Universidad de Valladolid

Escuela Ingeniería Informática Valladolid UVa

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TRABAJO FIN DE GRADO

Grado en Ingeniería Informática
Mención en Computación

Design of a Virtual Museum using Unity and VR

Autor: Cintia Simone Sequeira

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Tutor: Valentín Cardeñoso Payo

Persistence and dedication transform dreams into achievements. Keep believing in your potential and never give up!

Acknowledgements

Firstly, I would like to thank Professor Valentín for guiding my work and for the patience throughout this period in which I was developing this project.

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Resumen

Para ofrecer una experiencia inmersiva e innovadora, destacando la fusión entre tecnología, arte y educación, “VirtuMuse” explora exposiciones futuristas, permitiendo a los visitantes viajar virtualmente en el tiempo y descubrir obras de arte en un entorno digital. Con énfasis en la interactividad, la educación y el arte, el museo ofrece un viaje educativo y muy atractivo, basado en conceptos de gestión de proyectos como mecánica, para que el jugador pueda aprender y practicar estos conceptos de forma lúdica.

Abstract

To offer an immersive and innovative experience, highlighting the fusion between technology, art and education, “VirtuMuse” explores futuristic exhibitions, allowing visitors to virtually travel through time and discover works of art in a digital environment. With an emphasis on interactivity, education and art, the museum provides an educational and very engaging journey, based on project management concepts as its mechanics, so that the player can learn and practice these concepts in a playful way.

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Capítulo 1

Introduction

In the contemporary digital epoch, the genesis and proliferation of virtual environments have burgeoned into an intricate symphony of avant-garde technologies and interdisciplinary paradigms. The development of these immersive realms, often lauded for their capacious potential to transcend the limitations of corporeal existence, encapsulates a confluence of computational prowess, artistic ingenuity, and user-centric design philosophies.

At the crux of this phenomenon lies a panoply of sophisticated tools and engines, each endowed with a unique assemblage of capabilities designed to foster the creation of hyper-realistic and interactive milieus. The imperative to craft environments that not only emulate reality but also augment it with surrealistic elements necessitates an erudite understanding of spatial dynamics, real-time rendering, and multi-sensory integration.

Virtual environments serve as the nexus where imagination converges with algorithmic precision, enabling developers to conjure worlds that are both fantastical and functional. The acumen required to navigate the labyrinthine intricacies of these digital landscapes is not merely technical, it encompasses a holistic grasp of aesthetic principles, cognitive psychology, and immersive storytelling.

The sine qua non of virtual environment development today is the ability to engender experiences that resonate on an emotive level while maintaining a high degree of interactivity and engagement. This entails the meticulous orchestration of visual fidelity, auditory ambiance, and haptic feedback, thereby creating a seamless confluence of sensory stimuli that captivates the user's psyche.

In summation, the realm of virtual environment development stands as a testament to the inexorable march of technological advancement and creative exploration. It is an arena where the boundaries of possibility are continually being redefined, driven by an insatiable quest to merge the digital and physical domains into a cohesive, immersive continuum. As we delve deeper into this fascinating field, we uncover the latent potentialities that lie at the intersection of innovation and imagination, heralding a new era of experiential transcendence.

1.1 State of Art

The advancement of virtual reality (VR) technology has revolutionized several industries, including education and cultural preservation. Immersive virtual museums offer a new way to explore exhibitions and artistic collections, providing a unique and interactive experience. This state of the art examines key technologies, methodologies and trends in creating immersive virtual museums, highlighting the benefits and challenges involved. This technology has become popular in the last decade, thanks to an improvement in the tools that allow us to simulate these three-dimensional environments. There is currently a lot of content on video games suitable for these technologies. The creation of APIs such as openVR has also helped, that allow developers to integrate the functionality of their video games with the hardware of the virtual reality.

1.1.1 Virtual Reality Technologies

As VR allows the creation of simulated three-dimensional environments that users can explore and interact with using devices such as VR headsets (e.g. Oculus Rift, HTC Vive, PlayStation VR), the main technologies involved in developing immersive virtual museums include:

- VR Headsets: Devices that provide an immersive experience by allowing the viewing of 3D environments in 360 degrees.
- Motion Controllers: Tools that allow the user to interact with the virtual environment through gestures and natural movements.
- Game Engines: Software such as Unity and Unreal Engine are widely used to develop virtual environments due to their advanced graphic and physical rendering capabilities.
- Photogrammetry and 3D Modeling: Techniques used to create accurate digital replicas of artifacts and exhibits, allowing for a realistic representation within the virtual museum.

Examples of VR hardware product are Microsoft Hololens, Oculus Rift[47] shown in the *Figure* 1.1, HTC Vive, etc.

Figura 1.1: MetaQuest VR Headset

1.1.2 Benefits of Virtual Museums

Virtual museums offer several significant benefits, such as:

- **Accessibility**: Allows people from all over the world to access exhibits that would otherwise be out of reach due to geographic or physical limitations.
- **Interactivity**: Provides an interactive experience where visitors can explore works of art and artifacts in detail, often with additional information available at the touch of a button.
- **Preservation**: Helps in the digital preservation of historical artifacts and works of art, protecting them from physical damage and degradation.
- **Education**: Serves as a powerful educational tool, offering didactic and interactive content that can enrich learning.

1.1.3 Examples and Case Studies

Several museums around the world have already successfully implemented VR solutions:

- The British Museum: Offers virtual tours that allow visitors to explore exhibitions through a VR interface, providing an educational and immersive experience.
- The Louvre: Created a VR experience for the Mona Lisa, allowing visitors a detailed and interactive view of the famous painting.
- The Virtual Museum of Canada: A project that presents exhibitions from several Canadian museums, providing educational and interactive content through an online platform.

Below is a comparative table of some museums and companies that are implementing virtual museums with VR technologies, highlighting their characteristics and technologies used:

Museum/Company	Virtual Platform	Technologies Used	Sales/Revenue Model	Platform	Year Launched
Louvre Museum	Louvre Online Tours	360° Virtual Tours	Free Access	Website	2016
Prado Museum	Prado Online	High-resolution images	Free Access	Website	2009
British Museum	Museum of the World	VR, 360° Virtual Tour	Free Access	Website	2015
Metropolitan Museum of Art (Met)	Met 360 Project	360° Virtual Tour, 360° Videos	Free Access	Website, YouTube	2016
Smithsonian Institution	Smithsonian Open Access	Digital Archives, Big Data	Free Access	Website	2020
Google Arts & Culture	Google Arts & Culture	VR, AR, 360° Virtual Tour, AI	Free Access	Website, Mobile App (iOS, Android)	2011
National Museum of Anthropology (Mexico)	MNA Virtual	360° Virtual Tour	Free Access	Website	2015
Van Gogh Museum	Van Gogh Museum Online	High-resolution images, 360° Virtual Tour	Free Access	Website	2016
Museum of Modern Art (MoMA)	MoMA Online	360° Videos, Digital Archives	Free Access, Membership fees	Website	2010
Rijksmuseum	Rijksmuseum Online	360° Virtual Tour, Digital Archives	Free Access	Website	2013

Cuadro 1.1: Museums and Companies that Implementing VR technologies

1.1.4 Challenges and Limitations

Despite the numerous advantages, the development of immersive virtual museums faces several challenges:

- Cost: Creating high-quality VR content can be expensive, requiring significant investments in hardware and software.
- Technological Accessibility: Not all users have access to the devices necessary for a complete VR experience.
- Technical Complexity: Developing VR environments requires advanced skills in programming and 3D design, as well as a deep understanding of the underlying technologies.

1.1.5 Future and Trends

The future of immersive virtual museums looks promising, with several emerging trends that promise to further transform the user experience:

- Integration with AR (Augmented Reality): The combination of VR and AR can offer even more interactive and informative experiences.
- AI and Personalization: The use of artificial intelligence to create personalized tours based on visitor preferences.
- Multiplayer and Social VR: Developments in social VR environments that allow group visits, facilitating social interactions within the virtual museum.

1.1.6 Final Considerations

Immersive virtual museums represent an exciting convergence between art, culture and technology. By utilizing VR, these museums not only increase the accessibility and interactivity of exhibits, but also digitally preserve important cultural artifacts. Although there are challenges to be overcome, current trends indicate a bright and innovative future for this field.

1.2 Motivation

On a journey through the transformative power of art and knowledge, nowadays it is sometimes difficult to visit renowned museums made up of great works of art, as these are spread around several cities around the world. Therefore, what is found in this virtual environment called ”VirtuMuse”, which emerges as a passionate vision, was inspired by the wise words of Hermann Hesse in his seminal work, ”The Game of Glass Beads”(Magister Ludi), published in 1943 In this literary epic, Hesse proclaims that .ªrt is the most sublime way of giving us new eyes to see the world.”Motivated by this deeply rooted philosophy, VirtuMuse aims to be more than a simple virtual museum, but rather a celebration of art as a catalyst for transformation.

In Hesse’s words, ”there is no reality except the reality we understand.Ïmagine an environment with a fusion of technology, art and education that aims to create a unique and personalized reality for each visitor, a space where art is not only admired, but becomes a mirror that reflects the richness of personal understanding. This intrinsically inspired project seeks to convey the fundamental truth that art is not a mere contemplation, but a means of recreating our own reality especially when its presentation is facilitated through the use of technology.

Thus, anchored in the timeless words of Hermann Hesse, VirtuMuse comes to life as a tribute to art's ability to provoke questions, awaken emotions and trigger an incessant search for knowledge. This journey is not just an exploration of futuristic exhibits, but an invitation to self-discovery through artistic masterpieces. Ultimately, VirtuMuse sets out to be more than a virtual museum, but rather a testament to the transformative power that art possesses and the vision it inspires, a vision that transcends time and echoes into eternity.

With a fervent desire to explore the frontiers of technology and offer a unique experience, VirtuMuse seeks to transcend the physical limitations of traditional museums. By integrating innovation, education and art, the project aims to provide an immersive journey, inviting visitors to immerse themselves in futuristic exhibitions and discover a new horizon of knowledge. This deep motivation drives VirtuMuse to create a dynamic virtual space where education and art intertwine in captivating and inspiring ways.

1.3 Problem

The "VirtuMuse"project is based on the need to overcome the physical and geographical limitations of traditional museums, as well as the search for new ways to engage and educate the public in relation to art and culture and knowledge. Some of the issues this project aims to address include:

1. **Global Accessibility**: Many people around the world do not have access to physical museums due to geographic, financial or mobility restrictions. VirtuMuse seeks to democratize access to art by offering a virtual experience that can be accessed by anyone with an internet connection.

2. **Space and Exhibition Limitations**: Physical museums often face space constraints, which limit the number of works of art that can be displayed at any given time. With VirtuMuse, there are no physical limitations, allowing you to display a wide range of artworks and themed exhibitions.

3. **Audience Engagement**: It is not always easy to engage the public in a meaningful way in physical museums, especially when dealing with younger audiences or people who have no prior experience in art. VirtuMuse seeks to provide an interactive and engaging experience that captivates and educates audiences of all ages and skill levels.

4. **Preservation of Cultural Heritage**: The preservation and protection of cultural heritage are important concerns for many museums. With VirtuMuse, you can create accurate and detailed digital copies of works of art and historical artifacts, contributing to the preservation of cultural heritage for future generations.

⇒Therefore, this project seeks to solve the problem of limited accessibility to physical museums by offering a virtual alternative that is inclusive, engaging and educational. In doing so, the project aims to democratize access to art and culture, promote public engagement and contribute to the preservation of global cultural heritage.

1.4 Goals

The main goal of the current project is to create an Interactive Virtual Museum that democratizes access to art and culture, offering an immersive, educational and inclusive experience for a global audience.

In order for the general objective of this work to be achieved, the following specific objectives are defined:

1. Develop an accessible virtual platform through which users can explore art and culture exhibitions interactively.
2. Offer an educational experience by providing detailed information about relevant works of art, artists and cultural movements.
3. Engage audiences of all ages and knowledge levels, encouraging active participation and autonomous discovery.
4. Preserve cultural heritage by creating accurate and detailed digital copies of works of art and historical artifacts.
5. Promote cultural diversity, highlighting works of art from different eras, styles and regions of the world.
6. Explore new forms of interaction and technology, incorporating elements of virtual reality, augmented reality and artificial intelligence.
7. Establish partnerships with cultural institutions, artists and experts to enrich content and ensure the accuracy and relevance of exhibitions.
8. Constantly evaluate the effectiveness and impact of the Virtual Museum by collecting public feedback and performing data analysis for continuous improvement.

1.5 Justify

Based on the concepts presented by Susana Smith Bautista in ”Museums in the Digital Age,”the ”VirtuMuse”project emerges as a response to the significant transformations that museums have experienced in the digital age. In his work, Bautista highlights the growing importance of accessibility and public engagement in redefining the role of museums in contemporary society.

”VirtuMuse.emerges as a necessary innovation to meet the demand for accessible and inclusive cultural experiences. Bautista argues that museums need to transcend their physical and geographic limitations by reaching a wider audience through digital platforms. VirtuMuse addresses this need by offering a virtual experience that can be accessed by anyone with an internet connection, regardless of their geographic location.

Furthermore, Bautista highlights the importance of public engagement in creating meaning around museum exhibits and artifacts. VirtuMuse incorporates interactive and multimedia elements to meaningfully engage visitors, providing an educational and immersive experience that goes beyond mere passive observation.

Finally, ”VirtuMuseçontributes to the preservation of cultural heritage, a central theme addressed by Bautista. By creating accurate and detailed digital copies of works of art and historical artifacts, VirtuMuse helps protect and conserve cultural heritage for future generations, ensuring that these precious works of art are appreciated and studied for years to come.

Thus, the ”VirtuMuse”project aligns with the ideas presented by Bautista, representing an innovative and relevant response to changes in the museum landscape in the digital era. By democratizing access to art, promoting public engagement and preserving cultural heritage, VirtuMuse positions itself as a significant contribution to the evolution of museums in the 21st century.

1.6 Dissertation Structure

The structure of the dissertation is organized in a detailed and meticulous way to cover all relevant aspects of virtual museums in virtual reality.
The first chapter, Ïntroduction”, establishes the context of the dissertation, explaining the relevance of virtual museums and virtual reality technology. This chapter includes subsections such as the State of the Art, which analyzes current technologies, the benefits of virtual museums, examples and case studies, challenges and limitations, future trends and final considerations. Furthermore, the motivation, problem, objectives, justification and structure of the dissertation are addressed, providing an overview of the following chapters.

In the second chapter, ”Theoretical Foundations”, the necessary foundations to understand the development of virtual museums are presented. The history of museums and their social function are explored, as well as the sociocultural influence of art and the construction and transmission of knowledge. Specific game design concepts applicable to virtual museums, such as game genres, narrative, story documentation, characters, cameras, controls, mechanics, settings, sounds, music, sound effects, user interface and testing, are also discussed. The design of virtual environments is covered with a focus on the Unity 3D game engine, including a detailed understanding of how it works. The chapter ends with a discussion of project management in the context of virtual museum development.

The third chapter, Related Works and Related Platforms”, compares existing works and platforms such as Google Arts & Culture, the Virtual Museum of Modern Art (Virtual MoMA), the Virtual Museum of Computing (VMoC), and the Transnational Network of Virtual Museums (V-MusT.net), concluding with final considerations about these initiatives.

In the fourth chapter, ”Development, Implementation and Final Design”, the process of development and implementation of the virtual museum is described. The process description includes conceptualization, development and implementation, with a detailed analysis of the software tools used, such as Unity Tools and Packages, Cinemachine and Blender. The Firebase implementation is discussed, detailing the components used and the steps to configure authentication. Other essential tools are mentioned, as well as system definition and system modeling, including prototyping. Description of scenes and structure covers layout, login scenes, menu, entrance, sculpture, African arts, painting, and ancient technology. Hardware tools such as desktops, screens, and headsets are described, and a cost estimate, including development team member salaries and estimated total costs, is provided.

In the fifth chapter, ”Tests and Validations”, the tests carried out in the virtual museum and the validation of its functionalities are discussed. Alpha tests on specific features and the overall system are described, along with the different system versions and functional modules that make up the product backlog. An implementation plan with sprints is presented, followed by beta testing, including interpretation and conclusion of results.

The sixth and final chapter, Conclusions”, concludes the dissertation with a discussion of the results achieved, the contributions of the study and suggestions for future work. Future directions of work are divided into two phases: initial improvement and expansion, and technology innovation and integration. This detailed framework ensures comprehensive coverage of all aspects of the development and implementation of a virtual reality museum, providing a complete and systematic overview of the project.

Capítulo 2

Theoretical Foundations

2.1 Introduction

This chapter presents some concepts behind this project, with the aim of better illustrating the choices made and providing a better understanding of the topics covered. In this way, concepts such as museums, art, project management, knowledge and design of virtual environments are presented, also topics as game development, and platform of game engine.

2.2 Museums: History and Social Function

As the objective of this work is to build a virtual museum based on historical knowledge, it is important to understand its structures and functioning. Museums serve as important reservoirs of knowledge, culture and history., so according to Museums in a Troubled World (2009) by Robert R. Janes, museums not only preserve historical and cultural artifacts, but also play a crucial role in education and social responsibility. They are spaces where collective memory is stored and where the public can engage with the past in meaningful ways.

To understand the structures and functioning of virtual museums, it is essential to recognize the importance of adapting the traditional museum concept to the digital environment. This transition involves not only the digitization of collections, but also the creation of immersive experiences that take advantage of information and communication technologies. Virtual museums, therefore, are digital spaces where it is possible to access collections and exhibitions via the internet, allowing users to interact with the content in an innovative and educational way.

2.2.1 Art and its Sociocultural Influence

Art not only reflects the sociocultural conditions of its time, but also shapes and is shaped by those conditions. It acts as a powerful means of expression and criticism, capable of questioning norms, provoking reflection and instigating social change. As John Berger argues in Ways of Seeing (1972), the way we view art is deeply influenced by our own cultural and historical biases, which alters our interpretation of works. Berger highlights that art does not exist in a vacuum, it is always seen through a filter of visual and social conventions that determine what is seen and what is ignored. This process is crucial to understanding how art influences and is influenced by social and historical context. For example, the representation of women in Western art has often been mediated by a male perspective, something Berger discusses extensively, illustrating how social conventions can distort representation and perception.

Furthermore, art has the ability to transcend linguistic and cultural barriers, offering a universal platform for intercultural dialogue and understanding. In contemporary contexts, we see how artistic movements, such as street art, use public space to comment on social and political issues, reaching an audience that goes beyond traditional museum and gallery goers.

The influence of art on society can also be seen in the way it is used to reinforce or challenge the status quo. During periods of social or political unrest, art often emerges as a form of resistance or as a means of promoting solidarity. For example, during the civil rights movement in the United States, artists like Jacob Lawrence used their art to tell stories of struggle and resistance, helping to shape public consciousness and promote change.

In short, understanding art as a reflection and influencer of sociocultural conditions allows for a deeper analysis of its role as an agent of social change. By examining how art is perceived and interpreted, we can begin to better understand its ability to influence and be influenced by the social and historical context in which it is created and received.

2.2.2 Knowledge: Construction and Transmission

The process of building and transmitting knowledge is fundamental in any educational field, including museum environments. In The Social Life of Information (2000), John Seely Brown and Paul Duguid discuss how knowledge is constructed through social and technological interactions, reinforcing the idea that learning is a deeply social and contextualized activity. Digital games can represent a method of aiding learning in an interactive environment. In digital game-based learning, players learn to perform tasks, such as flying planes, driving fast cars, being theme park operators or war fighters. (SILVA ET AL. 2008.).

2.3 Game Elements and Specific Concepts in Game Design

The game design process can be one of the most rewarding experiences within Computer Science. It is a field in which creativity and technical experience merge, and this would not be indifferent when it comes to the development of platforms and visiting environments such as a virtual museum. To this end, it is essential to establish the main elements that make up these environments. In the game design process there are fundamentals on which most games are based.

2.3.1 Game Genre

The genre classification agrees with the main objective of the game to be created. Even though over the years, games have fragmented into many and varied genres and subgenres. (ROGERS, S., 2012).

Action games often coordinate hands and eyes. And these, in turn, are divided into several subgenres, such as Platform, like the famous game series Super Mario Bros or Grand Theft Auto[11], whose cover is seen in *Figure* 2.1. Or, action games can be adventure games, like Tomb Raider, or involve fighting, like Mortal Kombat[1], whose cover is shown in *Figure* 2.2, or Fortnite.

Figura 2.1: Grand Theft Auto

Figura 2.2: Mortal Combat

If the objective of the game is to shoot enemies, it is classified as a shooter. Shooters can be either first-person, known as First Person Shooters, or simply FPS, like Valorant, shown in *Figure* 2.3[14], or third-person, like games from The Resident Evil and Tomb Raider series, shown in *Figure* 2.4[5] .

Figura 2.3: Valorant

Figura 2.4: Tomb Raider

The adventure genre is generally focused on problem solving, collecting items and managing inventory. This genre includes two of the most loved subgenres by the public, Role-playing Game, better known as RPG, and survival games.

RPG is a style of game based on role-playing. The player chooses a character with specific skills, which are improved throughout the game. An example of a game in this style are the famous game series Diablo, shown in *Figure* 2.5 [2], and Final Fantasy. Nintendo, creator of the Mario Bros franchise, launched the game Super Mario RPG in 1996, which also falls into this subgenre. *Figure* 2.6 [17], shows a scene from this game with last update on 2023.

Figura 2.5: Diablo Scene

Figura 2.6: Mario Bros RPG

There are several other classifying genres for games, such as Simulations, which can be: to keep or loose Life in the game such as *The Sims*; Sports, which include titles such as *FIFA* and *Pro Evolution Soccer* ; Racing, such as *Gran Turismo* and *Forza*.
Strategy games can also be mentioned, with emphasis on the Real Time Strategy subgenre, known in Portuguese as Ëstratégia em Tempo Real", which encompasses famous titles such as Age Of Empires and Settlers.

The same game can fall into different genres and subgenres. For example, the Grand Theft Auto series, shown previously in *Figure* 2.1, popularly known as GTA, combines action, adventure, third-person shooter, driving and life simulation. This type of game also belongs to the genre of Sandbox games, or Open World, where the player has ample freedom to carry out actions without being tied to just a script or premeditated movements. (ROGERS, S., 2012).

2.3.2 Game Story or Storytelling

There is a constant battle between game designers who think graphics are more important, and those who think that without a story the player won't be captivated by the game. But in game producer Scott Rogers' view, both are right. There are games in which the story is the central element and involves the player, such as the mysteries of the Silent Hill franchise, or the surprising ending of Fatal Frame II – Crinsom Butterfly, depicted in *Figure* 2.7 [3].

Figura 2.7: Fatal Frame II

Equally famous games, such as the old Pac Man, depicted in *Figure* 2.8 [43], or the more recent Candy Crush which has become even more popular with its updates in 2024, or fighting games such as the Mortal Kombat and Street Fighter series, are capable of captivating the player without containing a plot of events.

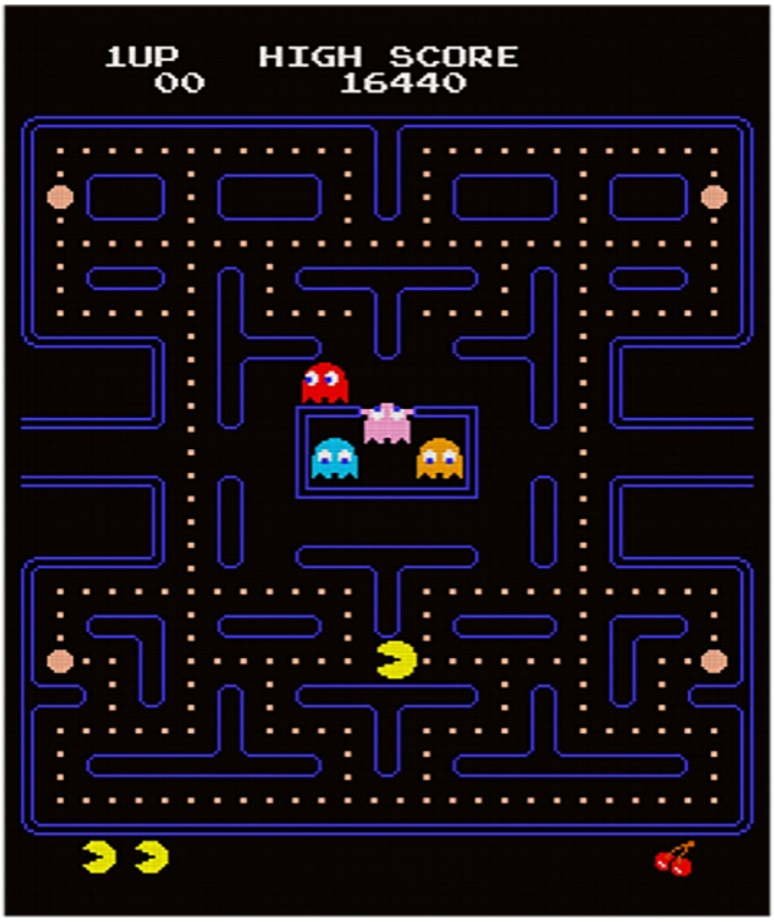

Figura 2.8: Pacman

Within a game there is not necessarily a story, even if the story is there. Games like Tetris don't need a story to engage the player. However, they have a narrative. In other words, even if a game does not have a defined story, it follows a logical, and almost always chronological, order of events. (ROGERS, S., 2012)

There is a natural fit between games and history. The main difference is that the story is told, and in a game it is something we do. But the fit is natural, and both have been intertwined for many years. For example, the game Monopoly is a story about going from modern resources to wealth, or poverty. (SCHUYTEMA, P., 2008)

When you decide to compose a story for a game you need to define what the objectives are. If the game follows a plot it is necessary to write a script to guide the construction of the game. Similarly, it's like a movie script, but instead of containing instructions for the cameraman, it contains a general list of actions. (ROGERS,S., 2012)

2.3.3 Story Documentation and its Elements

To determine all the requirements present in the game, the responsible team for production must compose a document, often called a Design Bible. The planning of this document must unite producers, programmers and designers, and there must be regular meetings to monitor the document throughout the project.

Producers must be present to determine requirements. Programmers to determine the technical requirements and any possible limitations on the design. And artists to suggest creative ideas and determine visual limitations.

This is a crucial point in the game planning process. The idea is to guide both programmers and artists. This document must contain any and all details of the game in writing, which may include:

- The genre or subgenre;
- The plot of the story;
- A list of environments and a detailed list of what they want to convey;
- Sketches or maps;
- The distribution of characters with their respective role, as well as physical and behavioral aspects;
- Storyboards for animations and their sequences;
- Technical aspects such as formulas, action outlines, etc.

Once this process is completed, the result will be a clear and concise document, where all parts can be used as reference. It also provides a checklist for developers to consult.

2.3.4 Characters, Cameras and Controls

For good ethics when creating games, there are three important elements that are always interconnected. The 3 C‘s are important for creating a game: Characters, Cameras and Control, or, in Portuguese, characters, cameras and controls. (ROGERS, S., 2012). If the designer decides to change one of these elements, it could cause problems with the other two.

1. **Characters**: Characters are the central elements of the narrative and the player’s interaction with the game world. They not only drive the story, but also represent the player’s identification and empathy with the game’s universe. It is important that characters are well developed and represented ethically, avoiding harmful stereotypes or representations that could promote discrimination.

2. **Cameras**: The camera is the lens through which the player views the game world. A good camera setup is essential to provide an immersive and intuitive experience. However, it is important to ensure that the camera does not compromise players’ privacy, avoiding invasive angles or angles that may cause discomfort.

3. **Controls**: Controls are the bridge between the player and the game, determining how the player’s actions are translated within the virtual world. The usability and accessibility of controls are key to ensuring that all players, regardless of their skill or physical ability, can enjoy the game. Furthermore, controls must be designed ethically, avoiding mechanics that could induce harmful or addictive behaviors.

2.3.5 Characters

All elements, controllable or not, with which the player interacts and which play a role in the game are classified as characters. The protagonist and his companions, the enemies, bosses, they are all characters. Each character plays a role within the context of the game, and must have characteristics capable of generating emotions. The player may feel captivated by characters such as the friendly and courageous plumber Mario Bros, portrayed in *Figure* 2.9 [8] . Or even the player may feel threatened when you make it to the last fighting tournament in Street Fighter II, and come across the villain M. Bison, depicted in *Figure* 2.10 [12] . In third-person games, the player feels like a character in the game.

Figura 2.9: Mario the Plumber

Figura 2.10: The Vilain M. Bison

The game's characters can be playable, called Player Characters, such as a hero character, controllable secondary characters, or even a vehicle in the case of racing games; or non-playable characters, called Non-Player Characters, which are enemies, level bosses, or characters that appear to assist the protagonist.

To illustrate, in the classic Super Mario World, Mario is the main character, Luigi, the secondary character and Yoshi, the faithful companion. All controllable in some way during the game. Among the non-controllable characters we have Princess Peach, who must be saved, and Toad, who occasionally appears to give some advice. Among the villains, we have the big villain, Bowser, his children, who are the bosses of each level, and the army of enemies, made up of turtles or ghosts.

2.3.6 Cameras

Choosing the most suitable camera for a game is important to define how the camera will be programmed, and mainly to determine how it will impact the game design and control mapping. There are several styles of cameras that you can work with in a game development project. The first style used was the static camera, that is, a camera fixed in one position. This camera style was very common in early video games. Firstly because it was the only one existing at the time, but it also allowed the player to stay focused on various elements, as well as allowing the designers to maximize the game's art. (ROGERS, S., 2012)
In the early 1980s, rolling cameras appeared. In parallax scrolling, when the camera moves, the world moves with it, so one way to utilize parallax scrolling is to make the camera controlled by the player's movement. Games like *Super Mario World* and the old and popular game *Donkey Kong Country* get used to have acoplate this type of camera. As for forced scrolling, the player is forced to stay in the camera.

Later, games like *Mario Kart*, illustrated in *Figure* 2.11 [21], used a more innovative style of forced scrolling called *Mode 7*. In this style, a screen background was created and the camera scrolled towards it, creating the illusion of three-way space dimensions. (ROGERS, S., 2012)

Figura 2.11: Mario Kart

In the first half of the 1990s, the first-person camera gained ground in the market. Mainly in shooting games, such as the game *Doom*, illustrated in *Figure* 2.12 [42] , released in 1993. This camera style has advantages such as the ease of creating atmospheric situations, such as horror and suspense.

Figura 2.12: Doom

However, among the disadvantages of this type of camera, there is the difficulty in estimating distances and seeing collectable objects, which need to be on a larger scale to be visible. Another problem with working with the first-person camera is the Doom-Induced Motion Sickness effect, known by the acronym *DIMS*.

This feeling of nausea occurs due to the fact that, sometimes, the eyes register a movement, but the inner ear does not, causing the player to feel sick. However, this effect can be minimized in a simple way, such as keeping the camera at an appropriate speed, and adding large stationary objects so that the player has something to focus on. The third-person camera manages to minimize the DIMS effect, as the player can at least see the character's head. (ROGERS, S., 2012).

2.3.7 Controls

Controls are essential for user interaction with the virtual museum environment. It is crucial that they are carefully designed to ensure a smooth and seamless experience during your visit. This aspect is also supported by ergonomics, which studies how to properly adapt the equipment to the user (Schuytema, 2008).

Furthermore, it is important to respect the conventions established by users. For example, if the up arrow moves the character forward in a hallway, it is recommended to maintain that same direction when he enters a room, only changing the camera plane, instead of changing the control pattern.

Another crucial aspect in programming controls is to avoid making key combinations overly complex for basic navigation actions. More elaborate combinations should be reserved for special actions, such as special moves like in fighting games.

In addition to the importance of respecting control conventions established by users and ensuring that basic interactions are intuitive, it is essential to consider the diversity of users when designing controls in a gaming or virtual tour environment such as a virtual museum. This includes thinking about accessibility for people with different abilities and needs.

Example, when designing controls, you need to consider usability for users with motor, visual, or cognitive disabilities. This may involve implementing alternative control options such as voice commands, gesture control, or simplified controls to facilitate interaction for those with motor difficulties.

Additionally, it is important to conduct usability testing with a variety of users to ensure that controls are understandable and comfortable for all target audiences. These tests can reveal usability issues that may not be obvious during the development process, allowing for tweaks and improvements before final release.

The ultimate goal when designing controls in these environments is to provide an intuitive, engaging, and accessible visiting experience for all users, regardless of their skills or familiarity with technology.

2.3.8 Mechanics

According to (ROGERS,S., 2012) there are four types of mechanics with which it is possible to work: mechanics, dangers, puzzles and support. Mechanics, in video games, are objects that create gameplay when the player interacts with them. (ROGERS, S., 2012). Some of the most common types of mechanics are opening and closing doors, slippery floors, manipulating items and moving platforms. Dangers are mechanics programmed to create problems during gameplay. The most common types are lava, fire, holes where the player must not fall or floors with spikes.

Another interesting game mechanic is the time puzzle, which are mechanics that move within a timed space. Normally they are also used as a form of danger, such as rotating blades or crushing blocks, present in almost all castles in Super Mario World. Support are mechanics that don't move, and are usually there to block the player's path. They can be present in the game in the form of buildings, posts, steps or trees, and need to be bypassed or jumped over, so that the player's journey can continue.

2.3.9 Scenarios

Virtual game development scenarios play a crucial role in creating an immersive and engaging experience for players. They constitute the environments where the game's action takes place, from natural landscapes to futuristic urban environments. Creating these scenarios involves a combination of art, design and technology to convey atmosphere, context and challenge to players.

One of the fundamental aspects in creating scenarios is attention to detail and cohesion. Developers need to ensure that setting elements such as terrain, architecture, vegetation, lighting, and visual effects work together to create a cohesive and convincing world. Furthermore, performance optimization is also important, especially in games that require complex graphics and large-scale environments. (ROGERS, S., 2014).

2.3.10 Sounds, Music and Sound effects

Sounds, as well as visual effects, are important factors in interaction with the player. They reinforce the main content and encourage exploration of the game. Music makes the human mind tend to assimilate the context and determine how to feel. The human mind is prepared to react to rhythm and tone and, therefore, music is a powerful vehicle for generating emotional reactions. (SCHUYTEMA, P., 2008).

The combination between visuals and sound could be good enough to make the game a classic. Great games like Super Mario Bros and Top Gear are easily remembered for their soundtracks. Background music in a game performs the same engaging role and is as important as the soundtrack in a film. (ROGERS,S.,2012)

Sound effects can be defined as the result of some event that occurred in the game, such as the firing of a weapon being responsible for reproducing its characteristic sound, for example (ROGERS,S.,2012). In addition to maintaining the appropriate realistic atmosphere during the game, they can help along the way, indicating progress or damage suffered by the character. Furthermore, sound effects function as feedback for the player, indicating that their actions generated the correct effects and even help the player to locate themselves in the scenario, in the case of spatial sound effects, such as sounds of water flow, machinery in operation and vehicles. (SCHUYTEMA, P., 2008).

2.3.11 User interface

User interface is one of the final elements in game creation. Usually, at the beginning of the project, programmers create a rudimentary interface to facilitate testing and development of the game. In the end, however, the artists make this interface really interesting for the user. The interface is the first thing the user will see, so it is important to make a good impression from the first contact. (SCHUYTEMA, P., 2008)

A poorly designed interface can be a destructive factor for the game. The user interface is the vehicle through which player and game communicate. This relationship needs to be preserved, and some care is necessary. (ROGERS, S., 2012)

In his book, (SCHUYTEMA, P., 2008) cites some principles to be respected when designing the game interface. Among them, it stands out that the interface must act in accordance with the user's expectations, with the elements working in an obvious way for the player. It is also important that the interface remains coherent, and that button patterns are maintained throughout the game.

The interface must provide information about the game situation, through health bars, for example, which decrease with each damage suffered to the character. Additionally, the player must be alerted to vital changes. This alert can be either a decrease in health or an auditory suggestion, through sound effects that indicate that the character has suffered a blow.

It is also important that the interface prevents the occurrence of errors. Buttons with no functionality must be disabled, and an alert must be transmitted, either auditorily or visually, each time the player tries to access an unavailable or non-existent resource. It is important to mention that the interface must provide feedback to the player when they are activated, so that the player realizes that their action reflected a reaction in the game environment. (SCHUYTEMA, P., 2008).

Finally, the interface design should reflect the tone and universe of the game. If the game world takes place in a dark and gloomy environment, the interface should match it, and not be colorful and cheerful. A game that takes place in a Wild West universe should not have an interface that suggests an industrial environment. (ROGERS, S., 2012)

2.3.12 Tests

In the testing phase, the game is almost finished and it is during this phase that problems that went unnoticed will appear. People who test usually find many small defects or things not yet discovered.

The purpose of testing is to ensure that the gaming experience is error-free. Additionally, testing will ensure that the difficulty is appropriate for the intended target audience. (SCHUYTEMA, P., 2008). Feedback is also important to know the expectations of end users and evaluate how it can be modified to make it better.

Importance of the Testing Phase:

1. Problem Identification: Even with careful planning and development, it is common for errors and problems to go unnoticed until subjected to rigorous testing. Systematic testing helps identify bugs and flaws that were not detected during development.

2. Functionality Validation: Testing ensures that all planned functionalities of the virtual museum are operating as expected. This includes everything from basic navigation and content viewing to advanced functionality such as 3D interactions and integration with external systems.

3. Quality Improvement: Thorough testing contributes to the overall quality of the product, ensuring it is robust, safe and reliable. This is crucial to maintaining user satisfaction and the platform's reputation.

4. User Experience: Usability testing is essential to ensure that the user interface is intuitive and pleasant. This involves evaluating the ease of navigation, clarity of information and the efficiency of user interactions with the system.

Activities Involved in the Testing Phase:

Functional Tests: Verify that all functionalities of the virtual museum are operating as planned. This includes navigation tests, viewing exhibitions, interactions with multimedia content, among others.

Usability Tests: Evaluate the user experience when interacting with the virtual museum. These tests may involve observing real users navigate the platform and providing feedback on their experience.

Performance Tests: Measure the efficiency of the virtual museum in terms of loading speed, responsiveness and ability to handle multiple users simultaneously. This is crucial to ensure a smooth experience, especially during traffic spikes.

Security Tests: Ensure that the virtual museum is protected against cyber threats. This includes scanning for vulnerabilities, protecting user data, and implementing robust security protocols.

Compatibility Tests: Check whether the virtual museum works correctly on different devices (computers, tablets, smartphones) and browsers (Chrome, Firefox, Safari, etc.). This is essential to ensure accessibility for all users, regardless of their preferred platform.

Accessibility Tests: Evaluate whether the virtual museum is accessible to users with disabilities, ensuring compliance with accessibility standards and guidelines, such as the WCAG guidelines (Web Content Accessibility Guidelines).

Integration Tests: Verify that all external components and systems integrated into the virtual museum work correctly together. This may include integration with content management systems, third-party APIs, and payment systems.

2.4 Virtual Environment Design

User-Centered Design

When developing virtual environments, adopting a user-centered approach is fundamental. This means understanding users needs, preferences and behaviors to create digital experiences that are intuitive and engaging. As mentioned by Jesse Schell, author of "The Art of Game Design: A Book of Lenses"(2008), user experience is essential to designing games and virtual environments effectively. This same philosophy applies directly to the design of virtual museums and online exhibitions.

By considering the user's perspective from the earliest stages of design, developers can create virtual spaces that captivate and inspire visitors. One of the ways to think about game design is through the Elementary Tetrad (*Figure* 2.13 [23]) proposed by Schell (2008), whose objective is to group and categorize the various elements that can make up a game, so this concept would also not be indifferent to the construction of a museum.

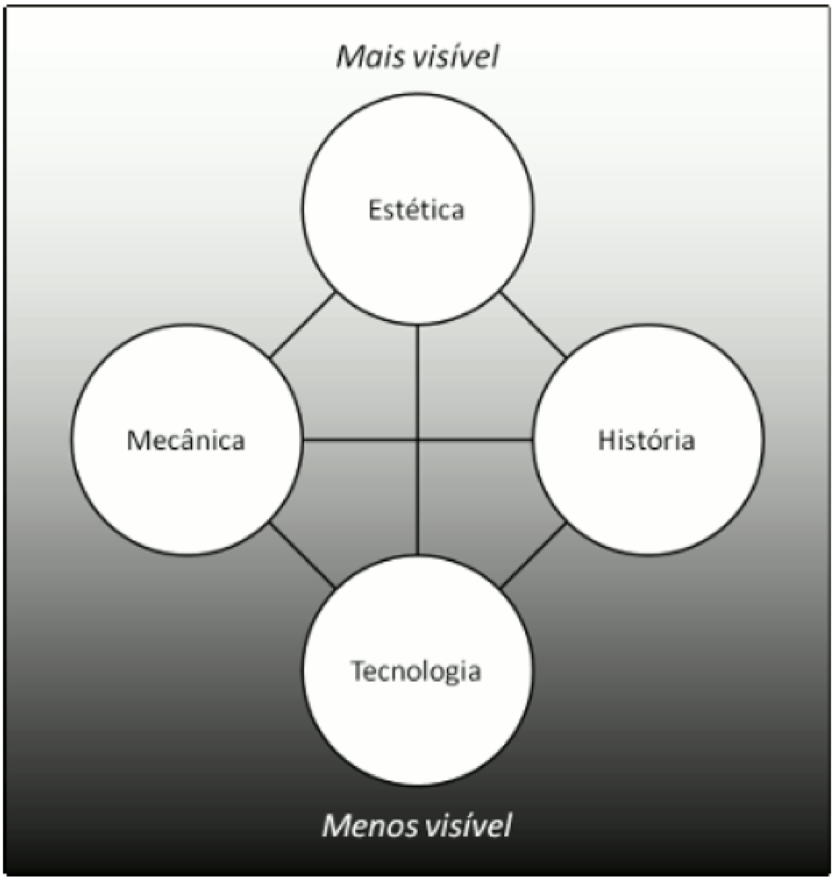

Figura 2.13: Shell´s Elementary Tetrad

Immersive Narrative

A crucial aspect of designing virtual environments is creating an immersive narrative. Just like a well-designed game, virtual museums can use narrative elements to guide visitors on an educational and exciting journey. Through techniques such as storytelling, digital ambience and sound design, it is possible to create an immersive atmosphere that transports users to different times, places and cultural contexts.

Integration of Emerging Technologies

The design of virtual environments must also be aware of emerging technologies that can enrich the user experience. This includes the use of virtual reality (VR), augmented reality (AR), artificial intelligence (AI) and other innovative technologies. These tools can be employed to create interactive and immersive experiences that go beyond the limitations of physical spaces, allowing visitors to explore works of art and cultural artifacts in new and exciting ways.

2.4.1 The Unity 3D game engine

Unity 3D is one of the most popular and widely used game engines in the game development industry. It is known for its flexibility, ease of use, and ability to create high-quality games for a variety of platforms, including PC, consoles, mobile devices, and even virtual and augmented reality.

One of the main advantages of Unity 3D is its component-based approach, which allows developers to create games by combining different elements, such as 3D objects, programming scripts, visual effects and physics, among others. This offers great flexibility and allows developers to customize and optimize their projects according to their specific needs.

Another strong point of Unity 3D is its wide range of built-in features and functionality. It supports high-quality graphics, immersive audio, realistic physics, artificial intelligence, multiplayer networks, and more. Additionally, the Unity Asset Store provides a vast library of ready-to-use assets such as 3D models, textures, scripts, and plug-ins, which helps developers speed up the process of creating and prototyping their games. Unity is also known for its active community and comprehensive support, with a wide range of tutorials, documentation, and online forums available to help developers at every stage of the game and virtual environment development process.

Another great advantage of Unity is the provision of a learning tutorial[1] for the developer. Several tutorials are available on the tool's website, in addition to all the documentation necessary for developers to use Unity classes in their scripts. In short, Unity 3D is a powerful game development tool that offers a combination of advanced features, ease of use, and robust support, making it a popular choice for developers around the world.

Game engine

Game engine, is a category of computer program that has a set of libraries for the development of electronic games and graphic applications. Functionality provided by a game engine includes:

- A graphics engine for rendering graphics;
- A physics engine to do collision detection;
- Support for creating animations;
- Sound effects and artificial intelligence;
- In addition to support for scripting languages, such as JavaScript, C Sharp or Lua.

2.4.2 Better understanding how Unity 3D works

Before starting to create games with Unity 3D, is needed to understand how the tool works. The main concepts used are: Scenes, Terrains, Game Objects, Models, Textures and Materials, which will be explained throughout this section.

Unity 3D operates based on scenes, internally called Scenes. Within the scenes, there are Game Objects, which are any objects inserted within the scene. Cameras, characters, Terrain, Models, Lights, all are classified as Game Objects.

[1]Source: http://unity3d.com

Graphic models are created using materials, textures and shaders. Materials are based on textures and shaders. The texture determines what will be drawn on the surface of the material, while the shaders define how it will be drawn.

Another important element is the terrain. This element is used to create the landscapes within the scenes, and it is what the character will travel through during the game, terrains can be altered to create mountains or depressions.

Furthermore, the addition of materials and models that represent water, grass, rocks or trees is allowed to increase the realism of the game. A concept widely used in projects developed in Unity 3D are the so-called prefabs, or prefabricated objects. These are a set of various objects, which are modeled and saved to be reused.
Another important point is knowing and working with cameras and lights. In Unity, each game can contain multiple cameras and lights depending on the developer's needs. Lights can be of 3 types: directional, punctual and spot.

Directional light is part of almost all outdoor games, representing the sun. It is a light with infinite range in a certain direction. The point light works like a light bulb. It transmits light spherically in all directions. Finally, spotlights are lights that start at a point and radiate in a certain direction in a conical shape.
An important detail to be observed when creating a game is the handling of collisions, to prevent the character from passing through objects in the scene. To carry out this treatment, simply select the desired object and click on Add Component, to add the component, Physics, to choose the physical property that will be inserted, Mesh Collider, which will add collision to the model's texture, and select the convex option. As shown bellow *Figure* 2.14 [16] illustrates a treatment of this type.

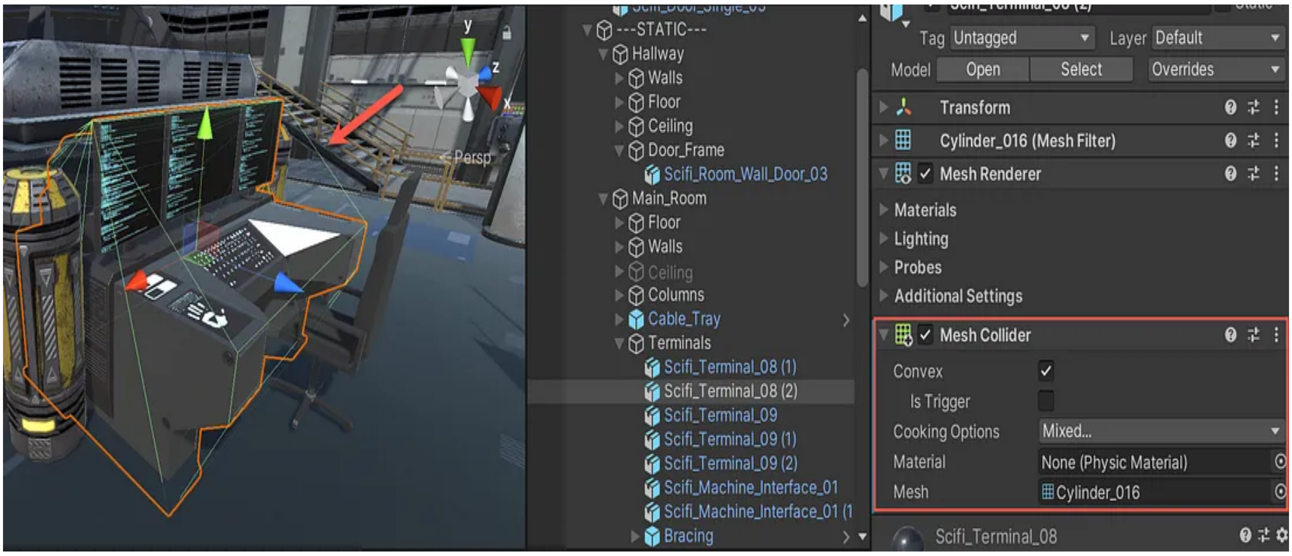

Figura 2.14: Collision Handling

Each element of the game plays its role. Scripts are assigned roles, defining a behavior for it. In Unity, these scripts can be created using the C Sharp, JavaScript or BooScript programming languages. All scripts are created in software attached to Unity, called MonoDevelop.

2.5 Project Management

Project management in virtual museums involves planning, executing and monitoring all the steps necessary to create and maintain these digital spaces.

According to the PMBOK Guide (Project Management Institute, 2017), project management is crucial to the success of initiatives that seek to achieve specific objectives within determined deadlines and budgets.

By applying these principles to the context of virtual museums, it is possible to structure projects that effectively communicate historical and artistic knowledge to the public.

Project management can be divided into five groups of activities (SILVA, 2015), shown on *Figure* 2.15 [10]:

- **Start**: This group includes the activities necessary to define the project, as well as authorization for its start.
- **Planning**: In this group, there are activities related to definition and refinement of project objectives, in addition to defining and scope planning so that objectives are achieved.
- **Execution**: This group contains activities related to the integration of people and resources to execute what was planned for the project.
- **Monitoring and Control**: The activities of this group aim to monitor and measure progress, identifying changes and problems that may divert the project from its objectives and taking action corrections when necessary.
- **Closing**: In this group, the delivery and acceptance of the result of the project, in addition to closing the project or phase in which is found.

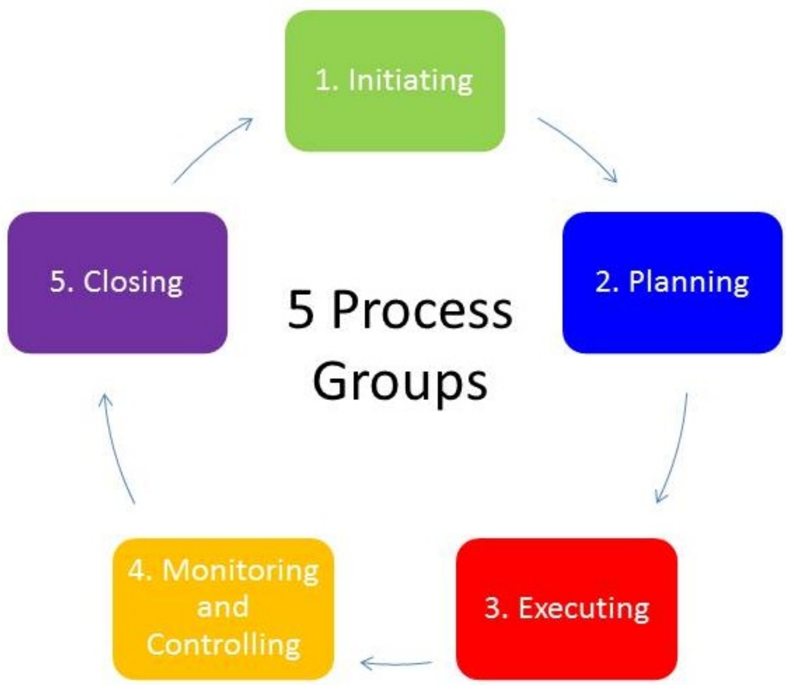

Figura 2.15: Activities groups of a Project Management

According to the five groups of activities presented in the previous paragraphs of project management, it is also possible to divide it by areas of knowledge (PMI, 2018) such as:

- Integration Management: which is the area of knowledge responsible for integrate and keep everything else in sync.
- Scope Management: is the area of knowledge responsible for define the activities that must be carried out to deliver the product, service or result and ensure that only the work necessary for the project is completed.
- Cost Management: is the area of knowledge responsible for estimate the cost of the project, plan and manage expenses to ensure that the project is carried out within the defined budget.
- Quality Management: is the area of knowledge responsible for ensure that the project satisfies the objectives and functions for which it was designed designed.
- Acquisitions Management: is the area of knowledge responsible for acquire goods and services external to the executing organization, in addition to managing deliveries, payments and contracts relating to these acquisitions.
- Resource Management: is the area of knowledge responsible for organize and manage the project team, as well as identifying the need to acquire materials, equipment or space for carrying out the work.
- Communications Management: is the area of knowledge responsible for ensuring the development, collection, distribution, storage, retrieval and delivery of project information in a timely and proper.
- Risk Management: is the area of knowledge responsible for constantly monitor and control risks1 that may appear throughout the project.
- Schedule Management: is the area of knowledge responsible for ensure that the progress of steps and activities are in accordance with the schedule and that the project delivery occurs on time, from initiation to project closure.
- Stakeholder Management: is the area of knowledge responsible for identifying groups, people or organizations that can impact or be impacted by a decision, activity or result of the project.

Project dynamics, on the other hand, is how the project is executed, how the project moves between these phases. For this, there are several models and methodologies that aim to guide the work of the project manager, structuring these phases and giving him a better vision of what is being accomplished.

Some of these are the waterfall model, the spiral model and agile methodologies, such as Scrum (*Figure* 2.16 [15]), Kanban, XP, among others. For the presently project, an agile methodology was chosen, in this case Scrum, which is an agile project management structure that helps teams structure and manage their work through a set of values, principles and practices.

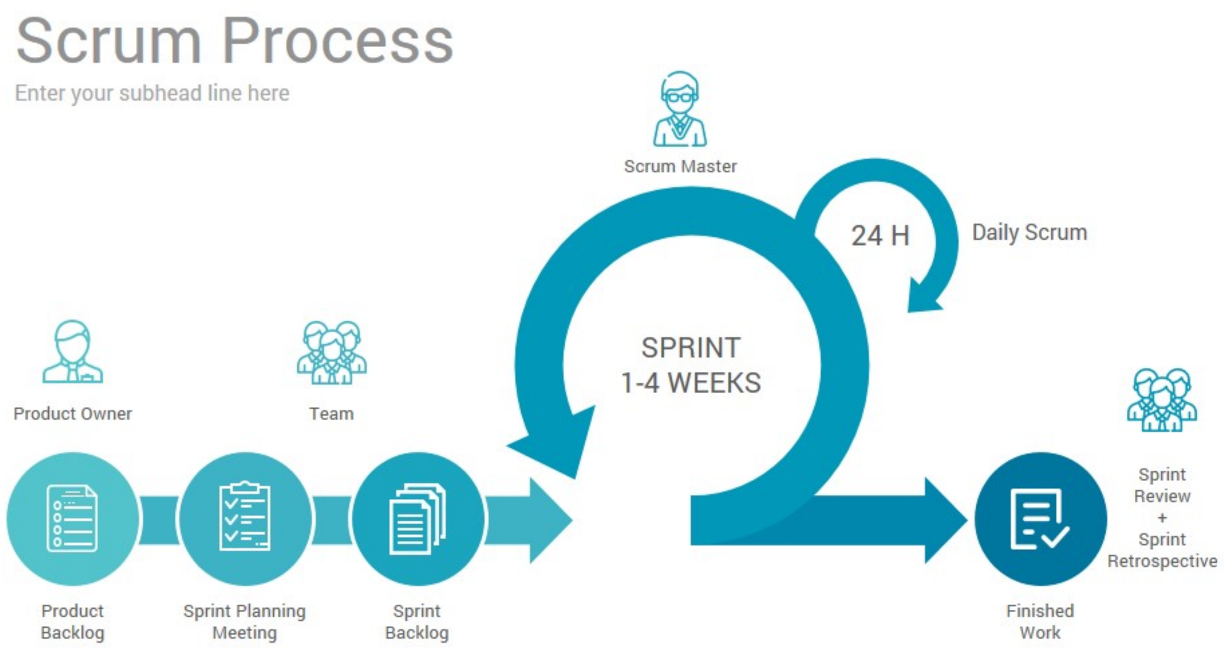

Figura 2.16: Scrum Process

Just like a rugby team (where it gets its name) training for the big game, scrum encourages teams to learn through experience, to self-organize while working on a problem, and to reflect on their wins and losses to continually improve.

The waterfall model (*Figure* 2.17 [22]) was also chosen to apply to the project, in which each stage of this project only occurs after the completion of the previous one, as this is how possible to use it as a means of demonstrating more clearly to the player the operation of each stage.

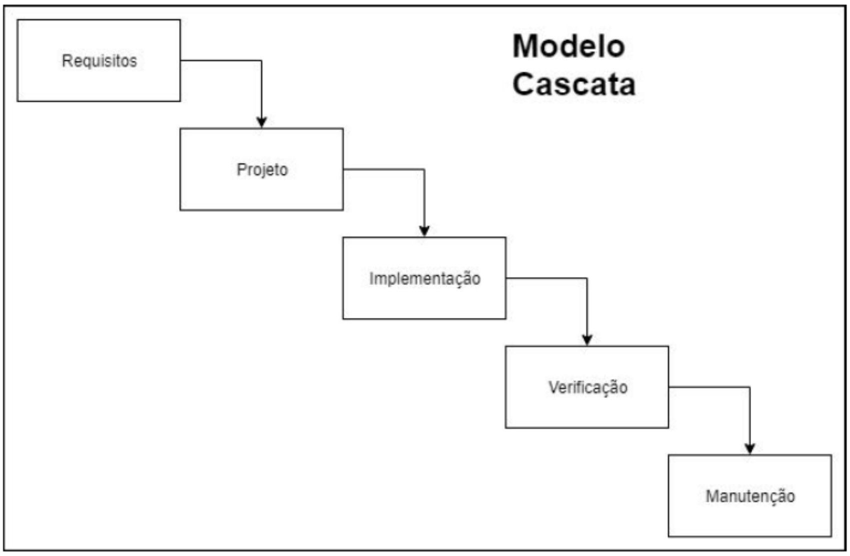

Figura 2.17: Waterfall Model

2.5.1 Final considerations

This chapter was focused on providing the project´s state of art in detail, highlighting the latest trends, there´s all the theoretical content studied to support this project. At other point showed the correlation between playful environment and motivation proving that a game can help with learning, because to learn you need to be motivated, knowledge was also given about the history of museums and the influence of art in a sociocultural way in a summarized way.
It also permit shown an extensive study to understand the structure of a digital game, in which was presented and explained all the elements of a game, knowing how a game is structured makes it easier to plan its creation. It also was explained what a game engine is, and presented the tool chosen to create the game, Unity 3D.
The concepts and techniques described in this chapter will be used to develop the environment proposed in this work, and for the last section was explained concepts to well manage a project basing in models and metodologies which were used to develop the virtual environment.

Capítulo 3

Related Works and Related Platforms

There is a wide range of research and projects that explore different aspects, from the technology used to cultural and educational impacts. Several researchers and developers have explored the development of virtual museum platforms using technologies such as virtual reality (VR), augmented reality (AR), and 3D virtual environments.

In the field of education, virtual museums have demonstrated significant potential as pedagogical tools. They offer valuable resources for teachers and students, facilitating learning outside of the traditional classroom. Studies indicate that the interactivity and immersion provided by VR and AR increase information retention and stimulate students' interest in cultural and historical topics. Additionally, these technologies can be used to create personalized learning scenarios where students can explore specific topics at their pace and interest.

The application of VR and AR in virtual museums not only democratizes access to cultural and artistic heritage, but also offers new forms of interactivity and engagement. Visitors can experience exhibits in ways that would be impossible in physical museums, such as 360-degree views of artifacts, interactive historical simulations, and tours guided by digital avatars. Furthermore, the technology allows the inclusion of multimedia elements, such as videos, audios and animations, which enrich the educational and informative experience of users.

These platforms allow users to explore art collections and museum exhibitions in an immersive virtual environment, so this chapter covers 4 of these platforms that are already including these technologies in their systems.

3.1 Google Arts & Culture

Google Arts & Culture is a digital platform that offers access to a vast collection of art and culture from museums around the world [13]. Developed by Google in partnership with cultural and educational institutions, Google Arts & Culture (*Figure* 3.1 [4]) allows users to explore virtual exhibitions, view high-resolution artworks, and learn about history, art, and culture through videos, interactive storytelling, and educational resources.
One of the most distinctive features of Google Arts & Culture is its high-resolution artwork visualization technology. Users can zoom in on artworks to examine minute details, allowing for a closer, more detailed appreciation of the pieces. Additionally, the platform offers interactive features such as guided virtual tours, themed exhibitions, and in-depth stories about artists and artistic movements.

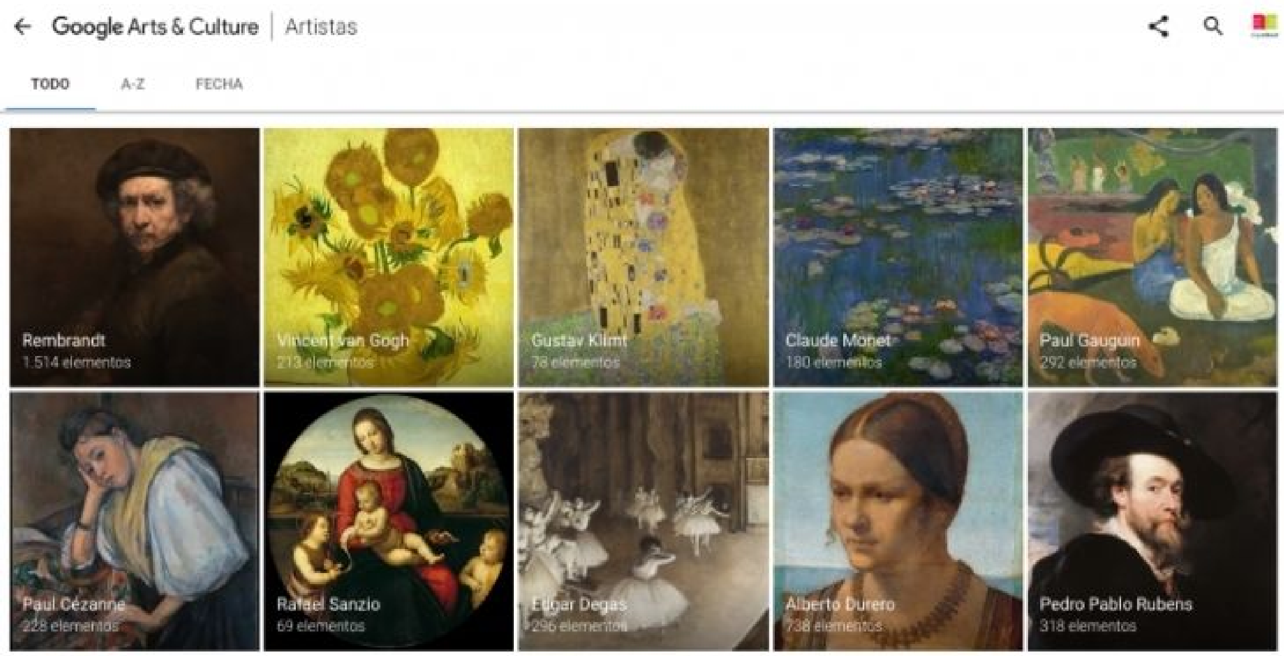

Figura 3.1: Artist Category

The platform offers an immersive and engaging experience, allowing users to discover and explore a wide variety of art and culture from different eras, styles and geographic regions. Users can browse the virtual galleries of renowned museums such as the Louvre Museum in Paris, the Museum of Modern Art (MoMA) in New York, and the National Gallery of Art in Washington DC. And it also includes educational resources that can be used by teachers and students to enrich learning about arts and culture. This includes educational material designed in collaboration with art and history experts, educational videos, hands-on activities, and classroom resources. In addition to offering access to museum collections, Google Arts & Culture also features special collaborations and exclusive exhibitions that explore diverse themes such as contemporary art, world history, cultural heritage, and more. These special exhibitions offer a unique opportunity to explore specific topics in a more in-depth and interactive way.

3.2 The Museum of Modern Art (MoMA) Virtual

It is a platform which initiative by the renowned New York Museum of Modern Art (MoMA) to offer visitors an immersive digital experience of its collections and exhibitions[20]. In response to the challenges presented by the COVID-19 pandemic, MoMA launched Virtual Views as a way to maintain access to art and culture during periods of physical museum closures. Through Virtual Views, users can virtually explore various MoMA exhibitions as showed on the *Figure* 3.2 [18] , as well as the museum's vast permanent collection, which encompasses a wide range of modern and contemporary art, including paintings, sculptures, photographs, films and design works. The platform offers a variety of interactive features, including virtual tours of the museum's galleries, explanatory videos about specific artworks, interviews with artists and curators, and educational activities for children and adults.

Figura 3.2: Virtual Views

One of the distinguishing features this platform is its innovative approach to presenting works of art in a digital environment. The platform uses technologies such as virtual reality (VR) and augmented reality (AR) to create immersive and engaging experiences, allowing users to explore works of art in ways that would not be possible in a physical museum.

MoMA Virtual Views has been praised for providing inclusive access to art and its ability to create meaningful connections between visitors and works of art, even from a distance. It represents an exciting evolution in the way museums are using technology to expand the reach and impact of their cultural mission.

3.3 Virtual Museum of Computing (VMoC)

The platform VMoC[7] was developed as part of a research project at the University of St Andrews in the United Kingdom. It is a virtual museum that aims to preserve and present the history of computing in an interactive and accessible way.

It allows users to explore a variety of virtual exhibits about different aspects of the history of computing, including hardware, software, computing pioneers, and important milestones in the evolution of technology. The platform uses technologies such as virtual reality (VR) and augmented reality (AR) to create an immersive experience for visitors.

Additionally, VMoC includes interactive features such as videos, animations, quizzes and hands-on activities to engage users and provide an enriching educational experience. It is often used as a teaching and learning tool in schools and universities, as well as a research source for scholars of the history of computing. It is an interesting example of a virtual museum platform developed in the academic context, demonstrating the potential of digital technologies to preserve and share cultural and scientific heritage in an innovative way.

3.4 Virtual Museums Transnational Network (V-MusT.net)

V-MusT.net is an initiative funded by the European Union [6] that aims to promote collaboration and innovation in the field of virtual museums. It offers an online platform where researchers, cultural professionals and technology developers can share knowledge, resources and tools related to virtual museums. Virtual Museums are personalised, immersive, interactive experiences that enhance our understanding of the world around us. The term 'Virtual Museum' is a general one that covers various types of digital creations including virtual reality and 3D.

This platform aims to facilitate international collaboration and the exchange of good practices in the development and use of digital technologies for the preservation and presentation of cultural heritage. Additionally, V-MusT.net promotes collaborative research projects and offers educational resources for professionals interested in learning more about virtual museums.

V-MusT.net is widely recognized as an important source of information and resources for those involved in the field of virtual museums and has contributed significantly to the advancement of research and practice in this area.

3.5 Final Considerations

This chapter presented four different works that have the same purpose in common, virtual museums. By analyzing and discussing related works and platforms, such as Google Arts & Culture, MoMA Virtual Views, Virtual Museum of Computing (VMoC) and Virtual Museums Transnational Network (V-MusT.net), it was possible to understand the diversity of approaches, technologies and impacts cultural and educational aspects associated with virtual museums.

While Google Arts & Culture stood out for its extensive collection of art and culture from museums around the world, offering an immersive and educational experience for users, MoMA Virtual Views exemplifies how traditional museums are adapting to technological and to the demands of the modern public. The Virtual Museum of Computing (VMoC) demonstrated how digital technologies can be applied to preserve and present cultural heritage in an interactive and accessible way. Finally, the Virtual Museums Transnational Network (V-MusT.net) highlights the importance of collaboration and innovation in the field of virtual museums.

In short, the study and analysis of these works and platforms offer valuable insights for the development of the virtual environment proposed for the FTP project, providing inspiration, references and direction for creating an immersive and educational experience for users. The project represents a significant opportunity to contribute to the field of virtual museums and to promote access to culture and knowledge in an increasingly digitalized world.

Capítulo 4

Development, Implementation and Final Design

4.1 Process Description

The process used in the development of the virtual museum environment project is the result of studies and experiences acquired as a game developer and designer during the internship, adapted and focused on the specific context of creating virtual environments intended for the presentation of art, history and cultural knowledge. While the field of game design still lacks well-defined standards for how games are made, the same applies to the development of virtual museums. However, tools and approaches are offered that can be adapted for this purpose. The flow of the virtual museum development process consists of three main stages:

1. Conceptualization
2. Development
3. Validation

In the conceptualization stage, the focus is on quickly identifying the theme, desired experience and main mechanics to be implemented. This involves defining the scope of the virtual museum, its educational and cultural objectives, as well as identifying the resources necessary for its implementation. In the development stage, based on the concepts established in the previous stage, the development of the virtual museum begins. This includes creating digital content, implementing interactive technologies and building the user interface. During this phase, tests and iterations are carried out to ensure that the virtual museum meets users' expectations and fulfills its educational and cultural objectives. In the validation stage, the virtual museum is subjected to final tests to evaluate its effectiveness and usability. This includes usability testing with real users, as well as review by experts in art, history and museology. Based on the feedback received, final adjustments are made before the official launch of the virtual museum. Choosing a simpler process like this instead of applying better-known methodologies such as SCRUM or even the waterfall model is due to the size of the team, which in this case was made up of just one person.

4.2 Conceptualization

The virtual museum environment project arises from the application of studies and experiences acquired as a developer of virtual environments during the internship, adapted and directed to the specific context of creating virtual environments intended for the presentation of art, history and cultural knowledge. As the field of game design still lacks well-defined standards for how games are made, the same applies to the development of virtual museums. However, tools and approaches are offered that can be adapted for this purpose.

In this sense, the conceptualization of the virtual museum is essential to establish a solid structure for the project. During this phase, it was necessary to clearly define the concept of the museum, taking into account the experience gained in game development and its application to the context of art, history and culture. This includes identifying the main themes and areas of interest that were covered in the virtual museum, as well as defining the target audience and creating an engaging narrative that will guide visitors through the virtual environment.

Furthermore, it was important to explore the tools and approaches available in game development that can be adapted to create an immersive and interactive virtual museum experience. This may involve using technologies such as virtual reality, augmented reality and gameplay elements to make the virtual museum visit more engaging and educational.

4.3 Development and Implementation

Starting from a critical analysis of existing practices and available tools, the aim is to create an engaging and educational experience that can be accessed by a wide audience, ranging from students and researchers to art and history enthusiasts. This chapter contains the tools used for the construction of the environment and the steps of the development process.

4.3.1 Software Tools

The applications or programs that helped with various tasks during the life cycle of virtual environment development. These include everything from conception and design to coding, testing, maintenance and project management.

Because through the tools used, it was possible for the developer to collaborate more efficiently, sharing ideas, resources and code in an organized and coordinated way. Furthermore, the programs used, has provided a means to ensure the quality and stability of the virtual environment, facilitating rigorous testing, bug identification and correction, and implementation of iterative improvements. Throughout the development process, these applications were also essential for tracking project progress and managing resources.

Engine and Programing Language

Engine, also known as Game Engine, is a development tool that serves to abstract part of the process of building a game. Clua and Bittencourt (2005) relate an engine to a car engine, where when starting the vehicle, the driver starts the engine and moves with it, without needing to know how the mechanical process works. The principle of a game engine is the same, during the development of a game part of the process is simplified with the help of this tool.

Each engine offers unique strengths and features, catering to different development needs and preferences. An example is Unreal Engine excels in high-fidelity graphics and cinematic tools, CryEngine is renowned for its advanced rendering capabilities, while Godot provides a lightweight and flexible solution with its open-source nature. The choice of engine ultimately depends on the specific requirements of the project, such as graphics quality, platform support, ease of use, and budget constraints.

Bellow is shown a comparative table between Unity and other well-known engines for game development and interactive applications: Unreal Engine, CryEngine, and Godot.

Engine	**Languages Supported**	**Key Features**	**Relevance**	**Licence**
Unity	C#, JavaScript	- Extensive Asset Store - Cross-platform support (PC, mobile, VR) - VR/AR ready - High performance	Highly Relevant	Proprietary
Unreal Engine	C++, Blueprints	- High-fidelity graphics - Blueprints (visual scripting) - VR/AR support	Highly Relevant	Proprietary
CryEngine	C++, Lua	- Real-time rendering - High-end graphics - VR/AR support	Less Relevant	Proprietary
Godot	GDScript, C#, C++	- Open-source and free - Node-based architecture - VR/AR support	Relevant	MIT License

Cuadro 4.1: Comparison of Game Engines

Unity Engine platform on the Virtual Museum implementation

As one of the best-known video game development engines, to the virtual museum development it has a series of programming routines that allows the projection, creation and operation of an interactive environment, that is, a video game, digital experience or film/animation. So to the project was used Unity 2024 which version 3.8.0.
As it has a very simple and friendly interface that aims to facilitate the development of games of different genres and other visualization systems, its work area is made up of several windows called views, each with a specific purpose.

Among the typical features of a game engine like unity are the following:

- Graphics engine for rendering 2D and 3D graphics;
- Physics engine that simulates interactions between objects;
- Lighting system;
- Animations;
- Sounds;
- Artificial intelligence programming;
- Programming by scripting, among others

For this reason, this powerful tool was strongly chosen to work in the environment chosen to be developed for the current project. Presenting a work area in which were very usefull for the environment as represented in *Figure* 4.1 [9].

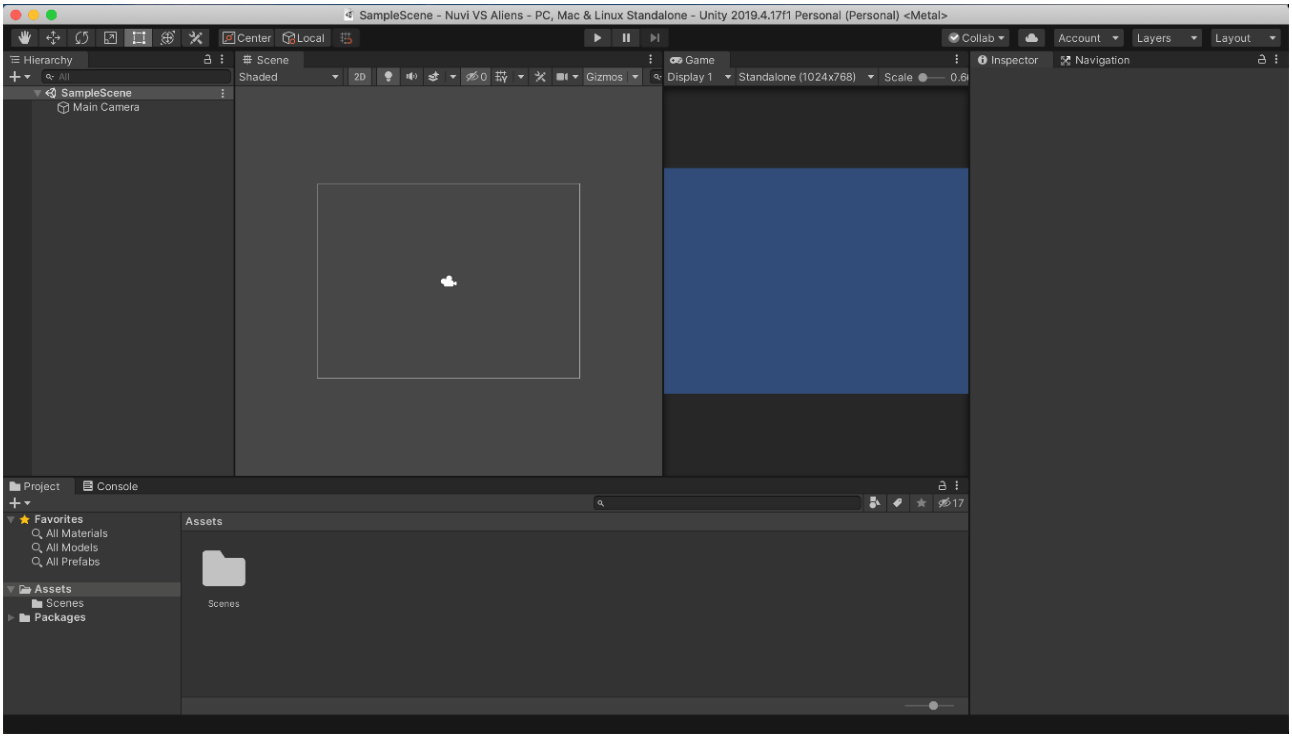

Figura 4.1: Unity Work Area

Game
This window shows what the camera is seeing - in other words, it's what the developer will see when they run and play the game. At the moment, only a blue screen is initially demonstrated, but that is exactly what Unity shows by default in 2D.

Scene
This window displays everything in the current scene, including some invisible things the developer might need. Allowing you to scroll in and out to zoom and right-click to move around the scene. But it's important not to confuse it with the Game window.

Hierarchy
This window shows each object in the current scene as a list of items that the scene contains, from models, prefabs, lighting components, among others.

Inspector
This window will show all the details about an object selected in the Hierarchy or Scene window, also giving space for possible changes to them.

Project
This window shows everything the developer needs to make the game or create the environment, including things they may not have initially used. It is the part of the Unity workspace that contains the project files, including packages, models, scripts and other resources necessary to build the environment or game.

Console
It is the window that shows the output of the game or environment, which serves to display errors contained in scripts or code files, allowing the developer to be aware of them and be able to correct errors in the game. An important part of Unity is the Play button at the top of its interface, as shown in *Figure* 4.2 [9] which contain three buttons:

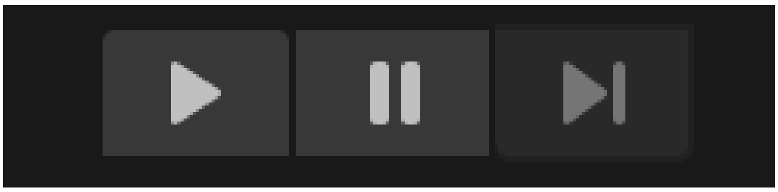

Figura 4.2: Play Buttons

4.3.2 Unity Tools and Packages

To build the Virtu Muse system, we used a combination of advanced tools in conjunction with the Unity platform, making the most of the resources it offers. Among the advanced tools we use, we highlight physical systems, which guarantee realistic interactions within the virtual environment, and graphic rendering systems, which allow us to create impressive and detailed visuals. In addition to native Unity tools, we also integrate several packages from the Unity Asset Store, which offer ready-made solutions to common game development problems.
These packages include everything from animation and artificial intelligence libraries to performance optimization tools and audio systems. Using these packages not only speeds up development but also ensures that the Virtu Muse system is equipped with the latest best practices and technologies on the market.

XR Interaction Toolkit

The XR Interaction Toolkit is a package developed by Unity Technologies to facilitate the development of Augmented Reality (AR) and Virtual Reality (VR) applications[46]. It provides a robust framework for creating intuitive and immersive interactions, allowing developers to focus more on the user experience and less on technical implementation details.
Integration in the Museum Environment

- For interactivity: The XR Interaction Toolkit was used to implement natural and engaging interactions within VirtuMuse. This includes manipulating virtual objects, navigating the 3D environment and interacting with informational elements in the exhibits.
- Its predefined components are: XR Ray Interactor and XR Direct Interactor, which were used to allow visitors to interact with works of art and associated information in an intuitive way, simulating real-world interactions.
- Customization and extensibility: the flexibility of the toolkit allowed the customization of interactions to suit the specific requirements of the virtual museum, such as the implementation of interactive zoom and the visualization of detailed 3D models of the works of art.

Benefits:

- Ease of Use: The toolkit simplifies the creation of complex interactions, reducing development time.
- Compatibility: It is compatible with a wide range of AR and VR devices, ensuring a consistent experience across different platforms.

XR Plugin Management

XR Plugin Management is a Unity system that makes it easy to integrate and manage different AR and VR plugins. As shown on the *Figure* 4.3 [41], it allows to easily configure different XR subsystems such as OpenVR, Oculus, ARCore and ARKit within a single Unity project.

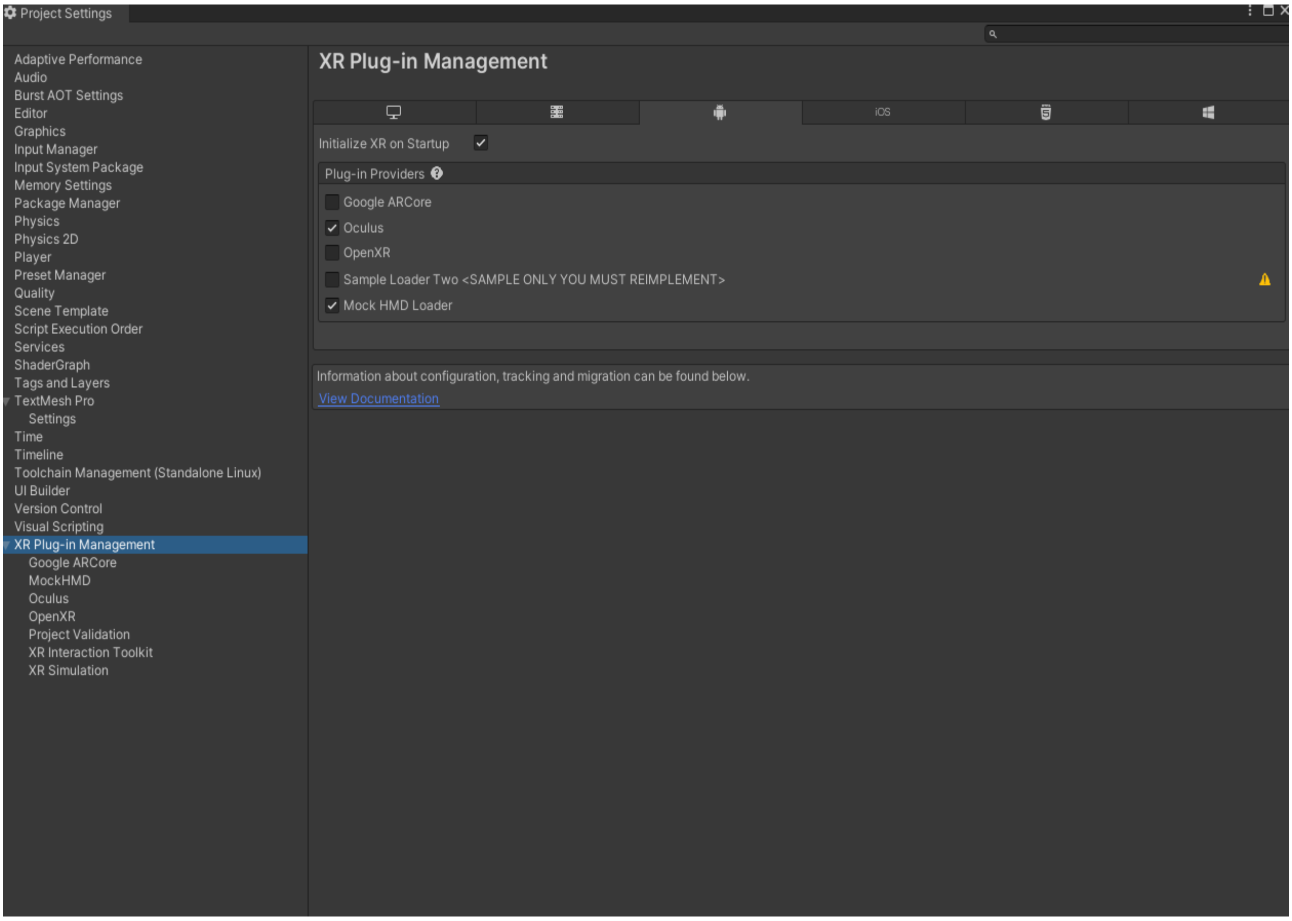

Figura 4.3: XR Plugin Management Interface

4.3.3 Cinemachine

Cinemachine is an advanced camera system for Unity that allows you to create dynamic, cinematic camera movements without the need for complex coding[45]. It offers powerful tools for controlling scene composition, tracking objects, and adjusting the camera in real time.

Integration on Virtu Muse:

- Immersive experience: Cinemachine is used to create smooth, immersive camera movements that follow the visitor through the virtual museum. This includes smooth transitions between different rooms and points of interest, improving immersion and user experience.
- Automated cameras: We implement automated cameras that dynamically adjust scene composition based on user interaction, ensuring that artworks are always presented in the best possible light.
- Dynamic Focus: uses features such as Dolly Track and Target Group to maintain focus on the most relevant exhibits, providing a visually pleasing and informative experience.

Benefits:

- Ease of Implementation: allows you to create complex camera movements without the need for detailed coding.
- Cinematic Quality: increases the visual quality and immersion of the application with professional camera movements.

4.3.4 Blender

Blender is open source software for 3D modeling, animation, rendering and compositing. It is widely used in the gaming, animation and visual effects industry due to its powerful functionality and flexibility. Advanced users employ Blender's API for Python scripting to customize the application and write specialized tools; often these are included in Blender's future releases. Blender is well suited to individuals and small studios who benefit from its unified pipeline and responsive development process. Examples from many Blender-based projects are available in the showcase.

Blender is cross-platform and runs equally well on Linux, Windows, and Macintosh computers. Its interface (*Figure* 4.4 [25]) uses OpenGL to provide a consistent experience. To confirm specific compatibility, the list of supported platforms indicates those regularly tested by the development team.

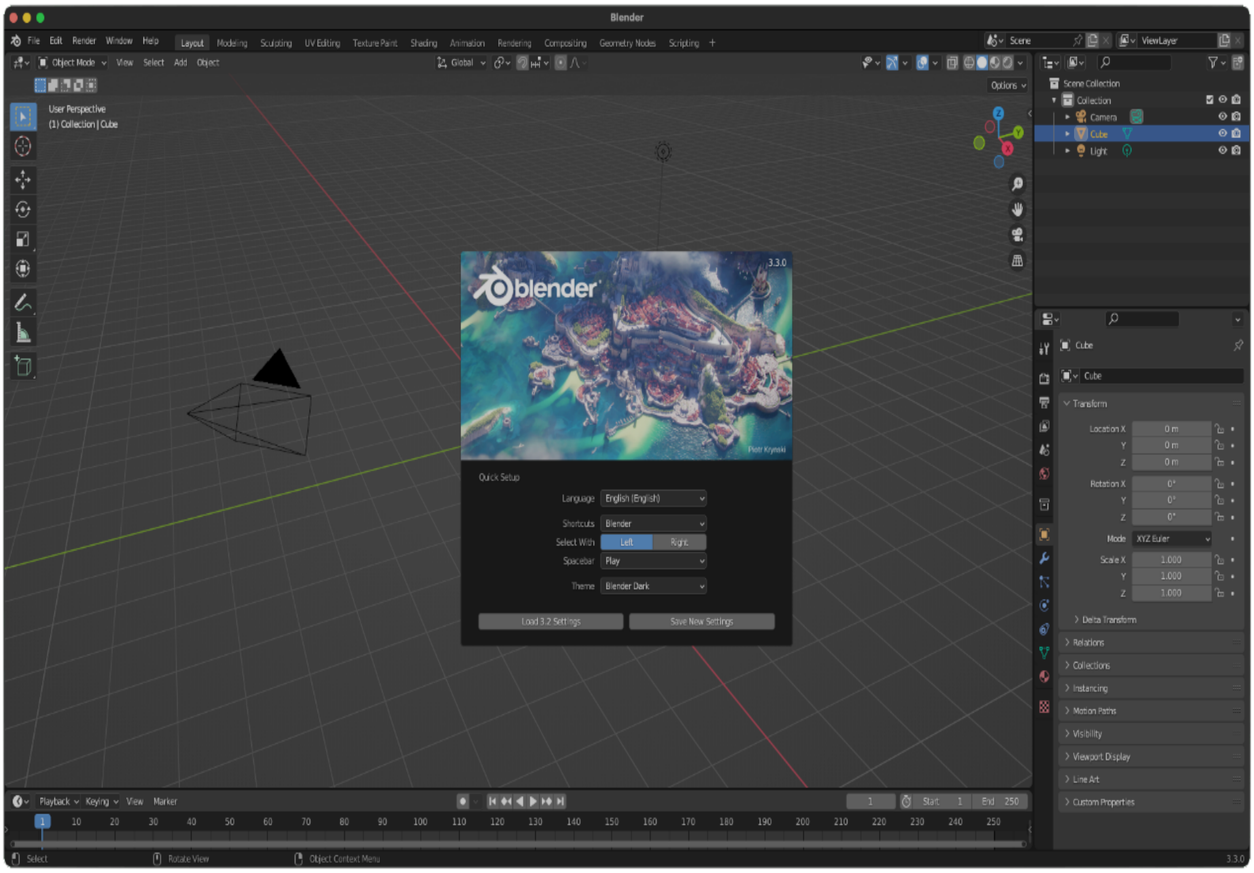

Figura 4.4: Blender Interface

Its application on the virtual museum environment

- Artwork Modeling: used to create detailed 3D models (example in *Figure* 4.5 [28]) of the artworks and artifacts displayed in Virtu Muse which included modeling, texturing and optimizing the models to ensure efficient performance in the virtual environment, and as shown on the example in the Figure which is a model developed by the autor.

- Export to Unity: the direct integration of Blender with Unity facilitated the import and use of 3D models, maintaining the visual quality and texture details, as that unity engine permits use files with *.blender* and *.fbx* format.

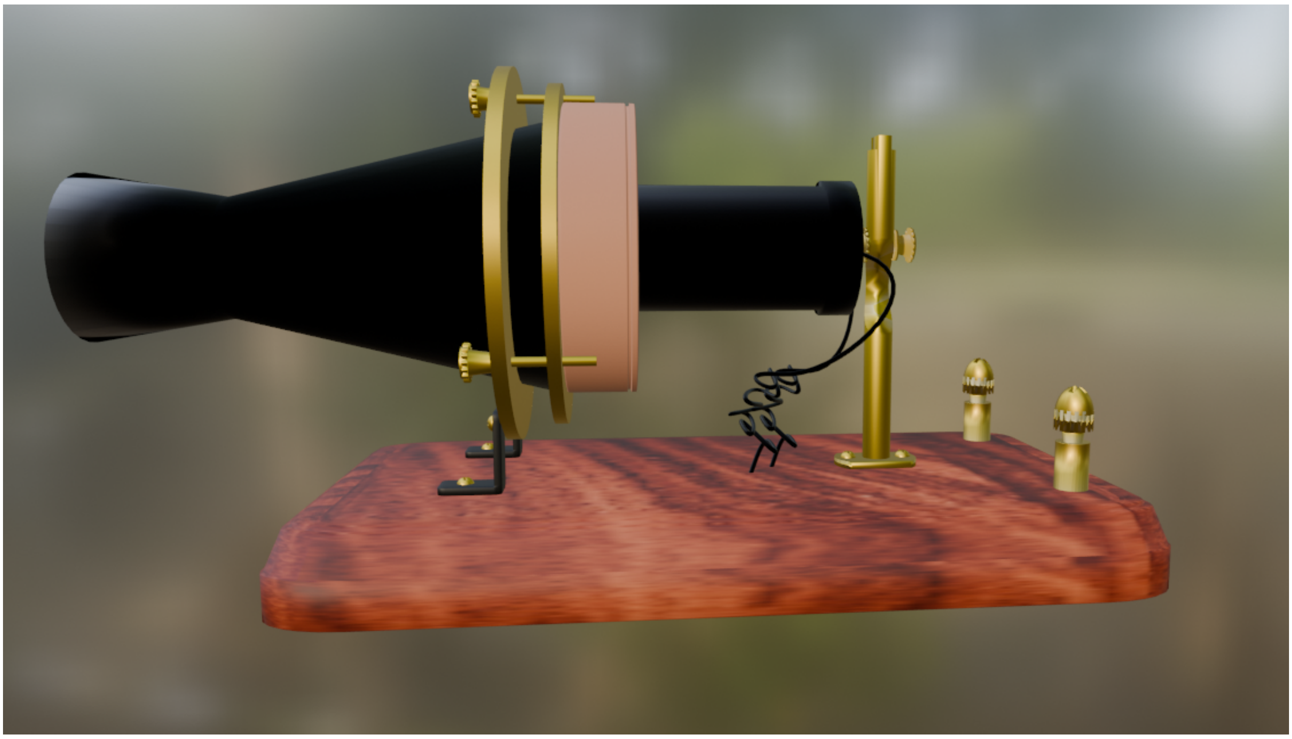

Figura 4.5: First Bells Phone modeled in Blender

Benefits

- Complete Tools: Provides a complete set of tools for modeling, animation, and texturing.
- Cost-Effective: Being an open source software, it is an economical solution for creating high-quality 3D content.

Using these tools, the construction of the virtual museum was based on a practical and efficient approach, guaranteeing an immersive and educational experience for visitors. The integration of these technologies made it possible to develop a virtual museum that not only presents works of art in a visually impressive way, but also provides meaningful and informative interactions, enriching learning and cultural appreciation.

4.4 Firebase and its Implementation

Firebase is a web and mobile application development platform created by Google. Offers a variety of tools and services to help developers create, improve, and expand their applications. Some of Firebase's main features include user authentication, cloud storage, real-time database, analytics, among others[19].
Furthermore, it comes with a comprehensive set of tools to simplify the development process. Features include support for Java, JavaScript, and Node.js languages, as well as Google Cloud Platform standard libraries for analytics, storage, and other services. Other features include data modeling, web hosting, and integration with other systems.
With so many tools and services available, it's a great option for anyone looking to maximize their investment, and with advanced features, a flexible free plan, and competitive pricing for premium users, it offers exceptional value for money for mobile app developers.

<u>Firebase main functions</u>:

- Provide dynamic user interaction using Firebase Authentication;
- Get our applications viewed and used by applying the share tool or Dynamic Links;
- Send notifications to various platforms with Cloud Messaging;
- Create results analyzes with Analytics.
- When implementing functions, they can be tested in advance on a subset of the user base to check if it works and the reaction to it;
- With it, it is possible to improve the public's experience and gain their loyalty, in addition, it can guide them and convert them into potential customers.

4.4.1 Firebase components used in Virtual Museum

For the virtual museum project, Firebase was mainly used for user authentication, and next is explained the relevant components:

<u>*Firebase Authentication*</u>

Description: Firebase Authentication provides easy-to-use and secure authentication services, allowing developers to authenticate users using passwords, phone numbers, and federated identity providers such as Google, Facebook, and Twitter. Role in the virtual environment project: In the VirtuMuse virtual museum environment, Firebase Authentication is used to authenticate visitors and administrators. This ensures that only authorized users can access and interact with the museum's content.

<u>*Firebase Realtime Database/Firestore*</u>

Description: Firebase offers two types of NoSQL databases: Realtime Database and Firestore. Both are cloud databases that synchronize data in real time with all connected clients. Function in Virtu Muse: The database can be used to store information about exhibitions, works of art, user interactions and visiting preferences, allowing for a personalized and dynamic experience.

<u>*Firebase Hosting*</u>

Description: High-speed and secure web hosting service for static and dynamic web applications. Function in Virtu Muse: Can be used to host the Virtu Muse web application, ensuring fast and secure delivery of museum content.

Advantages of Using Firebase

- Easy Integration: Firebase offers SDKs that easily integrate with Unity and other development platforms, making implementation easier.
- Security: Provides secure authentication, with support for multiple login methods.
- Scalability: Firebase is highly scalable, which is ideal for supporting a large number of simultaneous visitors to the virtual museum.
- Real-Time Synchronization: Allows data to be synchronized in real time between all connected users, improving interactivity and user experience.

4.4.2 Steps followed to configure Firebase Authentication

For it configuration in the Project in question in Unity Firebase:

- The first step was to integrate Firebase to the Unity project to use its authentication services. All authentication logic is managed by it, simplifying the development process and ensuring the security of user credentials. And this involved: Project creation in Firebase Console: A new project was created in Firebase Console on site1 itself, where authentication services were enabled. Addition of the Firebase SDK to Unity: The Firebase SDK was imported into the Unity project, allowing the use of its features. Firebase configuration in Unity: Firebase project credentials were configured in Unity, connecting the local project to the Firebase service.
- Add the Unity application i.e. in this case the name or package address of the application or environment to the Firebase project.
- Download the google-services.json file (for Android) and GoogleService-Info.plist (for iOS) and add them to the Unity project.
- Installation of the Firebase SDK for Unity:
- Download and import the Firebase SDK for Unity into your Unity project.
- Configure Firebase in the Unity project by initializing it in the main script.

Login Interface Design

As it is a fully immersive environment, the frontend part of this scene was also developed directly in unity presenting a design as shown in Figure 4.6 and it also includes:

- Input Fields which have two fields for the user to enter their email and password.
- Action Buttons for the user to log in and register.
- Feedback Messages which are areas to display error or success messages depending on user actions.

Using Unity to create the login interface allowed for smooth integration and intuitive user flow, ensuring a frictionless entry experience before exploring the virtual museum. Implementing Firebase Authentication on Virtu Muse provides an additional layer of security and customization, ensuring the user experience is secure and seamless.

4.5 Other essential tools used to create and describe the virtual environment

The following list describes the remaining software products that will be used to develop the virtual environment:

- MS Teams: Communication and collaboration platform between tutor and client.
- MS Word 2018: Word processor used to create, describe and edit the final thesis document.
- Google Chrome: Web browser to access online resources and tools.
- Visual Studio 2022: Integrated development environment (IDE) for programming and software development.
- Meta Quest Link: Tool for connecting Meta Quest virtual reality headsets to the PC, allowing the development and testing of VR experiences.
- MS Excel: Spreadsheet software used for data analysis and organization of information from 3D models placed in the project.

4.6 System definition

Platform

The virtual museum was developed for platforms based on the Android operating system, specifically targeting smartphones and tablets, as well as Android-compatible virtual reality headsets. The choice of this platform is justified by robust data from the mobile market in recent years, which indicates a significant predominance of Android devices, representing more than half of the market share in mobile device sales.

Additionally, the addition of support for virtual reality headsets will allow for an even more immersive and interactive experience for virtual museum visitors. Virtual reality headsets, like Oculus Quest and other Android-compatible devices, provide an innovative way to explore the museum, offering a sense of presence and engagement that goes beyond what's possible on traditional screens.

This predominance and popularity make the Android platform a strategic choice for the development of virtual museums, ensuring broad accessibility and ease of use for a large number of users. The combination of smartphones, tablets and virtual reality headsets will create a rich and diverse experience, making the most of the technological capabilities available on the Android platform.

Programming Language and IDE used with the Engine

As Unity was chosen as the main engine, it is a tool widely recognized for its versatility and ability to create high-quality interactive experiences for both mobile devices and virtual reality headsets. And it also offers a robust ecosystem with a wide range of resources, tools and an active community, facilitating development and problem solving during the creation process, it comes with a type of language attached to it which is C#.

The programming language selected for this project is C#, where Unity supports C# as its main language, which provides a number of advantages. C# is a modern, high-level, object-oriented language, which makes it easy to create efficient scripts and implement complex functionality. Additionally, C#'s integration with Unity is very well documented, offering numerous tutorials, code samples, and community support, which speeds up development and helps you avoid technical hurdles. To support the scripts codes created, the important tool used was the IDE in case Visual Studio Code 2022 in which is a powerful integrated development tool (IDE) that supports programming in multiple languages, including C#.

It is widely used for developing games and applications in conjunction with Unity, one of the most popular platforms for creating games and providing a smooth and efficient development experience. By the way it offers powerful debugging tools, including the ability to set breakpoints, inspect variables, and run code step by step which makes it easier to identify and fix bugs in the environment scripts.

4.7 System Modeling

Use Case

The use case model, according to Bezerra (2014), is a representation of observable functionalities and external elements that interact with it through representation with actors, however it is possible to use use cases from a "real world" perspective, that is, treating the interaction not only with functionalities, but also with actions that the actor can perform.

The actors in the use case diagram are represented by simple dolls made of dashes, the actions are represented by rounded boxes that describe in simple words the objective of that action, the relationships between actors and actions are represented by dashes and the relationship between actions is represented by a dashed line with an arrow at the end to represent which action is calling the other. Therefore, the system will have nothing less than two actors, the visitor and the administrator, to interact with the system, as represented in *Figure* 4.6 [40]).

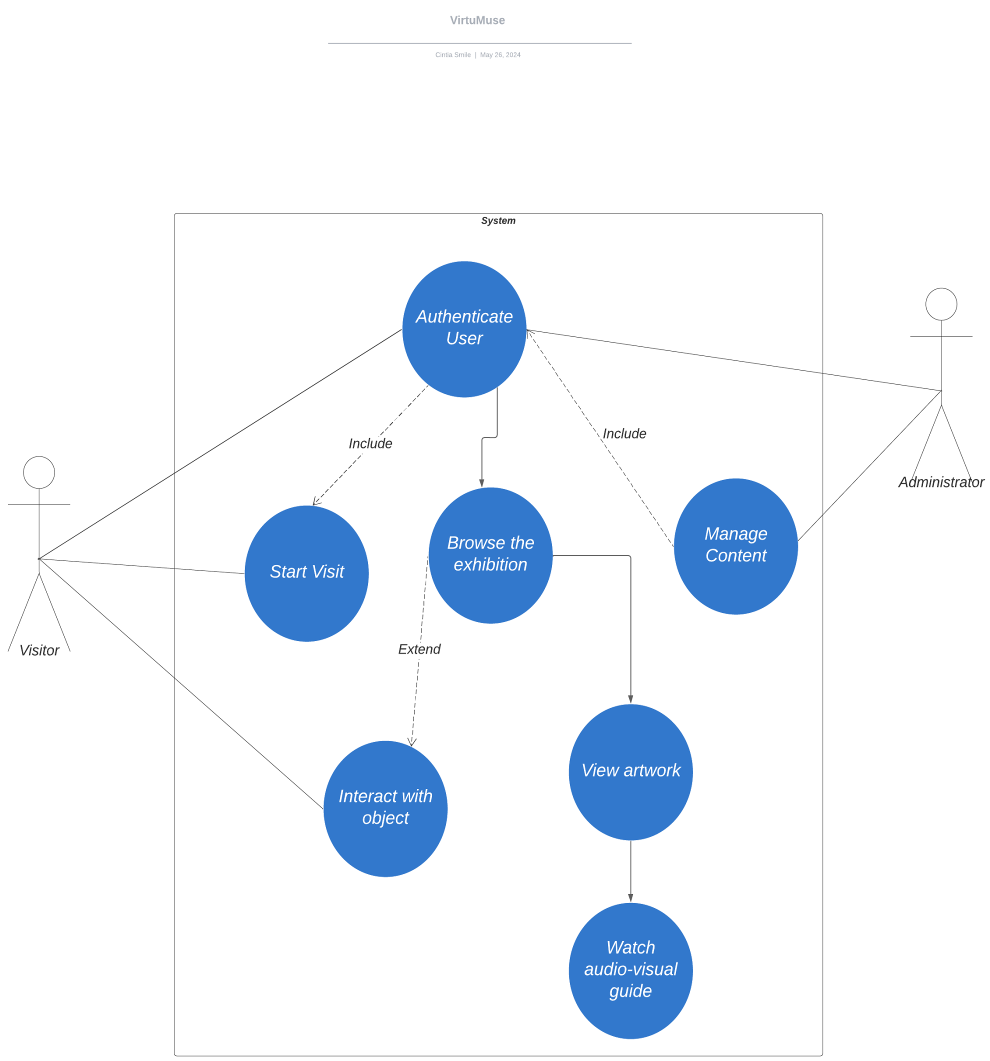

Figura 4.6: Use-Case Diagram

The use case diagram presented describes the main interactions that different types of users (Visitors and Administrators) have with the system. Here is the detailed explanation of the diagram:

Diagram Elements

Actors
Visitor: Represents users who access the virtual environment to explore and interact with the exhibitions.
Administrator: Represents users responsible for managing and maintaining content in the virtual environment.

Use Cases
Authenticate User: This use case is responsible for verifying the identity of users when they try to access the system.
Start Visit: Allows visitors to start their visit session in the virtual environment.
Browse the Exhibition: Allows visitors to explore the available exhibitions.
View Artwork: Visitors can view the works of art present in the exhibition in detail.
Interact with Object: Allows visitors to interact with the objects displayed in the exhibition, such as viewing additional information.
Watch Audio-Visual Guide: Visitors can watch audio-visual guides that provide information about the exhibits.
Manage Content: This use case allows administrators to add, remove, or modify exhibit content.

Relationships between Use Cases *Include*

- *Start Visit* includes *Authenticate User*: To start a visit, the visitor needs to authenticate first.
- *Browse the Exhibition* includes *Start Visit*: To browse the exhibition, the visitor must have started their visit.

Extend

- *Browse the Exhibition* is extended by *View Artwork*, *Interact with Object* and *Watch Audio-Visual Guide*: These additional use cases are options visitors have when browsing the exhibition. They are optional activities that can be carried out while browsing.

Relations with Actors

- Visitor interacts with use cases: Start Visit, Browse the Exhibition, View Artwork, Interact with Object, Watch Audio-Visual Guide.
- Administrator interacts with the use case: Manage Content.

Use Case Flow

1. Visitor:
   - The visitor authenticates himself in the system (Authenticate User).
   - After authentication, the visit begins (Start Visit).
   - During the visit, the visitor can browse the exhibition (Browse the Exhibition).
   - While browsing, the visitor can:
   - View works of art (View Artwork).
   - Interact with objects (Interact with Object).

- Watch the audiovisual guide (Watch Audio-Visual Guide).

2. Administrator: he manages the content of the exhibitions (Manage Content).

   In conclusion this use case diagram helps to understand the system's core functionalities and how different users interact with it to accomplish their respective tasks.

Class Diagram

The class diagram, according to Bezerra (2014), aims to describe the various types of objects in the system and the relationship between them. Classes are represented by rectangles and have a name, methods and attributes. This diagram can offer 3 perspectives:

- Conceptual Perspective
- Specification Perspective
- Implementation Perspective

To the Virtu Muse, the class diagram details the main components involved in building the virtual museum, showing how they interact and relate to each other. It is possible see detailed in *Figure* 4.7 [26]) the class diagram that was created for this project.

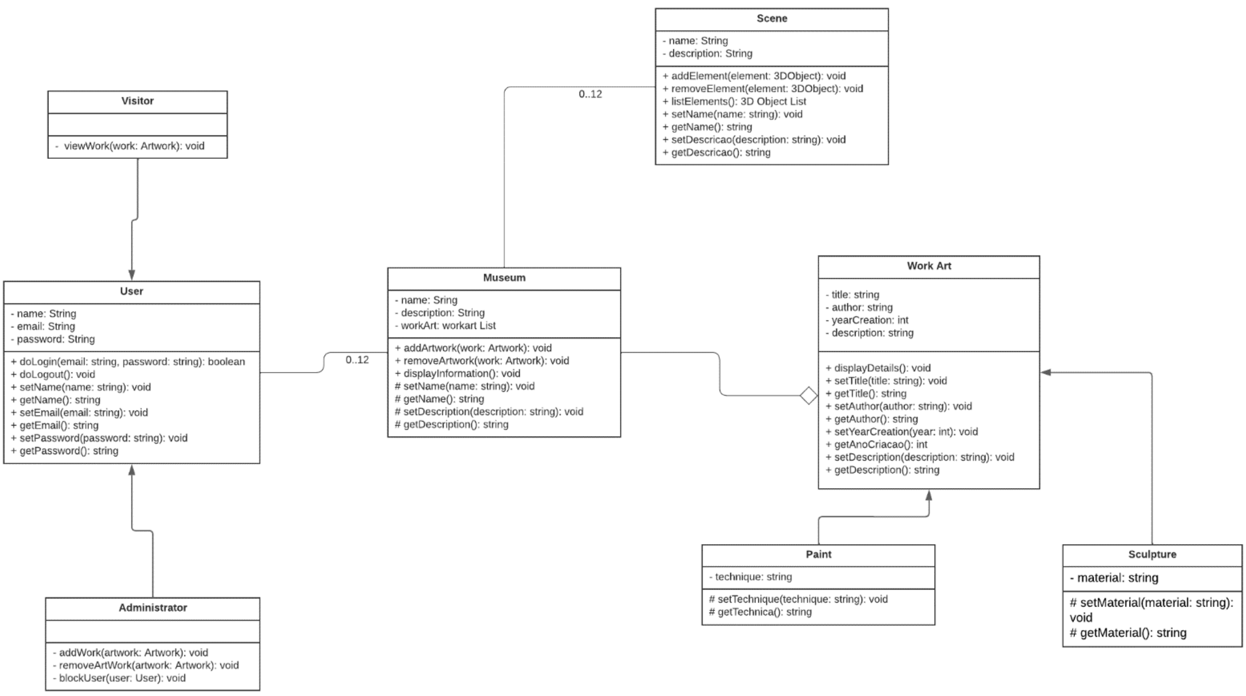

Figura 4.7: Class Diagram

System Functionality

- Visitor: Can authenticate to the system, start a visit, view works of art and interact with the museum's content.
- Administrator: Has additional permissions to manage museum content, such as adding or removing artwork and blocking problematic users.
- Works of Art: They can be specific, such as paintings or sculptures, each with its specific attributes and methods.
- Museum: Serves as a container for works of art, offering methods for managing and displaying information about the collection.

This class diagram provides a clear view of the main entities in the system and how they interact to support the virtual museum's functionalities.

4.7.1 System prototyping

In developing the virtual museum, prototyping played a crucial role in ensuring that our concepts and ideas were solid and viable before moving towards final implementation. This phase allowed the museum's design and functionality to be tested and refined, providing a solid foundation for subsequent development.

Start with Initial Sketches:

The prototyping process began with creating initial sketches. At this stage, brainstorming techniques and freehand drawing were used to capture the first ideas about the layout of the exhibitions, navigation through the museum and main interactions. These initial sketches were instrumental in aligning the team around the overall project vision and discussing different approaches and improvements.

Wireframes and Mockups:

From the initial sketches, we advanced to the creation of wireframes, using digital tools such as Figma to create simple and functional representations of the museum's pages and screens. Wireframes helped define the structure and hierarchy of the content, allowing it to be focused on usability and navigation without being distracted by visual details. High-fidelity mockups were then developed that added design elements such as colors, typography and images, giving a more realistic vision of what the museum would look like.

4.8 Scenes and Structure description

The visual representations of this digitally created space were constructed in the most appropriate way for the interactive demonstration of a fully immersive museum, and environments can range from simple simulations of a room or landscape to complexes of entire worlds, such as those seen in virtual reality video games (VR). So this would be no different for the construction of a virtual museum with good graphic representations forming scenes of an environment.

4.8.1 Layout

According to "Facilities Planning"by Tompkins et al. (2010), layout is "the physical organization of the elements of an environment, with the aim of creating an efficient flow of work and a positive experience for users."The layout may include the arrangement of equipment, workspaces, circulation areas and interaction points. Tompkins et al. (2010) emphasize that .ª well-planned layout can significantly increase productivity and user satisfaction"(p. 150). In the context of a virtual museum, an efficient layout not only makes it easier for visitors to navigate, but also maximizes the educational and emotional impact of the exhibits.

Layout Components

According to Tompkins et al. (2010), the main components of a layout include:

- Physical Space: The allocation of areas for different functions.
- Workflow: The path users take within the space.
- Ergonomics: Adapting the environment to the physical needs of users.
- Aesthetics: The visual appearance of the layout, which must be attractive and functional.

To develop the system, it was necessary to think about a layout of the system structure, making a total of 5 physical scenes, each with a different context for presenting content. Unity provides several packages that are tool plugins that can be used to help in the development of virtual environments and games, as in modeling the layout, a Probuilder plugin was used, which was downloaded through Unity's Window −>Package Manager.

Thus, making the final result of the layout as shown in *Figure* 4.8 [29] and also the *Figure* 4.9 [30]. Each scene is connected by corridors or portals and producing a transition between each others to make it easier for visitors to navigate.

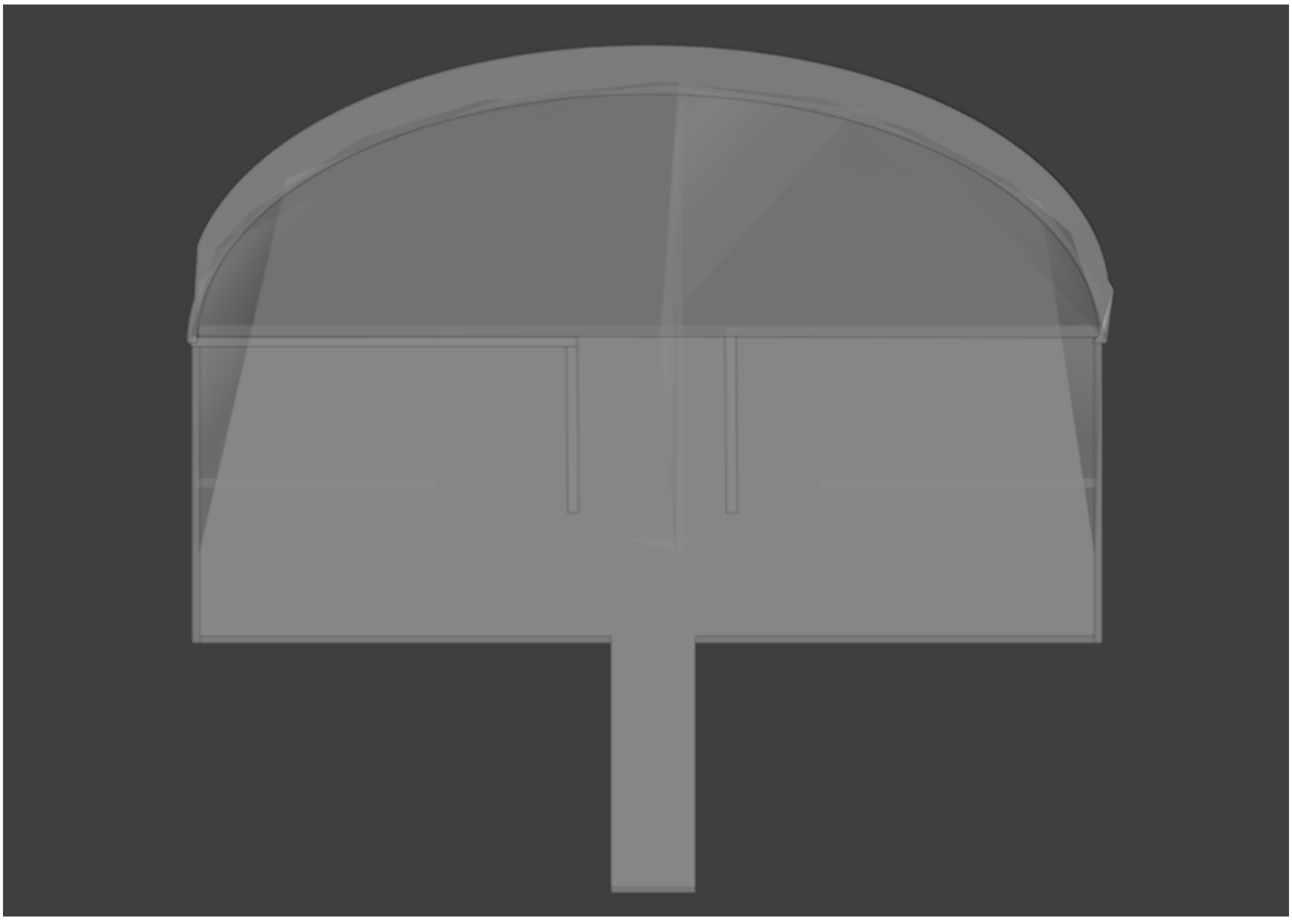

Figura 4.8: Layout Design

The layout was designed and built to provide an educational and immersive experience, combining traditional museum elements with the latest technologies to create an interactive and immersive virtual environment.

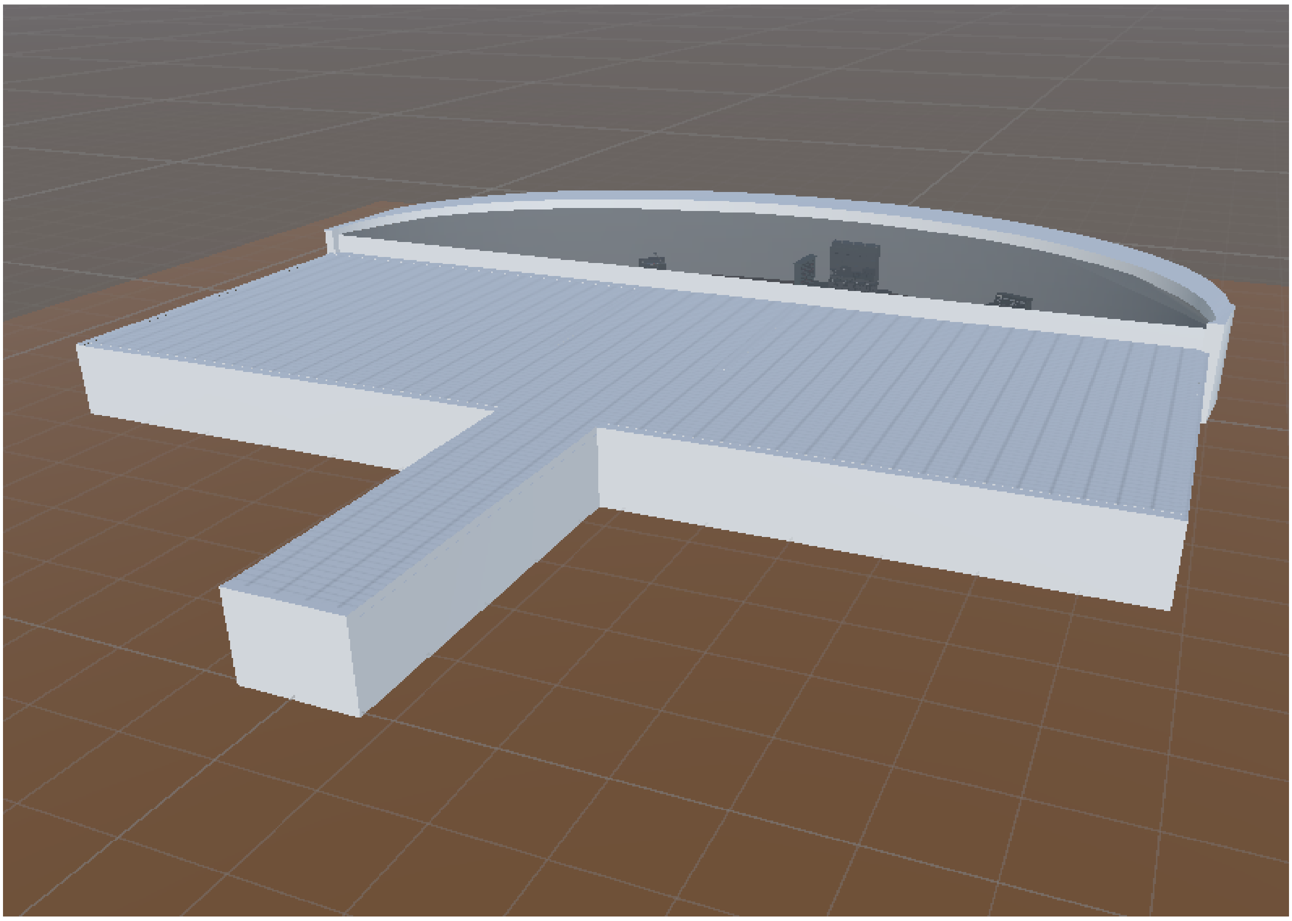

Figura 4.9: Layout Model

In the virtual museum, the layout components can be seen as follows:

- Physical Space: The five main scenes and transition areas.

- Workflow: Navigation between exhibitions, facilitated by corridors and portals.

- Ergonomics: Intuitive and accessible user interfaces.

- Aesthetics: Visual design of exhibitions and virtual environments.

4.8.2 Login scene

To develop an immersive and interactive experience in the virtual museum, a login scene interface (*Figure* 4.10 [31]) using Unity was implemented, where users need to register before starting their journey. The process of creating this login scene is explained on the 4.4 chapter, highlighting the use of Firebase for authentication management and the general implementation flow. In the Unity Editor:

- Canvas: A canvas was created to contain all UI elements.
- InputFields: Two InputField for email and password have been added.
- Buttons: Buttons for login, registration and password reset have been added and configured to call the appropriate methods in the FirebaseManager script.
- Text: Text elements have been added to display feedback to the user.

Figura 4.10: Login Interface

Authentication Functionality

Firebase Authentication was used to manage the login and registration process based on code through C# in Unity that interacts with Firebase to perform the following operations:

- New User Registration: When the user enters an email and password and clicks the register button, the code checks whether the fields are filled in correctly and then calls the Firebase registration function. If registration is successful, a success message is displayed.

- Existing User Login: The login process involves verifying the entered credentials. If login is successful, the user is redirected to the main scene of the virtual museum.

4.8.3 Menu scene

Creating a menu scene in Unity allows visitors to make profile changes that adjust their preferences, easily access the content contained in the museum, and begin their visit. This scene serves as a central hub, offering various options and features to improve user interaction with the museum.

Menu Design Interface

The interface (*Figure* 4.11 [32]) has been carefully designed to be intuitive and visually appealing:

- Menu Layout: The interface is organized with clearly labeled buttons for each available functionality as shown in Figure.
- Visual Identity: The museum's visual identity is maintained through the use of consistent logos, colors and fonts.
- Responsiveness: The layout is designed to be responsive, ensuring a smooth experience.

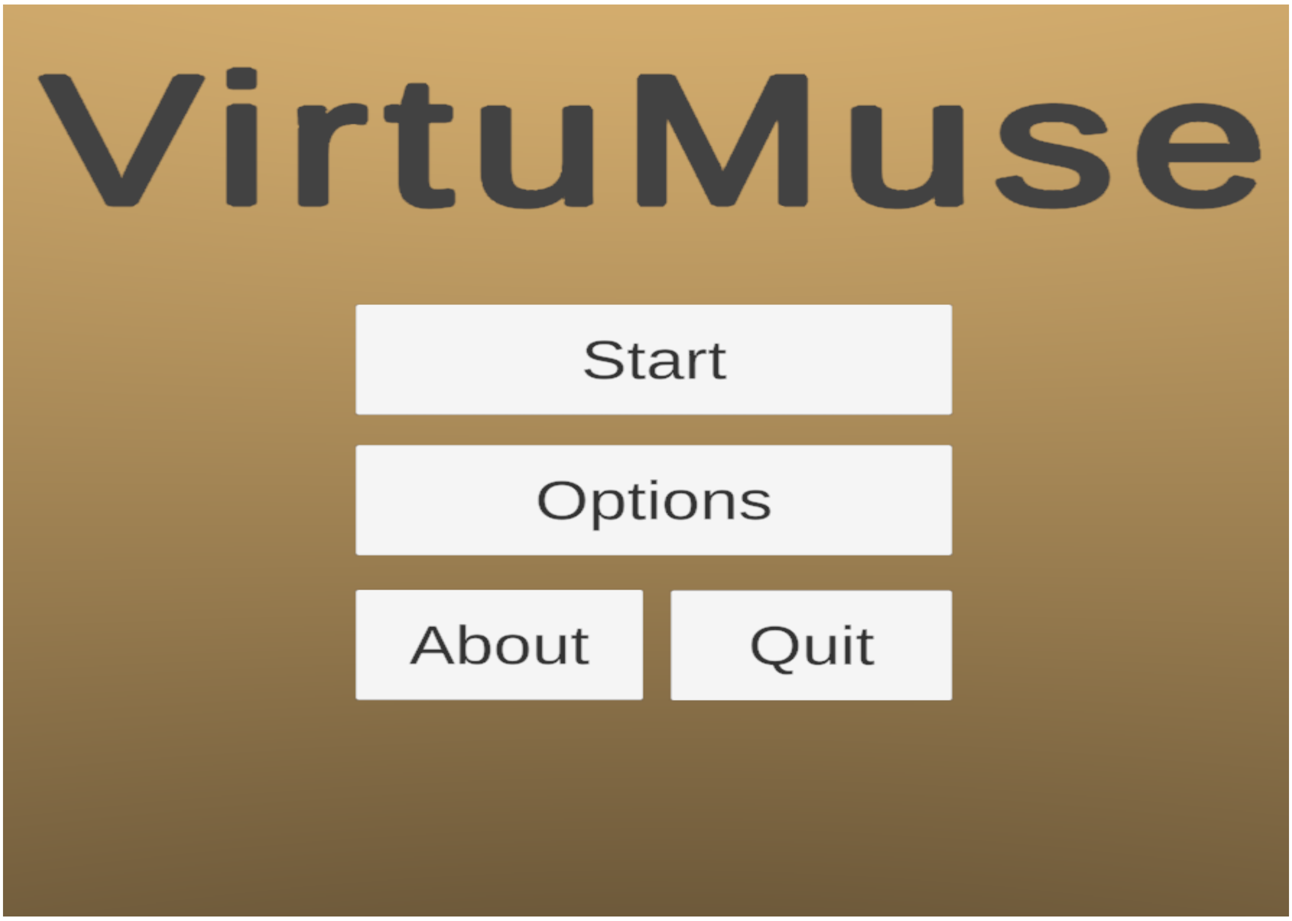

Figura 4.11: Menu Interface

4.8.4 Entrance Scene

After the Menu scene that the user will have access to make some choices and upon entering the so-called physical environment, visitors are immediately greeted by an impressive first scene that serves as an introduction to the rich diversity of art that the museum offers. This initial space (*Figure* 4.12 [27]) is designed to capture visitors' attention and imagination, preparing them for the immersive experience to come.

Figura 4.12: Entrance Scene

The mural features portraits of several renowned and emerging artists, each accompanied by a brief biography. This may include information about your origins, major works, and contributions to the art world. Each painting is accompanied by a small information plate that includes the title of the work, the name of the artist, the year of creation, and a brief description. This information helps visitors contextualize each piece and appreciate its importance and uniqueness.

4.8.5 Sculpture Scene

As visitors continue through Virtu Muse, they enter the grand sculpture room, an area dedicated to three-dimensional works that highlight the skill, creativity and innovation of sculptors. This scene is designed to provide an immersive and contemplative experience, where each sculpture can be appreciated from all angles.

The sculptures are displayed on platforms of various heights and sizes, allowing works of different dimensions to be presented harmoniously. Some larger sculptures may be directly on the floor to give a sense of grandeur. The works are strategically spaced as shown in *Figure* 4.13 [35], allowing visitors to walk around each piece and appreciate the sculptures from different perspectives.

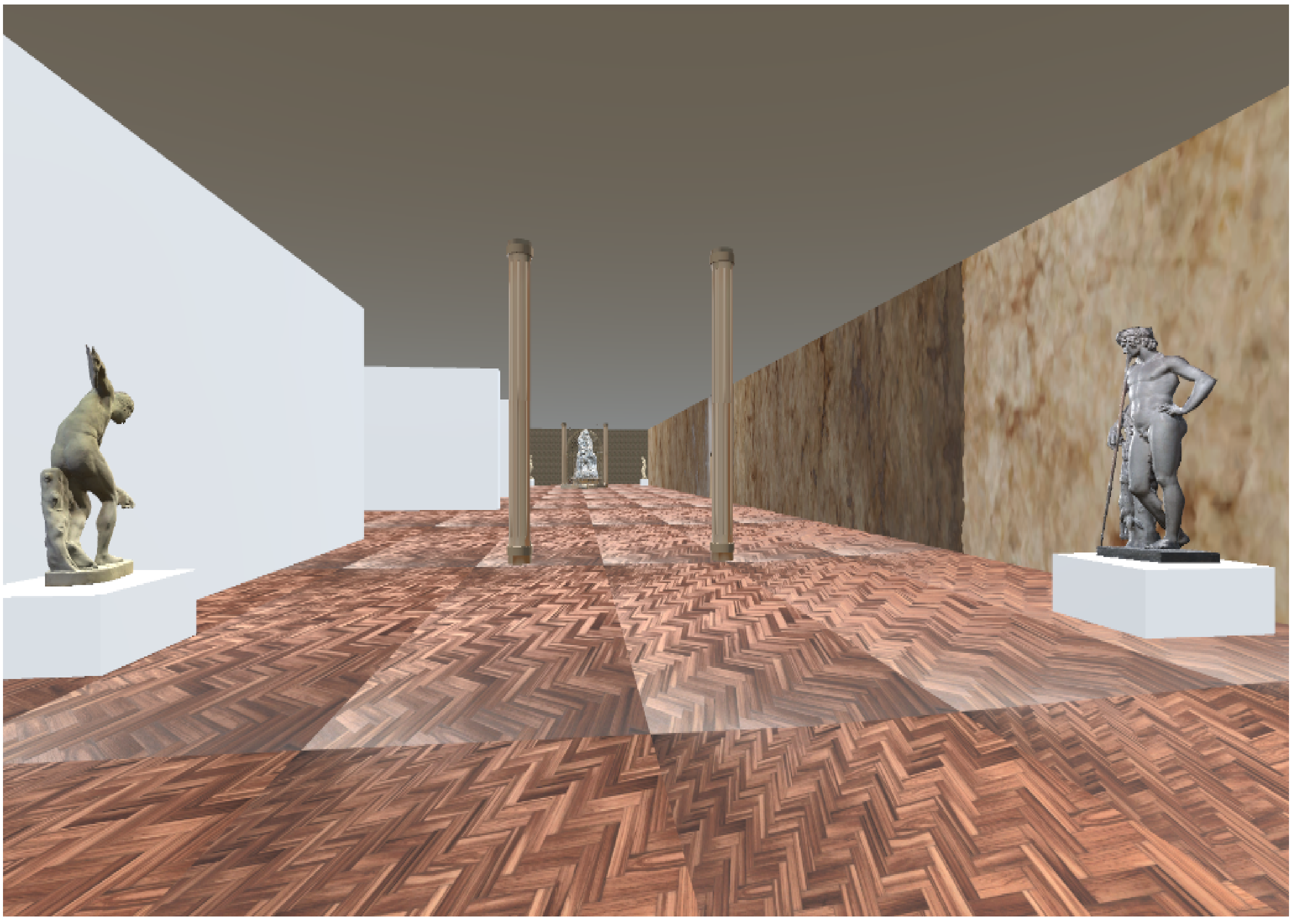

Figura 4.13: Sculpture Scene

4.8.6 African Arts Scene

As visitors continue their journey through Virtu Muse, they are transported to the vibrant and rich Scene of African ArtWorks(*Figure* 4.14 [24]). This area is dedicated to displaying the diversity, cultural richness, and historical depth of African art, featuring a carefully curated collection of traditional and contemporary artifacts.

The works are organized into thematic sections that represent different African regions, tribes and artistic styles. Each section offers in-depth insight into the art of a specific area. Smaller artifacts, such as masks and figurines as well as textiles, are displayed in glass cases for protection and visibility. Larger works, such as sculptures and canvases, are placed on pedestals or mounted on walls.

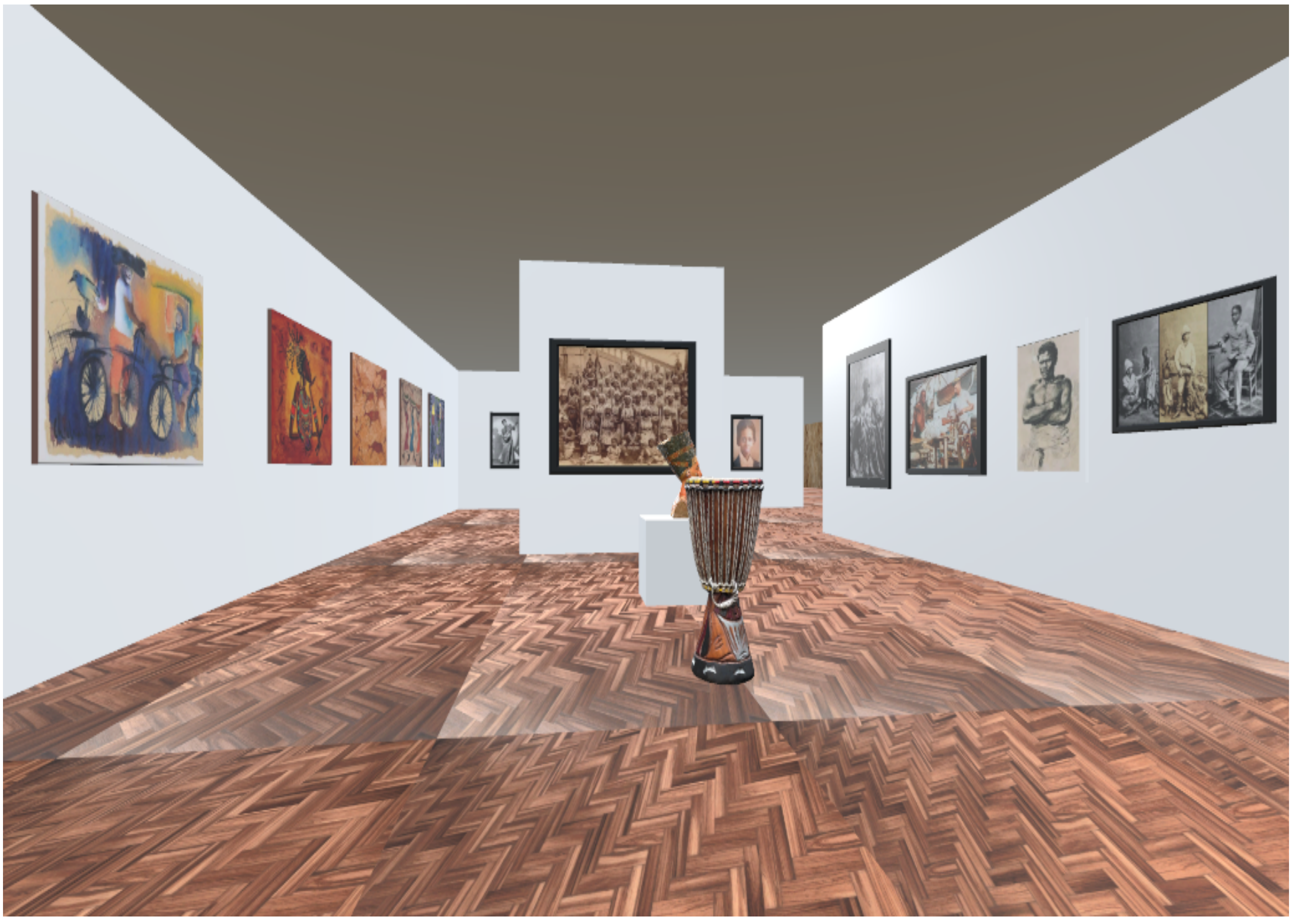

Figura 4.14: African Art Scene

Each artifact is accompanied by a detailed plaque that includes the name of the piece, the tribe or region of origin, the material used, and a description of its cultural and historical significance.

4.8.7 Paint Scene

Upon entering the Paints Museum scene (*Figure* 4.15 [34]), visitors find themselves in a space dedicated to celebrating some of the most iconic and influential works in art history. This gallery is a tribute to the masters of painting, presenting a curated selection of canvases that marked eras and artistic styles.

Works by iconic artists such as Leonardo da Vinci, Rembrandt, Vincent van Gogh, Frida Kahlo and more. Each section highlights these artists' characteristic style and contributions to art history. Each artistic movement is represented by its most significant works, allowing visitors to understand the distinctive characteristics and cultural impact of each style.

Figura 4.15: Paint Art Scene

4.8.8 Vintage Technology Scene

This scene is to show a fascinating journey through time, dedicated to exploring the technological innovations that have shaped civilizations throughout history(*Figure* 4.16 [33]). This area of the virtual museum highlights ancient inventions and devices, showing how cultures around the world have solved problems and advanced through ingenuity and creativity.
Smaller, fragile devices are displayed in glass display cases for protection, while larger machines are placed in sturdy display cases, allowing for 360-degree viewing.
Each piece of technology is accompanied by a plaque that describes its use, origin, and historical context. Descriptions include details about the invention, the inventor (where known), and the practical application of the technology. It is a tribute to the creativity and human curiosity that have driven the advancement of knowledge through the ages.

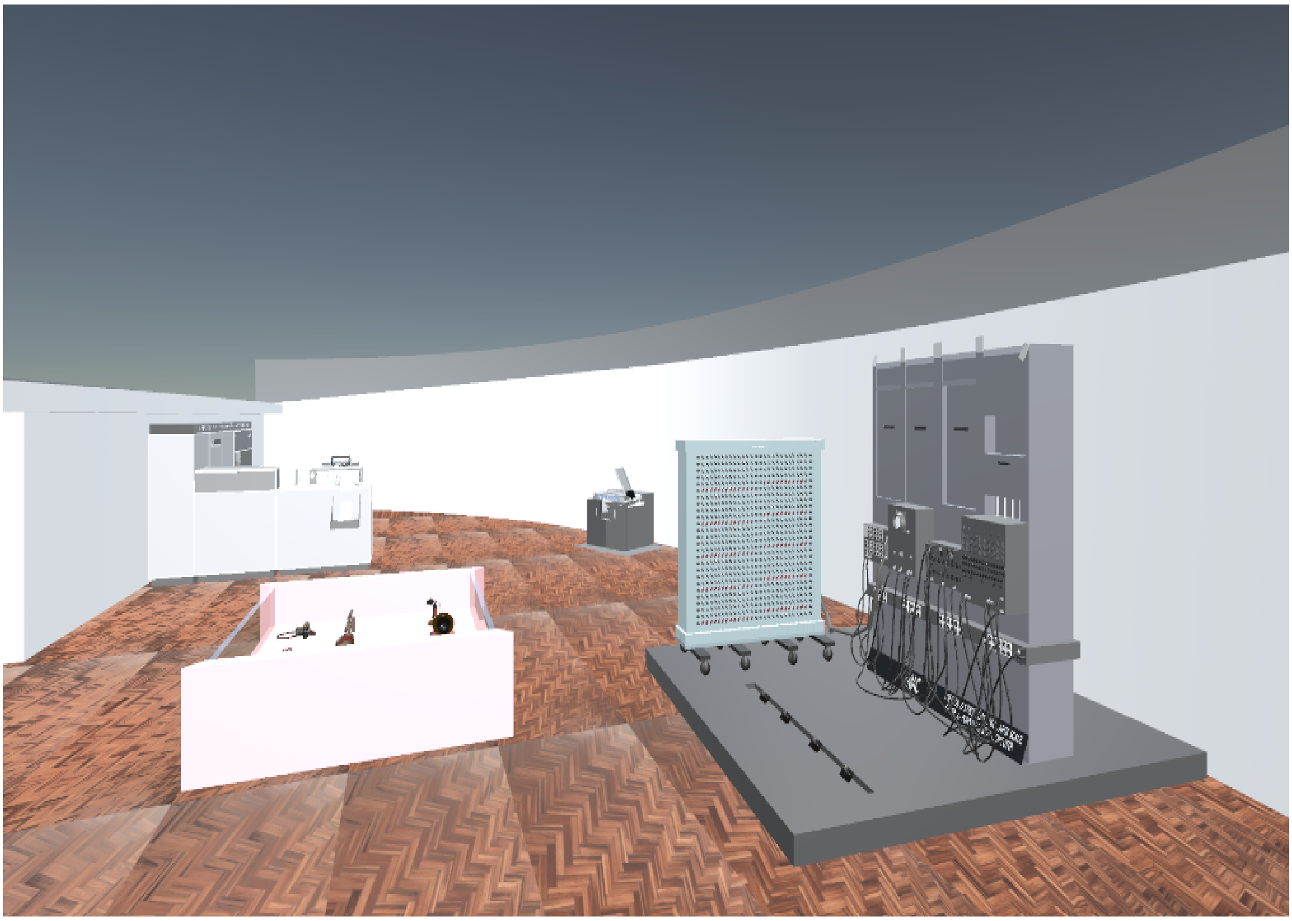

Figura 4.16: Vintage Technology Scene

The thematic layout and detailed explanations provide an in-depth understanding of how ancient technologies influenced the development of societies and contributed to human progress.

4.9 Hardware tools

Developing an immersive and interactive virtual environment requires a combination of powerful hardware to handle the demands of 3D modeling, texturing, rendering, and performance testing. The hardware resources used in the development of the virtual museum were selected to provide a balance between power and efficiency, allowing the creation and testing of a detailed and interactive virtual environment. From powerful workstations and robust servers to varied test fixtures and secure backup solutions, each component plays a crucial role in realizing this complex and demanding project.

4.9.1 Desktop

For the development of virtual environments, especially on platforms like Unity, it is crucial to have a desktop equipped with a powerful graphics card. The table below is a detailed description of an ideal desktop configuration with an excellent graphics card, suitable for the intensive demands of 3D modeling, rendering, and game development.

Desktop Specifications	**Details**
CPU	Intel Core i7 7th Gen
RAM	64GB
Graphic Card	NVIDIA GeForce GTX 1070 Ti
Motherboard	Z370 GAMING PLUS
SO	Windows 10 Pro

Cuadro 4.2: Specifications of the Desktop

4.9.2 Screens

To optimize the workflow and increase productivity during the development of the virtual museum, two high-quality monitors were used. The choice of monitors took into account the need for additional screen space, high resolution for precise details, and advanced color and contrast capabilities for graphic design.

Therefore, for this type of projects it is essential to work in a multi-screen environment, this way we can have the video game engine constantly in one window to make necessary adjustments, while in the other we can have the IDE to program the project's business logic. Since this type of project does not require much screen specifications, a standard monitor model was used that allows it to correctly display all Unity windows, always showing the important details.

4.9.3 Headsets

To create and test a virtual environment, especially if there is a virtual reality (VR) component, it is crucial to use high-quality VR headsets, as these devices allow developers and end users to explore the virtual environment in an immersive way, providing a realistic and interactive experience. Therefore, for this project, the Meta Quest Link 2 VR Headset was used with its specifications in the table below:

Technical Specifications	Details
Resolution	1832 x 1920 pixels per eye
Update Rate	90 Hz (upgradeable to 120 Hz)
Field of vision	Approximately 100 degrees
CPU	Qualcomm Snapdragon XR2
RAM	6 GB
Storage	256 GB
Tracking	Inside-out tracking with built-in sensors, no external sensors required
Conectivity	Wi-Fi, Bluetooth, USB-C for PC connection (Oculus Link)
Control	Two Oculus Touch controllers
Weight	503g

Cuadro 4.3: Technical Specifications of the Device

The high resolution (1832 x 1920 pixels per eye) and the 90 Hz refresh rate, upgradable to 120 Hz, guarantee a clear and fluid visual experience, essential for reducing latency and avoiding motion sickness. The approximately 100-degree field of view increases immersion, while the powerful Qualcomm Snapdragon XR2 CPU and 6GB of RAM ensure robust and efficient performance.

The 256GB storage allows for rich multimedia content, and inside-out tracking, along with versatile connectivity (Wi-Fi, Bluetooth, USB-C), facilitates a hassle-free, interactive experience. Oculus Touch controllers provide intuitive interactions, and the light weight (503g) contributes to comfort during long usage sessions. Specifications that help a lot in the development of a virtual environment.

4.10 Cost estimation

The following section is to describe the estimate values and costs implemented to develop the project covered in subject. Since it was designed and developed in Spain the costs were associated according to the Spanish Government's treatment of salary and tax relevance.

4.10.1 Development team member salaries

In the field of software development, professionals are classified according to their work experience and technical skills acquired throughout their careers. These classifications generally determine the salary range. The categories are as follows, from lowest to highest:

a) **Junior Developer**: Initial category with low or no level of responsibilities, your work must be supervised and experience less than 3 years, the salary is between 16,000 and 20,000 euros gross per year.

b) **Intermediate Developer**: The developer now has responsibilities and an advanced technical level. Experience is generally less than 6 years and salary ranges between 20,000 and 24,000 euros gross per year.

c) **Advanced Developer**: In this case, the professional has a high technical degree, but does not have the level of responsibilities of a senior developer, they generally have more than 6 years' experience and their salary is between 24,000 and 30,000 euros.

d) **Senior Developer**: The senior developer is the last purely technical category, because within software development, he has to have more than 10 years of experience, in which his technical level is very high and he has the highest degree of responsibilities within the technical category. They generally have salaries above 30,000 euros and less than 40,000 euros.

It should be noted that the categories described above are not official professional categories recognized by the general statute of workers, and therefore form part of a consolidated internal classification within companies in the sector, which serves to define the salary ranges of their professionals. These categories only refer to the specific sector of software development, in its more technical aspect, there are positions of greater responsibility at the managerial level, such as project manager.

In this case, the only member of the development team is Cintia Sequeira, who will perform all functions involved in the planning, management and implementation process. For this reason and given that the promoter has more than two years of professional experience. In the software development sector, the cost that would have to be paid is equivalent to 27,500 euros gross per year, which translates into 13.22 euros per hour.

- **Hardware resources**

  In terms of hardware, what was taken into account was the use of a desktop with two monitors and other input and output devices connected to it, and also a VR headset as one of the main devices used as well.

- **Software license** For this project, all software used has GPL or Community licenses, which implies that there will be no expenses associated with the use of these tools, which allows the overall project costs to be significantly reduced. Additionally, using software with these licenses promotes transparency and collaboration, making it easier to share improvements and integrate new features developed by the community.

- **Resources from Unity and other software or websites to add to the virtual environment** To enhance and modify the environment, other models will be added for aesthetic purposes, to increase engagement in interaction with the environment, and also to promote its originality. Models, packages and assets that can cost between 3 and 70 euros depending on characteristics, structures, and can also be purchased through the Unity asset store and websites such as Sketchfab, Mixamo and others.

- **Work space and others** To develop the project, it is necessary to have a conditioned work space, which is means, a closed, private space, which has a table and a chair, and services essential for the performance of the project, including light, connection to internet, etcetera. We consider rental options that have hourly billing periods. In this If so, it would cost us 4 euros per hour.

4.10.2 Estimation of total costs

The table below shows a total of all estimated costs for the project, resulting in a total of 8876 euros.

Concept	**Unit Cost**	**Units**	**Subtotal**
Wage Developer	13.22€	360 hours	5327€
Desktop Computer	1000€	1	1000€
Meta Quest2 Headset	428.99€	1	428.99€
Screens	190€	2	380€
Work Area	4€	360 hours	1440€
Unity and other Assets	3€ - 70€	10€	300€
Total	**8876€**		

Cuadro 4.4: Cost Breakdown

In conclusion, the cost estimate of €8876 for the development of the virtual museum is well balanced and covers all essential aspects, from salaries to equipment and software. Each item listed is crucial to ensuring that the project is developed efficiently and professionally. The total budget appears realistic and sufficient to create a high-quality immersive virtual environment, ensuring that all hardware, software and labor needs are met.

Capítulo 5

Tests and Validations

Taking into account that when developing a system, software or a virtual environment it is always necessary that they undergo testing in different aspects for good effectiveness and efficiency. In this sense, two main types of tests should be taken into account: Alpha Testing on specific functionalities and Alpha Testing of the global system.

5.1 Alpha Testing on Specific Features

Alpha testing of specific features is and was performed during the early phases of project development to ensure that each individual component or feature works correctly before being integrated into the overall system. These tests were typically conducted by the development team.

Below are some details that were accomplished:

- Focus on Isolated Components: Each functionality, such as navigation between rooms, interactivity with objects, or displaying information, was tested separately.
- **Early Error Detection**: Problems and bugs were identified and fixed before being integrated into the complete system, preventing major problems later.
- **Requirements Validation**: Each functionality was verified to meet the specified requirements and function as expected.
- **Rapid Feedback**: Developers receive immediate feedback on specific functionality, allowing for quick and efficient adjustments.

5.2 Global System Alpha Test

Alpha testing of the overall system occurs after all individual functionalities have been integrated into the complete system. This type of comprehensive testing assesses the behavior of the system as a whole.

The following tests are listed in terms of the overall system:

1. **Usability Tests** The developer in this case carried out this type of test to verify the interaction with the virtual museum to evaluate the ease of use, the intuitiveness of navigation and the understanding of the information presented for when it comes to user experiences.

2. **Functionality Tests** All features of the virtual museum, from navigation to interactions with virtual objects, are rigorously tested to ensure they work as expected across different platforms and devices.

3. **Compatibility Tests** The virtual museum is tested on a variety of devices and browsers to ensure it is compatible and displays correctly across different environments and devices.

4. **Performance Tests** The performance of the virtual museum is evaluated to ensure that it is responsive and fast, even under heavy load conditions, such as multiple users accessing it simultaneously. This is why some aspects that greatly affect rendering and that also overload the graphics card's functionality when the environment is running have been reduced.

5. **Security Tests** Security measures are implemented and tested to protect user data and ensure the integrity of the virtual museum against possible vulnerabilities, which is why in this case secure methods were used through the integration of Firebase into the system.

6. **VR Tests** As the virtual museum offers some support for virtual reality devices, specific tests were carried out to ensure an immersive and comfortable experience for users.

These tests are conducted iteractively throughout the development of the project, with adjustments and improvements implemented based on the results obtained. The ultimate goal is to ensure that the virtual museum is an engaging, educational and trouble-free experience for users, which also serves as a very important step in the Beta testing phase.

5.3 Versions

- **v1.0.0**: first executable version, in which you can navigate through the virtual museum, presenting a basic collection of exhibitions and interactive resources. This first version aims to provide a robust and functional initial experience for users, laying the foundation for future expansions and improvements.
- **v2.0.0**: In this version 2.0, significant improvements to the user interface will be implemented, adding more details to 3D models and introducing new navigation features.
- **v3.0.0**: version 3.0 will bring a substantial expansion of content, including new thematic exhibitions and more types of supports for virtual reality devices. Meanwhile, improvements to the virtual museum will continue with regular updates, incorporating user feedback and exploring new technologies to offer an even more engaging and educational experience.

5.4 Functional modules that make up the product backlog

Below in the table described an estimate in hours, a description and satisfaction conditions that must be comply with to validate the environment, once developed and which make up the product backlog.

Specification	Estimation	Description	Conditions of Satisfacti
General Environmental Integration	23h	As a customer, I want the application to have the Virtual Museum model that we provide, so the player can see the environment	- A unique structure with elements as scenes - The sc must be well coupled to ea - Each scene will have an independent element for th internal passable part
Camera Integration for VR	15h	As a customer, I want the application to be observable using the latest reality techniques virtual, so that the user can use the Meta Quest Link Headset equipment and increase the feeling of immersion.	- The scenery must be ren with the Meta Quest 2 vir reality glasses - VR contro must simulate the player's
Transition, teleportation and animation system	17h	As a customer, I want to have a very encouraging experience with each execution carried out.	- There will be an animati each transition phase, alon some information - VR co must simulate player move such as walking through c
Sound Effects and Audiovisual	18h	As a client I want to have the feeling of being in a relaxed environment with good background music, and also to have deeper knowledge about some historical art facts.	- Actions such as clicking a will have a sound effect - T environment itself will hav background music - There content demonstrated in vi information and animation

Cuadro 5.1: Project Specifications

5.5 Implementation Plan with Sprints

The application of the Scrum methodology in the development of the virtual museum provided an effective structure to manage the project in an iterative and incremental way. By following Scrum principles, the development team was able to plan, execute, and review progress in short, well-defined cycles known as sprints. Below you can find the descriptions of each sprint along with the burn down charts.

Sprint 1[36]

Implementation Details:

- Create the museum layout model in Unity using the Probuilder tool.
- Configure scenes and ensure smooth transition between them.
- Check the integrity of each passable internal element.

Validation Tests:

- Check the consistency of transitions between scenes.
- Ensure that each scene is well coupled and functional.
- Test the navigability of internal elements.

Burn Down Chart

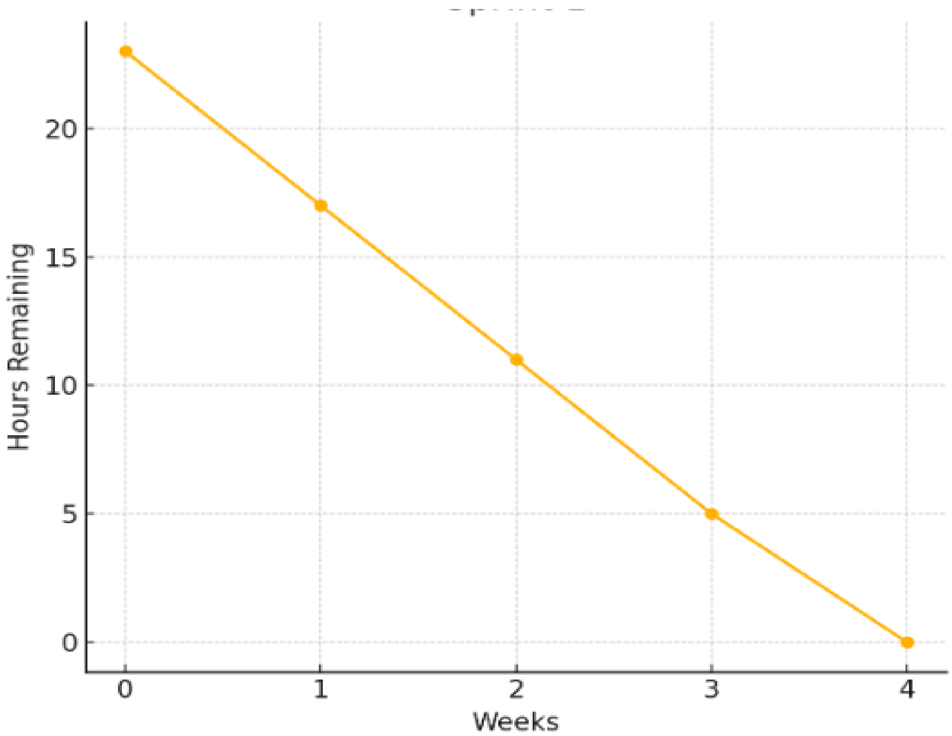

Figura 5.1: Sprint 1

Sprint 2[37]

Implementation Details:

- Configure the camera for compatibility with Meta Quest 2.
- Implement VR controllers to simulate the player's hands.

Validation Tests:

- Check the correct rendering of the scenery on the Meta Quest 2 glasses.
- Test the functionality of VR controllers to ensure accurate hand movements.

Burn Down Chart

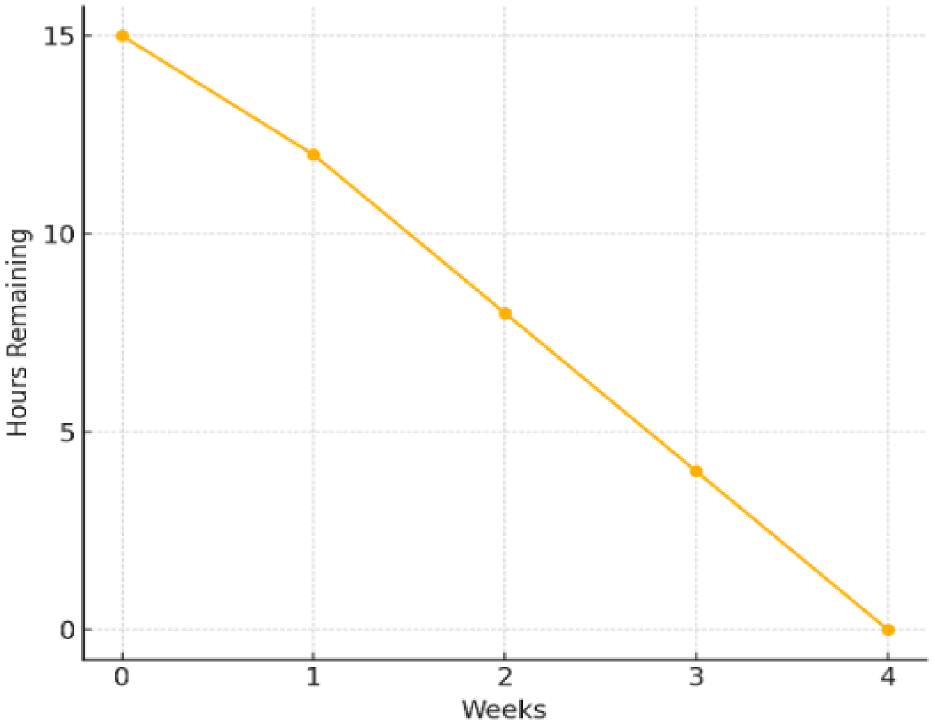

Figura 5.2: Sprint 2

Sprint 3[38]

Implementation Details:

- Develop animations for transition phases.
- Implement teleportation and animations in VR controllers.

Validation Tests:

- Check the functionality and fluidity of transition animations.
- Test VR controller motion simulation for walking.

Burn Down Chart

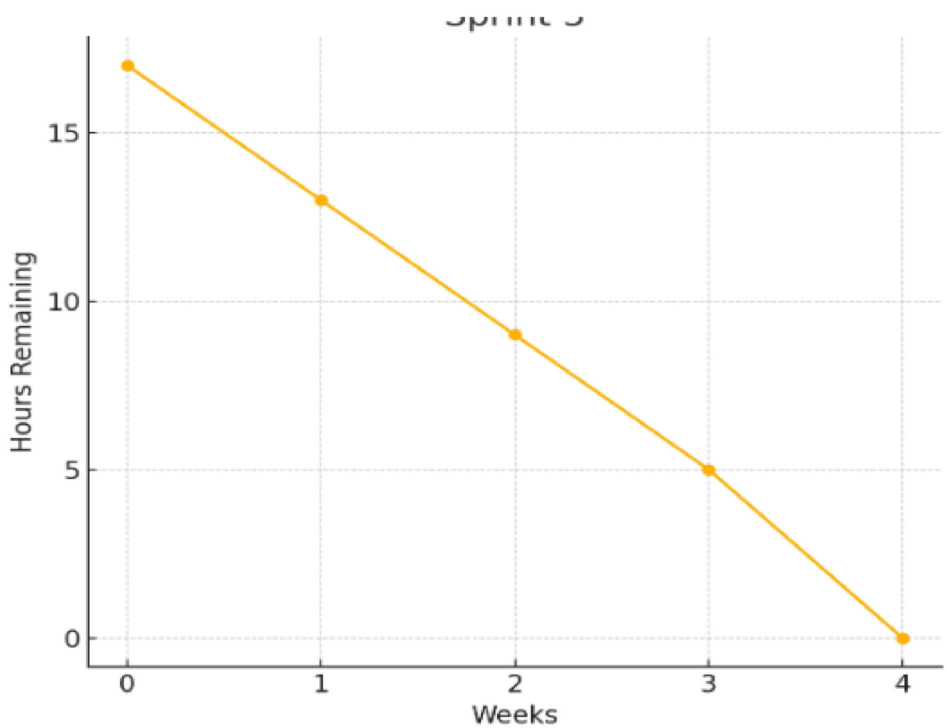

Figura 5.3: Sprint 3

Sprint 4[39]

Implementation Details:

- Add sound effects to interactions.
- Integrate background music into the environment.
- Implement informative videos and animations.

Validation Tests:

- Test sound effects to ensure they are in sync with the actions.
- Check continuous playback of background music.
- Test the playback and quality of videos and animations.

Burn Down Chart

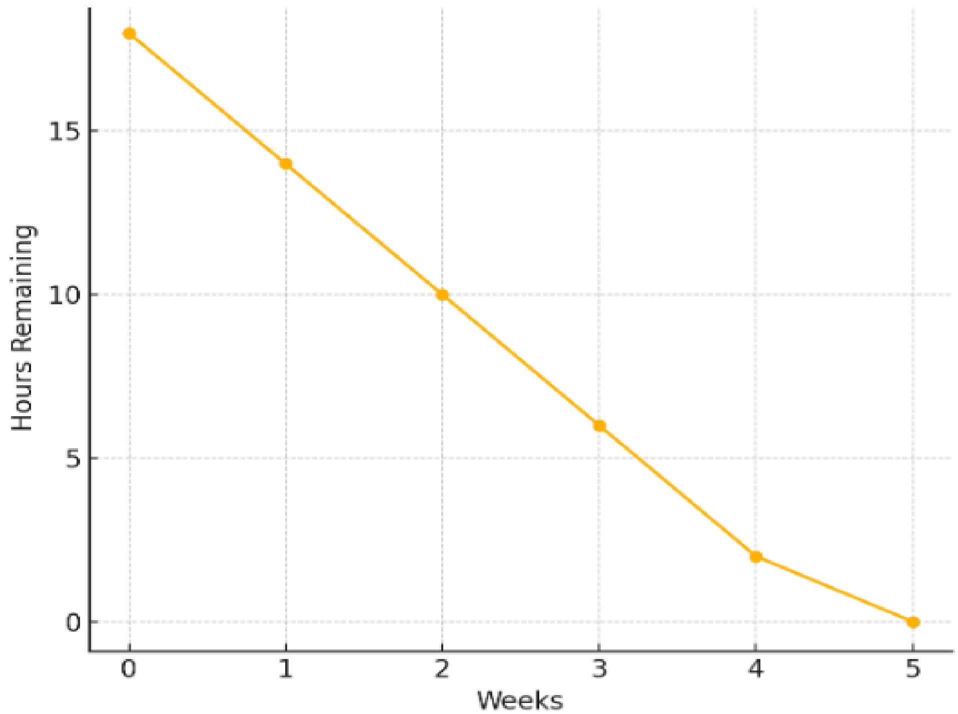

Figura 5.4: Sprint 4

Burn Down Chart

The Burn Down Chart is a visual representation of the amount of work remaining versus time. It helps monitor sprint progress and detect any deviations from the plan. For this project, a graph was considered that shows the expected reduction in hours throughout the sprints. Each sprint should be adjusted according to actual progress, and the Burn Down Chart should be continually updated to reflect work completed and work remaining.
With clear planning, structured execution and constant feedback, the project progressed cohesively and in line with expectations, resulting in a final product of high quality and relevance.

5.6 Beta Tests

Since most virtual environments are composed of large subsystems interconnected to create dynamics, it is very difficult for a group of developers to immediately identify all possible ”bugs”, implementation errors and “glitches”. The following is a description of them:

- **Bugs** refer to errors, flaws, or faults in a software program that cause it to produce incorrect or unexpected results, or to behave in unintended ways. Bugs can occur in various parts of the software, including the code, design, or even requirements. They can arise from a variety of reasons such as:

  - **Coding Mistakes:** Errors in the logic or syntax of the code.
  - **Design Flaws:** Issues in the overall architecture or design of the software.
  - **Integration Issues:** Problems when combining different parts of the software.
  - **Requirement Misunderstandings:** Misinterpretations or incorrect implementation of the requirements.

- **Glitches** are typically temporary malfunctions or anomalies that occur in software or hardware. Unlike bugs, which are often persistent and reproducible, glitches are usually brief and may not be easily replicated. They often manifest as visual or functional oddities that don’t follow the intended behavior of the software or hardware. Common causes of glitches include:

  - **Hardware Failures:** Temporary issues with the hardware that impact the software.
  - **Software Overloads:** Situations where the software or hardware is overloaded, leading to temporary malfunctions.
  - **Timing Issues:** Problems that arise from timing discrepancies in the execution of code.
  - **Random Errors:** Unpredictable issues that occur without a clear cause.

During the virtual museum beta tests, we performed extensive evaluation to identify and fix any issues before the final release. This process involved the participation of real users who tested the environment in different scenarios and virtual reality devices. The goal was to ensure the experience was fluid, immersive and free from significant glitches.

Therefore, at this stage, several bugs, glitches and failures were found, with one of the most common problems reported being related to the transition system between scenes. In some cases, the transition was not smooth, resulting in a noticeable delay or momentary stutters that compromised the user's immersion. This issue was particularly evident on devices with less processing power, such as some models of standalone headsets.

Another issue identified was the inconsistency in the behavior of VR controllers. The controllers, which were supposed to simulate the player's hands, sometimes did not respond correctly to movements, especially during more complex interactions like picking up and dropping objects. This caused frustration among users, as it undermined the feeling of presence and control within the virtual environment.

Another problem that greatly affected the development of the environment was the sudden disconnection that occurred between the screens. In this case, when the environment was running, the machine disconnected one of the displays and after a few seconds it also turned off, which indicated that there would be a failure in the rendering of the even if it was the overload caused by the amount of elements in the environment.

Visual glitches were also found, in some parts of the museum, textures did not load correctly, resulting in blurred or invisible surfaces. This not only affected the aesthetics of the environment, but also confused users, who were unable to correctly identify objects and exhibits. These glitches were attributed to problems in optimizing the loading of graphic resources and were addressed with adjustments to memory management and rendering.

Additionally, there were reports of problems with sound effects and background music, at certain times, interaction sounds, such as clicking buttons or touching objects, were not played, or the background music stopped abruptly. These issues were diagnosed as flaws in the audio system implementation, where priority conflicts and playback sequence errors caused these erratic behaviors.

While navigating the museum, some users encountered areas where teleportation did not work as expected. Instead of moving the user smoothly to the new location, the system sometimes placed them in the wrong locations or even outside the boundaries of the virtual environment. This issue was traced back to errors in defining teleportation zones and destination coordinates, which were fixed with a detailed review and additional testing.

Finally, some beta test participants reported that the environment did not load completely on certain occasions, especially after long sessions of use. This incomplete loading issue was attributed to memory leaks in the code, which were resolved by reviewing and optimizing the application's resource management.

5.6.1 Interpretation of the Results

Bugs Identified

During the beta tests, several bugs were detected that impacted the functionality and user experience of the virtual museum.

1. Bugs suggest the need for transition code optimization or memory management improvements.
2. There were failures that required a detailed review of the control interface and motion detection algorithms.
3. The environment still requires a need for optimization in the loading of graphic resources and a possible improvement in memory allocation.
4. Highlighted issues in the audio system were fixed by adjusting the sound playback sequence and resolving priority conflicts in the audio system.
5. A review of teleportation logic has been carried out and additional checks have been implemented.
6. Long usage sessions resulted in incomplete loading of the environment, indicating memory leaks, but this issue was addressed with a review and optimization of resource management in the code.
7. When the displays were disconnected, a problem that indicated a rendering failure, caused by system overload, the solution involved optimizing graphics resources and reducing the load on the GPU to avoid overload.

5.6.2 Conclusion of the Results

Beta testing played a crucial role in identifying a series of issues that could compromise the user experience in the virtual museum. Detecting bugs and glitches allowed the development team to make significant adjustments and improvements, ensuring that the final product was more stable, functional and immersive.

Resolving bugs related to scene transitions, VR controller behavior, texture loading, sound effects, teleportation, resource management, and display disconnection was essential to providing a satisfactory user experience. Adjustments to visual and audio glitches ensured that immersion was not compromised by temporary glitches.

Overall, the beta testing phase provided valuable feedback that guided the development team in optimizing the virtual museum, resulting in a more robust and polished environment for end users. The meticulous approach to resolving identified issues demonstrates the effectiveness of beta testing in improving the quality of software before its official release.

Capítulo 6

Conclusions

The conclusion of this thesis work on the development of a virtual museum reflects the commitment and dedication invested in each stage of the project, from the initial conception to the final implementation. In this sense, a first version was completed of the fully functional environment, which satisfies all proposed objectives. Throughout development, meticulous research, design, prototyping and testing processes were followed, which ensured the creation of a robust, innovative platform centered on user experience.

It is necessary to take into account the cost of developing a serious virtual environment, which also uses cutting-edge technology, as in our case of virtual reality, for which it is very high. We must bear in mind that developing a video game is a task very laborious process, which requires the participation of many professionals, both technical and creative, so that the product is viable in a timely manner and maximum performance is obtained promotional product of the product being promoted. For future developments it would be advisable we will work as a team to improve not only the speed of development, but also to provide power better compartmentalize work.

The prototyping phase stood out as a critical step, allowing the concepts to be validated and refined before moving towards final implementation. The initial sketches, wireframes and mockups provided a solid foundation for structuring the content and defining the navigability of the museum. Using Unity to develop high-fidelity interactive prototypes was essential for testing the user experience in a simulated environment, revealing valuable insights that guided the necessary adjustments to improve usability and visitor satisfaction.

Testing carried out with real users was essential to identify strengths and areas for improvement, ensuring that the virtual museum not only met technical requirements, but also provided an engaging and educational experience. The iterative approach allowed the project to continually evolve, adapting to users' needs and expectations, resulting in a dynamic and accessible platform.

This work also highlights the importance of interdisciplinary collaboration and the use of advanced technologies in creating innovative cultural experiences. The virtual museum developed demonstrates how the integration of art, history and technology can offer new ways of accessing and interacting with cultural heritage, expanding reach and inclusion.

In short, this work contributes significantly to the field of virtual museums, presenting a development model that can be replicated and improved in future projects. The virtual museum created is not only a digital platform, but also a bridge between the past and the present, allowing people from all over the world to explore and learn about diverse cultures and histories in an interactive and immersive way through advanced and prepared technologies. . This project symbolizes an important advance in the democratization of knowledge and the promotion of culture, establishing a new level for the preservation and dissemination of cultural heritage in the digital era.

6.1 Future Works

The main line of future work should be to increase the functionality of the video game in all sections. And to ensure the continuous evolution and improvement of the virtual museum, future work will be divided into two distinct phases.

Each phase will address specific aspects of development and expansion, aiming to improve user experience, accessibility, interactivity and content relevance.

6.1.1 Improvement Environment

Phase 1: Enhancement and Initial Expansion

1. **Performance and Usability Optimization**:
   - **Performance Improvement**: Optimize loading times and browsing fluidity to ensure a smoother, more efficient experience, especially on lower-spec devices.
   - **Usability**: Refine the user interface based on initial feedback, ensuring navigation is intuitive and information is easily accessible.
2. **Content Expansion**:
   - **New Exhibitions:** Add new exhibitions and collections to expand the diversity and richness of available content. This may include partnering with other cultural institutions to digitize and present their collections.
   - **Multimedia Resources:** Integrate more multimedia resources, such as videos, audios and 3D models, to enrich the user experience and offer different ways of interacting with the content.
3. **Accessibility and Inclusion:**
   - **Accessibility Standards:** Implement and improve accessibility standards, ensuring compatibility with screen readers, keyboard navigation, and other assistive tools.
   - **Multilingualism:** Add support for multiple languages, allowing a global audience to access and understand museum content.
4. **Advanced Interactivity:**
   - **Interactive Resources:** Develop additional interactive features, such as quizzes, guided tours, and simulations, that involve users in a more dynamic way.
   - **Augmented Reality (AR):** Explore the integration of augmented reality technologies to provide an even more immersive and interactive experience.

Phase 2: Innovation and Technological Integration

1. **Virtual Reality (VR) and Immersive Experiences:**
   - **VR Environments:** Create virtual reality environments that allow users to explore the museum in a fully immersive way, using VR devices for a more immersive experience.
   - **Multi-sensory Experiences:** Develop experiences that incorporate multi-sensory elements, such as spatial sound and haptic feedback, to enrich immersion.

2. **Integration with Artificial Intelligence (AI):**
   - **Virtual Guide:** Implement AI-based virtual guides that can interact with users, answering questions and providing additional information about exhibits.
   - **Content Personalization:** Using AI to personalize the user experience, recommending exposures and content based on their interests and browsing history.

3. **Gamification and Engagement:**
   - **Gamification Elements:** Integrate gamification elements, such as achievements, scores and challenges, to increase user engagement and encourage museum exploration.
   - **Events and Competitions:** Organize virtual events and competitions, such as scavenger hunts and knowledge challenges, to create an active and engaged community.

4. **Expansion and Strategic Partnerships:**
   - **International Collaborations:** Establish collaborations with museums and cultural institutions around the world to share resources and exhibits, increasing the diversity and depth of content.
   - **Integration with Educational Platforms:** Integrate the virtual museum with educational platforms, offering resources and tools that can be used in formal and informal educational contexts.

6.1.2 Virtual Environment to Promote Cape Verde

In addition to the improvements proposed in phases 1 and 2, essential future work will be the development of a virtual environment dedicated to promoting Cape Verde and increasing knowledge about the country. Cape Verde is a fascinating archipelago with a rich history, vibrant culture and stunning landscapes, but it is still relatively unknown to many people around the world. A virtual environment focused on Cape Verde can help highlight its natural beauty, cultural heritage and social contributions, attracting both tourists and scholars interested in learning more about the country.

Objectives of the Virtual Environment

The virtual environment will be developed to offer an immersive and educational experience, allowing users to explore Cape Verde in an innovative and interactive way. The main objectives include:

1. **Cultural and Historical Education**: Present the history of Cape Verde, including its colonization, independence and development over the years. Show cultural diversity and local traditions, including music, dance, gastronomy and festivities.
2. **Virtual Tourism**: Highlight the main tourist attractions, such as beaches, mountains, national parks and historic cities. Allow users to ”visit”these locations through 3D virtual tours.
3. **Environmental Awareness**: Show environmental conservation efforts and the natural beauty of Cape Verde, encouraging preservation and sustainability.
4. **Promotion of Local Talents**: Present Cape Verdean artists, musicians, writers and other talents, promoting local culture and arts.

Features and Functions

To achieve these objectives, the virtual environment will include several features and functionalities:

1. **Interactive Virtual Tours**
   - **Island Exploration**: Detailed tours of the main islands, allowing users to virtually explore cities, beaches and tourist attractions.
   - **Virtual Guides**: AI-based virtual guides that provide detailed information and answer user questions about the places visited.
2. **Multimedia and Educational Content**
   - **Videos and Documentaries**: Multimedia content about the history, culture and nature of Cape Verde.
   - **Virtual Exhibitions**: Exhibitions on specific themes, such as traditional Cape Verdean music, the history of independence, and environmental practices.

3. **Immersive Experiences with VR and AR**
   - **Virtual Reality**: VR environments that allow complete immersion in iconic locations in Cape Verde, using VR devices.
   - **Augmented Reality**: AR integration to enrich the user experience with additional information and increased interactivity.
4. **Gamification and Interactivity**
   - **Quizzes and Challenges**: Educational games that test users' knowledge about Cape Verde and reward them with virtual prizes.
   - **Gamified Exploration**: Missions and challenges that encourage exploring the islands and discovering important information.
5. **Partnerships and Collaborations**
   - **Collaborations with Local Institutions**: Partnerships with Cape Verdean museums, universities and cultural organizations to guarantee the accuracy and richness of the content.
   - **Integration with Educational Platforms**: Connect the virtual environment with educational platforms for use in formal and informal teaching contexts.

Expected Impact

The development of this virtual environment will not only increase global knowledge about Cape Verde, but will also contribute to tourism, education and cultural appreciation of the country. This initiative is expected to:

- **Attract Tourists**: Encourage real visits to the country, promoting tourism and the local economy.
- **Educate the Public**: Provide a valuable educational tool for schools and universities, both in Cape Verde and internationally.
- **Preserve Culture**: Help preserve and promote Cape Verde's rich cultural heritage, making it accessible to a global audience.
- **Encourage Partnerships**: Create opportunities for international collaborations and cultural exchanges.

With this virtual environment, Cape Verde will be able to stand out as a cultural and educational destination, providing unique and enriching experiences for users from all over the world.

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Appendices

Apéndice A

Acronyms

List

VirtuMuse: Virtual Museum
FPS: First Person Shooter
3D: 3 Dimensions
FTP: Final Thesis Project
VR: Virtual Reality
AR: Aumengted Reality
API: Application Programming Interfaces
SDK: Software Development Kit
PC: Personal Computer
IDE: Integrated Development Environment
RPG: Role-Playing Game
PC: Personal Computer
PMI: Project Management Institute
PMbock: Project Management Body of Knowledge
XP: Experience Point (Windows XP)
MITLicense: Massachusetts Institute of Technology License
GDScript: Dynamically and statically typed scripting language for the free and open source game engine Godot
Washington DC: Washington, District of Columbia
ARcore: Google's platform for building Augmented Reality experiences
ARkit: Augmented Reality Software Development Kit
SO/OS: Operating System
USB: Universal Serial Bus
RAM: Random-Access Memory
CPU: Central Processing Unit
GPU: Graphics Processing Unit
GB: Gigabyte
Hz: Heartz
AI: Artificial Intelligence

Apéndice B

Installation Manual

Installation File Download

Firstly, the user can download the VirtuMuse installation file from the GitHub repository. File Unzip:After downloading, unzip the file in a folder of your choice on your system. Environment Setting: Make sure you have Unity installed on your system (Windows, Linux or MacOS), as Virtu Muse was developed using the Unity Engine, which also allows its use on Android. Afterwards, the user can open the project folder in Unity.

Compilation and Build

In Unity, select the compile and build project option in ´File´ –>´Build and Run´. Follow Unity's instructions to compile the project for the desired platform (Windows, macOS, or Linux).

Application Execution

After the compilation process is complete, the user can run the generated application. Log in to the system without forgetting that you must be connected to the internet to do so and to be able to save your credentials automatically in the online server database.

Then follow the on-screen instructions to launch VirtuMuse and begin exploring the virtual museum.

Navigation Upon launching Virtu Muse, the user will be greeted with the Main Menu. Here are the available options:

Start Visit: Start exploring the virtual museum. Volume: Allows you to adjust the application's audio settings. About: Displays information about Virtu Muse and its development team. Quit: Allows you to exit the system and return to the login screen.

Exploring the Museum After selecting "Start Visitïn the Main Menu, the user will be taken to the virtual museum. Here are some features to explore:

Navigate Exhibitions: if directly on the computer and without using controllers or VR Headset, use the arrows or WASD keys, and the mouse to move around the museum and explore different exhibitions. View Work: zoom in on a work of art to view additional details, such as title, artist and description. Watch Audio-Visual Guide: Some exhibitions have audio-visual guides available. Look for signs or icons and click on them to start the guide. Volume Settings: On the "Volume Settings"screen in the Main Menu, the user can adjust the application's audio volume according to their preference.

Apéndice C

Virtual Museum 3D Models

In this work, a detailed list of models used to compose the Virtual Museum can be accessed in the public GitHub repository. The list includes a variety of artworks, sculptures, and artifacts organized by specific themed scenes within the museum. Each entry in the list provides information about the model name, type (such as painting, sculpture, painting, etc.), source of the 3D model or original image, and the date it was last updated.

GitHub List Access
The full list of templates can be found in the following GitHub repository:

Repository on GitHub

- README.md[44]

The README.md file in the repository provides a detailed description of the listed models, their categorization by scenes in the virtual museum, and details about their sources and updates. This document serves as a useful guide to understanding the composition and organization of visual elements within the context of the virtual museum.

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