activities. Speaking of virtual environments, it is inevitable to have to distinguish between immersion and presence, the first represents an objective aspect of this type of technology while the second is more a psychological one that gives the "feeling of being there". Immersion is an important parameter in VR as it affects the user's experience and affects the user's sense of presence. There are different types of VR, which will be explained in the next chapter, which can be grouped into three categories: non-immersive, semi-immersive, or fully immersive. An example of this categories are shown in Figure 1.1, 1.2, 1.3.

That said, there are also potential risks associated with VR such as motion sickness. This is why it is important to take into account any cases of discomfort in the simulator and therefore design the virtual environment correctly. A peculiarity of this technology that helps the patient in the immersion of these virtual environments is the tactile feedback that is given by particular devices such as the Dataglove, which simulates force and pressure as if they were in a real environment. In fact, it has been shown that haptic feedback facilitates immersion in a virtual environment, which also means that being able to stimulate other senses in a VR environment can lead to a more active participation on the part of the user [1].

1.1.2 Alzheimer's Disease

Alzheimer's disease is one of the diseases that are increasing the most in recent years, as shown in the figures 1.4. In accordance with to the World Health Organization [2], AD is the most common form of dementia and may contribute to 60–70% of cases. In 2015, dementia affected 47 million people worldwide (accounting, approximately, for 5% of the older adult population); nevertheless, recent reviews have estimated a new case of dementia develops every 3 seconds for a total of 9.9 million each year. Dementia impacts not only those affected, but also their families

Figure 1.1: Non-immersive Virtual Reality

Figure 1.2: Semi-immersive Virtual Reality

and society, moreover is a leading cause of disability among older people around the world [3]. Alzheimer's disease is the most common form of senile dementia, a state caused by an alteration of brain function that implies serious difficulties for the patient in carrying out normal daily activities. The disease affects memory and

Figure 1.3: Fully-immersive Virtual Reality

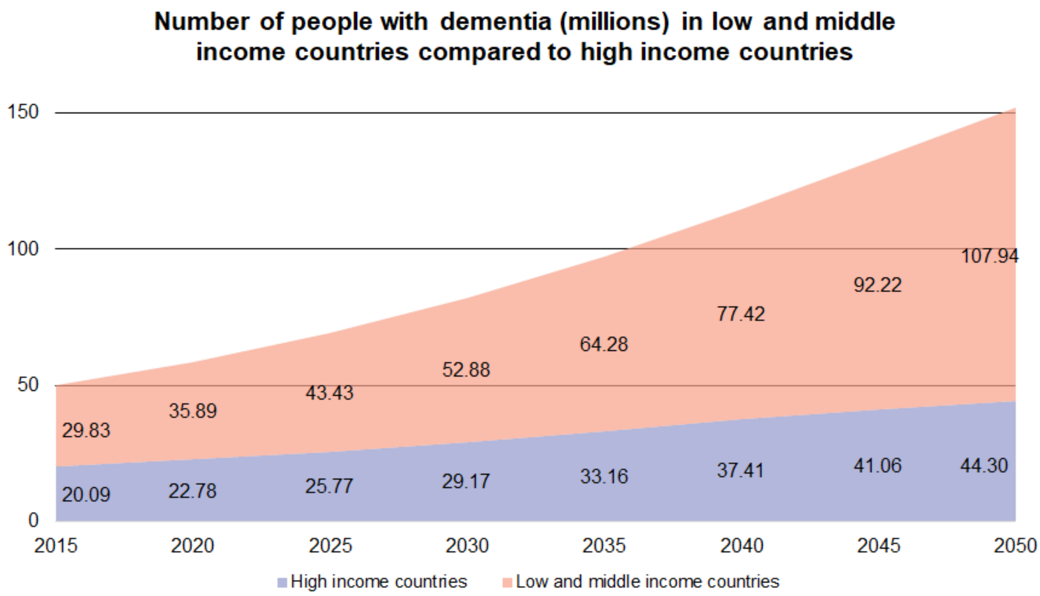

Figure 1.4: Number of people with dementia over the years. Source: *World Alzheimer Report 2021: Journey through the diagnosis of dementia*

cognitive functions, affects the ability to speak and think but can also cause other problems including states of confusion, mood changes and space-time disorientation. The disease takes its name from Alois Alzheimer, a German neurologist who for the first time in 1907 described its symptoms and neuropathological aspects. At the post-mortem examination, the doctor noticed particular signs in the brain tissue of a woman who had died following an unusual mental illness. In fact, he highlighted the presence of agglomerates, later called amyloid-beta (Aβ) plaques, and of bundles of tangled fibers, the neuro-fibrillar tangles. Today the plaques formed by amyloid proteins and the tangles are considered the effects on the nervous tissues of a disease of which, despite the great efforts put in place, the causes are still not known. In patients with Alzheimer's dementia, there is a loss of nerve cells in areas of the brain that are vital for memory and other cognitive functions. There is also a low level of those chemicals, such as acetylcholine, which work as neurotransmitters and are therefore involved in communication between nerve cells [4]. Alzheimer's dementia manifests itself with mild memory problems, leading to severe damage to brain tissues, but how quickly symptoms worsen varies from person to person. During the course of the disease, cognitive deficits worsen and can lead to severe memory loss, repeatedly asking the same questions, getting lost in familiar places, being unable to follow precise directions, getting confused about time, people and places, to have deficits with language abilities (e.g. aphasia) [5] and semantic knowledge in learning and social cognition, but also to neglect one's personal safety, hygiene and nutrition. However, cognitive impairments can also be present years before a diagnosis of Alzheimer's dementia is made. Today the only way to make a certain diagnosis of Alzheimer's dementia is through the identification of amyloid plaques in the brain tissue, possible only with an autopsy after the patient's death. This means that during the course of the disease only a diagnosis of "possible" or "probable" Alzheimer's can be made. For this, doctors use several tests:

- Clinical tests, such as blood, urine, or spinal fluid tests.
- Neuropsychological tests to measure memory, the ability to solve problems, the degree of attention, the ability to count and talk
- Brain CT scans to identify any possible signs of abnormality.

Pharmacological interventions, unfortunately, have not shown much efficacy in changing the course of AD dementia [6]. To ensure that people with dementia can maintain a level of functional ability, the need for a more definitive cognitive assessment and effective nonpharmacological intervention for age-related NCDs, including AD, becomes of the utmost relevance, given that no definitive diagnostics or efficacious therapeutics are currently available for these conditions [7]. Among the various pharmacological therapies for the treatment of Alzheimer's there is reality orientation therapy (ROT), for which there is more evidence of efficacy. This therapy is aimed at orienting the patient with respect to his personal life and the surrounding environment. The present thesis, as will be shown in the following chapters, proposes a type of non-pharmacological and non-invasive therapy through the use of new technologies and cognitive stimulation. But what is cognitive stimulation? we must first of all distinguish between Cognitive and Motor Rehabilitation. By motor rehabilitation we mean a therapeutic path with the aim of allowing the patient to progressively recover his normal motor skills (in part or completely, depending on the severity of the cases), lost following an illness (for example Parkinson's disease and multiple sclerosis, two of the diseases that most often require motor rehabilitation), trauma, surgery or a mix of factors of different nature. This path can be of a purely orthopedic nature or involve other disciplines: this depends on the extent of the damage and its location in the organism. The causes of the partial or total loss of motor skills of the subject can be attributed to trauma to the bones, joints and / or muscles, or involve other systems, with particular (but not exclusive) reference to the central nervous system. In the latter case, we speak of neuromotor rehabilitation. Cognitive rehabilitation, on the other hand, is a therapeutic path that is outlined in targeted, structured cognitive interventions of increasing difficulty and intensity, used in a multi-strategic way with the aim of:

- Rehabilitate cognitive skills that have been impaired due to brain damage.
- Promote a slowing of cognitive impairment.
- Globally stimulate the mental activity of the subject.

This type of rehabilitation bases its theoretical assumptions on the plastic properties of the brain and uses computerized and / or paper-pencil devices as working tools that allow to work in parallel in a targeted and specific way on impaired and residual cognitive functions. These tools are aimed at enhancing residual abilities and at acquiring compensation strategies for deficient abilities, in order to restore the best state of well-being to the subject. A summary of the discussion just covered is shown in Table 1.1.

The project of the following thesis aims to develop an experience for this last type of rehabilitation through cognitive stimulation, which will be introduced in the following paragraph.

1.1.3 Cognitive Stimulation and the use of Virtual Reality

Cognitive stimation means interventions aimed at increasing the well-being and autonomy of the elderly with dementia, with the aim of reactivating / stimu- lating his residual skills and slowing the loss of cognitive functions. Although the virtual reality has been in development for several years, in recent times it has been taken

Table 1.1: Type of Rehabilitation

Type of Rehabilitation	What it consists of	Who it addresses
Cognitive Rehabilitation	Nonpharmacological treatment that consists of learning compensatory strategies and exploiting residual abilities in order counteract the degenerative course.	People who suffer injuries or trauma of varying degrees (such as stroke and multiple sclerosis).
Motor Rehabilitation	Therapeutic path with the aim of allowing the patient to progressively recover his normal motor skills	People with primary dementia (Alzheimer's Dementia) or secondary dementia (Parkinson's Disease and Multiple Sclerosis).

into consideration in the medical-health field for its great therapeutic potential. Virtual reality allows you to experience the sense of presence: the user feels inside the experience and, through specific commands, can interact with the surrounding environment. the sense of presence depends on the perceptual, emotional and cognitive processes associated with the virtual experience. the immersive virtual environment involves all of the patient's senses and gives the sensation of perceiving an authentic reality. Virtual situations are capable of determining bodily responses similar to those experienced in the real world with variations in heart rate, skin conductance and peripheral temperature. The result is a high degree of ecological validity that brings therapeutic and rehabilitative situations closer to those of the real world. According to various neuropsychological theories, the interaction of the senses with Virtual Reality can generate inputs that, reaching the neocortex, facilitate the modification of certain cognitive associations. c

1.2 The Pedal Project

The aiming of this unique project is to provide one solution to address the gamut of cognitive, mental and physical health and Quality of Life (QoL) problems for People living with dementia (PlwD). The basis on which the project works are the benefits that Physical Activity (PA) offers to PlwD and their informal caregivers (IC). This project aims to address behavioural and psychological symptoms of dementia (BPSD) at an early stage through a combined cognitive and physical training programme embedded in VR games. Dementia is a multi-dimensional syndrome that progressively affects functionalities, such as memory, cognition, spatial and temporal orientation, and emotional regulation, which in turn affect QoL and social health. This project focusses on several of these aspects at the same time to help improve QoL for PlwD and their ICs.First, in Alzheimer's Disease (AD), patients show a severe lack of navigational skills, even finding it difficult to return home (McShane et al., 1998). Memory loss affects the planning and execution of many such day-to-day tasks, lowers patients' quality of life and reduces their participation in society (Porcelli et al., 2019). This project will train memory and navigation in PlwD, thereby strengthening independence and self-confidence both inside and outside their home. Second, The WHO guidelines[2] advocate PA and a healthy lifestyle as important strategies to prevent dementia. Unfortunately, PlwD cannot do PA easily. This project will help PlwD engage in PA as an enjoyable and health enhancing activity. Third, nearly all community-dwelling PlwD show behavioural and psychological symptoms of dementia (BPSD). This includes a range of neuropsychiatric disturbances such as agitation, aggression, depression, and apathy, which impact on disease progression, the ability to stay at home and QoL of PlwD and their IC (Cloak & Al Khalili, 2020). ICs have to cope with a number of challenges (anxiety, depression, stress, burden, sleep problems), which greatly impair their own QoL. The objective of this proposal is to develop a platform that allows combined cognitive and physical interventions to accelerate the translational and therapeutic benefits of gamification and Virtual Reality (VR), particularly for early intervention in dementia and comorbid conditions. Specifically, the focus of this proposal is to build a VR-based exercise bike with which PlwD can train their spatial navigation and memory abilities in a safe environment (their home). The effect of combining PA with such cognitive tasks, will be tested in a controlled study, comparing matched samples with and without this training. Combined training is hypothesized to lead to immediate and long-term benefits for PlwDs and their environment: improved spatial navigation and memory capacity, reduced IC load, reduced agitation, improved muscle strength and / or aerobic endurance, and better QoL.

1.3 Reasons for the development of this project

Before going on in the discussion it is necessary to highlight the differences that distinguish classical rehabilitation from virtual rehabilitation. Generally the classical rehabilitation is performed with a on-site therapist and therapies typically are one-to-one. The costs of the treatments rise above all for those with severe brain injuries. There isn't one collection of various patient data and therapies performed for it this leads to not having a clear collection of the therapies and data collected. Virtual rehabilitation on the other hand, it allows you to follow and monitor more patients at the same time, solves the problem of the distance and therefore becomes more accessible and more economic as it removes all those ancillary costs which would involve travel and treatment to the therapist Virtual rehabilitation can be used for many therapies for both musculo-skeletal and children suffering from attention deficit. The biggest advantage presenting virtual rehabilitation is undoubtedly the ability to create immersive and interactive experiences, capable of entertaining the patient during treatment. There therefore the possibility of creating gamified experiences, induces patients to active behaviors and then to their own involvement.

1.4 Conclusions

Virtual Reality has already taken hold in some particularly innovative contexts of physical and mental health, even if its diffusion is still slow. Overall, the results, albeit positive, seem to have difficulty in gaining a foothold outside the academic sphere. This thesis supports the idea that rehabilitation through new tools such as virtual reality could positively influence the outcomes of patients suffering from dementia or brain injury, increasing participation in order to obtain a better response to treatment. In particular, VR can be used to enhance the effects of conventional therapies, favoring longer training sessions and a reduction in overall hospitalization time. To support this thesis even more is the idea by now consolidated thanks to Covid-19 of the need for a tele-treatment that can assist both the therapist but above all the patient, if the latter is not able to physically present himself to the sessions.

Chapter 2

State of art

The aim of this thesis is to integrate a virtual assistant in the PEDAL project capable of assisting the patient during the experience. The research is therefore focused on the integration of an assistant in an immersive virtual environment. It is looking for a method that makes the experience more usable, through cleaner interfaces and the clearest possible interventions of the virtual assistant (VA).

In this chapter, an introduction will be made on virtual reality, what it is and how it has developed over the years. Followed by a brief analysis of the various application areas and concluding with the virtual assistants used for rehabilitation.

2.1 What is virtual reality?

2.1.1 Virtual Reality

Virtual reality is a combination of hardware and software devices that generate a synchronized multisensory stimulation, able to create in the user the illusion of being physically located in a three-dimensional space and of being able to interact with the objects and agents placed inside it. By definition, a virtual reality system should involve all the sensory channels, however, the most common virtual reality systems are limited to stimulating only the visual, auditory and tactile channels as the taste, smell and interception simulators are still in the phase of development. development. For this reason, the term virtual environment is often used by the scientific community as a synonym for the term virtual reality. Going deeper into the discussion it is possible to differentiate the systems of virtuous reality according to the level of immerisiveness[1].Unlike any other type of media such as cinema or

[1]Immersiveness indicates a characteristic a quantifiable characteristic of a technology that includes the extent to which it is possible to immerse oneself in the virtual world.

photography, with virtual reality the user becomes the protagonist of the experience and therefore passes from the feeling of being "perceiving information" to the feeling of "being in a place of information". In other words, in virtual reality systems every movement becomes information, this is made possible thanks to the peculiarities of this technology or the level of immerisiveness and the sense of presence. Although often regarded as similar, immersion and presence are two distinct concepts. The first indicates an objective level of sensory fidelity of a virtual reality system, the second indicates the psychological response of a user within virtual reality systems. In conclusion, based on what has been said so far, virtual reality can be divided into three categories: *Immersive virtual reality*, *Semi-immersive virtual reality* and *Non-immersive virtual reality.*

Immersive virtual reality

Is a particular way of using contents in which the user is completely immersed on a sensory level within the three-dimensional environment generated by the computer. Examples of immersive VR are commercial systems such as Oculus Quest, Oculus Rift, Oculus Go, HTC five and Playstation VR as shown in Figure 2.1,2.2,2.3.

Figure 2.1: Oculus Quest

Figure 2.2: HTC Vive

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Figure 2.3: Playstation VR

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Diving is made possible by:

- A display device (usually a head-mounted display) capable of isolating the user from the external environment and displaying the environment generated by the computer;
- One or more tracker position sensors that detect the user's movements and

transmit them to the computer;

Semi-immersive virtual reality

Includes the CAVE (term which stands for CAVE Automatic Virtual Environment), i.e. a room in which the environments generated by the computer are projected onto the walls. Compared to immersive virtual reality, it has significantly higher costs. This solution is very useful in the case of VR experiences of groups of people, since it allows the sharing of the experience among multiple users. An example it's shown in Figure 2.4.

Figure 2.4: EON ICUBE CAVE (Cave Automatic Virtual Environment)

Non-immersive virtual reality

Is composed of computer-generated environments made in 3D but shown on a 2D display. It uses a monitor as a display device (i.e. that of the television computer or a smartphone). Compared to the previous types, it has lower costs and is easier to implement both in terms of hardware and software.

To summarize the discussion made so far, the table below illustrates the main differences between the three types of virtual reality. In addition to this type of distinction, it is possible to distinguish virtual reality on the basis of the technologies on which they can be implemented. They are divided in particular into:

- **Systems integrated with PCs and consoles**, i.e. virtual reality systems that require a connection between a head-mounted display and a computer or game console.
- **Portable systems**, which are part of this technology the so-called "passive viewers" such as Google Cardboard.
- **Standalone systems**, which do not require other technological devices to function (Oculus Go, Oclulus Quest)

2.1.2 Application Areas

VR can be considered an experiential interface in which the perceptive, visual adaptive and kinesthetic component merges with interactivity. The interaction between these aspects generates what is called a sense of presence or the sensation of being inside the virtual environment even if physically they are in a different space. The interactivity of the environment and the sense of presence allow virtual reality to be used successfully in numerous application areas ranging from training to the administration of a certain type of therapeutic treatments. Historically, the first applications of virtual reality concerned the military and space sectors, however the progressive reduction of the costs of hardware and software devices, the increase in processor power and the rapid evolution of computer graphics have paved the way for many other sectors. such as industry, learning, scientific research, medicine and entertainment.

Design

Until now, to come up with a design, designers used drawings on paper, college or renderings displayed on a computer screen. The introduction of virtual reality offers designers new opportunities to represent their creations by creating three-dimensional models of spaces and products that can be experimented in an immersive way before being physically constructed. Added to these opportunities are the potential of augmented reality, which allows you to view a product directly within a physical space, making the decision-making process even easier and more effective. One of the great advantages of virtual reality for the world of design is the possibility of realistically representing a product, simulating its functions in contexts of use and allowing designers to improve its characteristics during the prototyping process. Virtual reality can be used in the main phases of design, from the modeling of the constituent elements, to the spatial organization of these elements, to the final comparison of the different versions. During the design process, there is often a need to explore variants of the shape or functionality of the product before its final realization. For this, the use of alternative representations - physical or digital - of the prototype is a fundamental strategy to help designers make correct decisions. In the industrial, engineering and architectural fields, virtual reality offers several assets to make the overall design process more effective and less expensive. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) systems are simulation technologies that allow the designer to develop three-dimensional models of a prototype, visualize it and modify its characteristics interactively. The most widespread current CAD-CAM visualization systems are non-immersive; however, immersive CAD systems are also rapidly spreading [8]. Immersive simulation has the advantage of significantly reducing design costs and thus increasing the integration of the different phases of the prototyping process by making available a shared work platform for the visualization and processing of technical data concerning the various components. In architecture, a rapidly spreading method is Building Information Modeling (BIM), used to support the planning, construction and management phases of buildings. In particular, these systems make it possible to digitally collect and integrate all the data relating to the construction of a building, as well as allowing the visualization as a three-dimensional geometric model even in immersive mode.Shared virtual reality presents additional opportunities to make the design process more efficient. Through immersive telepresence technology the members of the design group can be simultaneously present and operate in the same design space, even if, physically they are in distant places such as in decentralized organizations. Augmented reality is also starting to be integrated into production processes. For example, some companies are exploring the possibility of using this technology to help workers with remote maintenance. In this scenario, an operator who needs to repair or maintain a device, but does not have the adequate knowledge to do so, can wear an augmented reality viewer and receive images, data and indications that can guide his actions step by step, displaying everything directly on the object.

Education and training

Education and training have been elective areas of application of virtual reality since the beginnings of this technology. Today, education systems face the challenge of helping students understand often abstract and complex concepts. To achieve this goal, an effective stratagem is represented by the use of analogical and metaphorical reasoning, with particular reference to scientific disciplines. With reference to analogical reasoning, it allows abstract concepts to be translated into “concrete” terms. For example, by describing the concept of the chemical bond through the analogy of the functioning of a magnet, it is possible to help the student to form a mental image of a process by referring to an experiential context. According to education theorist David Kolb, experience plays a central role in the learning process. The model that this scholar has developed assumes that this process takes place following a cycle divided into four main phases. The first stage is represented by concrete experiences, in which learning is mainly generated by perceptions and responses to environmental stimuli. This phase is followed by the stage of reflective observation, where learning is substantiated through observation and reflection on this experience. The next level, that of abstract conceptualization, is characterized by the formation of abstract concepts through a process of analysis. These concepts are subject to empirical verification in the final stage of the cycle, that of active experimentation, which involves the experimentation of new situations, which in turn will offer the opportunity for new experiences [9].

Scientific Research

In the field of scientific research, virtual reality is used both as a tool for visualizing complex data and as an approach to conduct simulated experiments. With regard to the first type of applications, in many scientific disciplines it is becoming increasingly important to have scientific instruments capable of analyzing large, often time-dependent data sets. Typical examples are climatic, geological and astronomical models. However, the traditional symbolic-numerical representations prove inadequate to represent in a synthetic way the complexity of these models. Virtual reality offers researchers the ability to interact intuitively and directly with three-dimensional representations of data. Furthermore, by being able to manipulate parameters visually, virtual reality can help scientists better understand the relationships between variables and develop new solutions. Another promising field of application of virtual reality in scientific research concerns the field of experimental psychology and neuroscience. Researchers in these disciplines have traditionally been confronted with two interrelated types of problems, namely, variable control and experimental neuroscience. Control refers to the need to identify the possible variables of the disorder that could influence the outcomes of a psychological experiment. For example, suppose a researcher is interested in understanding the effects of increasing stress levels on the ability to concentrate. To do this, he could conduct the experiment in environments that are chaotic and noisy, such as city traffic. The problem, however, is that in these environments it is difficult to be able to strictly control all the factors that could influence the outcome of the experiment: for example, the weather could suddenly change and the outside temperature, higher or higher. low, it could have an indirect effect on the concentration of the participants. Or, some pedestrians may attract attention for the way they are dressed. In order to reduce these possible interferences, it is necessary to carry out the observations within the strictly controlled conditions of the laboratory, where the temperature can be kept constant and it is possible to plan exactly how many and which stimuli will be presented to the individuals participating in the experiment.

Medicine and health

The use of VR in medicine and in professional contexts dedicated to health represents one of the most advanced and promising frontiers of this technology. In these areas, virtual reality is already used in a large number of applications, such as surgical training, diagnosis, neuromotor rehabilitation and psychotherapy. Surgical training on VR has the advantage of allowing the student to learn a specific technique or procedure by operating on an organ or a simulated anatomical structure. If the simulation is sufficiently realistic, the knowledge acquired in virtual training can be transferred to a real operating context, obviously after passing an intermediate training phase with real patients. Research has shown that by practicing virtual reality, the length of traditional training can be significantly reduced. Another advantage of using virtual reality in surgical training is the ability to objectively evaluate the skills acquired. Traditionally, the assessment of surgical skills has simply been based on observation by experienced surgeons and on qualitative scales. Thanks to the integration of tools capable of automatically tracking and measuring the surgeon's actions, immersive simulation systems offer the possibility of obtaining quantitative measures of technical competence and monitoring the progressive advancement of skills. As far as diagnosis is concerned, virtual reality is also proving effective as a support tool for cognitive and neuromotor rehabilitation.In the field of cognitive rehabilitation, virtual reality can represent a complementary approach to that of the most commonly used strategies, which can be divided into two main categories: reconstructive and functional. The strategies of the first type focus on the rehabilitation of cognitive processes and are intended to train patients to plan and design actions correctly, while the functional approach aims to teach patients to perform the functions necessary for daily survival. Virtual reality, in this sense, offers the opportunity to integrate the two approaches into a single strategy, because it allows you to program exercises aimed at the rehabilitation of specific cognitive deficits and to contextualize them in situations that simulate those of everyday life. It also allows the use of scenarios designed on the principles that regulate and facilitate neuroplasticity, that is the neurobiological process underlying the recovery of cognitive and motor functions. Virtual reality also allows you to customize the intensity and difficulty of training based on the recovery of cognitive and motor functions. Virtual reality also allows you to customize the intensity and difficulty of the training based on the specific needs of the patient without particular difficulties on the part of the operator. Thanks to the flexibility of this technology, it is possible to easily change the presentation of stimuli, the complexity of the task, the type of response, based on the patient's disability and progress. Finally, it allows you to record all data accurately and precisely. Thanks to the sensors integrated in the virtual reality systems, it is possible to record a large amount of data relating to the actions performed by the patient within the virtual scenario and use this data to build indices with which to measure the observable performance improvements in a quantitative and objective way. during the rehabilitation process.

Pain therapy

Pain therapy is used as a complementary or alternative strategy to analgesic drug treatment mainly based on the use of opiate drugs (such as morphine and codeine). For example, when patients with severe burn injuries are undergoing the dressing process, the unbundling and rewinding procedure can be very painful. Virtual therapy consists in involving the patient in interactive experiences that attract his attention, with the aim of reducing the subjective perception of pain during medication. This technique was first developed in the 1990s by psychologist Hunter Hoffman of the University of Whashington. The virtual experience developed by Hoffman and his collaborators, called SnowWorld, consists of a completely frozen landscape that the patient explores. trying to hit targets with snowballs. Because patients often reported having the sensation of reliving the original burn experience during the dressing treatment, the virtual experience of SnowWorld was designed by Hoffman to induce a diametrically opposite perception in patients, as it is known that the perception of the pain is modulated by the level of attention. In other words, halogen signals are interpreted by the brain as more or less painful based on what a person is thinking about. (the results of several studies have revealed that the virtual technique is able to significantly reduce the pain perception of patients and therefore represents a complementary approach to pharmacological treatment.

Mental Health

Virtual reality applications in the field of mental health are increasingly numerous and, as an article by Riva (riva, Wiederhold and Mantovani) explains, these aids are effective in the treatment of anxiety and stress disorders, acute pain. and body image disorders associated with obesity and eating disorders. The goal of virtual therapy, defined as cyber therapy, is to make the patient experience simulation experiences that recall real-life situations perceived as particularly critical or threatening, with the aim of facilitating the management of the negative emotions that these situations elicit. The virtual experience takes place in the protected and safe environment constituted by the psychotherapist's office, whose role is to guide the patient on the virtual path, helping him to manage and process the emotional experiences that emerge during the simulation. For example, specific phobias are marked and persistent fears triggered by particular stimulus situations, such as animals or objects. The psychotherapeutic intervention aims to reduce the intensity of the response to the phobic stimulus. For this purpose, one of the most used techniques is to expose the patient in a gradual and controlled way to the stimulus situation. The virtual reality exposure strategy has also been used successfully to help people overcome severe psychological trauma.Posttraumatic stress disorder (PTSD) is characterized by severe anxiety and other psychological distress; generally, it results from exposure to a traumatic event, for example, a serious car accident or a terrorist attack. PTSD is also known as war neurosis because it was first observed in soldiers who survived dangerous combat and war situations. One of the most effective approaches to treating PTSD is the combination of cognitive therapy (that is, the restructuring of dysfunctional thought patterns, such as the belief that traumatic events can repeat themselves again) and exposure therapy (the goal of which is to reduce symptoms of PTSD, inviting the patient to confront the memory of the traumatic event). Another area is the treatment of obesity and eating disorders, such as anorexia, bulimia and bing eating. Patients suffering from these disorders are characterized by pathological eating habits, problems in the ability to regulate their emotions and those related to food, as well as an altered perception of their emotions and those related to food, as well as an altered perception of their body size and weight. Virtual reality can be a valid support for modifying the negative emotions associated with food, through controlled exposure to foods that generate the greatest level of anxiety, and to deconstruct the cognitive distortions that alter the body image. An example of this technique is the experience of body swapping, in which patients "wear" a virtual body that has a different size and shape from those perceived subjectively.

Video games

The possibility of entering video games as if it were a physical reality has represented the dream of many generations of players, made popular by the success of the film tron, produced by Disney which already in 1982 represented an immersive virtual world. Virtual video games are 3D interactive games designed to be used in immersive mode, through the use of a viewer and tools to interact with the content. As a result of the spread of low-cost display devices, the market for immersive games has grown significantly in recent years, convincing large companies in this sector to also integrate virtual reality hardware (Playstation VR) into their consoles. However, the available content is still relatively limited compared to the non-immersive gaming application.

Immersive cinema

It represents a sector of natural expansion for virtual reality. In fact, the goal of film technology has been, from the very beginning, to increase the realism of cinema. In this direction it is possible to frame both the evolution of stereoscopic technology and 3D audio in cinemas, and the use of virtual reality viewers to enjoy cinematic content in immersive mode. The success of virtual reality cinema, however, requires not only the availability of new technologies, but also the development of new processes and new techniques for creating content. In fact, while in conventional cinema the director controls the camera's point of view, in virtual reality the viewers can turn their gaze in all directions. The possibility for the viewer to visually "explore" the scene at 360 ° and in interactive mode poses new challenges to the screenwriters, as the logic of the narrative structure must necessarily take into account the greater degrees of freedom that characterize the viewer's attention in an immersive medium.

2.2 Virtual Reality over the years

Virtual reality had a rapid development in recent years even if it has historically distant origins, which are based on man's desire to create « other realities », worlds different from the real one. The beginning of the twentieth century is perhaps the most prosperous period as with the outbreak of the first and then with the second world war, research is pushed towards the creation of new man-machine interactions.

This historical period can be divided into three phases, which will be discussed in the following paragraphs.

2.2.1 First phase

In this historical period Charles-Emilie Reynaud created stereo cinema in 1907, one of the first experiments in cinema in three dimensions. In 1916 Albert Pratt patented a periscope viewer, the first head-mounted display project associated with a pointing device. In 1928 Edwin Link developed the first flight simulator, called Link Flight Simulator and Trainer, a device similar to a fuselage with a cockpit and controls capable of reproducing the movement and sensation of flight. The following year Link founded the Aeronautical Corporation to start the series production of the simulator, even if it aimed at the military aviation its first customers were amusement parks, but the scenario changed in the mid-thirties when the Air Corps of the United States buys six simulators. From there the pilots will be trained with Link Trainer[2]. In 1939, Freddy Waller presented at the World Fair in New York Cinerama[3], a complicated shooting and projection system that required shooting movie scenes with three cameras and projecting them on special screens. Finally, in 1944, IBM created the first real computer in history with the name of Automatic Sequence Controlled Calculator (ASCC or more simply Harvard Mark I).

2.2.2 Second phase

The urgency of technological development within the United States military corps leads to the birth of the Advanced Research Projects Agency (ARPA). Through the collaboration between academia, industry and government, ARPA supports numerous research projects aimed at experimenting with new graphic interfaces and simulation technologies. In the 1960s, the Augmented Research Center (ARC), directed by the electronic engineer Douglas Engelbart, was founded at Stanford University. In the same year Ivan Southerland, researcher at MIT in Boston, develops his doctoral thesis Sketchpad, a rudimentary form of computer graphics that represents the foundations of the current graphic interfaces used for the development of virtual reality scenarios. In 1962, Morton Heiling, American scientist and cinematographer, invented the Sensorama simulator with the aim, according to the inventor, to create a multisensory cinema in which he completely immerses the spectators. This device consists of a stereoscopic color display, fans, odor emitters, a stereo sound system and a mobile chair. In 1968 Southerland with the help of Bob Sproull invented a head-mounted display. It is the first viewer to use computer-created images and not just movies. However, the device is too bulky to occupy an entire room, suspended in the air on an arm connected to the ceiling called the Sword of Damocles shown in Figure **??**. In the following years virtual reality takes hold, thanks also to the important funding of the ARPA (in the meantime called Defense Advanced Research Projects Agency - DARPA). In the following years virtual reality takes hold, thanks also to the important funding of ARPA (in the meantime called Defense Advanced Research Projects Agency (DARPA). Subsequently in 1982 Atari, an American video game company created in 1972 by Nolan Bushnell and Ted Dabney, founded Atari Reserch, laboratory dedicated to virtual reality. In 1985 Scott Fisher, who from Atari Research who had moved to NASA in the NASA Ames laboratory, developed together with other

[2]known as the AN-T-18 Basic Instrument trainer but called in jargon by pilots Blue Box. Having been very successful, the company later founded a new company called Link Aviation Inc., which became one of the most important companies in the training of pilots.

[3]from the crasis of cinema and panorama

researchers the Virtual Visual Environments Display (VIVED), a head-mounted display, produced for the first time at an affordable price (about $ 2000). A closed visor, made using a diving mask that includes two medium-resolution monochrome LCD screens capable of offering a field of view of 120° per eye. Subsequently in 1985 Jerome Lanier and Thomas Zimmerman left Atari to found the Virtual Visual Environment Display (VIVED), with the aim of designing and producing visors, wearable gloves (glove) and software for virtual reality. It is in this period that Lanier coined the term virtual reality in an attempt to give a definition to the various projects that were underway in those years in US universities and research centers.

2.2.3 Third phase

After a previous period of strong interest and important funding, the following decades see the interest in virtual reality decay. In 2012 there is a new revolution in the evolution and diffusion of this technology thanks to the invention of Palmer Luckey, who will present to the public a new head-mounted display called Oculus Rift. In 2014 Mark Zuckemberg announced in March 2014 the purchase of Oculus VR (company founded by Luckey). In November 2017, the smartphone compatible virtual reality headset, called Samsung Gear VR, was launched on the market. Developed by Samsung Eletronics in collaboration with Oculus VR, this head-mounted display uses a compatible Samsung mobile phone as a device and processor, while the unit made up of Gear VR acts as a controller and delimits the user's field of vision. In October 2016 the Playstation VR viewer was released on the market, a head-mounted display developed by Sony Computer Entertainment and known during its development under the name of Project Morpheus. The viewer is designed to be compatible with the Playstation 4 Pro video game console. In March of the same year, two PC compatible viewers are also released on the market: OCulus Rift and HTC Vive (able to track the user's movements in an entire room).

2.3 VR for rehabilitation

Over the years VR for rehabilitation has proved to be a powerful tool for standardized, reproducible and controllable therapeutic environments. As already mentioned in the previous chapters, virtual reality presents a stimulating and fun rehabilitation approach that is much more engaging than traditional therapy. The integration of virtual reality in the rehabilitation field has shown that it is possible to carry out treatments in stimulating, safe and ecologically sound environments. In addition to giving a stimulus in real time, VR also offers the possibility of personalizing the treatment while providing greater standardization of evaluation protocols and rehabilitation training, in fact, the literature shows that virtual reality provides a unique therapy in a functional and targeted. Furthermore, the entire part of training and data collection can be documented and saved. Another important feature that virtual reality introduces is interaction, in fact the user can interact in the surrounding environment in various ways both through haptic feedback and through a digital input such as a keyboard or joypad. Other ways of interacting with the environment in a natural way and the graphic display of the user's hand through special controllers or cameras capable of tracking the user's movements. Today, applications in the rehabilitation field mainly provide feedback of a sensitive and auditory type and indirectly proprioceptive and vestibular in the case of immersive VR. Tactile devices such as gloves and pens provide the user with a sense of touch and allow the user to perceive a variety of shapes and surfaces thus giving more meaningful feedback. The training programs developed through VR provide interactive sensory stimuli and biofeedback using representations of the patient's limbs as will be shown below. The last interesting feature of virtual rehabilitation is the possibility of manipulating virtual environments by adapting them to the patient's needs and thus stimulating the senses more and capturing the latter's attention. After discussing how important virtual reality is in rehabilitation, it is necessary to highlight the different types of rehabilitation. VR for rehabilitation can be classified in several ways. One way is to divide it into Virtual Musculo-skeletal, Post-stroke Virtual Rehabilitation, and Cognitive Virtual Rehabilitation. Patients with musculo-skeletal problems who suffer from pain in the bones or injuries to the muscles / ligaments are in general the youngest and most numerous of the patients who need a rehabilitation program. Studies showed which patients with musculo-skeletal disorders had better results after VR treatment [10]. One example of this treatment is showed in Figure **??**, where a group of researchers focused on musculo-skeletal rehabilitation of the upper body in particular in the rehabilitation of a patient after a carpal tunnel operation. The VR-rehabilitation system used consists of a PC a 3D tracker and an haptic interface[11]. Post-stroke patients, on the other hand, are those who have survived an ischemic or hemorrhagic stroke, the first is caused by an obstacle to blood flow to the brain, the second is caused by the rupture of a cerebral artery. According to the American Stroke Association, there are more than 500,000 cases per year. In the Figure 2.6 it can see an experiment where patients with different motor problems in the upper part of the body practice a shooting game that was based on the movements of the patient as in traditional rehabilitation. The tasks of this experiment were to load the cannon, aim and shoot the ship[12].

Finally, the category of patients with cognitive problems consists of people with various psychological disorders, such as attention deficit and hyperactivity. An example for this type of therapy, shown in Figure 2.7 is VIRCOG(VIRtual COGnitive System)[13], an experience in a virtual environment that is divided into two parts:

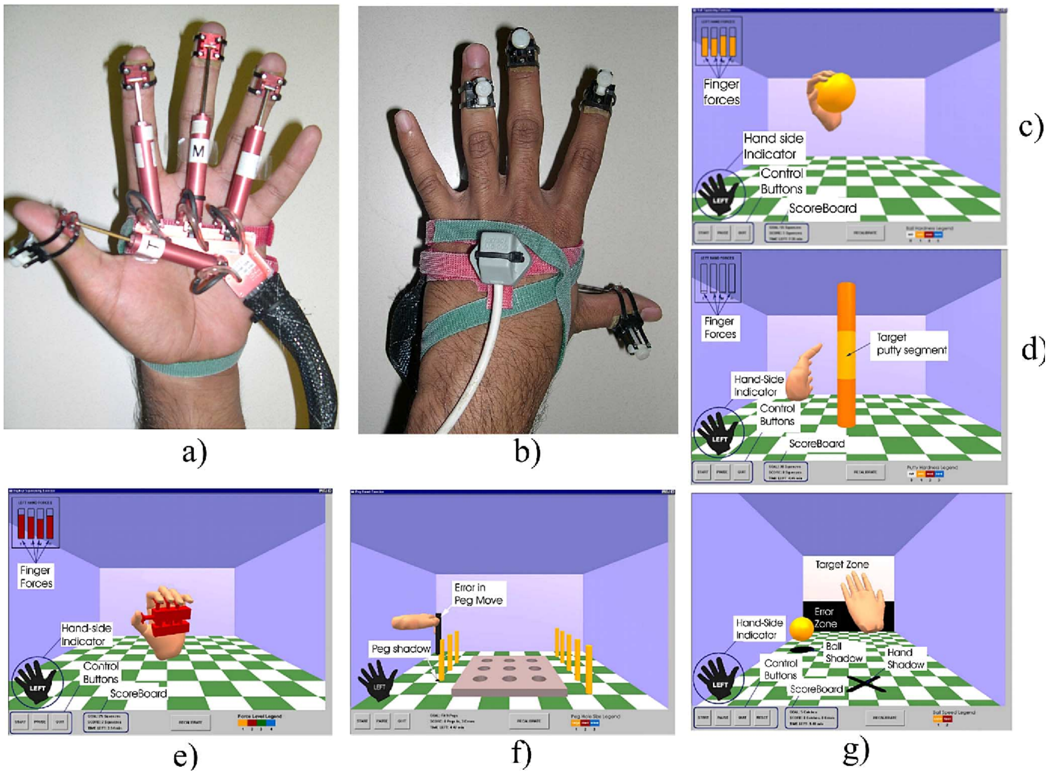


Figure 2.5: Virtual Reality system: a),b) Rutgers Master II glove; c) rubber ball squeezing; d) power putty; e) Digikey; f) peg board filling; g) hand-ball exercise. © Rutgers University.

- Walking in the Street: this part is a virtual environment for patients with neglect[4] that replicate different streets, where the patient's objective is to go to the supermarket via the streets.
- Shopping in the Supermarket: the second part is a treatment for the patients with cognitive disorders that simulates a supermarket. The aim is to buy objects and to memorize prizes, opening hours, etc.

Another way to classify virtual rehabilitation concerns the rehabilitation protocol. The latter can be distinguished between VR-augmented and VRbased therapy. In VR-augmented, they receive a mix of classic exercises that they can perform

[4]Spatial awareness deficit secondary to brain damage it is also referred to as one-sided spatial neglect. Generally the damage (eg, due to a stroke) is to the right parietal lobe, resulting in a deficit in the perception of the space of the left side

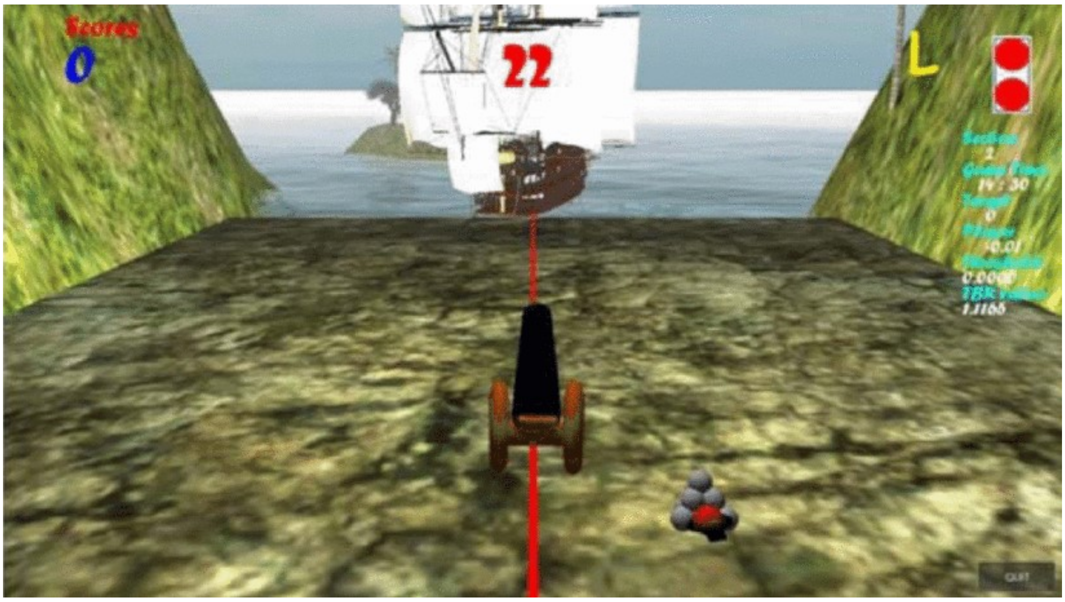


Figure 2.6: Screenshot of VR game.

Figure 2.7: Walking in the Street in the VIRCOG setup system (A) and Shopping in the Supermarket (B).

wherever they want. VR-based rehabilitation eliminates classic exercises, integrating a more innovative approach than VR-augmented therapy. Virtual rehabilitation simulations can also differ according to the type of therapeutic approach such as: "teaching by example", "video gamelike" or "exposure therapy". The first is used for chronic post-stroke patients, for example MIT (Massachusetts Institute of Technology) researchers have developed motor training for the arm in which, through a virutal "teacher", they monitored the correct execution of the exercise through sensors. Another approach, on the other hand, is the one similar to a video game, in which it usually has an immersive 3D experience. Typically this type of approach is done to try to cure phobias or trauma. In this experiment there is no "teacher" and here the patient has a greater cognitive load during the execution of the exercise. Finally, virtual rehabilitation can be classified according to proximity to the therapist who assists the patient. If the therapist is unable to follow the patient for logistical reasons, therapy is administered through virtual Tele-rehabilitation. Table 2.1 is a summary of this discussion.

Table 2.1: Pros and cons of rehabilitation therapies

Rehabilitation	Pros	Cons
Post-stroke	It adapts to the patient's conditions, can also be used in extreme cases, the treatment can be integrated into daily life	Dedicated only to the upper part of the body and always requires a professional figure
Neuro-muscular	Motivating type of therapy and with the possibility of collecting the data obtained from the therapy	The need for a professional figure to be carried out and the equipment or the treatment is often expensive
Cognitive	Engaging and motivating, it allows a safer therapy that also preserves privacy	Lack of adequate interfaces and no equipment is available for very young patients.
Tele-rehabilitation	Therapist always available online, moreover there is a reduction in costs since it is possible to do it at home	the equipment is very expensive and a good connection is also needed to maintain constant communication and data flow.

2.4 Virtual Assistants for Rehabilitation

Before talking about virtual assistants in the field rehabilitation it is necessary to make an introduction on what they are and what they are used for in VR / AR environments immersive and not. A virtual assistant is a software that interprets natural language (Natural Language Processing) and, if properly trained, he can dialogue with human interlocutors in order to provide information or perform certain operations [14]. A virtual assistant can accompany a user during the experience with the aim of supporting him in times of need. Starting with the most famous type of virtual assistant, we can observe the first voice assistants such as Alexa, Siri and Cortana, developed by Amazon, Microsoft and Apple respectively. This type of assistants refers to a broader and more consumerist target since they are omnipresent in people's daily lives. This type of assistants, usually vocal, work in two ways, the first direct, in which through a call such as "Hey Siri" they are activated waiting to perform a function, the second way is the indirect one where they collect user data learning the habits and tastes of those who use it and then adapting to the different type of user that comes before. Typically these types of assistants are thought of as passive listening devices that respond to a command or greeting. Another peculiarity of these assistants is that they must be connected to the internet in order to conduct web searches and find the answers that the user asks them. This type of assistant can be considered as the most common and widespread among users, but of generic utility. In general you can find virtual assistants also in the videogame field, especially at the beginning of an adventure like in Rayman 3, which has also been made diegetic[5] with the aim of making the initial tutorial part more usable by the player in this phase the virtual assistant helps the protagonist Rayman in the initial phases of the game showing them the basic commands and a brief introduction to the game world, an example is shown in Figure 2.8. This type of assistants also used in the web environment as a chatbot as a project done by a Turkish research group that created a chatbot that would answer the various questions regarding Covid-19 [15], would have the task of giving you answers based on questions already by default, this type of assistants are only functional in the environment in which they are being used. Outside this context, their function ceases.

In other fields, such as the Manufacturing Industry, virtual assistants is capable to support the user step by step in the execution of a job, where the user is followed in the execution of the work through an augmented reality system [16]. Other uses are those of chatbots or those used to improve human-machine interaction.

[5]The diegesis is a narratological concept, developed by Gérard Genette, whose use has been extended to the world of cinema. It means a space-time construction in which actions and events concerning the characters take place.

Figure 2.8: Diegetic Assistant in Rayman 3

With the aim for example of improving communication between the presenter and the public [17]. Regarding the theme of this thesis and therefore the virtual assistants in the field rehabilitation there are many studies in merit. Most of the environments in virtual reality that have been developed for rehabilitation they were born to support the therapist in patient care. In particular way when the latter is unable to participate physically to the sessions. One of these is the 2Vita-B project, the project can be understood as a capable virtual assistant to support the patient during the rehabilitation exercises and on the other hand as a support to the therapist in the organization of the internal rehabilitation plan [18]. In practice the physiotherapist has the possibility to assign exercises and the patient can count on the support of the system for execution by offering feedback on time real about the execution of the latter. The key component of the project is represented by an intelligent motion tracking and on the analysis components, both based on machine techniques learning and Microsoft Azure Kinect. This information provided by the assistant are useful both for the patient if the execution is carried out in such a way correct and for the therapist who can access the exercise record to evaluate any errors. An example of this project is shown in Figure 2.9. The VirtualPT project [19], on the other hand, despite having like ultimate purpose is to monitor the correct execution of the exercises through a tele-rehabilitation process differs from the first for two main reasons. The first is that VirtualPT unlike 2Vita-B uses as a process of acquiring body movement two main approaches, the first is

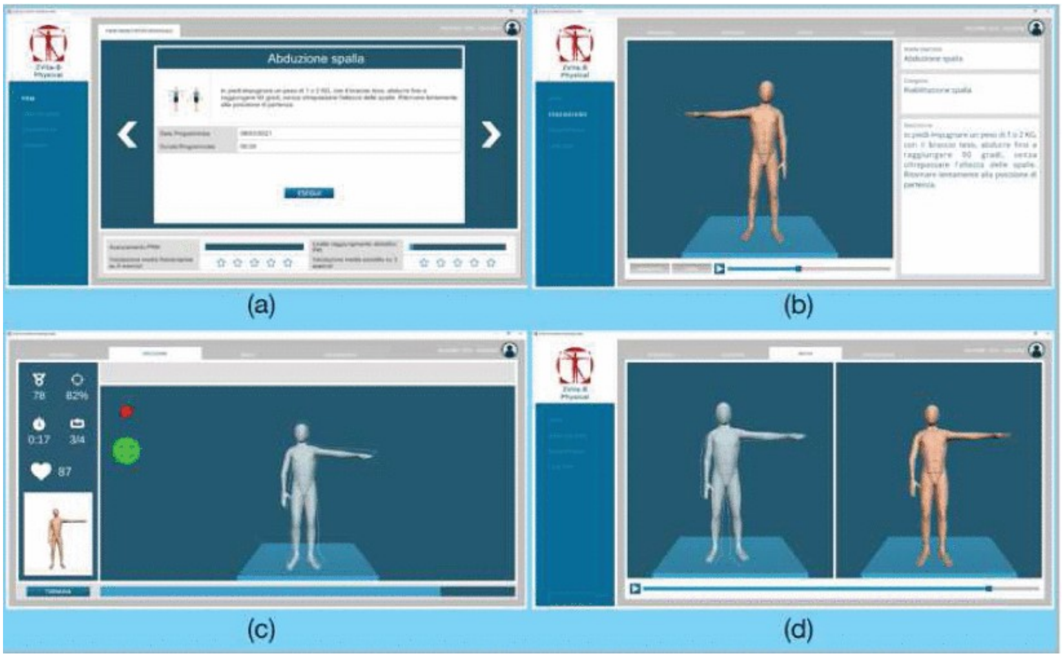


Figure 2.9: 2Vita-B Physical Project

motion tracking via Microsoft Kinect, and the second approach is to analyze the acceleration and rotations of the body parts using the MPU9250 sensor which are a combination of magnetometer, gyroscope, and accelerometer. Experience moreover, it was made usable in immersive mode through a headset for virtual reality. The second reason is that at the beginning of the exercise, unlike 2Vita-B they are captured the body parameters that will be used by the software to monitor the patient's medical condition during exercise. The aim is to provide real-time feedback as soon as a movement is performed the wrong way. An example of GUI is shown in Figure 2.10. Other studies in the rehabilitation field were conducted by the group of research of the "Sistemas Inteligentes de Soporte a la Educación". Which proposes a virtual assistant as support to rehabilitation and educational activities for children diagnosed with Dyslalia. The peculiarity of the project, which can be used in both smartphone and desktop version, it lies in the capacity to customize the avatar to your liking, to make it more versatile in based on the type of user on whom you want to administer the treatment [20]. A project supported by NEDO (The New Energy and Industrial Technology Development Organization in Japan), develop a support system for patients with a disability in the hand caused by hemiplegic reasons composed of a virtual environment and a symmetric master-slave motion assistant system for independent rehabilitation therapies [21]. The goal of the experiment is to provide movement exercises for the injured hand

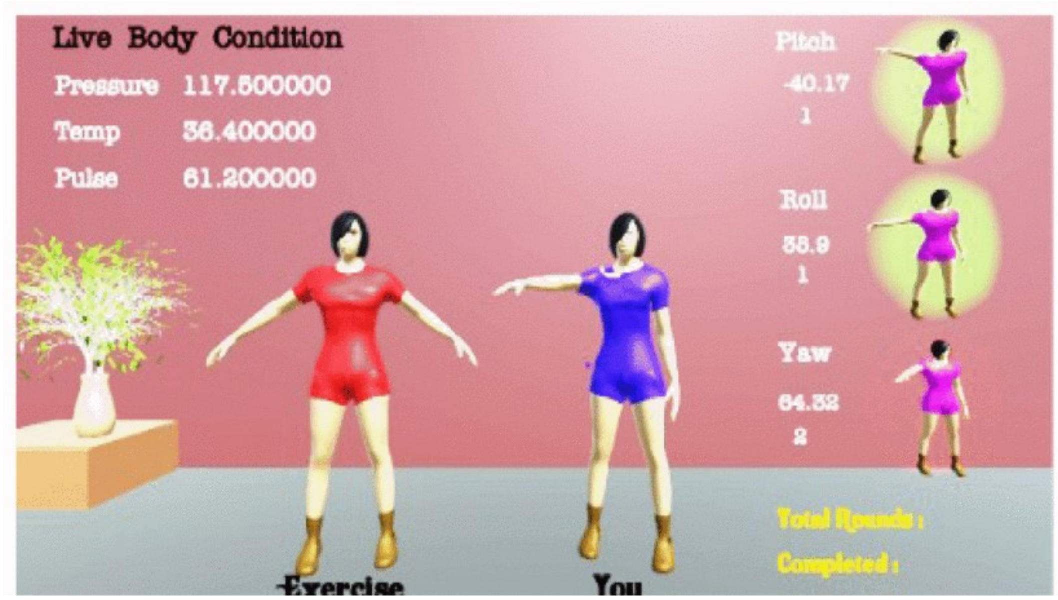


Figure 2.10: VirtualPT: Movement capturing stage process.

by guiding it through the healthy hand via an exoskeleton connected to both hands. The VR environment shows a guided exercise that the patient will have to replicate, an example of the experiment and exoskeleton is shown in Figure 2.11,2.12.

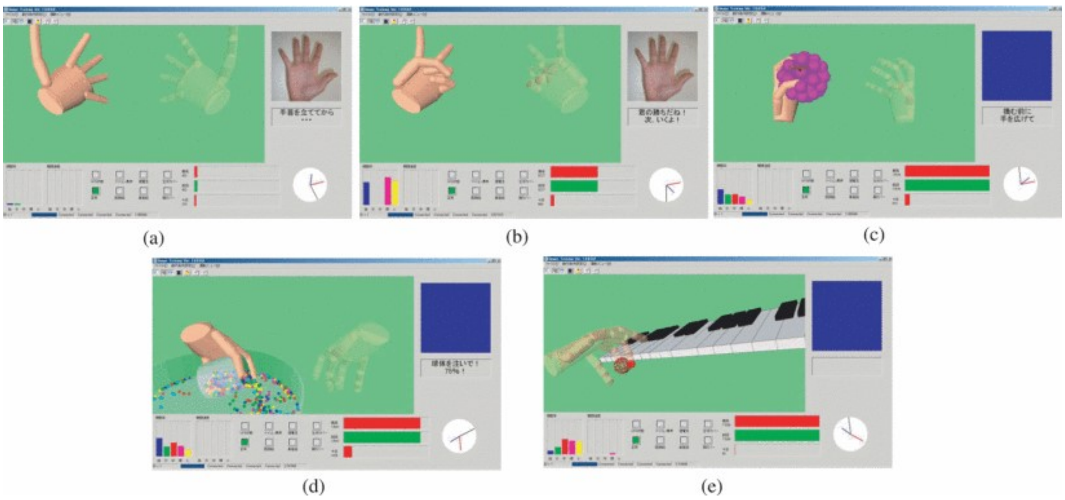
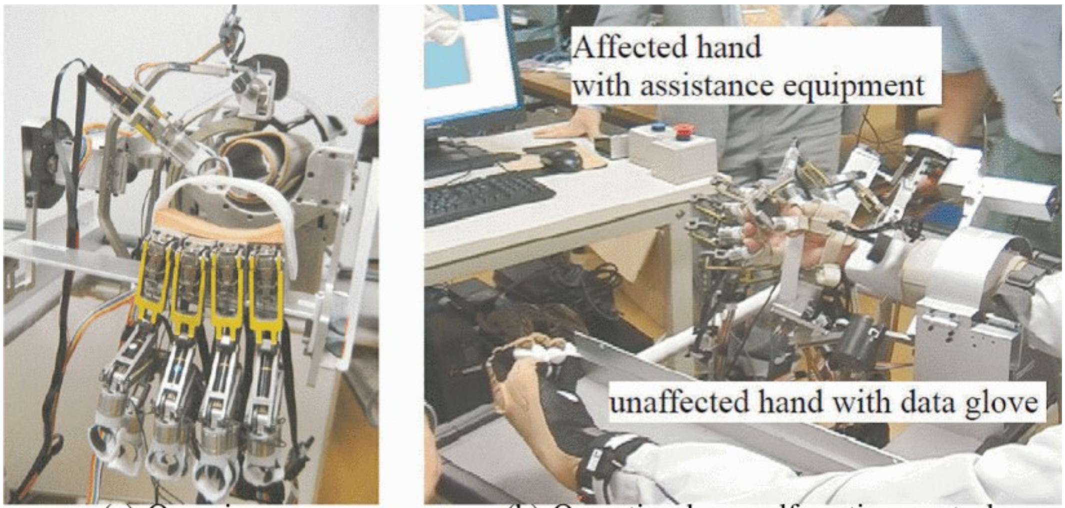


Figure 2.11: Virtual Reality system: (a) Measurement of movable range, (b) Scissors-paper-rock,(c) Pinching (or grasping) fruit,(d) Pouring movement,(e) Tapping a ball makes piano sounds.



(a) Overview. (b) Operation by a self-motion control.

Figure 2.12: A hand rehabilitation equipment with 18 DoFs.

The discussion just concluded shows how virtual reality has taken hold in the rehabilitation field, demonstrating the need for virtual reality applications to improve patient therapy. Today, most of the studies serve as a support to therapy and virtual assistants have the ultimate goal of monitoring the user in the execution of the exercise. All the studies just covered provide theoretical and practical evidence on the importance of using telemedicine and virtual assistance for the remote treatment of patients [18]. The Table 2.2 below summarizes the topic just discussed.

Table 2.2: Type of Assistant

Type of Assistant	What purpose it has	Who it addresses
Virtual Assistant	Help the user with pre-set actions	Generic target in a specific situation
Vocal Assistant	Help the user in real time in various tasks	Generic target in a generic situation
Rehabilitation Assistant	Help the patient in real time in a specific exercise	Specific target in a specific situation

Chapter 3

Technology analysis

This chapter focuses on the analysis of the software and hardware equipment chosen for the project. The software used for the project is a cross-platform graphics engine called Unity. This application enables the development of video games and other interactive content, such as architectural visualizations or real-time 3D animations. Thanks to this application, gamified interactive experiences can be created with the ability to create desktop-based or VR-based environments, the latter possible through the support of external hardware equipment such as headsets. The creation of an interactive application, as discussed in previous chapters, is key to virtual rehabilitation therapies.

3.1 Unity

Unity is a cross-platform graphics engine developed by Unity Technologies, first announced and released in June 2005 at Apple Worldwide Developers Conference as a Mac OS X game engine. The software enables the development of video games and other interactive content, such as film, automotive, architecture, engineering, construction, and real-time 3D animations [22]. An example of the interface is shown in Figure 3.1. Unity is available in two versions: free and Pro. It is advisable to start with the free version, partly because it is already complete with everything you need to create games and export them for any platform. The Pro version includes some advanced tools and performance tools. The license of the software is EULA[1]and it runs on both Microsoft Windows and macOS, with the ability to produce cross-platform games such as Microsoft Windows, Linux, Mac, Xbox 360, PlayStation 3, PlayStation Vita, Wii, iPad, iPhone, Android, Windows

[1]stands for End User Licence Agreement. This term is often used with regard to software intended for the public, including smartphone applications and video games.

Mobile,Playstation 4 Xbox one and Wii U. Unity gives users the ability to create games and experiences in both 2D and 3D, and the engine offers a primary scripting API in C# using Mono, for both the Unity editor in the form of plugins, and games themselves, as well as drag and drop functionality. Prior to C being the primary programming language used for the engine, it previously supported Boo, which was removed with the release of Unity 5, and a Boo-based implementation of JavaScript called UnityScript, which was deprecated in August 2017, after the release of Unity 2017.1, in favor of C#.

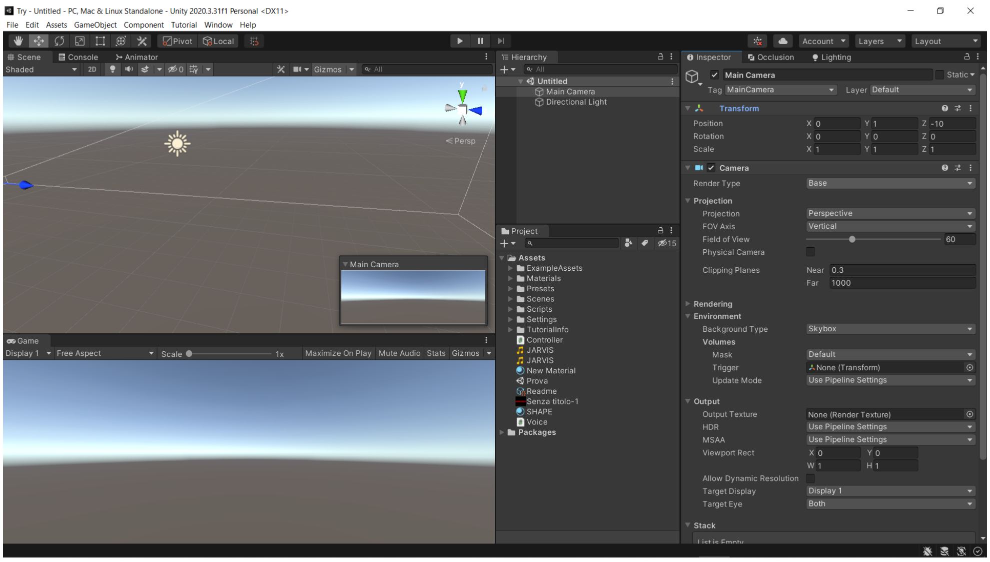


Figure 3.1: Default interface offered by Unity

3.1.1 Default settings

As seen in Figure, the initial layout of Unity may seem poor in content, but in fact the intial interface is very customizable based on the type of application you want to develop. In fact, as shown in Figure 3.2, Unity allows you to set up your project in a variety of ways because of the different templates available right at the start. This facilitates the development of projects, even complex ones, helping even those who are new to the software. It is possible to develop projects in 3D, 2D, immersive virtual reality, augmented reality and mixed reality, and it is also possible to develop multi-user applications. The advantage of Unity, compared to other platforms is the vast asset store, from which it is possible to download, free of charge and otherwise, various models and templates as shown in Figure 3.3, this makes the development of applications much easier, managing to please

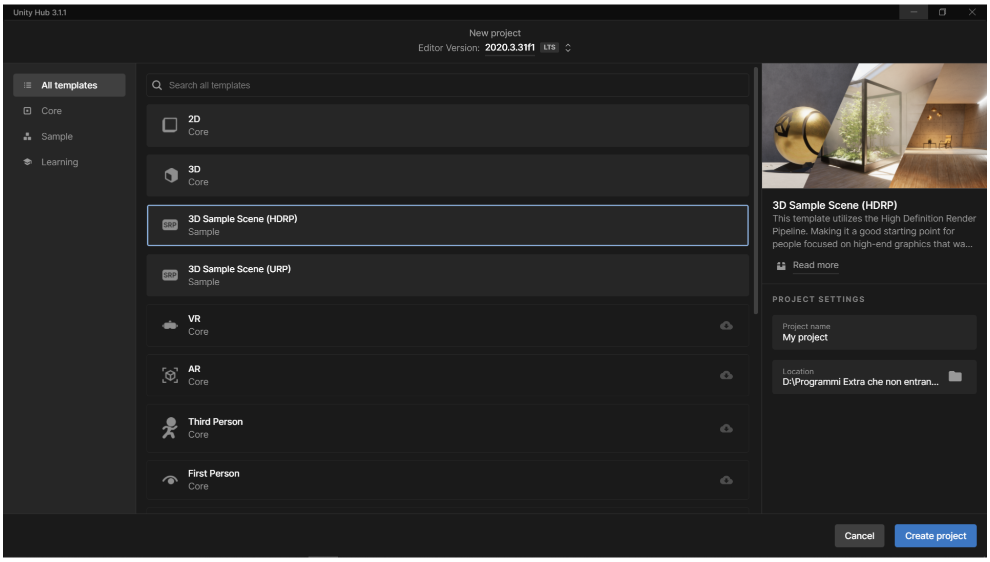


Figure 3.2: Unity Template

various professional figures, thus resulting a valuable support especially for indie developers.

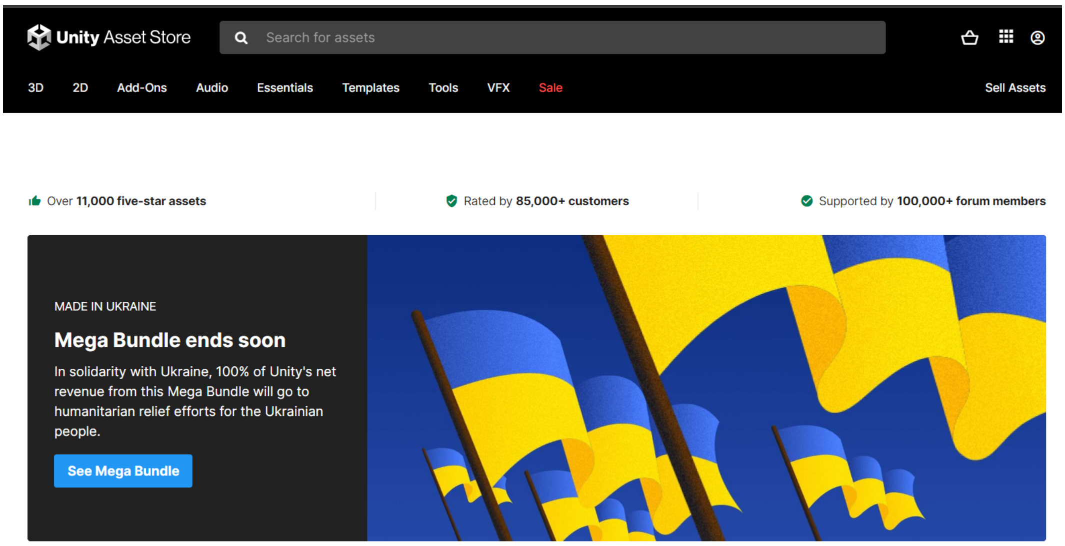


Figure 3.3: Asset Store

This is the most common classes found in Unity:

a) **GameObject:** Represents the type of objects which can exist in a Scene.

b) **MonoBehaviour:** The base class from which every Unity script derives, by default.

c) **Object:** The base class for all objects that Unity can reference in the editor.

d) **Transform:** Provides you with a variety of ways to work with a GameObject's position, rotation and scale via script, as well as its hierarchical relationship to parent and child GameObjects.

e) **Vectors:** Classes for expressing and manipulating 2D, 3D, and 4D points, lines and directions.

f) **Quaternion:** A class which represents an absolute or relative rotation, and provides methods for creating and manipulating them.

g) **ScriptableObject:** A data container that you can use to save large amounts of data.

h) **Time (and framerate management):** The Time class allows you to measure and control time, and manage the framerate of your project.

i) **Mathf:** A collection of common math functions, including trigonometric, logarithmic, and other functions commonly required in games and app development.

j) **Random:** Provides you with easy ways of generating various commonly required types of random values.

k) **Debug:** Allows you to visualise information in the Editor that may help you understand or investigate what is going on in your project while it is running.

l) **Gizmos and Handles:** allows you to draw lines and shapes in the Scene view and Game view, as well as interactive handles and controls.

3.1.2 Code

Scripting is an essential part in all applications developed in Unity. Most applications need scripts to respond to input from the player and to arrange for events in the gameplay to happen when they should. Beyond that, scripts can be used to create graphical effects, control the physical behaviour of objects or even implement a custom AI system for characters in the game. An integrated development environment (IDE) is a piece of computer software that provides tools and facilities to make it easier to develop other pieces of software. Unity supports the following IDEs:

- Visual Studio
- Visual Studio Code
- JetBrains Ride

Only the language used in Visual Studio, the default IDE, will be discussed in this thesis. The language that is generally used then in Unity is C#. The core syntax of the C# language is similar to that of other C-style languages such as C, C++ and Java.

Monobehaviour is the class from which all components are inherited. It is essential to talk about this class, since it allows us to associate with each object on the scene, some particular behavior when certain conditions occur. The conditions are represented by the methods of the Monobehaviour class in the form of events, to which each object can react. The functions used to handle events typically are called event handlers but in Unity they are named event functions, for simplicity. At each frame, Unity scrolls through all the active scripts in the scene, and if it finds one of these predefined functions, it calls it (thus passing control to the function). At the end of execution, the control is returned to Unity. an example of a newly created script is shown below 3.1. Every single function/event will not be analyzed in detail here, but it is necessary to introduce the main ones in order to better understand in operation of the application.

The Awake and Start methods are called only once at the beginning of an object's life cycle. The difference between the two lies in the fact that Awake is called very early, during scene preparation. At that time the objects in the scene are not fully valued, so in Awake it is inadvisable to perform operations that require the values of other objects, such as reading the tag of another object in the scene.

Listing 3.1: Example

```
public class Test : MonoBehaviour
{
    //Start is called before the first frame update
    void Start()
    {

    }

    //Update is called once per frame
    void Update()
```

```
        {

        }
}
```

Start is useful for performing pregame operations, such as creating arrays that will be filled later, or searching for elements in the scene that we want to save a reference for later work on during execution. The big differences between Awake and Start are two:

- Awake is always called before Start: if, for example, in one script on an object we insert an Awake function and in another a Start function, we will be sure that when Start is called Awake will have already been executed;
- while Awake is always executed when an object is loaded, Start is executed only if the script is active (via the checkbox in the Inspector next to its name).

For this reason, a script with only Awake and no Start usually does not have the checkbox next to its name, because in fact there is no concept of active or inactive: whether it was active or inactive, Awake would still be executed on it.The Update method is called at each frame, making it dependent on the framerate (see below) just before the rendering is performed. For this reason, often in Update the position of moving objects is updated (by operations on their Transform and/or Rigidbody components), so that they are rendered at the new position giving the player the illusion of motion. In Update, controls are also usually performed on the player's input. For example, many functions in the Input class are designed to read the player's input in that given frame. It is important to understand that everything in the Update is executed completely in the space of one frame, before the player can see anything.

3.1.3 Why the choice of this application

As discussed earlier the versatility of the application and the extensive asset library and large community make Unity the best choice for this project. In addition, the available libraries and plugins make integration with the head-mounted display easier. Over the years, it has also been expanded to support more than 25 platforms including Nintendo Switch. The engine is very flexible and can be used to create 3D, 2D, VR, and AR games as well as simulations and other experiences such as movies and cinematics. Frequent updates always provide additional features that in most cases are sufficient to create richly detailed video games. It is therefore a valid option for anyone who wants to start creating video games thanks too to a large community that provides projects and online video tutorials thus giving valid support to those who want to start and above all to those who want to learn more.

Unity supports C# as a native programming language, a language widely used in many application areas and similar to C ++ and Java.

3.2 Oculus

To develop the immersive virtual reality part, it was necessary to integrate an HMD to the application. The mounted-display model that was used for the project of the following Thesis is the Oculus; more precisely, the Oculus Rift was used in the part developed at the Politecnic of Turin and the Oculus Quest 2 for the part developed in Essex. The technical characteristics of the two models are listed in the table 3.1 below:

Table 3.1: Oculus models

Model	Resolution	Display Panel	Refresh Rate	FOV
Oculus Rift	2060x1200	OLED	90Hz	110°
Oculus Quest 2	3664x1920	Fast-switch LCD	90Hz	90°

The Rift needs an HDMI connection and a USB 3.0 connection to the PC to work, the Quest on the other hand was designed as a stand-alone viewer, with a catalog partly shared with the PC catalog, but for example without a computer one cannot take advantage of the titles on Steam. Facebook then created Oculus Link, a USB Type C-based cable to connect the Quest to the computer, which can then be used as a replacement for the Rift and Rift S. This made it possible to work in sync with other students during the project.

3.2.1 Oculus Setup

The first thing to do is to install the Oculus proprietary software from the official site as shown in Figure 3.4 and create an account. The product already comes with the headset, sensors, and controllers. For installation you must have an HDMI input connected to the GPU and a USB 3.0 port. Two other USB inputs are needed for the sensors. the software is a great support during the installation, as it shows in Figure 3.5, if everything has been connected properly in real time [23]. the installation is very simple and guided with the advantage of being able to use the same application for different Oculus models. Finally, to allow developers to

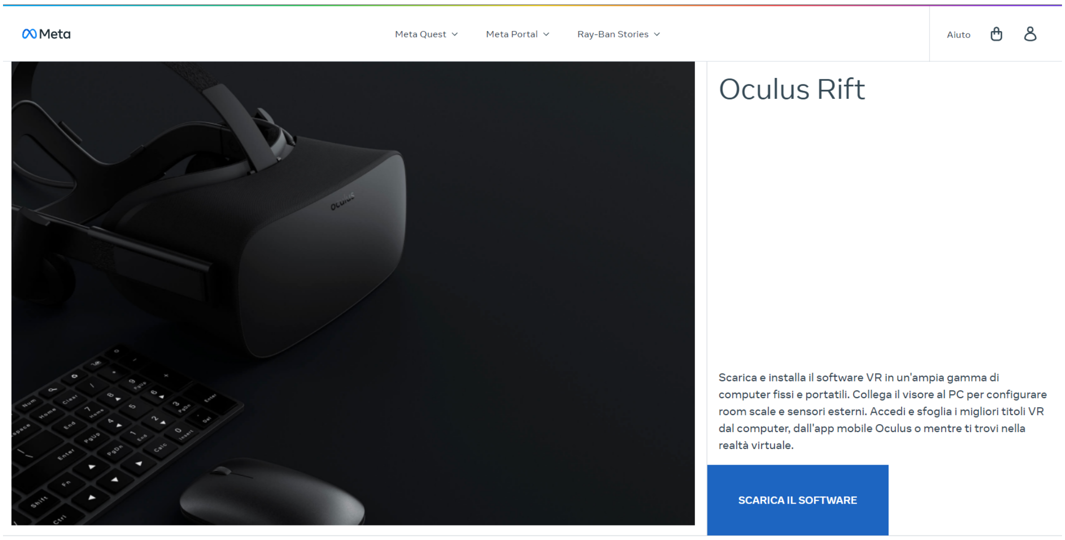


Figure 3.4: Oculus official site

be able to use the Oculus through third-party applications, *Unknown Sources* must be enabled as shown in the Figure 3.6 .

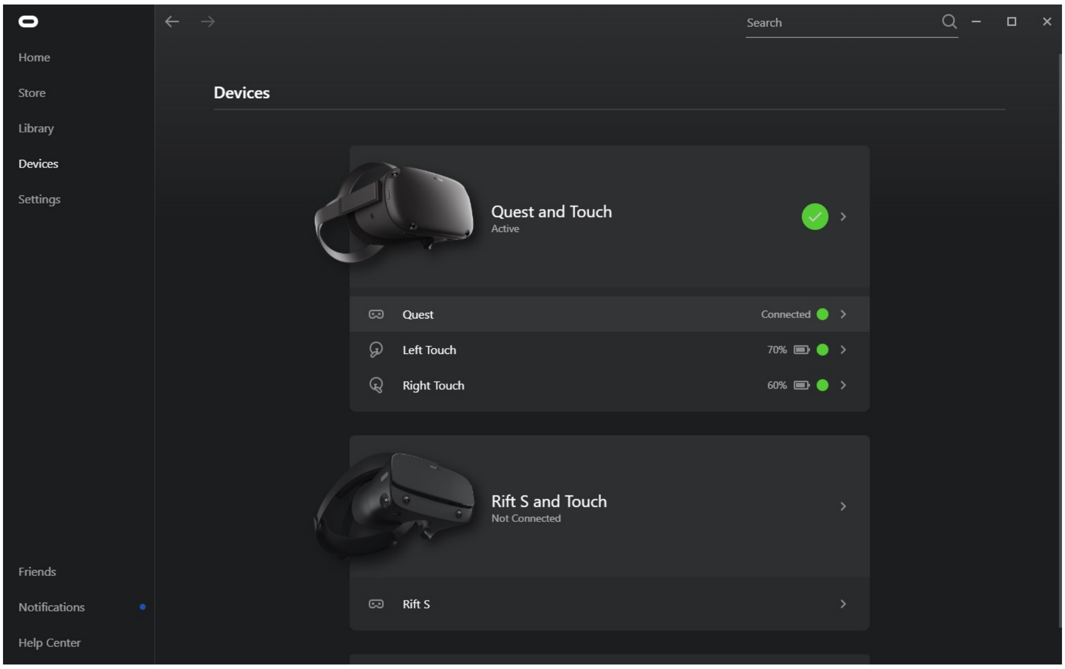


Figure 3.5: Oculus setup

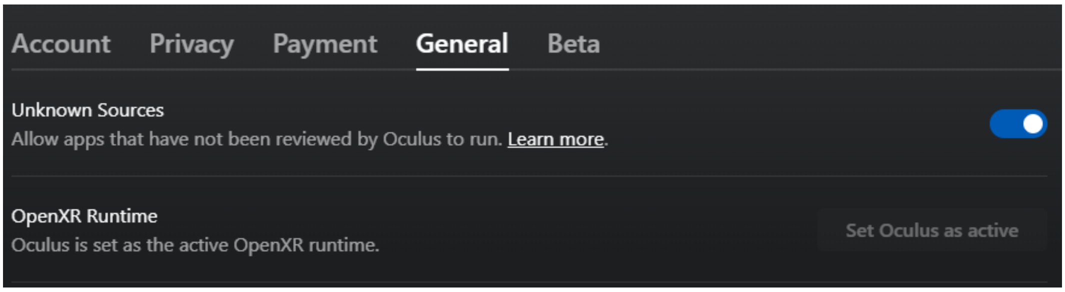


Figure 3.6: Enable Unknown Sources

3.2.2 Integration with Unity

Creating a VR experience with Unity requires a few steps that while cumbersome are simple to perform. The project was initially developed as desktop-based, and later interest was introduced in changing it to a VR-based project. This made it necessary to recreate a project from scratch on Unity with the Android Build Support, and the various sub-packages; since the Oculus is in fact an Android device. Next, it was necessary to recreate the project via Univeral Render Pipeline (UDR), a template that optimizes mobile performance and thus also the performance of the Oculus. As mentioned earlier, the steps of integrating Oculus on Unity are cumbersome but simple, so the steps that were required to make this possible will be shown below. It was necessary to change the Build Settings and change the development platform from Windows to Android with an ASTC texture compression. Finally, through the installation of some plugins such as:

- XR plugin manger
- XR interaction toolkit

It was possible to enable the Oculus as the input device and change the input system from device-based to action-based. Respectively, XR plugin manger provides simple management of XR plug-ins. Manages and offers help with loading, initialization, settings, and build support for XR plug-ins. On the other hands, the XR Interaction Toolkit package is a high-level, component-based, interaction system. It provides a framework that makes 3D and UI interactions available from Unity input events. The core of this system is a set of base Interactor and Interactable components, and an Interaction Manager that ties these two types of components together. It also contains helper components that you can use to extend functionality for drawing visuals and hooking in your own interaction event [22]. In the Unity documentation it is explained in an exhaustive way all the functionalities that are introduced with this plugin and all the new interactions that are supported.

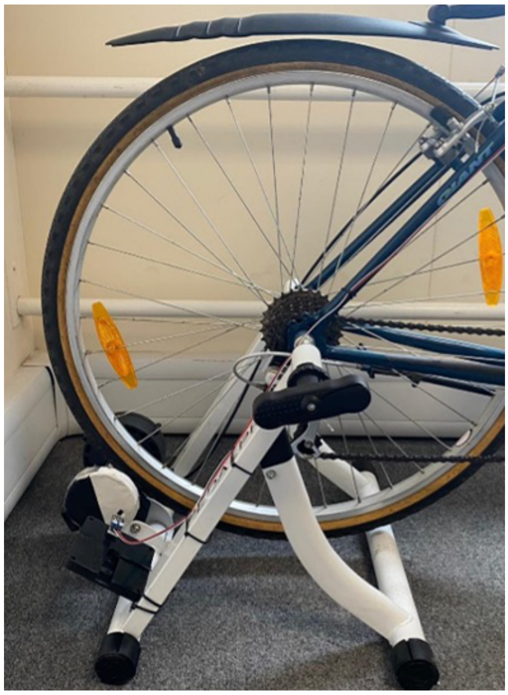
3.3 Photon

From the very beginning of the game's development, there was a desire to develop a multiplayer solution, which would then provide a way to monitor, guide, and collect data on the end user's performance while playing the game. The way in which this task was initially performed was through a two-tier communication system: a high-level one, using one of Unity's many multiplayer packages, and a low-level one, through scripts, one for the client in C# and one for the server in Python, which would be used to exchange information not immediately related to the game but later useful for assessing the player's level of disorientation (e.g., time spent at an intersection). The choice of multiplayer package was not trivial, as Unity's proprietary multiplayer solution (UNet) has been deprecated for years and the new one is still under development, shifting attention among the many third-party packages that have arisen in recent times. Mirror was used for the first implementation of the game, which seemed to fit purposes of the project: no limitations, free, good reputation among the community, and many examples and support. Mirror is a high level Networking API for Unity, supporting different low level Transports. With Mirror, the Server & Client are ONE project (hence the name) [24]. Instead of having one code base for the server and one for the client, it simply use the same code for both of them. One limitation that was found was that Mirror was not suitable for FPS games, as it was not easy to handle one camera per player, partly because the examples and documentation on the net showed only third-person games. As the development of the project moved toward virtual reality, it was found that we found that almost all of the examples and tutorials pointed to Photon as the best network package for implementing multiplayer VR games. implementing VR multiplayer games. Photon Unity Networking (PUN) is a Unity package for multiplayer games. Flexible matchmaking gets your players into rooms where objects can be synced over the network [25]. With the progress of the project in the virtual reality version, in the various forums it was noticed that almost all of the examples and tutorials indicated Photon as the best network package for the implementation of multiplayer VR games: even in its free version it is can connect up to 20 simultaneous users and above all its simple client server architecture is easy to use even by a beginner.

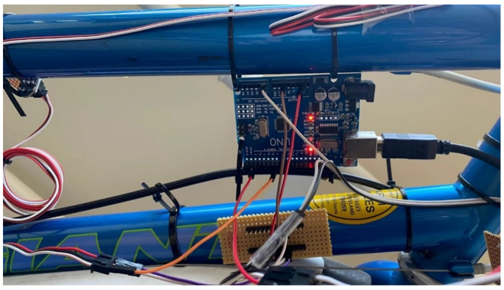
3.4 Bicycle prototype

For the sake of completeness of the present thesis, a brief introduction will be made in this paragraph of the prototype of a bicycle developed in the University of Essex by their research group. For the implementation of the prototype, potentiometers were used for the handle, The revolutions per minute of the wheel that are recorded as input / output of the signal are detected by a simple switch. Finally, the values converted to the desired format are sent to the Game Engine. The components used to make were Arduino UNO that is an open-source platform developed based on microcontroller ATmega328P. The board has a custom-made IDE go with it, which would make the coding much easier. The board can handle a large array of sensors as well as both digital and analogue inputs . An infrared module that is a combination of an IR transmitter and receiver capable of sensing some objects in the surroundings. The transmitter is an IR LED (Light Emitting Diode), and the receiver is an IR photodiode. The IR light emitted by the transmitter when it falls on the receiver resistance/ voltage change based on the amount of IR light that falls on it. In the end were used a Rotary Encoders that are electro-mechanical devices that can translate the angular movement into an equivalent change in the analog or digital signal. Below in the Figure, for illustrative purposes, some images of the prototype and the components used.

(a) *Pedal Handlebar*



(b) *Pedal Back*



(c) *Pedal Arduino*

(d)

Figure 3.7: Pedal Implementation

Chapter 4

Planning and development

This chapter will analyze what has developed within the project and the improvements that have been made. There will be a first analysis of the initial prototype to continue with the development of the VR-based project, concluding with the changes discarded during the development of the project.

4.1 Initial prototype

The studies and work carried out have produced a new prototype of the project. Starting from the initial prototype, as previously mentioned, the interface has been improved and some new features have been added, including the virtual assistant, a topic that this thesis mainly deals with.

The following paragraphs will highlight step by step what has been done during the working of the project. It'll start by studying the initial project and then move on to the first processing processes and graphic updates, up to the final phase of converting the project from a desktop-based experience to a VR-based one.

A final analysis will instead deal with some updates that were then discontinued for reasons that will be explained later.

4.1.1 How it looked

The initial project was presented as a desktop-based application, with a city inside that can be explored through a player in first person and an arrow at his feet that indicated the direction to take to complete the path, everything is shown in the Figure 4.1. The initial project, developed by Iliana Atzini, although apparently finished, was lacking in content and with almost no interaction with the user. Furthermore, there was no visual continuity as the models, having been taken through the asset store, had evident differences, shown in Figure 4.2. The purpose of the project therefore, at the beginning, was to improve the interface but, as will be shown in the following paragraphs, during the development of the project we realized the need to migrate to a new project, VR-based, with new models and adding new paradigms of interaction with the user.

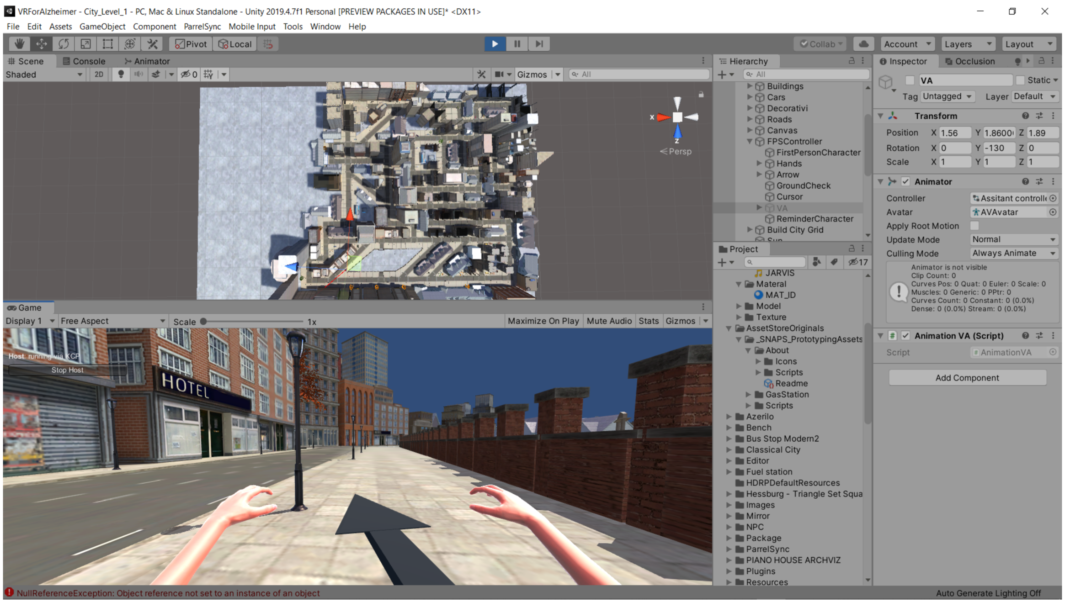


Figure 4.1: Initial prototype

4.1.2 Optimization of the old project

In the initial stages of the project it was tried to work on what had already been developed, trying to optimize the rendering and develop a first prototype of a virtual assistant. In these phases we tried to use the internal Unity functions such as L'Occlusion Cullign and Light Probes, to optimize the rendering of the project. The Occlusion culling is a process which prevents Unity from performing rendering calculations for GameObjects that are completely hidden from view (occluded) by other GameObjects, Light Probes, on the other side, store information about light hitting surfaces in your Scene and provide a way to capture and use that information, an example of this two are shown in Figure 4.3, 4.4.

Regarding the virtual assistant, a 3D model was created and subsequently animated, which will be explored in the following paragraphs. The virtual assistant communicates with a shortest path algorithm, developed by Daniele Bigagli, which has the purpose of calculating the best path having as input a starting point and an arrival point and subsequently communicating to the assistant the information

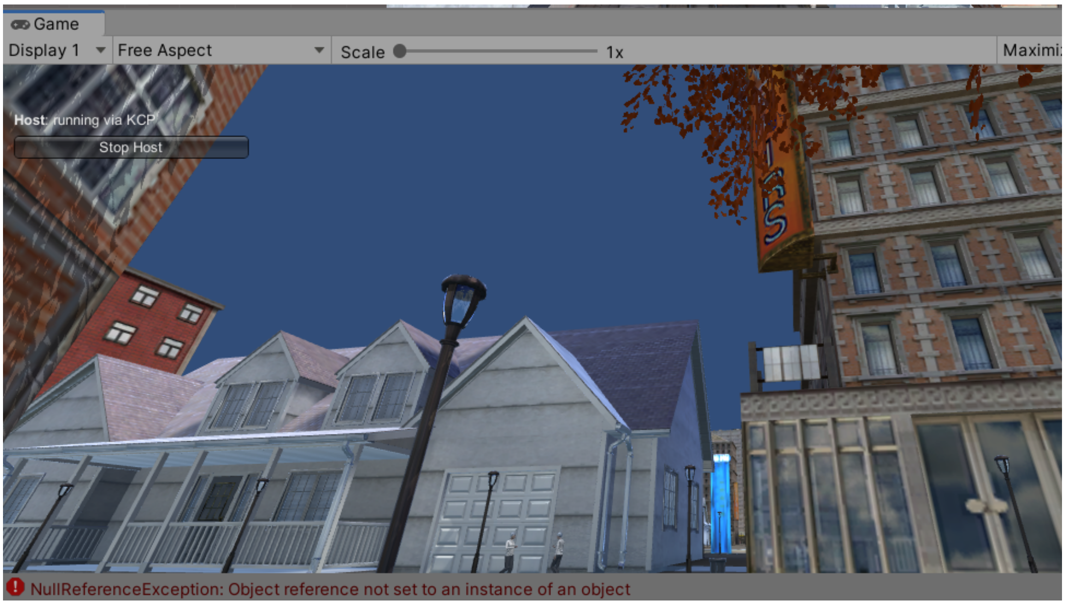


Figure 4.2: Buildings

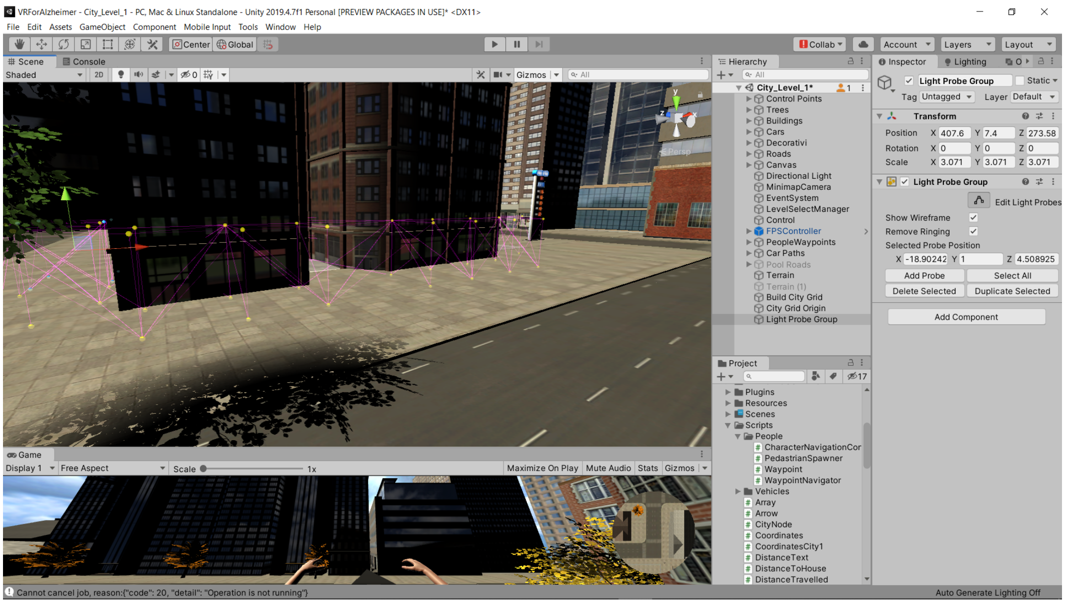


Figure 4.3: Light Probes

on the various past checkpoints and on the correct direction to follow during the route. This phase in particular developed in the old project and maintained in

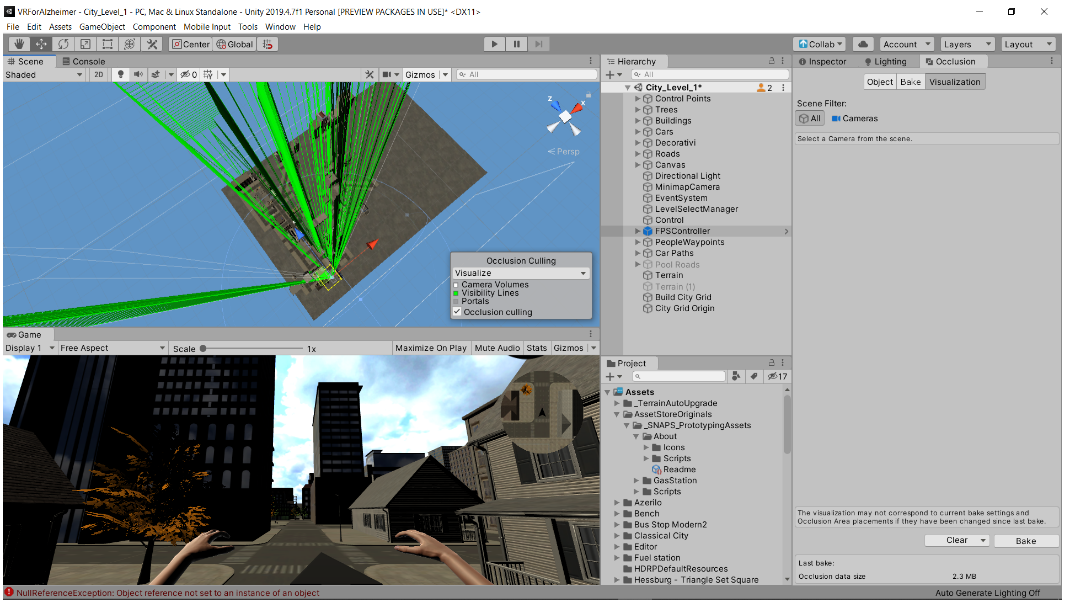


Figure 4.4: Occlusion Cullign

the new one will be explored in the paragraph concerning the virtual assistant. The reasons for the development of the new project and the implementations that followed will be explained in the next paragraph.

4.2 Rebuild of the project

Given the need of the project to migrate from a desktop-based application to a VR-based one, it has been moved to one in the Universal Render Pipeline (URP), this is because according to the Unity documentation, there is an optimization for the Oculus for Graphic Shaders in URP projects. In the project, therefore, after having been entirely modified and migrated into an immersive virtual reality, it has been improved through the programs that will be listed below.

4.2.1 Blender

Blender is a free and multi-platform software for modeling, rigging, animation, video editing, composition, rendering and texturing of three-dimensional and two-dimensional images. It also has features for UV mapping, fluid, coating, particle simulations, other non-linear simulations, and 3D game / application creation. The program was then used to create the 3D models imported into the project and the assistant animations, an example is shown in Figure 4.5.

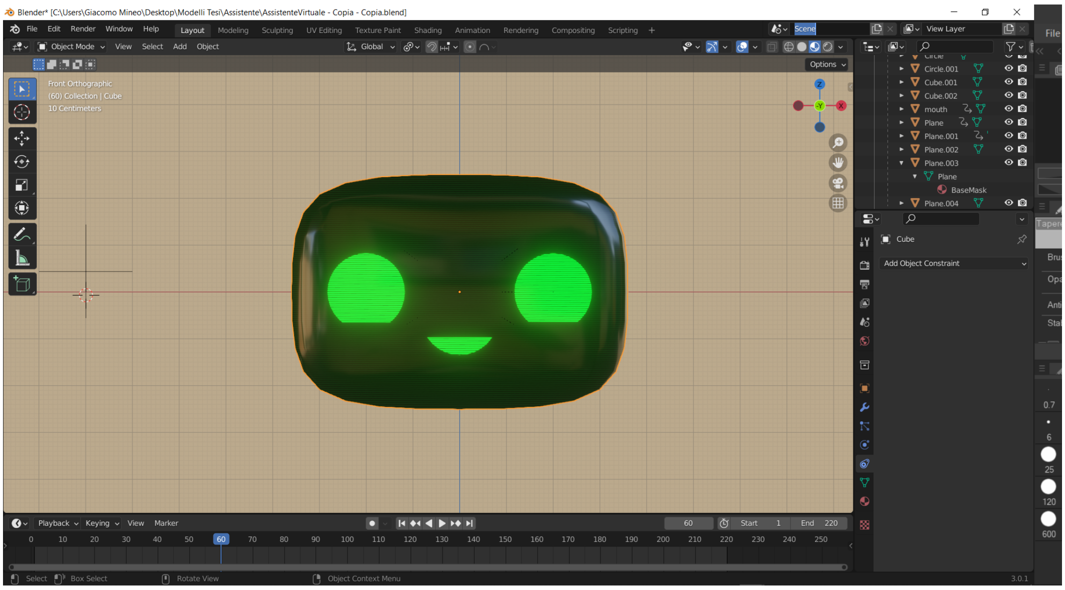


Figure 4.5: Interface example. *Virtual assistant head model*

4.2.2 Substance Painter

Substance Painter is an application that allows you to create textures or put existing ones on important 3D models from other modeling programs, such as Blender, Maya, Cinema4D. The peculiarity of the program lies in speeding up the texturing process of the model as, thanks to the already existing Materials, it is possible to cover a wide range of needs and details. An example of interface is shown in the Figure 4.6. It was possible to work with Substance painter under a student license, as it is a paid program from Adobe.

4.2.3 Adobe's Application

Finally, Adobe suite was used to create the various virtual assistant interfaces. From Photoshop to create UI screenshots graphics to PNG images to shape the particles used later in Unity, this last part will be discussed in detail in the virtual assistant paragraph. Finally with Adobe Premiere and After Effects to create 2D animations and videos for the UI. Those applications are shown below in Figure 4.7. These three programs and substance painter being all adobe programs and with a layered logic, have optimized the workflow.

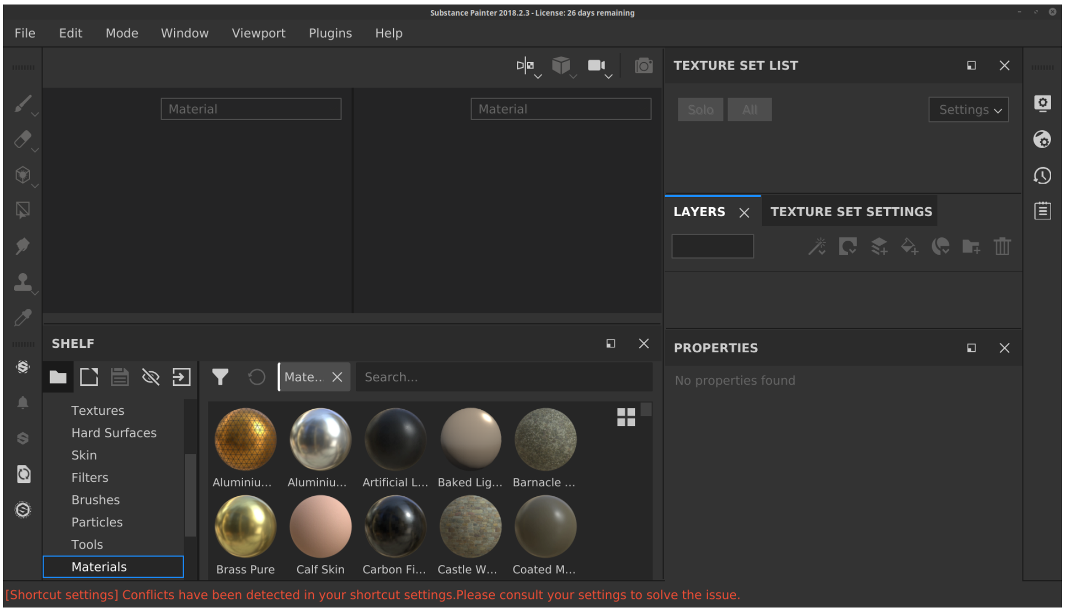


Figure 4.6: Substance Painter interface

Figure 4.7: Adobe's Application used

4.3 Virtual Assistant

The virtual assistant was developed to assist the patient in completing the course with the aim of developing simple and clear interactions. Since the target people of the project are elderly people with dementia, it was decided to develop a Robot without too many complex shapes and with a clear interface in such a way as not to cognitively load the user. Below will be illustrated the whole procedure of realization of the assistant and the interactions developed for the project.

4.3.1 Develop of the Virtual Assistant

As discussed above, the idea of the robot arises from the need to create an assistant with simple shapes that do not weigh down the patient's cognitive load. For this reason, both in the modeling and in the textures it was tried to reproduce a sinuous and clear image. The model was created using Blender, and subsequently UV-mapped and exported to fbx[1] to be then textured on Substance Painter, the images below 4.8 show first the model in UV-Mapping and then the textured model.

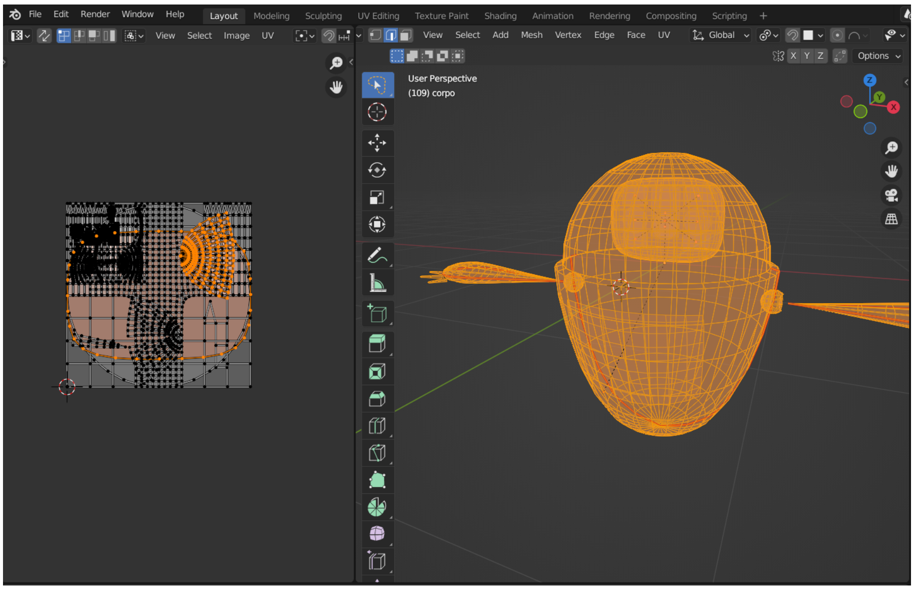
Finally, the model was imported into Unity, as the latter used a rendering engine other than Blender, it was necessary to internally correct the materials through the program's internal settings. In fact, two special materials have been created to give both the metallic effect and the transparency effect for the assistant's helmet, the Figure 4.11 below shows the materials created for the model imported into Unity.

4.3.2 Animations

The various animations were created via Blender and once finished they were important in Unity. We can divide the animations into two different groups, one for movement and the other for interaction. The first group was used to give truthfulness to the movements of the robot as it follows those of the user. The second group is used to interact directly with the user. To make these animations a manually created armor, shown in Figure 4.10, was used as it was not a human armor.It consists of a series of bones controlled by the head, one for the body, two for the arms and sixteen for the fingers as they were the most important parts. Below, in Figure, are shown the main animation developed for the virtual assistant.

Another block type animations were made for the bicycle model, shown in Figure 4.12. The bicycle was created to give a greater sense of immersion to the user, it was suitably modeled and animated in Blender. The animations had to essentially

[1]FBX (Filmbox) is a proprietary file format (.fbx) developed by Kaydara and owned by Autodesk since 2006. It is used to provide interoperability between digital content creation applications.

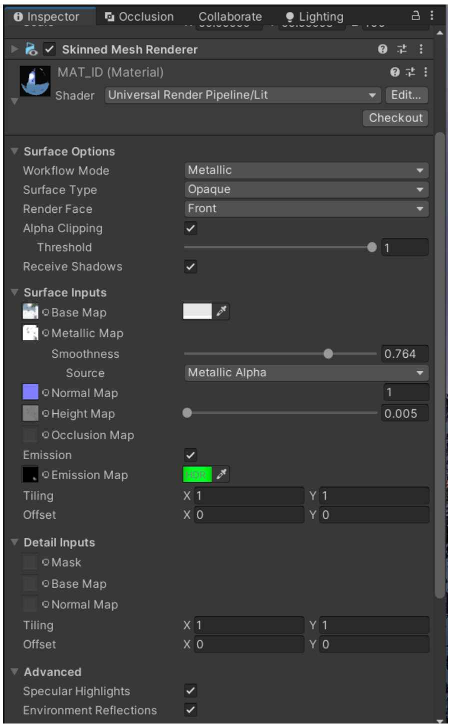


(a) *UV-mapped 3D model*

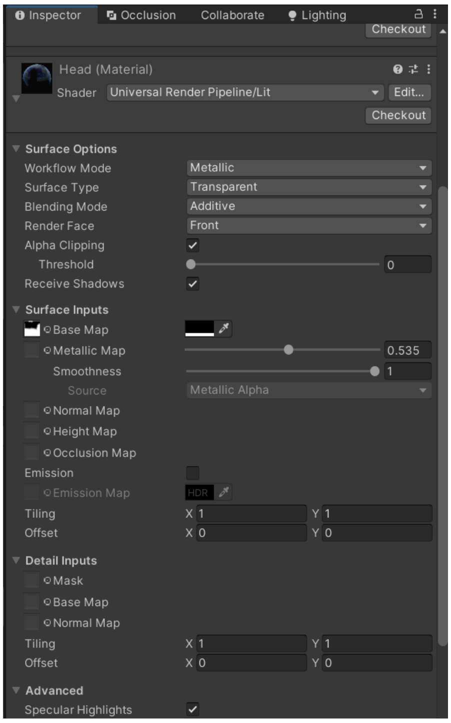
(b) *Textured model in T-Pose*

Figure 4.8: Model in UV-mapping and Textured Model

replicate the left and right movements of the real bicycle which is used as an input device. To better understand the logic behind the virtual assistant, a flowchart has been created as shown in the Figure 4.13.



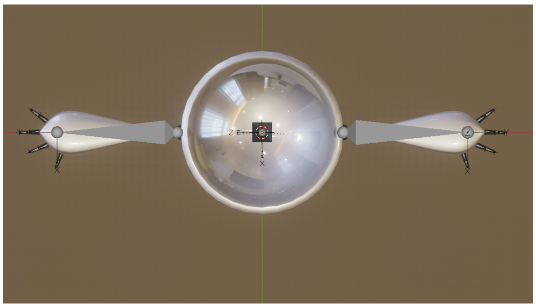
(a) *Material for the body*



(b) *Material for the head*

Figure 4.9: Materials created for the Virtual Assistant

(a) *VA armature.* Front view



(b) *VA armature.* Upper view

Figure 4.10: VA armature

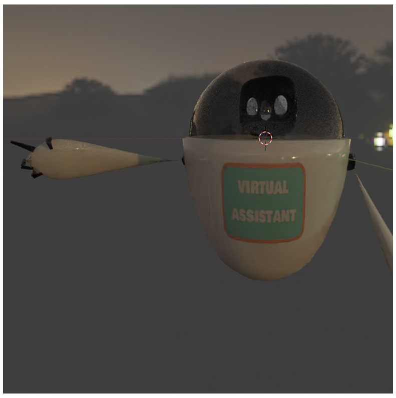
4.3.3 Interaction with the User

As regards the interactions between virtual assistant-user, since they are interactions with elderly patients with precocious dementia, we have tried to make them clear

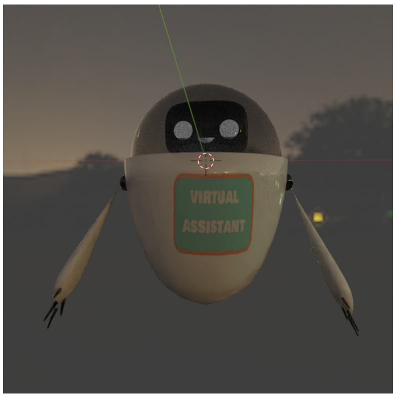
(a) *GlideSX*

(b) *GlideDX*

(c) *PointDX*



(d) *PointSX*



(e) *Idle*

Figure 4.11: Animations for virtual assistant

and accessible. The stages of the virtual assistant can be divided into three macro-phases. The first essentially indicates that all is well and that the user is continuing

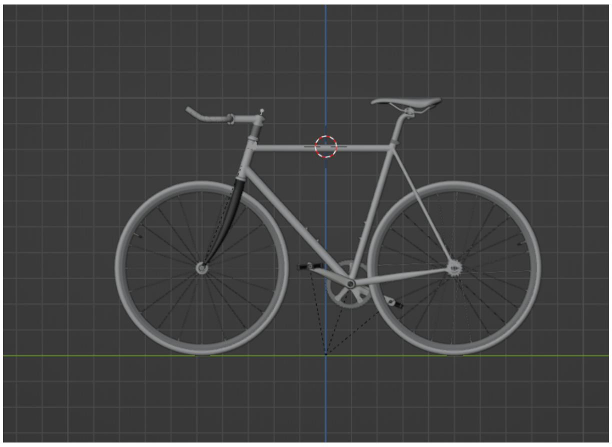


Figure 4.12: 3D bike model

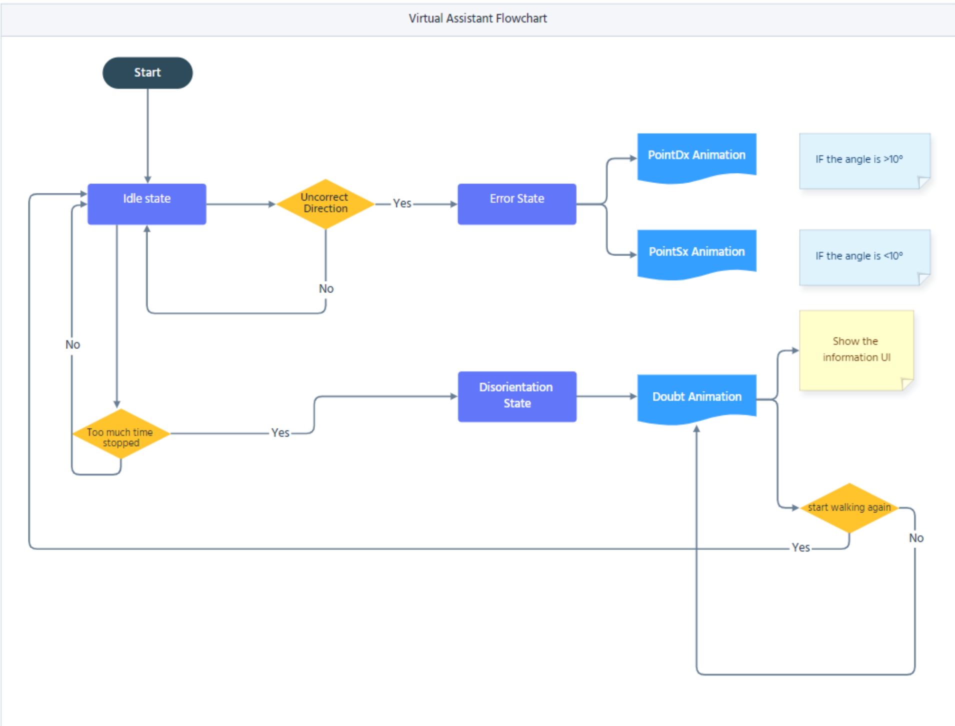
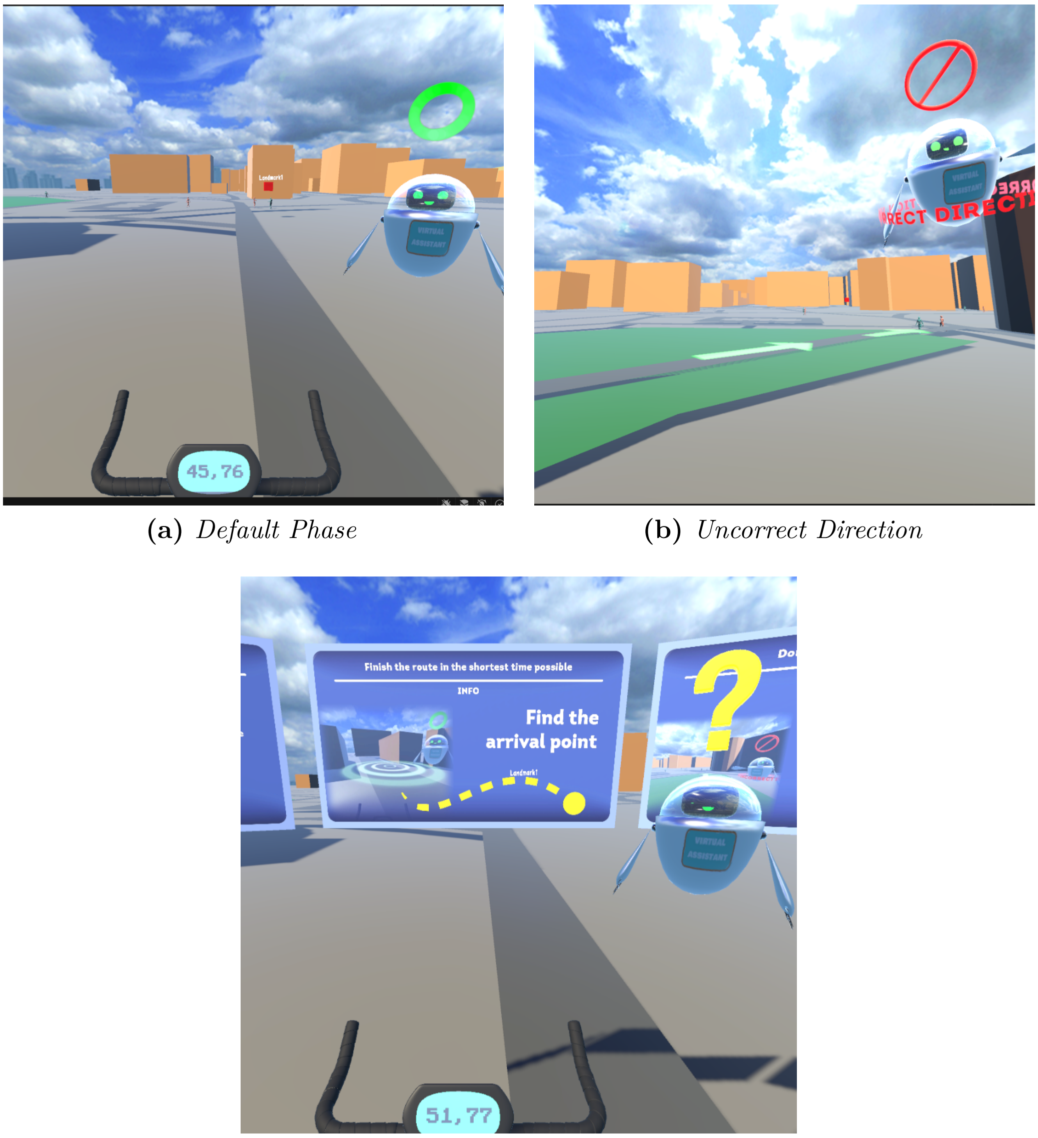


Figure 4.13: Virtual Assistant Flowchart

in the correct direction. This phase has been graphically represented with a green ring which, through the psychology of colors, refers to a "correct answer". In the

Figure 4.14a you can see how everything has been graphically reproduced; the green ring was created using Unity particles. In fact, Unity allows you to create



(a) *Default Phase* **(b)** *Uncorrect Direction*

(c) *Disorientation*

Figure 4.14: Different phases of Virtual Assistant

internal particles, which although more complex in the act of creating a VFX than Blender, is more comfortable as it is fully customizable through the internal graphics engine of Unity itself. The second phase is the one in which the user takes the wrong direction and therefore needs to be brought back in the correct direction.

In this phase, as shown in the figure, two types of feedback are observed, one visual and one auditory, the first rendered through an inconography that refers to a "no entry" and a writing around the assistant with the words *"Uncorrect Direction"*, the second part through a sound produced by the assistant that refers to that of an alarm, to capture the user's attention. To further help the user in the moment of "error", there are two directional aids, the first is an arrow, shown in the Figure 4.14b, which always refers to the last visited checkpoint, the second is the virtual assistant that changes animation and indicates always the right orientation in which to continue. The last phase, on the other hand, is as soon as the user remains motionless for more than a certain number of seconds, three screens will appear in front of him that will remind the latter what to do within the environment but above all it will remind him that every once he gets in the wrong direction, the assistant will bring him back in the correct direction; this phase is shown in the Figure 4.14c. In detail, in Figure 4.16, 4.15, you can see the screens created on purpose in the moment of disorientation of the user and the Animator Controller used to organized all the animations.

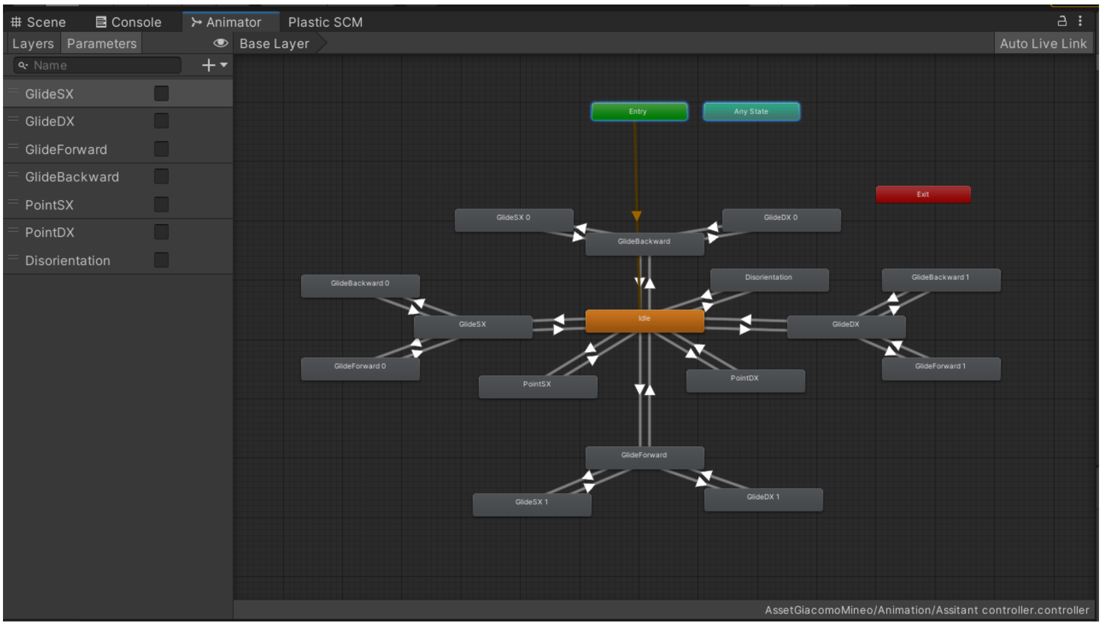
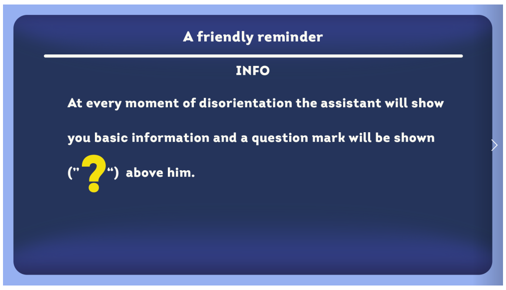
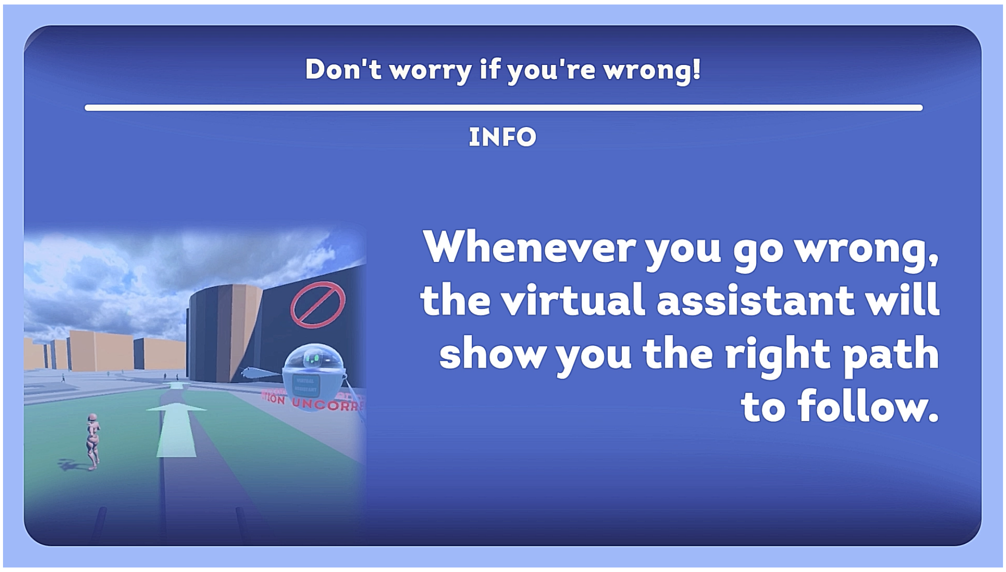


Figure 4.15: Animator Controller for Virtual Assistant



(a)

(b)



(c)

Figure 4.16: UI for disorientation moments

4.3.4 Code

This paragraph will shows various pieces of code developed for the user interactions just discussed. The first image, shown in 4.1, explains the logic behind the moments of disorientation.

Listing 4.1: Code used for the disorientation phase

```
//Update Doubt Timer

    public IEnumerator CheckIfMoving()
    {
        while (true)
        {
```

```
            Vector3 currentPosition = transform.position;
            yield return new WaitForSeconds(1f);

            if (currentPosition == transform.position)
            {
                StartCoroutine(DoubtTimer(currentPosition));

            }
            else if (currentPosition != transform.position)
            {
                effectControl[0].SetActive(true);
                effectControl[1].SetActive(false);
                effectControl[2].SetActive(false);

            }

        }
    }

    public IEnumerator DoubtTimer(Vector3 currentPosition)
    {

        yield return new WaitForSeconds(6f);

        if (currentPosition == transform.position &&
            effectControl[1].activeSelf == false)
        {
            effectControl[0].SetActive(false);
            effectControl[1].SetActive(false);
            effectControl[2].SetActive(true);
            anim.SetBool("Disorientation", true);
            if (stopped == true)
            {
                zoomIN.Play();
                stopped = false;

            }

            StartCoroutine(RepeatLerp(
                containerVideo.transform.localScale,
                maxScale,
                duration));

            videoPlayer[0].Play();
            videoPlayer[1].Play();
            videoPlayer[2].Play();
        }
        else if (currentPosition != transform.position)
        {
```

```
56              if (stopped == false)
57              {
58                  StartCoroutine(RepeatLerp(
59                      maxScale, new Vector3(
60                          1, 0, 1), duration - 0.5f));
61                  zommOut.Play();
62              }
63
64
65              videoPlayer[0].Stop();
66              videoPlayer[1].Stop();
67              videoPlayer[2].Stop();
68              stopped = true;
69              anim.SetBool("Disorientation", false);
70
71          }
72
73      }
```

In this particular case the RepeatLerp function was used which allowed a smoother animation. As can be seen in lines 40 and 60, the animations are accompanied by sound feedback. Below, in the code 4.2, it can see the function in detail. This phase in particular is controlled by a Corountine which starts as soon as the user stops for a few seconds.

Listing 4.2: RepeatLerp function

```
public IEnumerator RepeatLerp(
    Vector3 a, Vector3 b, float time)
 {
     float i = 0.0f;
     float rate = (1.0f / time) * speed;
     while (i< 1.0f)
     {
         i += Time.deltaTime * rate;
         containerVideo.transform.localScale =
         Vector3.Lerp(a, b, i);
         yield return null;
     }
 }
```

As regards the error phase, a control has been created on the vector that joins the current position of the user and that of the next checkpoint, the animation of the assistant then changes as the angle of the vector changes, the code 4.3 of this case is shown below.

Listing 4.3: Uncorrect Direction phase

```
//Uncorrect Direction
if (distance.magnitude >= maxDistance)
            {
                if (uncorrect.isPlaying == false)
                {
                    faceExp.transform.localScale = new Vector3(1, -0.5f, 1)
                    uncorrect.Play();
                }

                if (angle <= -10f)
                {
                    effectControl[0].SetActive(false);
                    effectControl[1].SetActive(true);
                    anim.SetBool("PointDX", true);
                    anim.SetBool("PointSX", false);
                    if (_uncorrectDir.activeSelf == false)
                        _uncorrectDir.SetActive(true);
                }
                else if (angle >= 10f)
                {
                    effectControl[0].SetActive(false);
                    effectControl[1].SetActive(true);
                    anim.SetBool("PointSX", true);
                    anim.SetBool("PointDX", false);
                    if (_uncorrectDir.activeSelf == false)
                        _uncorrectDir.SetActive(true);
                }

                if (!_farFromPath)
                {
                    _farFromPath = true;
                    StartCoroutine(ReturnOnPathArrow());
                }
            }
            else if (distance.magnitude <= maxDistance)
            {
                faceExp.transform.localScale = scaleface;
                uncorrect.Stop();
                _farFromPath = false;
                arrowObject.SetActive(false);
                anim.SetBool("PointDX", false);
                anim.SetBool("PointSX", false);
                _uncorrectDir.SetActive(false);
            }
```

Finally the Arrow script 4.4 which recalculates a path made of "steps" between the user's position and the position of the next checkpoint to be reached. the arrow indicates the cell that corresponds to the first step of the route just calculated. In practice it guides the user but does not simply indicate the first step but indicates the direction of the road that you must take to return to the nearest checkpoint.

Listing 4.4: Arrow script

```
private IEnumerator ReturnOnPathArrow()
    {
        while (_farFromPath)
        {
            List<CityNode> path = null;
            Vector3 startingPosition = transform.position;
            Vector3 nextCheckpointPosition =
            GetNextCheckpointPosition();
            Vector3 originPosition =
            pathManager.GetOriginPosition();

            var temp = Time.realtimeSinceStartup;
            _thread = new Thread(() =>
            {
                path = CalculatePath(
                    startingPosition,
                    nextCheckpointPosition,
                    originPosition);
            });

            _thread.Start();

            while (_thread.IsAlive)
            {
                yield return null;
            }
            if (path != null)
            {
                CityNode targetNode = null;

                foreach (CityNode node in path)
                {
                    targetNode = node;

                    /* 10 is the min distance to consider
                    as the next node to point */
                    if (Vector3.Distance(node.GetPosition(),
                        transform.position) > 10)
                        break;
                }

                if (!arrowObject.activeSelf)
                {
                    arrowObject.SetActive(true);
                    _arrowParticle.Play();
```

```
                }

                arrowObject.transform.position =
                transform.position + 0.2f * transform.up;
                arrowObject.transform.forward =
                targetNode.GetPosition()- transform.position;
            }
            /* Waiting time between the recalc of the path
            and the repositioning of the arrow */
            yield return new WaitForSeconds(5f);
        }
    }
```

4.4 Discarded changes

This last paragraph wants to deal, for the sake of completeness in the discussion, of the changes that have been developed but discarded for the reasons that will be listed below. A substantial change that was added to the project was that of being able to interact through voice controls with the virtual assistant. The initial idea was to make the virtual assistant interact with the user when the latter presented cases of disorientation. In practice, the assistant asked the user if he needed help, at the affirmative voice response of the user, the latter was spawned in the last checkpoint visited. This part was no longer developed because it did not take into account the cognitive load that it brought to the user when he had to remember the voice commands, and the user himself, since the project still deals with subjects suffering from dementia, he could present of aphasia[2] problems. For the sake of completeness, the code of this part is shown below 4.5.

Listing 4.5: Vocal Control

```
//Inizialize Dictionary

        actions.Add("Yes", HelpUser);
        actions.Add("Perfect", Thanks);

        keywordRecognizer = new KeywordRecognizer(
            actions.Keys.ToArray());
        keywordRecognizer.OnPhraseRecognized += RecognizedSpeech;


```

[2]Aphasia is the partial or complete loss of the ability to express or understand written or verbal words. It is caused by damage to the areas of the brain that control language. People may have difficulty reading, writing, speaking, understanding, or repeating language.

```

//Update Vocal control
    private void RecognizedSpeech(
        PhraseRecognizedEventArgs speech)
    {
            Debug.Log(speech.text);
          actions[speech.text].Invoke();
           }

    private void HelpUser()
    {
        Debug.Log("Ok. I'll help you!");

        respawnEffect.Play();
        respawnEffectCircle.Play();

        transform.position =
        lastVisitedCheckpoint.transform.position;


    public IEnumerator RespawnPosition ()
    {
        yield return new WaitForSeconds(1f);
        if (playerPosition.transform.position !=
        lastVisitedCheckpoint.transform.position)
        playerPosition.transform.position =
        lastVisitedCheckpoint.transform.position;
    }

    private void Thanks()
    {
        Debug.Log("You're Welcome");
    }
```

An internal Windows library called *UnityEngine.Windows.Speech* was used to enable voice control.

Chapter 5

User Test

After having developed a first level of the prototype and defined paradigms that distinguish the interactions between Assistant-User, user tests were carried out to verify if the feedback regarding the virtual assistant was positive. The Survey, shown at the end of the thesis in appendix A and submitted to a sample of 13 people, including physiotherapists and non-physiotherapists, includes questions regarding personal data, the SUS questionnaire, and direct experience with the virtual assistant. The test is based on the completion of a path and through the feedback of the virtual assistant the latter must be able to complete it. For this test a path was calculated using the pathfinding algorithm developed by Daniele Bigagli, an image of the path is shown in Figure 5.1. The testers were asked to look at the image for 10 seconds to get an idea of the path, in order to try to emulate a patient suffering from Alzheimer's disease. A Desktop version was used for the test, which can be navigated with the aid of a mouse and keyboard.

5.1 Questions asked

In this paragraph the various categories of questions that have been administered to the various testers will be analyzed in detail

5.1.1 Questions about the usability of the Virtual Assistant

The questions in this case are related to the usability of the developed assistant, some for this questionnaire will therefore be related to the user's workload to the complexity or not in the use of the various interfaces and user interaction. This questionnaire therefore has the task of understanding whether the developed prototype can integrate well into the environment and whether the constructed paradigms are easy to interpret even for people with Alzheimer's.

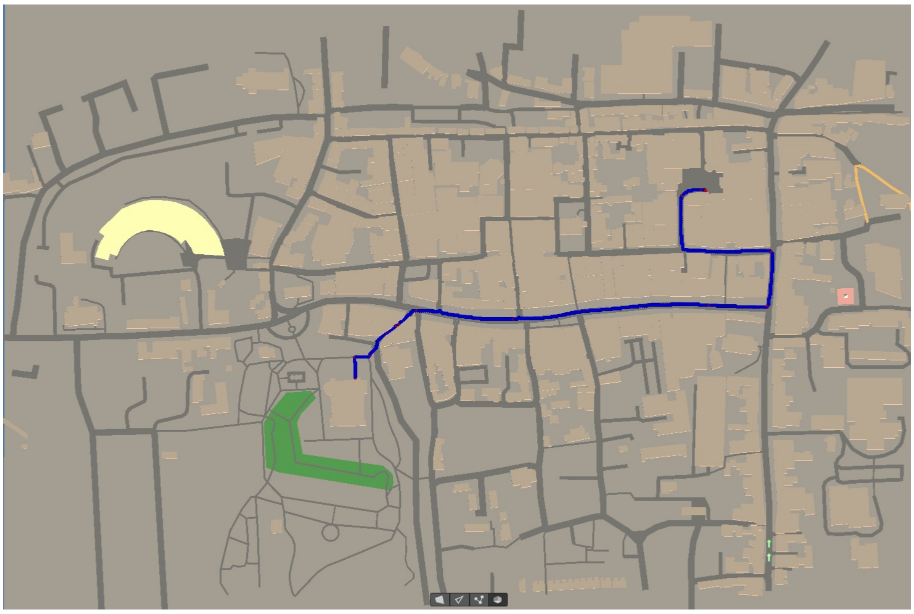


Figure 5.1: Path created by the pathfinig algorithm

5.1.2 Questions about interacting with the virtual assistant

This part of the questions is dedicated to the sensations experienced when interacting with the Virtual Assistant. We tried to understand if the aspect conveyed serenity and if the cognitive load of the interfaces and interactions were easy to use. If the auditory and visual feedback were easy to interpret. Finally, a section was dedicated to open questions to get feedback from the various testers regarding the virtual assistant.

5.2 Users sample

The sample of selected users is very generic, the age is between 18 and 35 years, passing from professionals in the sector such as physiotherapists to a more generic sample of people mostly graduates. More than 50% of users have a family member suffering from dementia, which confirms the data cited at the beginning of this thesis. Finally, more than 60 % of the sample of users knew what virtual rehabilitation was. The diagrams below show the results just mentioned.

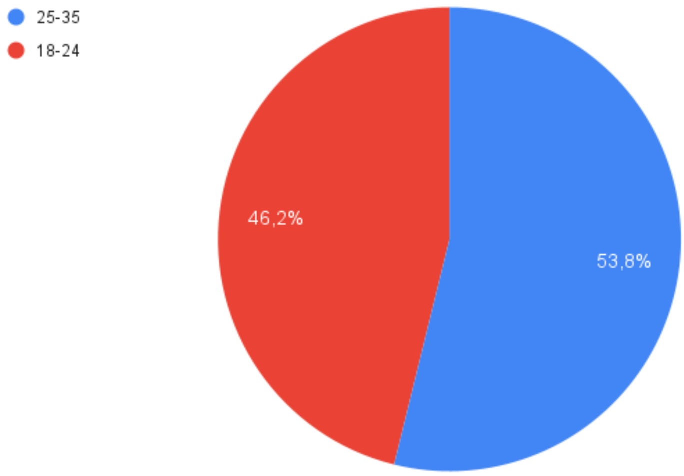


Figure 5.2: Age of the sample

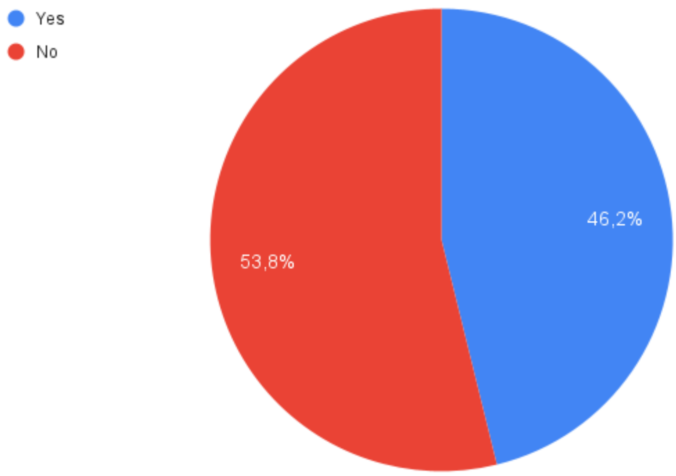


Figure 5.3: Relatives suffering from dementia

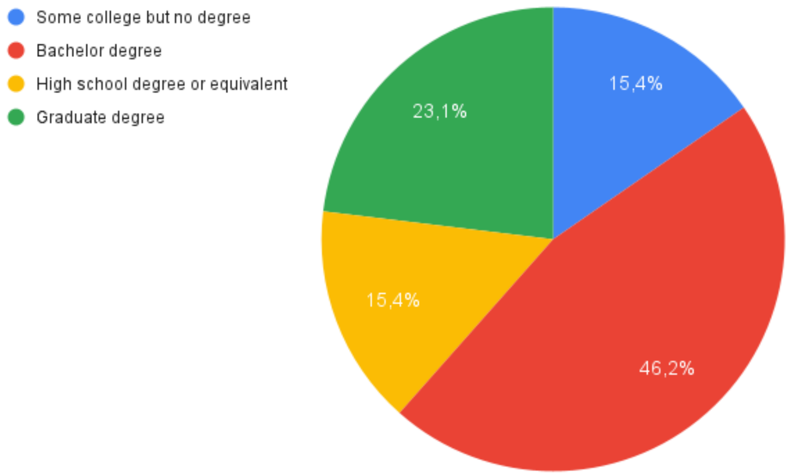


Figure 5.4: level of education of the sample

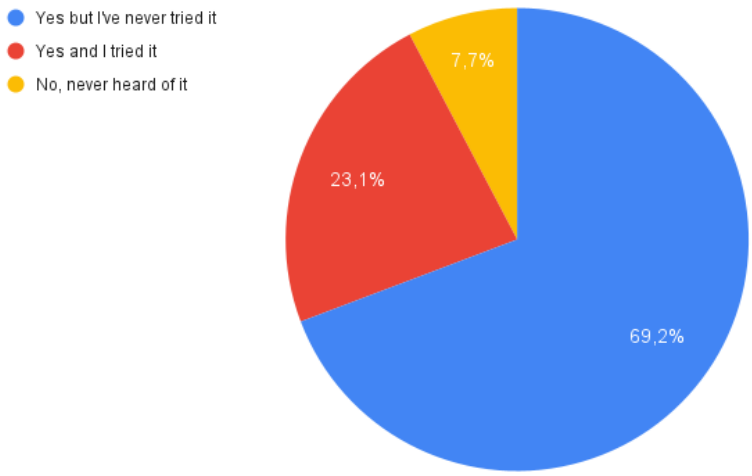


Figure 5.5: Familiar with virtual rehabilitation

5.3 Achieved results

The results of the test submitted after the experience are shown and stated in the following paragraphs.

5.3.1 Virtual Assistant Usability Feedback

The questionnaires submitted are based on questions which are intended to identify how much the user agrees or disagrees based on the sentence read. The values ranged from a scale from 1 (completely disagree) to 5 (completely agree) at the end of these questionnaires a *"SUS score"* was calculated by which the usability index of the virtual assistant was understood. The average gave the final result 77.5 and since the average for this type of questionnaire is around 68 [26], the score is above the latter.

As shown in the graph in Figure 5.6, the test results reported that the virtual assistant was easy to use during the experience with an average of 4.3 and a learning curve on using the very fast virtual assistant with an average of 4.46.

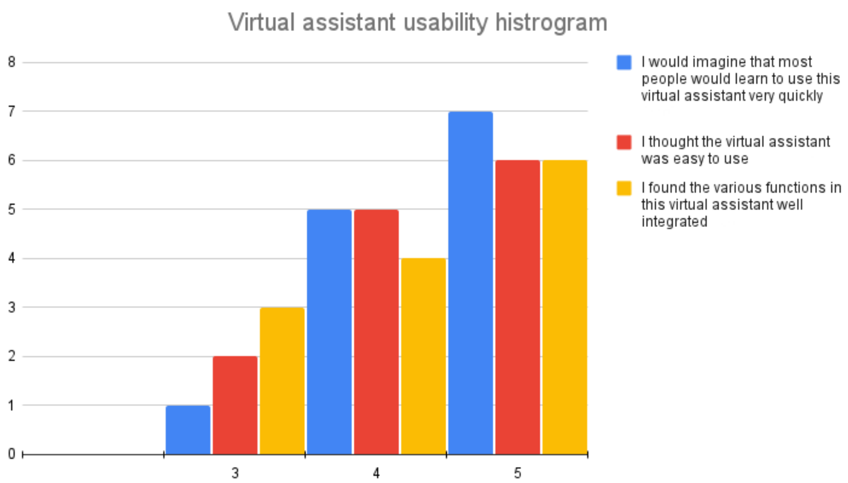


Figure 5.6: Usability feedback

The histogram in the Figure 5.7 also shows a positive trend here, attesting that it was not complex to interact with the virtual assistant and that it was well integrated into the virtual environment.

As can be seen in the Figure 5.8, the only inconsistency arose when it was asked whether to take advantage of the experience it was necessary to use technical support with an average value of 2.7.

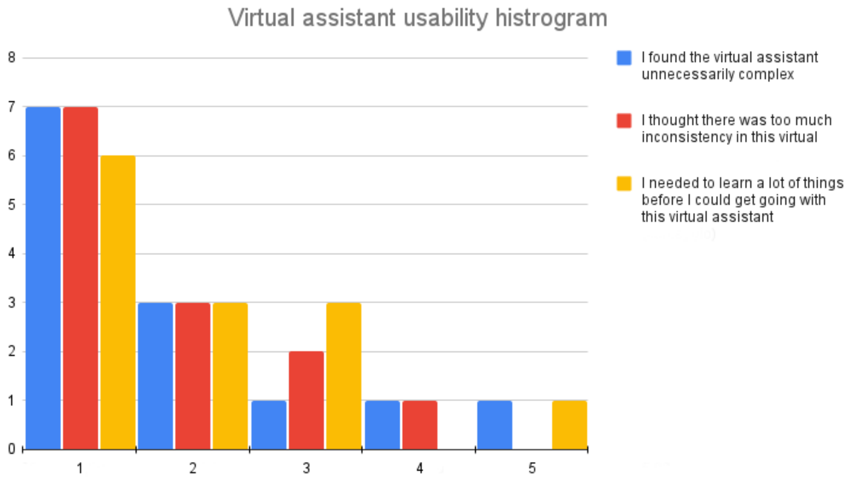


Figure 5.7: Usability feedback

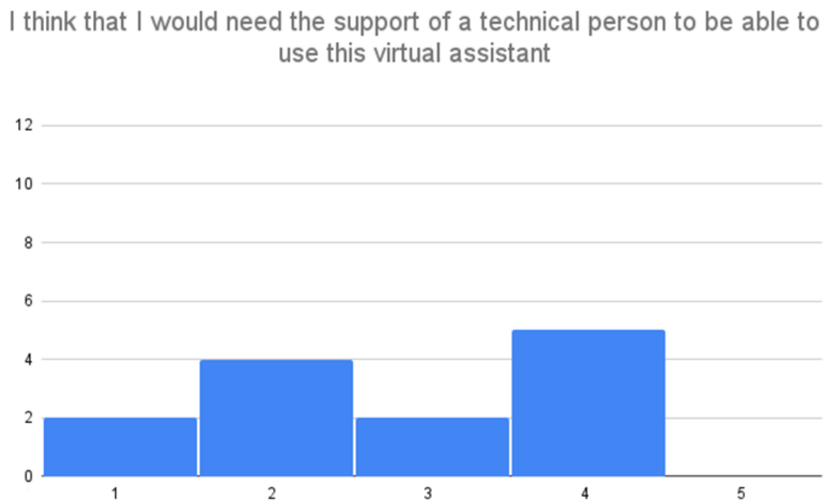


Figure 5.8: Question with conflicting opinions

5.3.2 Questions about Virtual Assistant interactions

The results of the following questionnaire were used to understand whether the virtual assistant's appearance conveyed serenity and whether the shapes and appearance of the latter caused an excessive cognitive load to the user or not. In the histogram in the Figure 5.9 you can see the responses of the users.

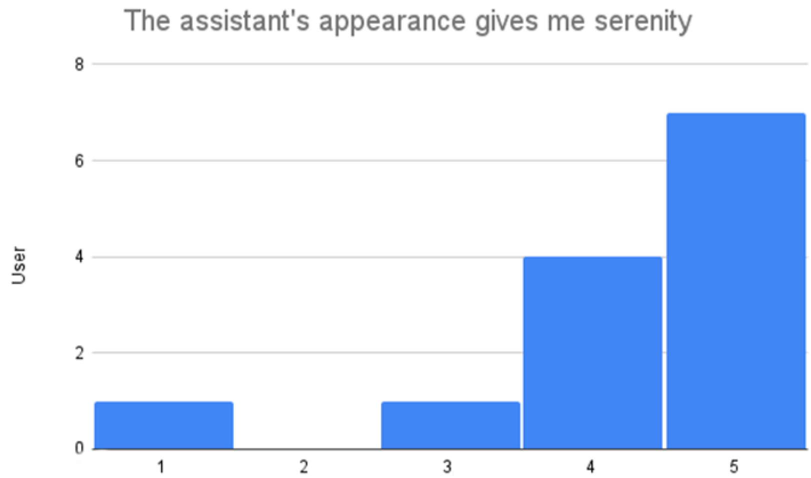


Figure 5.9: Familiar with virtual rehabilitation

In the histogram in the Figure 5.10, instead of you can see how the Assistant's feedback was useful for completing the path, all users in fact gave a score greater than or equal to three (on a scale from 1 to 5).

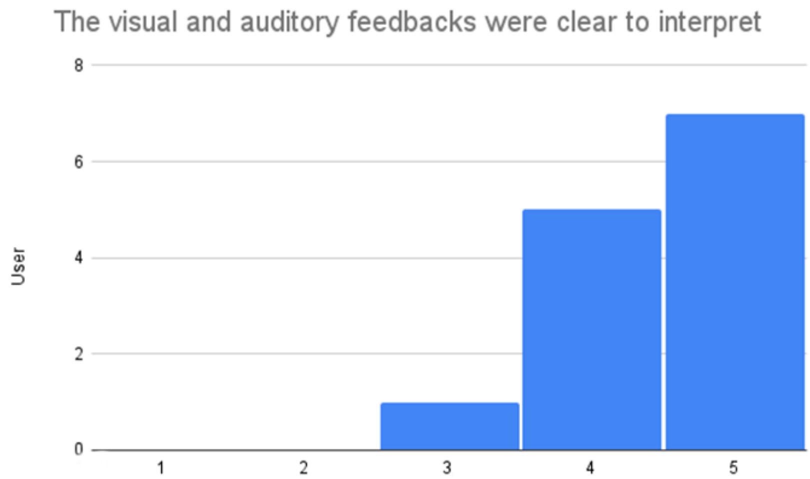


Figure 5.10: Familiar with virtual rehabilitation

A last part, on the other hand, was dedicated to improving the feeds of the graphical interfaces during moments of user disorientation and those when the user

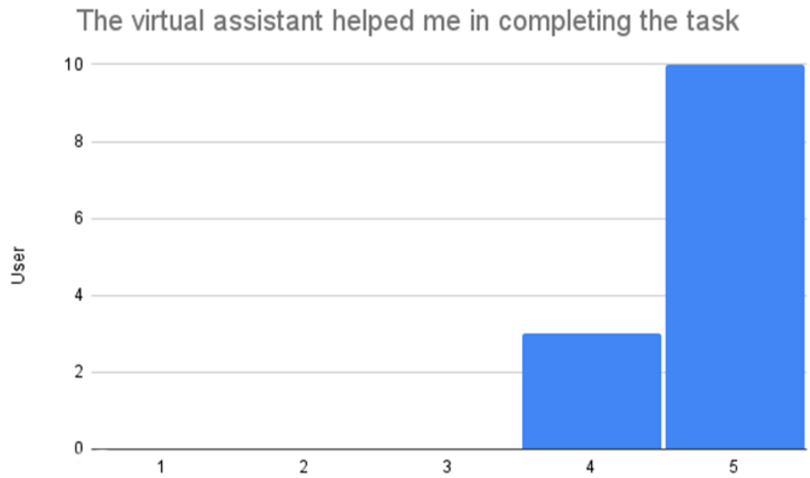


Figure 5.11: Familiar with virtual rehabilitation

was in the wrong direction. As can be seen in the Figure 5.12, most users found the UI and interactions easy to understand.

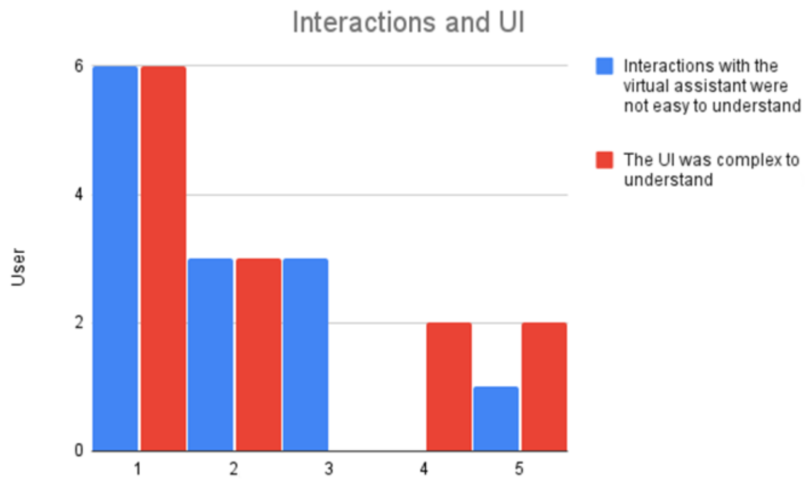


Figure 5.12: Familiar with virtual rehabilitation

Finally, a last section was dedicated to collecting user feedback through an open-ended question, the table 5.1,5.2 shows the responses of the latter.

Table 5.1: Answer to the question: *What would you change and / or add in the User-Assistant interaction?*

User	Answer
id01	-
id02	-
id03	I considered the sound emitted by the virtual assistant too loud (for example when the trajectory was wrong), even if on the one hand I think it is useful to warn the patient that he is heading in the wrong direction compared to that in which he should go, from on the other side I think it is too loud and noisy and would bring the Alzheimer's patient into a confusional state that would lead him to stop and not complete the entire process. In conclusion, I think that everything else is really helpful for the patient especially the interfaces that pop up when the patient is disoriented, I think this function is of fundamental importance and should not be underestimated, because a patient of this type can easily get disoriented and this function can only help calm him down and direct him in the right direction.
id04	I think that the indication of the direction (when i got it wrong) was unclear. I couldn't understand where to go unless i faced the correct direction. I noticed the assistant raised its arm in the correct direction, but it still was unclear. I guess a couple of arrows more would get the job done, though. Another thing that I noticed is that the time between me going wrong and the assistant noticing was very big. I had hard time understanding I was going wrong.
id05	Voice feedback when certain checkpoints are reached or in the event of an error
id06	-
id07	The audio should not be so impactful, if a patient goes wrong he should be notified with a gradual and not sudden "alarm". For the assistant concept, I would say that it is reassuring, pleasant to have next to you.
id08	i would like to change the sound of the warning because i think it makes a little bit of pressure, but its presence makes you feel relaxed and you are not afraid to be wrong the path because the assistance will help in many ways to find the right one.
id09	Very interesting project. To be evaluated with the viewer, but perhaps the indicator arrow could be positioned near the virtual assistant, in case of use with mouse and keyboard it is more complex to have a complete view between virtual assistant and indicator arrow.

Table 5.2: Answer to the question: *What would you change and / or add in the User-Assistant interaction?*

id10	When you are headed in the wrong direction it might be helpful to not only highlight the area (as it is already done) but also maybe show an arrow when you are facing the wrong direction when you are not seeing the highlighted area.
id11	-
id12	Nothing, I think it's easy to use.
id13	-

5.4 Conclusions

The tests carried out have highlighted a useful and reassuring Virtual Assistant. The usability of the latter appeared to be more than good, as well as the interactions and the various visual / auditory feedbacks. The prototype itself turned out to be interesting and helpful to the future patient even if the need for accompaniment of a professional figure emerged during the questionnaires.

In conclusion, the various comments at the end of the questionnaires highlighted the need for an audio correction through good sound design and subsequent user tests.

Chapter 6

Conclusions and final considerations

The data collected from the various tests and the technologies used to create the prototype produced a valid upgrade to the initial project, the virtual assistant proved to be of valid help to the user and never cumbersome or annoying at the latter. The production of this prototype required knowledge learned during the studies of Cinema and Media Engineering, more specifically modeling, animation and shading skills were required, for the creation of the 3D models imported into Unity, programming for the part concerning the Interaction Assistant-User and Assistant-Algorithm of pathfinding and video post-production for the UI. The criticisms collected during the tests led to interesting ideas for improvement, some already estimated, others emerged during the tests.

6.1 Defects of the prototype

The prototype used to carry out the tests revealed some defects, some of which were already mentioned in the previous chapter. A fairly obvious flaw is the sound feedback that the virtual assistant sends to the user when the latter moves away from the correct path. Most users said the sound was too loud or otherwise caused stressful moments the first few times it was heard. A first update regarding this feedback can be to use a sound that increases in intensity as it moves away from the predetermined path in order to prepare the user gradually, for this a graphic interface can be developed that says explicitly that you are in the wrong direction even before direct help from the assistant. Another problem that emerged during the tests was that of the arrow projected on the ground which, together with the assistant, brought him back to the correct path. The latter in most cases appeared behind the user in the event that the correct direction was behind him this led to an inconsistency in the system which in some cases was resolved through the indications of the virtual assistant. A possible solution would be to always block the arrow in front of the user and rotate it 180 ° when the correct position is behind the user. Another possible modification could be to integrate auditory feedback from the assistant that makes the user understand the correct position of the arrow.

6.2 Future developments

As for future developments, there are various updates already planned during the development of the first version of the prototype and the possible updates that emerged after user tests. Starting from the first point, if the project were to continue in this direction it would branch into various levels, as shown in Figure 6.1. The first would be a level of training where the user becomes familiar with

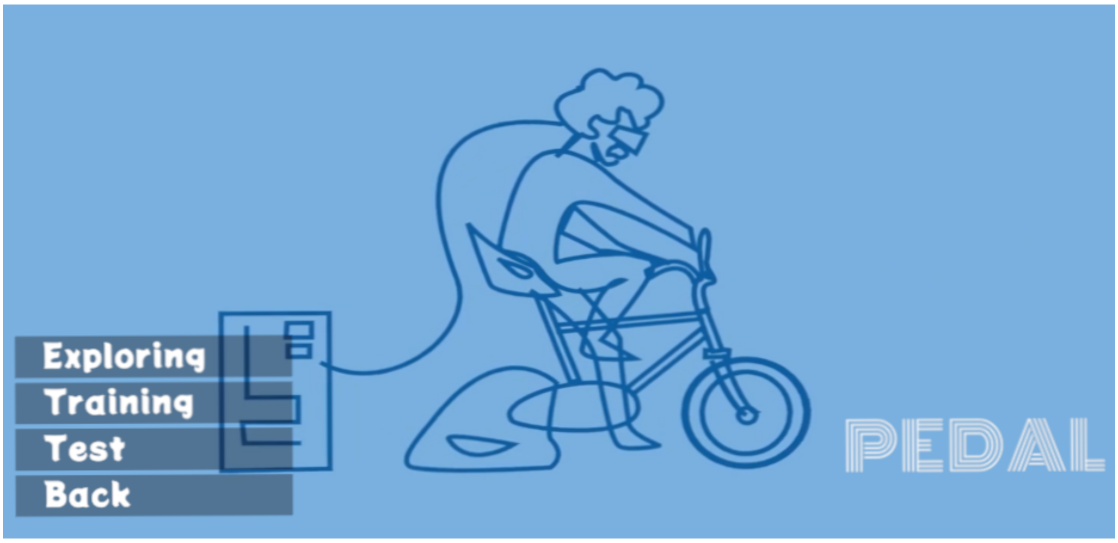


Figure 6.1: Menu prototype

the commands, the virtual environment and the various interfaces. In this training phase, the user visits the most important places in the city in order to memorize the routes. A further level is that of the memory journey, of which you can see an alpha[1] version in the Figure 6.2, that is a level in which in addition to the path tested by users with the latest version of the prototype, objects are also added along the way. The task of the user, or patient in this case, is to remember not

[1]An Alpha version of a video game means a first version that is functional, but not sufficiently tested.

Figure 6.2: Memory Journey prototype

only the road but also the objects. As you can well understand this would lead to a greater cognitive load of the user, but it is designed to be done gradually through the levels just mentioned. Another addition, is to add voice feedback from the assistant not when the path is wrong but also at the moment in which it passes the various checkpoints giving a sense of gratification to the user during the journey. To do this, since the project was developed in English, one would have to take people to record their voices and give them to the viral assistant. Finally, an implementation on the hardware side, with the help of a Kinect[2] it would be possible trak a person in a simpler way and directly insert more natural interfaces into the environment, thus bringing consequently a level of immersion greater than that which is perceived now.

[2]Microsoft's motion sensor for Xbox 360

Appendix A

Survey

This section is dedicated to showing the questionnaires filled in by users immediately after trying the application developed in this thesis.

Personal Data

*Campo obbligatorio

1. What is your gender? *

   Contrassegna solo un ovale.

   - Male
   - Female
   - Other

2. Which category below includes your ages? *

   Contrassegna solo un ovale.

   - 18-24
   - 25-35
   - 36-45
   - 46-60
   - 60 or older

3. What is the highest level of school you have completed or the highest degree you have received? *

   Contrassegna solo un ovale.

   - Less than high school degree
   - High school degree or equivalent
   - Some college but no degree
   - Bachelor degree
   - Graduate degree

4. Do you have relatives in your family who suffer from some kind of dementia? *

Contrassegna solo un ovale.

- Yes
- No

5. You know what virtual rehabilitation means? *

Contrassegna solo un ovale.

- Yes and I tried it
- Yes but I've never tried it
- No, never heard of it

SUS Test

*Campo obbligatorio

1. I think that I would like to use this virtual assistant frequently *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

2. I found the virtual assistant unnecessarily complex *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

3. I thought the virtual assistant was easy to use *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. I think that I would need the support of a technical person to be able to use this virtual assistant *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

5. I found the various functions in this virtual assistant well integrated *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

6. I thought there was too much inconsistency in this virtual assistant *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

7. I would imagine that most people would learn to use this virtual assistant very quickly *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

8. I found the virtual assistant very cumbersome to use *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	⬭	⬭	⬭	⬭	⬭	Strongly agree

9. I felt very confident using the virtual assistant easy to use *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. I needed to learn a lot of things before I could get going with this virtual assistant *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Virtual Assistant

*Campo obbligatorio

1. The virtual assistant helped me in completing the task *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

2. Interactions with the virtual assistant were not easy to understand *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

3. The assistant's appearance gives me serenity *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. The UI was complex to understand *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

5. The visual and auditory feedbacks were clear to interpret *

Contrassegna solo un ovale.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

6. What would you change and / or add in the User-Assistant interaction?

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