UNIVERSIDADE
LUSÓFONA

João Filipe Villar Dias

Development of VR Application for cultural heritage preservation and re-curation

Orientador: Professor Doutor Louis Philippe Simões Castelo Branco Lopes

Universidade Lusófona – Centro Universitário de Lisboa
Escola de Comunicação, Arquitetura, Artes e Tecnologias da Informação
Lisboa
2025

www.ulusofona.pt

UNIVERSIDADE
LUSÓFONA

João Filipe Villar Dias

Development of VR Application for cultural heritage preservation and re-curation

Dissertação defendida em provas públicas na Universidade Lusófona – Centro Universitário de Lisboa, no dia 25/3/2025, para a obtenção do grau de Mestre em Engenharia Informática e Sistemas de Aplicação, perante o júri nomeado pelo Despacho de Nomeação n.º: 207/2025, de 3 de março de 2025, com a seguinte composição:

Presidente: Professor Doutor Paulo Jorge Tavares Guedes da Universidade Lusófona – Centro Universitário de Lisboa

Arguente: Professor Doutor Rui Filipe Nicolau Antunes da Universidade Lusófona – Centro Universitário de Lisboa

Orientador: Professor Doutor Louis Philippe Simões Castelo Branco Lopes da Universidade Lusófona – Centro Universitário de Lisboa

Este trabalho também foi orientado pelo Professor Doutor Filipe Luz da Universidade Lusófona – Centro Universitário de Lisboa

Acknowledgements

This work was carried out with the valuable support and mentorship of Professor Philippe Lopes and Professor Filipe Luz.

This work was funded by the European Union under the FILMEU RIT – Research | Innovation | Transformation project Congo VR – Decolonising the Panorama of Congo: A Virtual Heritage Artistic Research (Grant Agreement No. 101035820, H2020-IBA-SwafS-Support-2-2020).

Abstract

This dissertation presents the development of an interactive Virtual Reality (VR) application that explores the education potential of this technology in promoting the cultural heritage, Panorama of Congo. The developed application aims to preserve, and educate, through re-curation and decolonization, this colonial heritage for future generations in an immersive, engaging and interactive way. The project implementation features the collaboration of five artists from Congo and Congolese Diaspora in the form of interactive artistic installations within the virtual world, bringing a new narrative to the panorama colonial history. The development of the application was divided into three prototypes, testing the usability and user satisfaction with the use of questionnaires and playtesting in museum exhibitions. The final version of the application was presented to the public in the *National Museum of Natural History and Science* in Lisbon for 3 months. The contribution of this dissertation is the development of a platform that serves as a template for the preservation, re-curation and education of cultural heritages, such as Panoramas, to the public through museum exhibitions.

Keywords: Virtual Reality Technology, Digitization of Cultural Heritage, Virtual Interaction, Cultural Heritage Preservation, Unity Development

Contents

List of Figures

Chapter 1

Introduction

Virtual Reality (VR) applications provide an immersive experience to end-users with 3D computer-generated environments. Even though VR technologies are not a recent subject, being introduced around three decades ago by Rheingold (1991), its uprising in popularity started around 2016, with the release of more accessible devices such as Oculus Rift and HTCVive, and software support from the likes of Unity and Unreal engines. The use of VR technologies allows for the exploration of new forms of immersive and engaging experiences, permitting the generation of realistic scenarios that simulate the users physical presence, movements, in a virtual environment. These VR experiences also host the possibility of containing other media formats, such as videos, documentaries, pictures, music, etc, (Eugene Ch'ng et al., 2020). Enabling the creation of virtual worlds for a plethora of purposes, such as the simulation of environments for psychology treatments, public construction, video game entertainment, and cultural education, including the virtual reconstruction of lost artifacts. In this context, VR technology has the potential for communicating aspects of cultural heritage that are not possible with the use of other media formats, if used properly VR can bring entire new and better experiences to museum displays (Eugene Ch'ng et al. 2020).

Museums are locations with the intent of preserving and educating individuals about specific cultures and history through tangible historical artefacts and exhibitions. Usually museum displays and cultural heritage sites group artefacts according to their historical periods and contextualize them so that visitors acquire maximum information while saving space, a valuable resource in museums. However, displaying cultural heritages of substantial size such as Panoramas, large 360º canvas illustrating a broad scene, in a museum is a very challenging and expensive endeavor. In recent years, with advancement in VR technologies and the release of more accessible tools, the digitalization of these heritages became possible, using the virtual environments to contextualize and provide deeper information to the visitors while preserving space. Furthermore, the use of VR in museums added the ability for

the public to interact with the historical artefacts. In this context, enhancing museum exhibitions and collections through the creation of new immersive, engaging, and interactive forms of education and cultural heritage preservation has become increasingly relevant. Technologies such as 360° VR video storytelling, documentaries, 3D virtual reconstructions, and interactive experiences offer innovative ways to present and preserve historical artefacts, making them more accessible to the public while overcoming spatial and logistical constraints.

In this dissertation we address the developing process of a VR application (VR_CongoPanorama) that, through exhibitions in museums, artistic co-collaborations, and multiple usability tests in the form of prototypes and questionnaires, aims to present, preserve, re-curate and decolonize the cultural heritage, the Panorama of Congo, in a interactive and engaging way. This application features the virtual recreation of the classical panoramic exhibition, the digitalization of the painting and the implementation of interactable artistic installations in the form of videos, animations, mockumentaries, etc.

The dissertation is organized in the following chapters: Chapter 2 provides an overview of the literature on the application and usability of VR in museum exhibitions; Chapter 3 introduces the pilot project and its established goals; Chapter 4 describes the VR application build, its philosophy and main features; Chapter 5 establishes the methodology used for the development of the application, including the tools used for the program and the implementation of its features; Chapter 6 presents results of the application and its prototypes; Finally, Chapter 7 concludes the paper and discusses future work.

Chapter 2

Background

This section explores how Virtual Reality (VR) has been used in the context of museums and cultural heritage, while also identifying a research gap in the specific application of VR to panoramic heritage. It presents relevant literature and studies that look at both the potential and challenges of integrating VR into heritage education, exhibition, and preservation efforts.

According to UNESCO (2024), cultural heritage plays a crucial role in addressing global challenges like climate change, inequality, and the digital divide. Heritage not only reflects creativity but also carries the weight of historical injustices—particularly in postcolonial contexts. Museums are at the center of this, acting as both preservation spaces and critical platforms for reinterpreting cultural narratives. However, museum visitor demographics show a tendency toward older age groups, with younger generations showing less engagement (Ch'ng et al., 2020). This has led many institutions to adopt interactive digital technologies like VR to appeal to wider and younger audiences.

The use of VR in museums allows visitors to immerse themselves in cultural experiences, transforming them from passive viewers into active participants. This connects with John Dewey's (1938) theory of experiential learning, which argues that knowledge is best acquired through direct interaction and participation. The immersive quality of VR makes it ideal for this kind of learning, where interaction and exploration contribute to deeper understanding.

Ch'ng et al. (2020) explored the impact of VR environments on how young people engage with cultural heritage. Their study showed that VR was widely accepted by younger audiences and enhanced their learning experience. Interestingly, prior experience with gaming or VR didn't necessarily improve the quality of the experience itself, but did make users more adept at navigating the environment. This is an important design insight, especially in museum settings where not all users are familiar with VR. The application developed in this dissertation took this into account by integrating an introductory tutorial to

improve accessibility for all users. The same study also noted that object-based interaction contributed significantly to the feeling of presence and meaning in the virtual space. This aligns closely with the project developed for this dissertation, where interactable artistic installations—created in collaboration with five Congolese artists—play a key role in reshaping and re-curating the narrative of the Panorama of Congo.

Another relevant study is by Theodoropoulos and Antoniou (2022), who conducted a review of how VR games are used in cultural heritage. While the project developed here is not a VR game per se, their findings highlight that interactivity and enjoyment are key factors in making cultural content more accessible and memorable. Their review shows that VR applications can fulfill a wider range of user expectations, not just in terms of learning but also emotional and social engagement. This informed the use of interactive elements in the developed application—designed to support both educational and immersive objectives.

Ali (2024) focused on a VR game created to educate users about Saudi heritage. His work confirmed that VR technologies are well received by younger audiences and support motivation and curiosity in learning. Like the present application, Ali evaluated users through open-ended questionnaires, helping collect more detailed feedback. Costa et al. (2024) also approached VR from a preservation angle, with their XiloVR project, which teaches traditional woodcutting techniques from Pernambuco through immersive simulation. Although their project was not tested in a public setting like a museum, it demonstrates how VR can preserve and transmit endangered cultural techniques. The current dissertation builds on this by evaluating the application in real museum contexts (Lisbon's Bordalo Pinheiro Museum and the National Museum of Natural History and Science), including feedback collection during public exhibitions.

Beyond these examples, it's also important to note that not all academic perspectives view VR in museums as purely positive. Sanders (2014) and critics like Parry (2019) warn that digital tools, while powerful, can oversimplify or even distort historical narratives if not critically applied. Antunes (2024) builds on this argument by emphasizing that immersive technologies often risk creating overly coherent, decontextualized experiences that may obscure the historical and cultural complexities of the past. In a related case study, Antunes (2024) critiques a VR reconstruction of medieval Silves, arguing that even well-intentioned immersive representations can unintentionally reinforce myths of historical unity or neutrality. These reflections are particularly relevant in the context of this dissertation, where the re-curation of a colonial object—the Panorama of Congo—is central. The artistic interventions and interactive installations developed for the project aim to address these

concerns by making space for alternative perspectives and more inclusive, critical storytelling.

Despite the increasing number of projects and research combining VR and cultural heritage, there is little academic work specifically focused on VR applications for panoramic heritage. Panoramas are unique cultural artifacts that represent immersive, historical storytelling in their own right. Yet, academic attention has largely bypassed them in VR research. This creates a gap that the present work seeks to address—by building a VR experience around a specific panorama, with the goal of preserving it and also opening it up to new forms of interpretation.

In summary, VR is becoming a promising tool for engaging broader audiences in museum and heritage settings, especially younger generations. At the same time, there is a need for careful design and critical thinking in its implementation, particularly when dealing with complex histories. The application developed for this dissertation contributes to this conversation by combining interactivity, artistic collaboration, and cultural critique, offering a new approach to the preservation and reinterpretation of panoramic heritage.

Chapter 3

Congo-VR

Introduction

CONGO-VR is a pilot project focused on the “decolonisation of media heritage” as referred to by Flores et al. (2022) . In doing so, it brings media heritage artefacts into debate on the decolonisation of museum collections . The objective of this project is the inclusion of unheard voices about the colonization of Congo in contemporary museum practices, which investigates the re-curation and decolonisation of the Panorama of Congo (see 3.1). To present the Panorama of Congo, CONGO-VR explores the concept of 'virtual heritage'—a relatively recent term describing the use of digital and virtual technologies to document and communicate cultural heritage (Sanders, 2014). To critically re-curate this historical object for contemporary and future audiences, CONGO-VR investigates how virtual reality can be used to create and showcase complex, multi-layered, and diverse narratives about the colonial past within a single virtual space (Flores et al, 2022). These narratives are developed through the collaboration, co-creation, and artistic research by both Diaspora and Congolese artists and the research team (see chapter 4).

As a scholarship holder in this project, my role focused on the technical development of the VR application. I was not directly involved in curatorial or conceptual decisions but contributed by implementing and optimizing the application’s systems to ensure performance and usability in various exhibition settings. Motivated by the challenge of supporting this international and interdisciplinary project through technological means, I aimed to provide a stable and accessible platform capable of hosting and enhancing the immersive experience of these decolonial narratives within a museum environment. A detailed overview of the tasks carried out during the development process is provided in annex 1.

3.1 The Panorama

The Panorama was the most popular picture-going entertainment of the 19th Century (Flores et al, 2022). It consists of an extremely large canvas depicting a broad scene visualized in a circular rotunda, providing one of the first illusions of 'Virtual Reality.' During the 20th century World Fairs, namely in the Colonial Exhibitions, the Panoramas were revisited as a powerful means of persuasion and propaganda (Flores et al, 2022).

CONGO-VR studies and re-interprets one of these late Panoramas, the Panorama of Congo, a callback icon of the violent imperialist policies performed in the former Belgian colony of Congo (1885-1960), by Paul Mathieu and Alfred Bastien. This enormous 360º panorama painting, measuring 14mx115m, was displayed in two colonial exhibitions (world fair of Ghent, 1913; and Brussels, 1935). As referenced by Flores et al. (2022) the painting represents the "four pillars of colonialism: the missionary church, the colonial industry, the colonial administration and the colonial police", it also displays the country's natural beauty and the people's daily life and local customs.

Figure 1. Digitized painting of the panorama (155,526x17626 pixels).

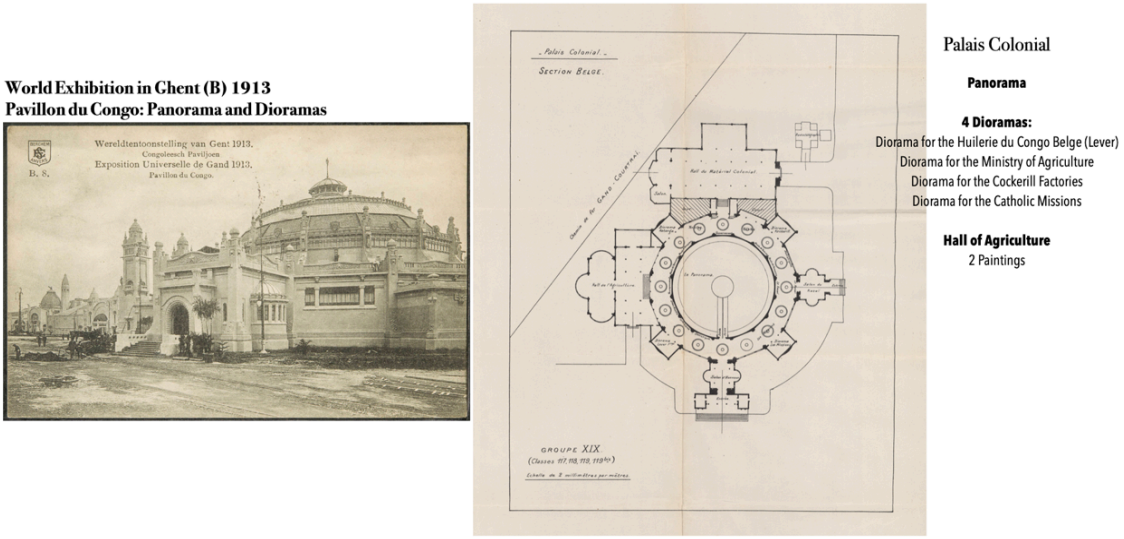

Figure 2. Panorama of Congo – Installation building 1913, images courtesy Africa Museum, Tervuren, Belgium.

3.2 Project Goals

CONGO-VR aims to integrate this media heritage into current discussions of decolonization in museum collections. By photographing and re-curating these images through archival and artistic research within a Virtual Reality interactive experience, CONGO-VR intends to prepare this heritage for future generations, fostering critical engagement from various stakeholders. For this purpose the following goals were established (Flores et al, 2022):

1. Ensure a high-resolution photographic reproduction of the Panorama of Congo;
2. Bring this colonial panorama into the debate of colonial museological practices and the decolonisation of collections;
3. Use artistic research to both decolonise the Panorama and to test VR affordances;
4. Use artistic research to reflect this decolonisation process on a documentary film;
5. Provide future access to this new kind of Virtual Heritage produced by this pilot through exhibitions in the Africa Museum (Tervuren), in the War Heritage Institute (Brussels) and in the Natural History Museum (Lisbon);
6. Research the history of this panorama along with the colonial policies and polemics around Congo atrocities;

This thesis specifically addresses point 1 and point 3: The process to achieve the high-resolution panorama image in a digital format for the Virtual Reality application and the technical implementation of the artist's interventions in the VR experience.

Chapter 4

VR Application

Introduction

The strategic use of a virtual reality application in this project is crucial due to the nature of the cultural artifact involved, which is not easily accessible by the general public. Modern VR systems provide immersive capabilities that simulate the sensation of being present within 19th-century panoramas. This immersion is further enhanced by integrating additional layers of information—such as video, images, and sound—allowing users to engage with the artwork in a way that goes beyond passive observation. By enabling users to navigate and interact within the virtual space, VR fosters a heightened sense of presence and agency, making the experience more personal and impactful. Therefore, the application developed for this project not only engages users through interactivity and embodiment but also enhances the communication process, facilitating the re-curation of the Panorama from a post-colonial perspective into an immersive and interactive experience.

4.1 VR_CongoPanorama

The *VR_CongoPanorama* is the VR application created for this project, it was designed for both Oculus Quest headsets and personal computers, and developed with the *Unity* engine. The development followed an iterative process using an agile methodology. The application was developed into two versions, the *Historical* and the *Artistic* versions.

4.1.1 Historical

The Historical version of the application focuses on the decolonization of the painting, representing a relatively faithful historical immersive experience of classic 19th-century panoramic exhibitions while showcasing this media heritage and raising public awareness about the need for its restoration and proper preservation. Another important goal is to bring awareness that this media heritage was a propaganda and why it is so. By presenting a counter narrative using information, testimonies and documents unknown to the public and un-presented in the original propaganda, this application aims to contribute to the decolonization of the panorama. One of the main challenges was to present this counter-narrative in an immersive and visually engaging way using the VR platform while maintaining a serious tone with minimal interaction. To achieve this a audio narrative was created using a more “theatrical” approach using images, videos, and lighting effects to guide the user's attention and keep them engaged (see annex 2). Given the author's minimal contribution to this version of the application, the focus of this dissertation will be on the Artistic version of the Panorama (see below).

4.1.2 Artistic

The Artistic version of the application focuses on the decolonization and curation of the panorama of Congo, using a remediation approach. Furthermore with the co-collaboration of the congolese and diaspora artists, and the artistic research team, interactive artworks were created (see 4.2.3), to provide new insights and create a new decolonized narrative of the panorama of Congo.

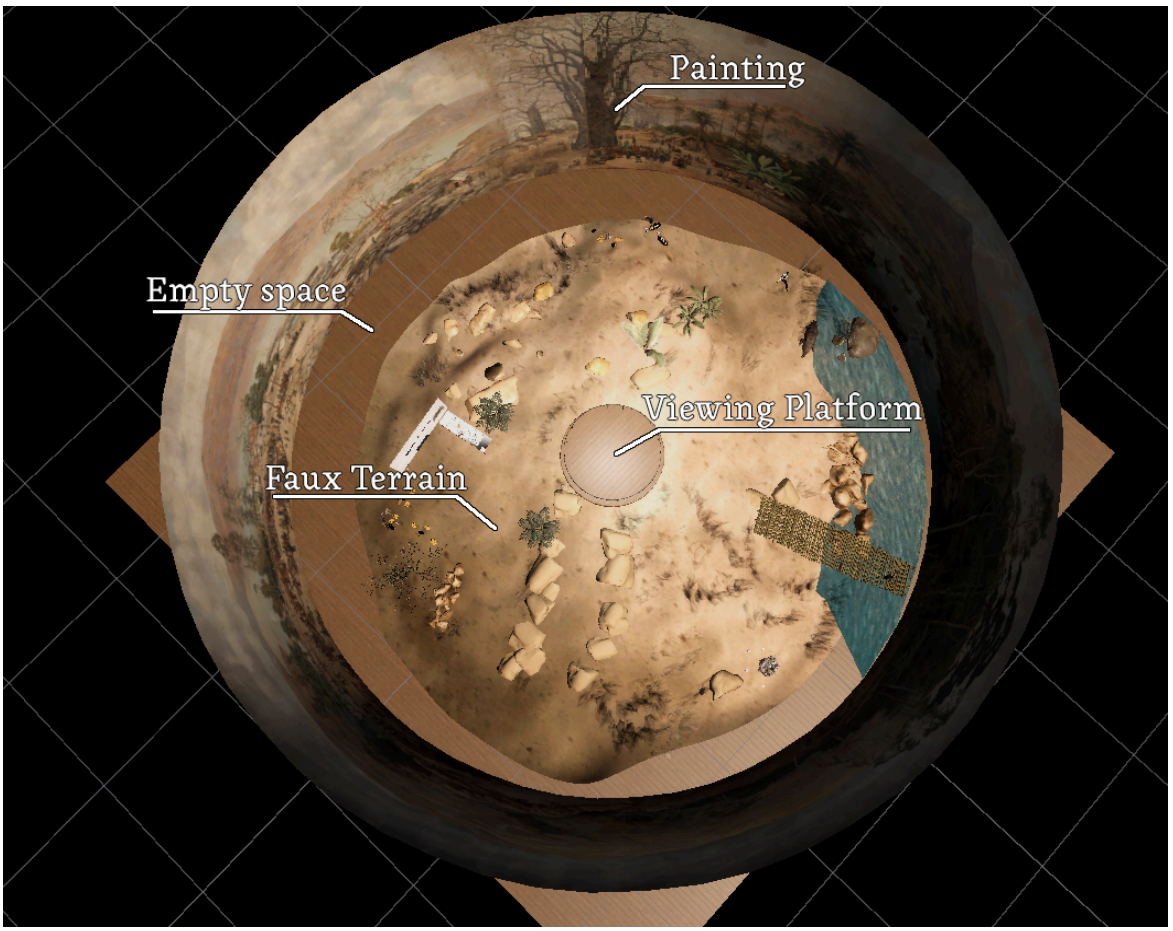

Figure 3. Top down view of the application with descriptions of key locations in a panoramic exhibition: Viewing platform- location from where the user is supposed to observe the painting in the classic panoramic exhibitions; Faux terrain- space between the painting and the viewing platform filled with physical objects to elevate the level of immersion; Empty space- technical space for control and maintenance of the painting; Painting- location of the 360 panoramic painting.

To challenge the traditional framework of this panoramic exhibition (The Panorama of Congo)—historically used as colonial propaganda—the VR experience allows users to leave the intended viewing platform and fully explore the surrounding space. This break from the fixed perspective of classical panoramic exhibitions symbolizes a shift in agency, granting users the freedom to navigate beyond imposed limitations. By stepping off the designated platform, users metaphorically reject the restrictive viewpoints embedded in these historical displays, actively engaging with the artwork on their own terms. This interactive element plays with the concept of decolonization by subverting the controlled, one-directional gaze imposed by traditional panorama presentations. In this context, allowing users to move freely transforms their role from passive observers to active participants, challenging how colonial narratives were historically framed and consumed.

The *faux terrain* is an area in between the central viewing platform and the painting where physical objects are placed to strengthen immersion between the painting and the environment in the traditional panoramical exhibition (see figure *3*). In addition to this, to better synchronize the artist's works with the curatorial concepts in this digital format, the artworks produced by the invited artists were placed in the areas of *faux terrain* that expressed more the objectives of their artistic installations (see 4.2.3).

4.2 Features and Functionality

In this section we will present the main features and functionality of the Artistic version of the VR_CongoPanorama application. We will begin by providing an overview of the features of the application. Next we will delve into the sound application for the project. Finally we will discuss the features and interactions developed for the installation of the artist's work.

4.2.1 Main Features

For the purpose of achieving the goals established for this project the application needed the following features:

- **Language** chosen at the beginning of the application (Portuguese or English).
- **Tutorial** to teach the movement and interaction of the application (see annex 3).
- **Locomotion movement** to allow movement in the real space to be transmitted in the VR application.
- **Point-based Teleportation** the main form of translocation in the application (see annex 4).
- **Teleporting Menu** for easy accessibility allowing the teleportation to the artworks via a menu (see annex 5).
- **Replay feature** to reset the application automatically, when someone removes the glasses.
- **360º Painting** of the panorama in full detail showcasing the re-curation results.
- **Faux Terrain** to bring the immersion and connectivity to the painting.

- **Lighting** to make the entire painting visible and create an immersive atmosphere.
- **Artists Works** to bring new views and decolonize the panorama of congo.
- **Sound** is essential for establishing an immersive experience (see 4.2.2).
- **Subtitles** to facilitate what is being said, as the experience can take place in noisy environments such as museums.
- **Artistic installation specific features**: Vídeo snippets; Interactable user interface (main form of interaction); Interactable objects; Highlights.

4.2.2 Sound

The state of immersion is a crucial part of this application. Sound plays a key role in an immersive experience, it can completely direct a person's attention, emphasize context or provide feedback about the environment (Volha Saroka, 2024). In this application, sound is used for effects such as footsteps, ambient sound, music, dialogue, sound effects, and sound embedded within video.

The use of these effects is more prominent in the narrative developed for the Historical version (see 4.1.1) and in artworks made in collaboration with the artists for the artistic version (see 4.2.3).

4.2.3 Artistic Installations

As mentioned in section 4.1.2, to dwell with the concept of decolonizing the Panorama of Congo in the VR application, a collaboration with Diaspora and Congolese artists was established. This collaboration consisted in implementing each artist's work into the VR application. A total of five artists assisted with this collaboration (Deogracias, Castélie, Lukah, Hadassa and the Kongo Astronauts). In this section we will only discuss the work that the author implemented, that being the collaborative artworks of three artists - Deogracias, Castélie and Hadassa.

I. Hadassa

Hadassa´s installation invites us to reflect on crony capitalism as a rational system of domination whose principles continue to manifest themselves, namely through the interest in various metals in the Democratic Republic of Congo and the inhumane means used to obtain them. The art installation consists of a long table (4 meters), a symbol of negotiations, coexisting with other elements, such as over 1000 pennies, meant to represent the luxury and consumption in Europe due to natural resources from Congo (see figure 4).

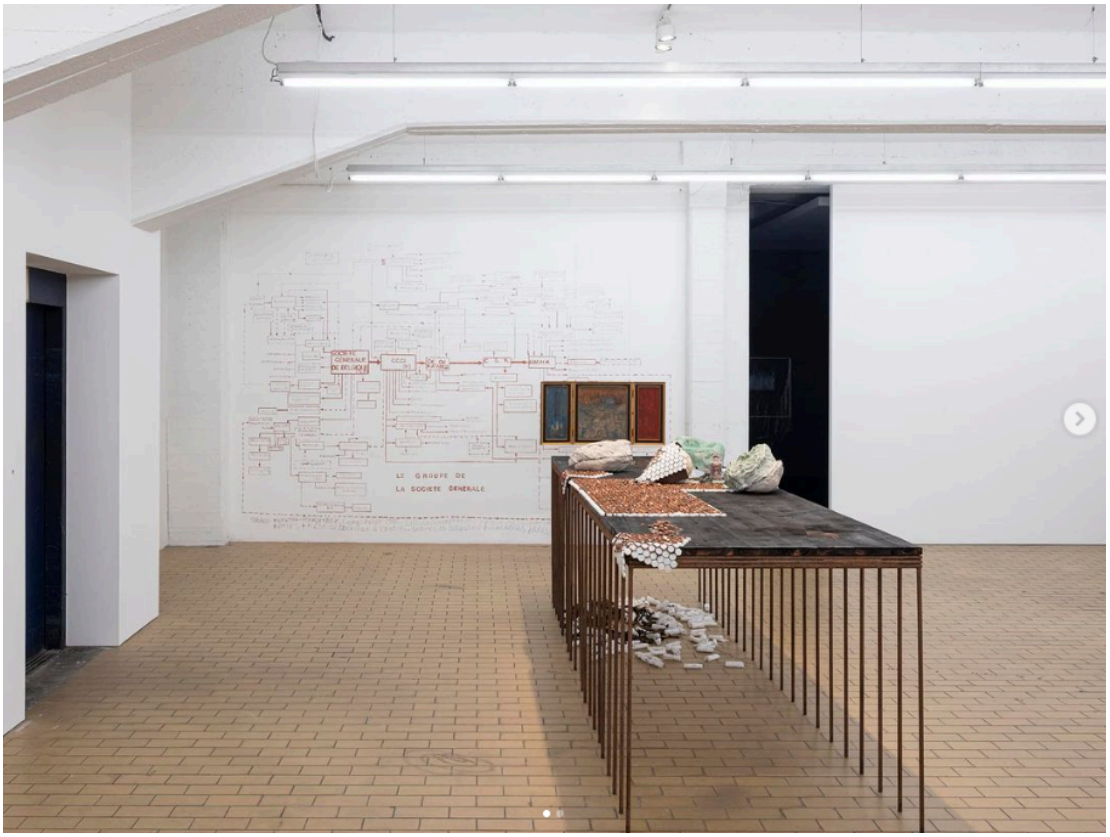

Figure 4. Gallery installation of Hadassa's table.

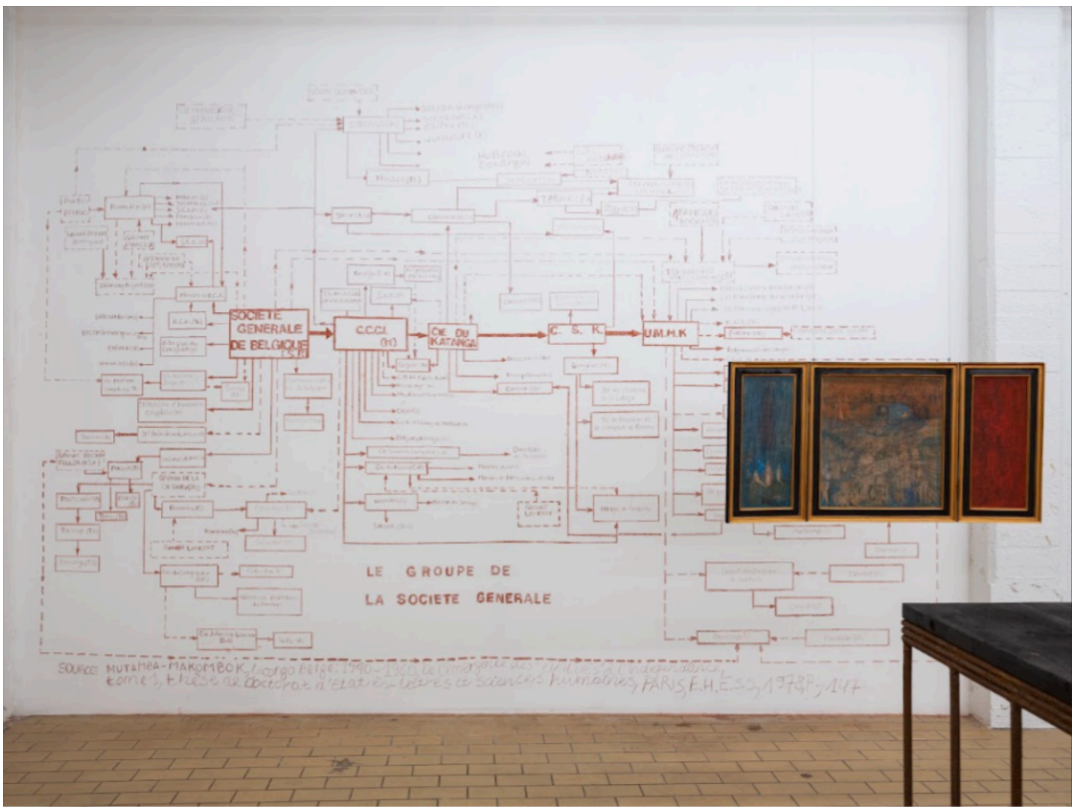

Figure 5. Close up of hierarchical diagram in Hadassa's gallery installation.

The installation also includes an interpretation of a colonial archive object: a diagram that recalls the hierarchical complexity and rationality of the system (see figure 5). Hadassa´s work raises issues regarding religion, economics, knowledge/power systems and social justice.

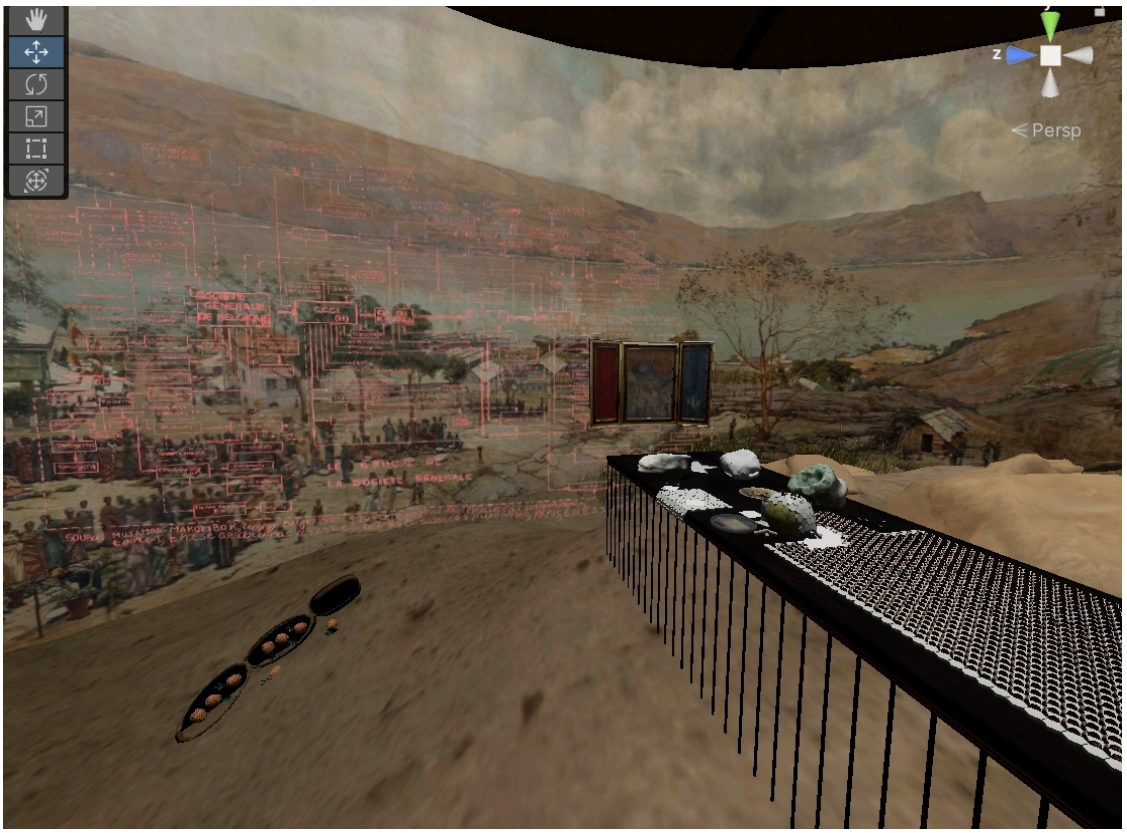

Figure 6. Hadassa´s artwork in the VR application.

For the VR application, Hadassa's installation was photoscanned and then digitized into a 3D model by the development team's 3D artist (see figure 6). This artwork plays with the idea of balance, as it features a long table with many skinny legs (42 legs) to give a false sense of stability at a distance, but when approached it starts shaking intensively as the violent exploitation system in Congo (see annex 6).

II. Castélie

Castélie's installation, titled *Ghost's Word*, is an animated dance performance that explores the tension between identity and belonging. As described by Castélie (see annex 7), the piece reflects on the conflicting forces that shape individuals caught between their place of origin and their lived experiences in a new environment. Through choreography, it conveys the struggle of navigating multiple cultural identities and the emotional friction that arises from this duality. The artist explores narratives, memories, and territories where her body becomes a site of tension, suspended between the gaze of the spectator and her own

subjectivity. Her body, both subject and object, carries stories of domination, displacement, exile, and hope.

The dance itself was recorded using motion capture and later edited with special effects. These special effects consisted of an “inflating" effect (effect not developed by the author), causing the character proportions to grow and shrink uncontrollably, during the performance made by the artist (see annex 8). In addition to this another animation starts at the end of the dance. This animation makes the character grow to enormous proportions filling most of the virtual scene, when the character grows to the point of reaching the ceiling it stops and disappears, to later reappearing where it was situated in the beginning (before starting this second animation), marking the end of the piece (see annex 9).

Figure 7. Castélie´s installation in the VR Application.

III. Deogracias

Deogracias' work in this project installation is called *“past-present”*, because “it speaks of the past in the present, showing that the past is not distant, but close, keeping us living in its continuous haunting”, as explained by Deogracias (see annex 7). Deogracias further reinforces this by stating “my work in this project has the same meaning as the

Panorama of Congo itself, a painting that crosses time to illustrate a period that has already passed but that is still present in many ways today“ (see annex 7). This installation pretends to overwrite colonial propaganda with intensive and real words such as: invasion, foreign occupation, capitalism in the Congo, severed hands, veils, humiliation, trauma and so many others (see annex 7). Its main goal is to go through the denunciation, the resistance or the fight by touching the wound to clean it, to heal it by dialoging, by demanding the reparation which will lead to resilience (see annex 7). To achieve this Deogracias installation was separated into two parts: The nest; and the mockumentary;

Figure 8. 3D models of the nest and the eggs for Deogracias installation, created by the 3D artist in the team.

The first part focuses around the nest and the placement of 5 eggs in it (see figure 8). After placing all the eggs inside the nest, by grabbing them (see annex 10), the second part of the installation begins. This first part of the installation symbolizes resilience, renewal and the cycle of life, being reborn (see annex 7).

The second part of the installation focuses on overwriting the colonial propaganda, with the use of five audio mockumentaries talking about specific sections of the painting. This installation invites the user to explore and engage with the painting in a more informed way. To facilitate this, users are teleported to the specific section of the painting being discussed in the corresponding mockumentary, with that area visually highlighted to guide their attention. When the user looks at the highlighted region, the audio begins playing. These

audio mockumentaries are further supported by subtitles that follow the user's gaze, ensuring that no matter where the user decides to look, they can always follow the narration (see annex 11). After all 5 mockumentaries are listened to or the user decides to stop, the artwork is considered completed.

Chapter 5

Application Implementation

Introduction

In this chapter, we will delve into the implementation of the VR_CongoPanorama application. The scripting language used was C#, chosen both for its familiarity to the developers and its close integration with Unity, allowing direct and efficient access to Unity's API and official documentation. The project's full codebase is hosted in a dedicated GitHub repository (see Annex 12), providing an organized and versioned overview of all implemented scripts and assets. This chapter begins with an overview of the Unity engine and the sound design process, followed by a detailed explanation of the painting interaction system. We conclude by discussing the integration of the artist's original work into the VR environment.

5.1 Unity

Unity is a game development engine used for creating 2D or 3D interactive experiences, it provides real-time rendering, Cross-Platform support, VR and Augmented Reality (AR) integration and built-in physics support, allowing developers to simulate realistic movement, collision, and environmental interactions. Before getting in more detail about the implementation it is necessary to explain some of the key tools used in development provided by this engine, such as a Scene, GameObjects, Components, Collider, Coroutine, Shaders and Timeline:

- A Unity *Scene* is a fundamental building block in the Unity game development environment, representing a space in which all *GameObjects*, *Components*, and logic are organized and executed. Everything inside a *Scene* is rooted in a *GameObject* which is an empty container that can hold components like scripts, meshes, lights, physics, etc. *GameObject* can have various *Components* Attached to them, which define their behavior

and properties. Some common *Components* include: A Transform Component (controls the position, rotation, and scale of the GameObject) and Collider Component. A *Collide*r defines the shape of an object for the purposes of physical collisions.

- A *Coroutine* is a "method that can pause execution and return control to Unity but then continue where it left off on the following frame" (Unity Technologies, 2024). In most situations, when you call a method, it runs to completion and then returns control to the calling method. This means that any action that takes place within a method must happen within a single frame update. In situations where the use method call to contain a procedural animation or a sequence of events over time is necessary, a coroutine can be used (Unity Technologies, 2024).

- A *shader* is a program that runs on the GPU, designed to manage and customize the visual appearance of objects within the Unity scene (Unity Technologies, 2024). Furthermore the *shader* emission property controls the color and intensity of light that the surface of a *GameObject* emits, making it appear as a visible source of light.

- The Unity Timeline Editor is a "built-in tool where you create and edit cinematic content, gameplay sequences, audio sequences, and complex particle effects"(Unity Technologies, 2024). This tool was used to create audio and subtitles sequences for the artistic representation of Deogracias.

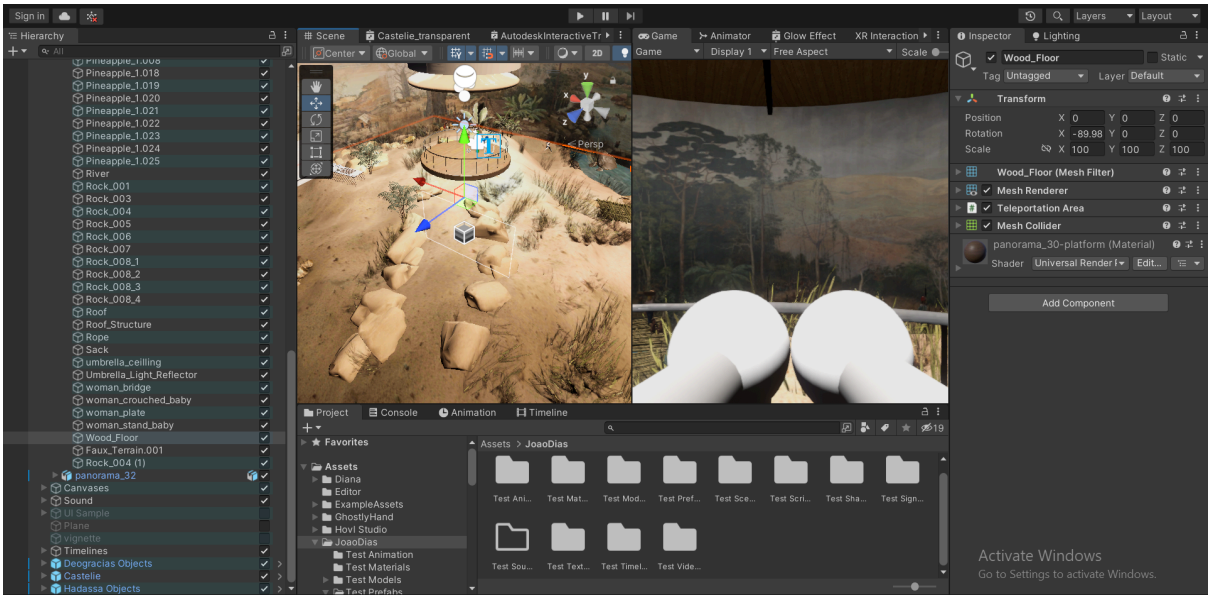

Figure 9. Unity development environment.

5.2 Sound

Sound plays a crucial role in enhancing both the experience and immersion of the application. The sound implementation in this project is centered around two main classes: *AudioManager* and *ActivateSound*.

The *AudioManager* class is responsible for managing all sound interactions, allowing for the creation of *EventInstances*—each representing an instance of an audio event. These instances serve as references to audio files, enabling control over when specific sounds should play or stop. Additionally, the AudioManager class includes a feature that ensures only one area-based sound is playing at a given time, preventing audio overlap.

The *ActivateSound* class, on the other hand, is responsible for triggering all sound playback in the project. Every object that needs to produce sound requires this class. Its primary function is to play and pause the soundtracks associated with interactive objects. There are two main types of audio objects used in this project:

AreaSounds – These objects play sound when a user approaches a specific area in the scene, using an area *collider* (see 5.1) to detect proximity. When the collider is triggered, the PlaySound method of the ActivateSound class plays the corresponding audio.

EnvironmentSounds – These invisible objects provide continuous ambient audio, such as wind or distant footsteps, to enhance immersion.

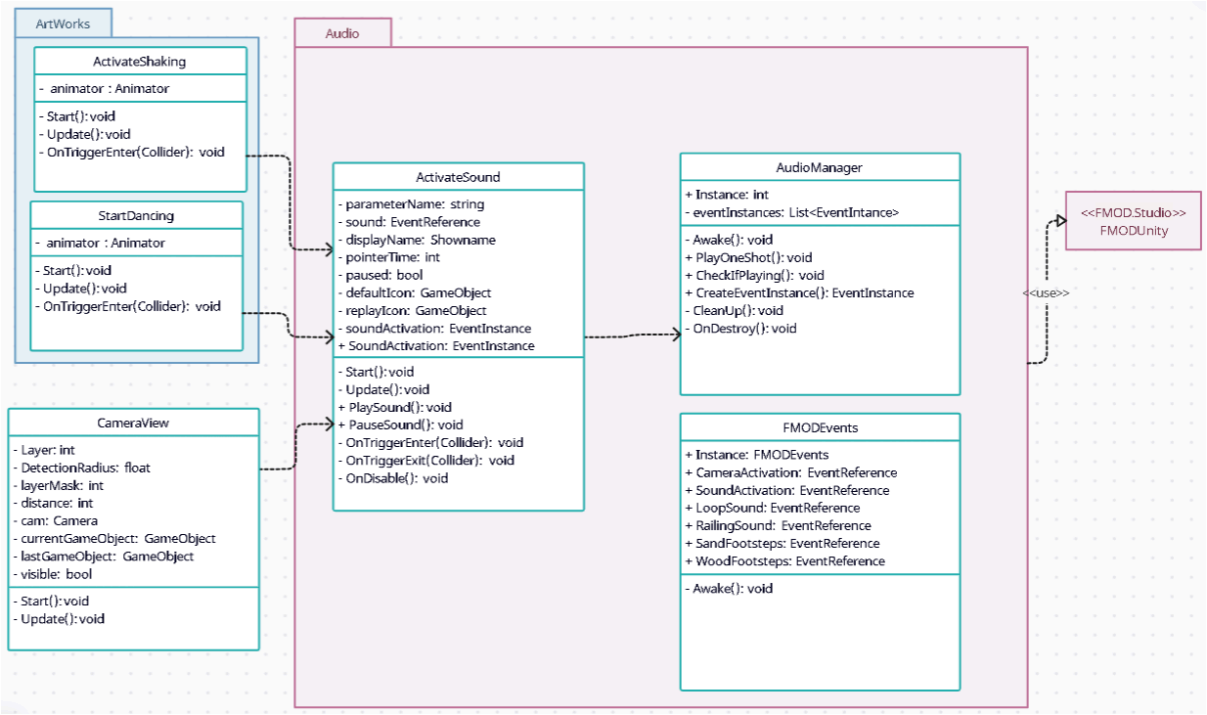

Figure 10. Relation chart between ActivateSound script.

To facilitate sound design and interaction, the FMOD engine was integrated into the project. FMOD provides seamless support for Unity, enabling real-time sound design adjustments. By using FMOD's CORE API, the project benefits from improved control over audio interactions and dynamic sound behavior.

FMOD's sound implementation is built around Events—known as FMOD Events—which act as triggerable, controllable units of sound. As described by Firelight Technologies (2024), "everything that produces a sound in a game should have a corresponding event."

Another method of implementing sound in this project is through FMOD Event tracks, which are used in *timelines* (see 5.1). These tracks contain FMOD Events, allowing for precise control over when audio files play or stop throughout the experience.

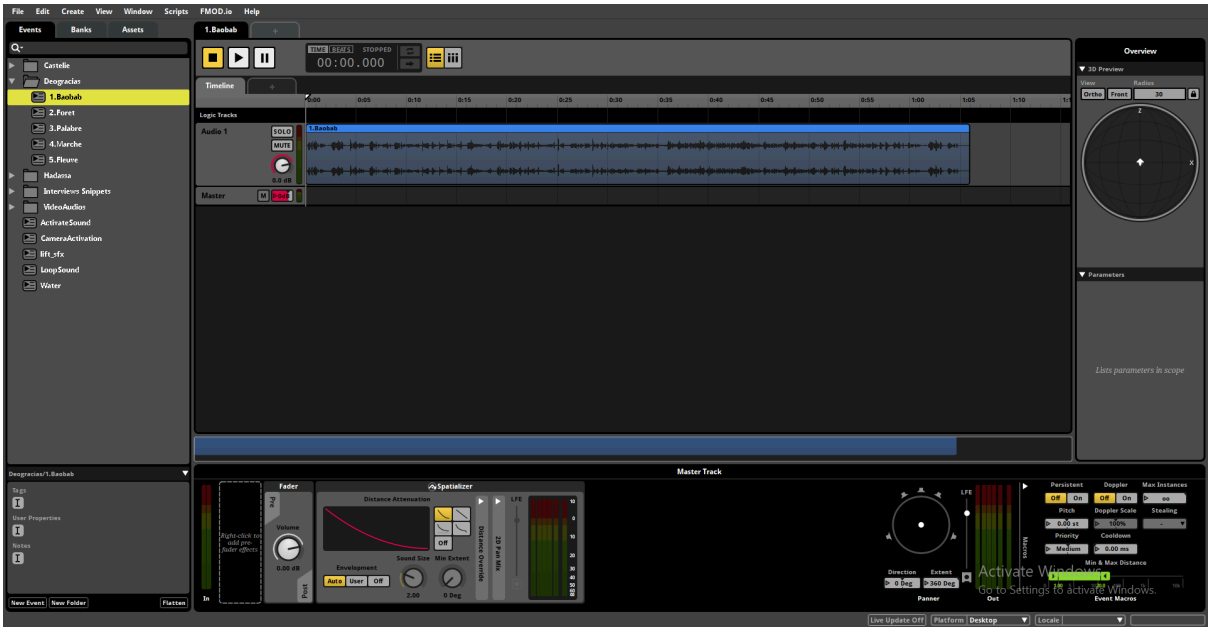

Figure 11. FMOD sound editing workspace.

5.3 Painting

The implementation of the digital painting was one of the most challenging and important tasks in the project, as the painting is the central piece of any panoramic exposition. The first step of the implementation consisted of the transformation of the painting from a physical art piece into a digital one. To achieve this, the project team traveled to the War Heritage Institute in Belgium and unrolled the original painting for the first time in almost 100 years (see Figure 12). The painting was photographed in multiple sections and digitally stitched together by the photography team to form a complete, unedited digital image of the artwork.

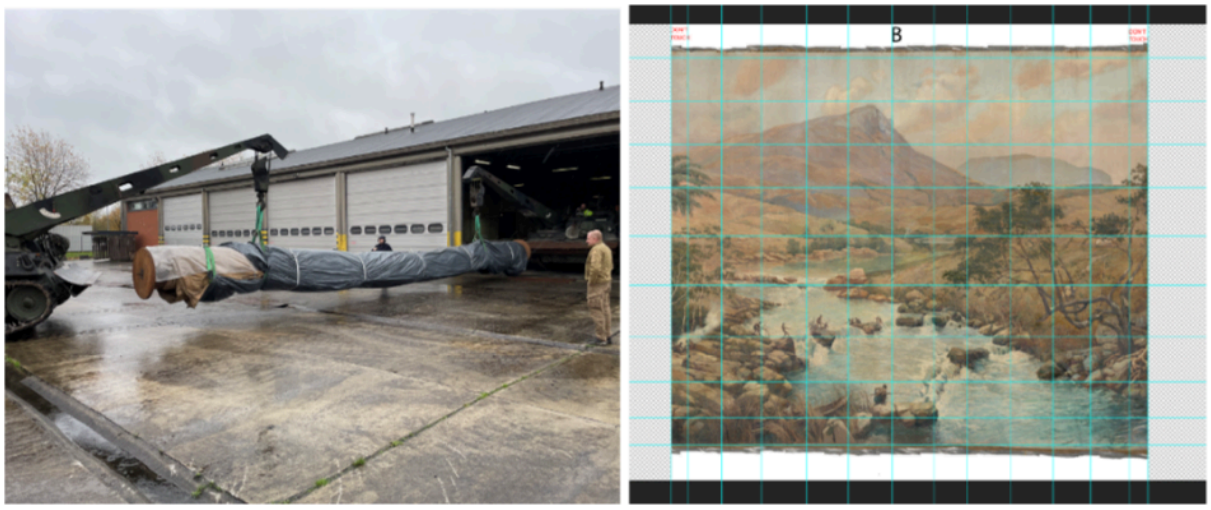

Figure 12. Picture of unrolling the painting in the War Heritage Institution (Belgium) and example of the digitalization of the painting through a stitching process.

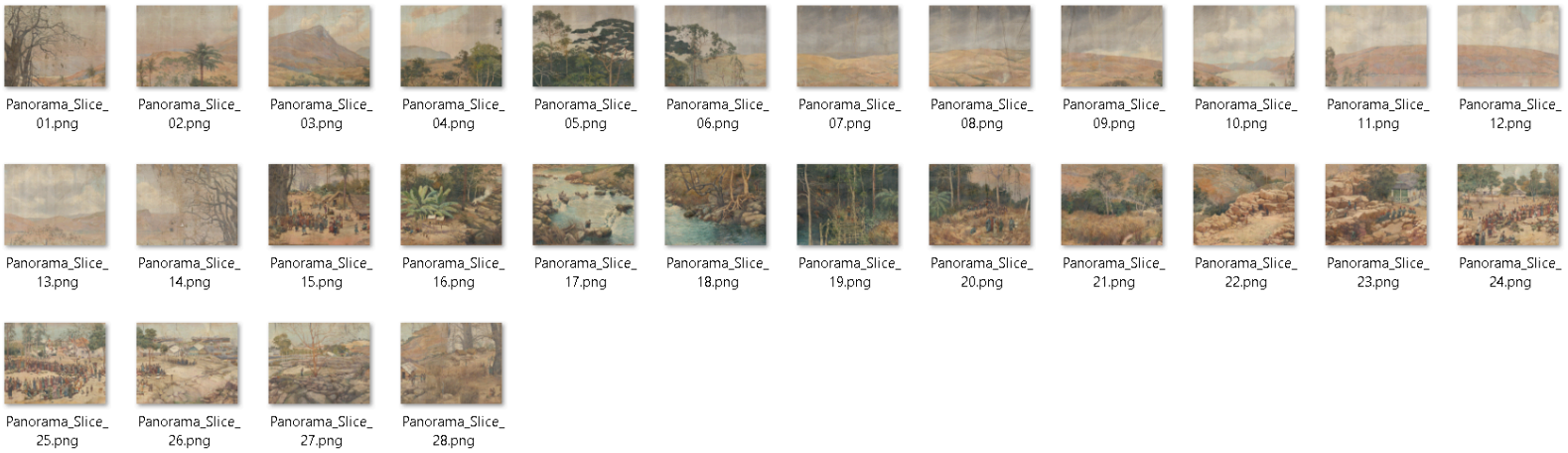

Figure 13. Full digital picture of the painting sliced into 28 symmetrical image pieces in a 16k range resolution.

However, the resulting image could not be used directly in the VR application. The final resolution of the full digital painting was 155,526 × 17,626 pixels—far beyond the capabilities of the Unity engine, which supports a maximum texture size of 16,384 pixels (Unity Technologies, 2024). To make the image usable, it was sliced into 28 symmetrical segments, each within the 16K resolution range (see Figure 13), allowing for the integration of the painting into the VR application while preserving as much visual quality as possible.

Further challenges emerged from performance limitations. The application was designed to be experienced with all artistic elements and the surrounding environment active simultaneously. This meant the system needed to be able to render approximately half of the high-resolution images at once—since the VR camera's field of view typically captures half

of the panorama—alongside other dynamic features like dances, special effects, and audio, without causing crashes or significant performance issues.

To address this, the 16K images were compressed down to 2K resolution. This compression did not compromise the visual fidelity, as the VR headsets used in the project—Oculus Quest 2 and 3—have maximum display capabilities of around 2K resolution per eye (1832×1920 and 2064×2208, respectively). As a result, compressing the images to 2K allowed the application to deliver optimal visual quality while maintaining performance.

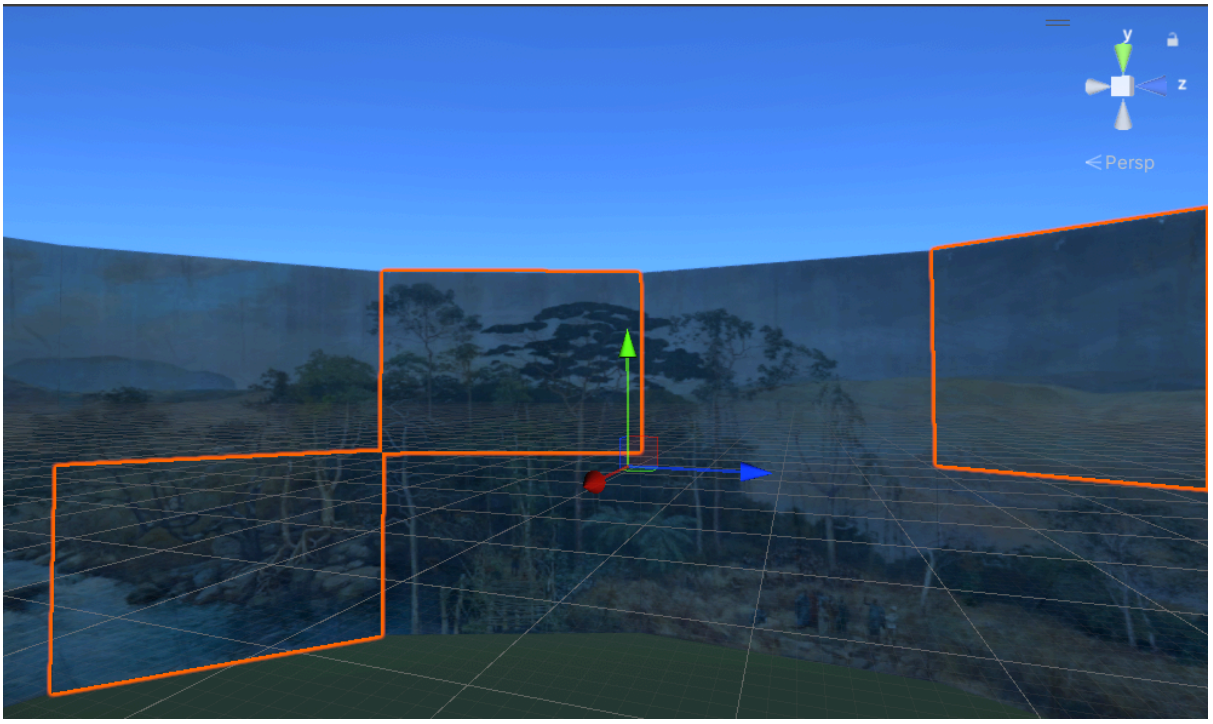

Figure 14. Implementation of the 28 slices in the virtual panorama.

An even more refined solution was later developed to further enhance image fidelity without relying on compression. Instead of downscaling the 16K slices, the full digital painting was divided into 2048×2048 pixel tiles—totaling 1,368 separate images. This approach preserved the maximum possible resolution observable through the VR headsets and eliminated quality loss from compression algorithms. A procedural cylinder was created in Unity to dynamically generate the necessary number of faces and shaders, organizing and mapping the image tiles in their correct positions (see Figure 15).

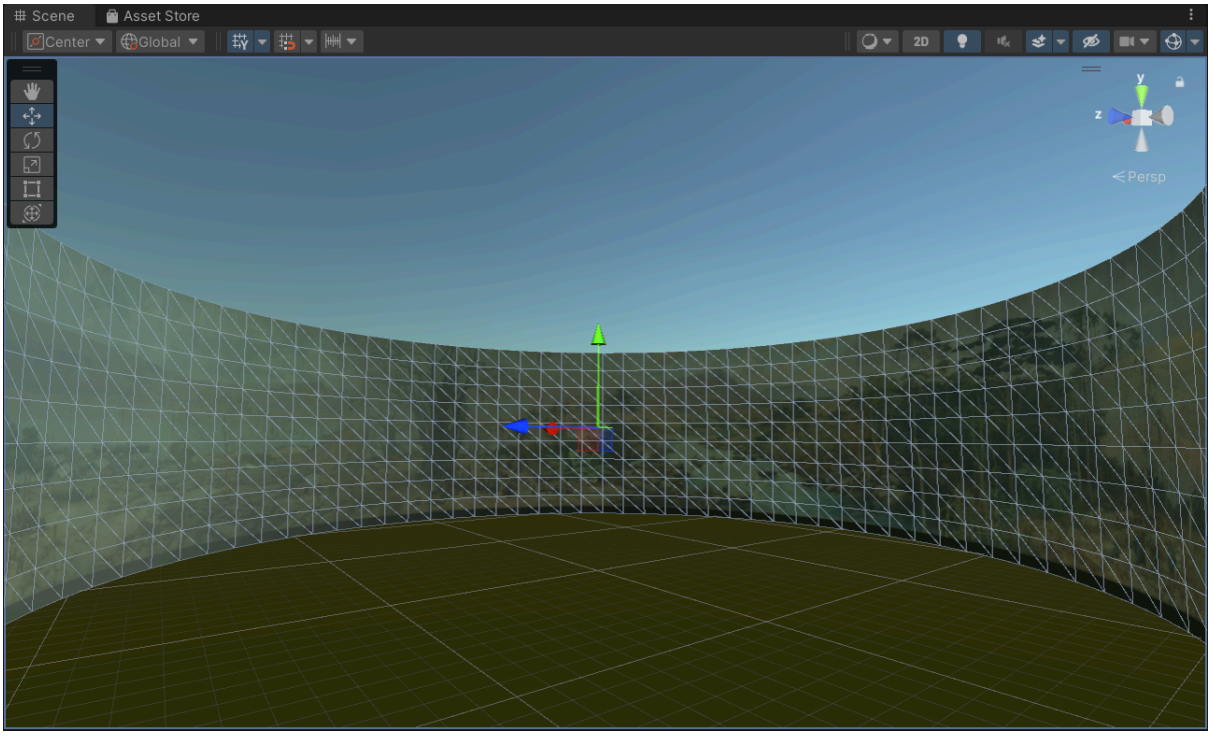

Figure 15. Generated panorama (2k resolution slices).

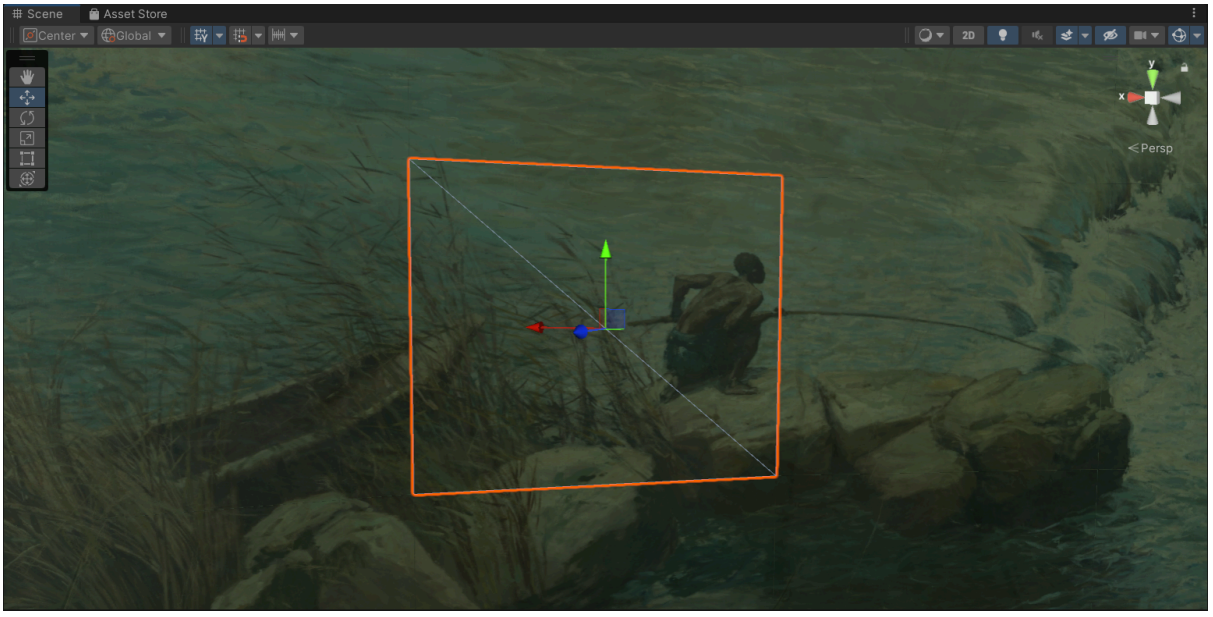

Figure 16. Close up of a 2k resolution slice.

The slicing process was automated using a Python script (see Annex 13), developed specifically to preprocess the high-resolution images before their integration into the VR_CongoPanorama application. This script operates outside of Unity, which is why it's provided separately from the main project codebase (available on GitHub, see Annex 12). It begins by loading the 16K vertical slices previously exported from Photoshop, reassembling them into the full panoramic image. The script then divides this large image into 2048×2048

px tiles, ensuring consistent sizing across all slices. To preserve a seamless layout in the VR environment, the script also adds padding to edge tiles when needed.

These evenly sized image slices were then used to construct the panoramic environment in Unity. To properly display the panorama in virtual reality, a cylindrical mesh was generated procedurally using a custom C# script. Rather than relying on a pre-made 3D model, this script dynamically builds the cylinder face by face during runtime. Each face of the cylinder is assigned a single 2048×2048 px texture tile, wrapping the full panorama around the inner surface. To ensure a clean and continuous visual experience, the script takes into account padded areas introduced during the slicing stage—especially on the outer edges of the image. These padding offsets are carefully handled in the texture mapping (UVs), avoiding visible seams and preserving immersion in the VR environment. This procedural approach offered full control over geometry and texture placement, allowing for rapid iteration and visual accuracy inside Unity.

5.4 Artists

The implementation of the artist's works was structured around one main class, the *ArtistManager* class. This class controls all the states of the artworks and its related classes, it uses a *Dictionary* to store the state of each artwork, and updates it when necessary. This update consists in a restart feature, when activated it will signal all artists related classes (see figure 17) to restart themselves, making sure every artwork can be replayed by the user. This feature is important because the users have the freedom to walk to each art piece at their own pace, meaning that it has to consider that other artworks aren't playing simultaneously.

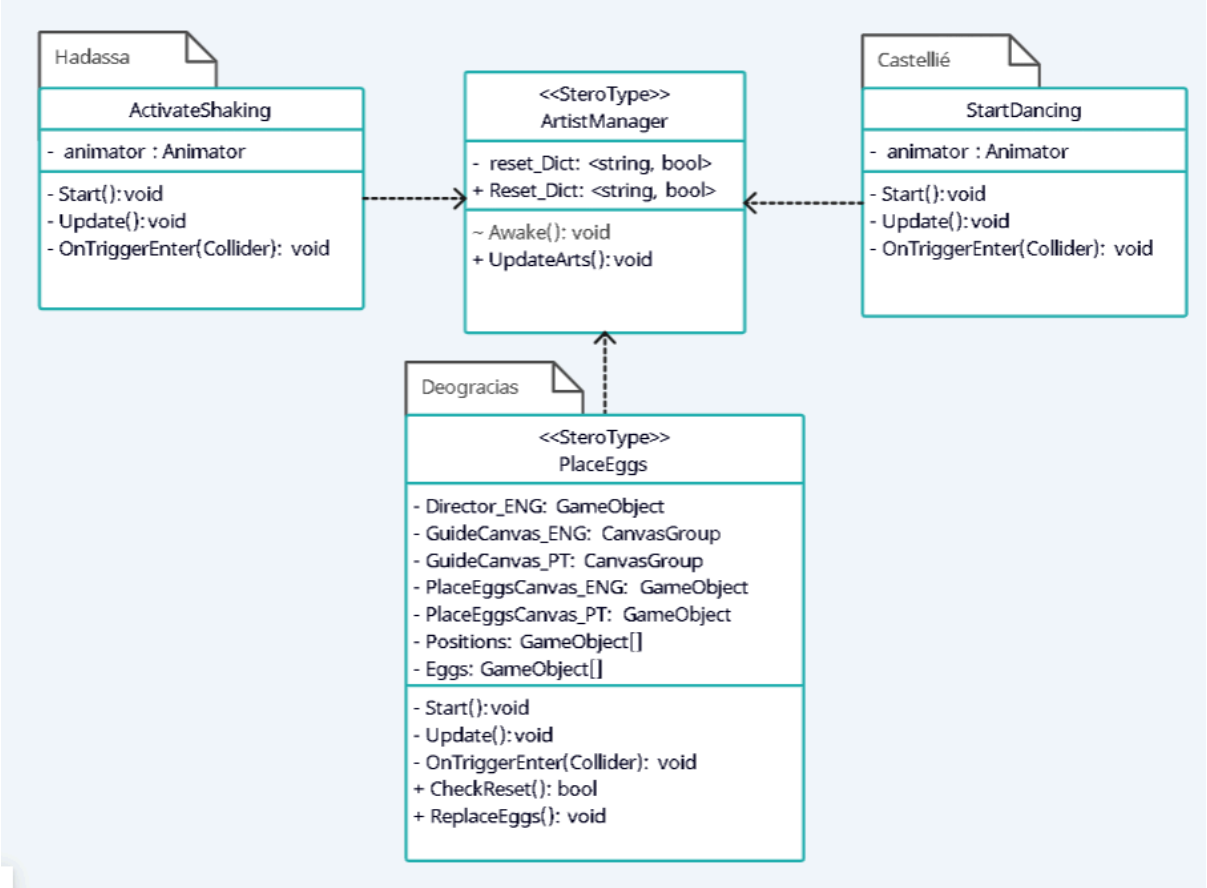

Figure 17. Relation chart between all artworks and ArtistManager script.

5.4.1 Hadassa

Hadassa artwork has simple interactions, when the user approaches the table it starts shaking. For this purpose two scripts were created, the *Shake* and *ActivateShaking* classes:

- The *Shake* class manages the shake motion, using a variable to control its intensity and speed. These values change the table position back and forth in its *Z axis*, giving the illusion of a shake (see annex 6).

- The *ActivateShaking* class is responsible for updating the table if the restart feature is activated by the *ArtistManager* class (see 5.4). It also verifies when the shaking animation is to be played, this animation consists in changing the intensity and speed values of the variable in the *Shake* class in a period of time with the use of a *timeline* (see 5.1 for more information about timelines).

5.4.2 Castélie

Castélie artwork implementation only uses one script, the *StartDancing* class, containing the same functions as the *ActivateShaking* class from Hadassa's artwork (see 5.4.1). The script verifies when to play Castélie's dancing animation, if the user approaches the character (see figure 7) it starts the dance, and restarts the artwork if the restart feature is activated (see 5.4).

5.4.3 Deogracias

The implementation of Deogracias artwork required more features, which include: Implementation/management of timelines; Sound edits; Special effects; UI interactions (menus and subtitles); And player interactions (grabbing, teleporting, camera verifications). As mentioned in section 4.2.3, for the purposes of clarity, this piece is divided into two parts:

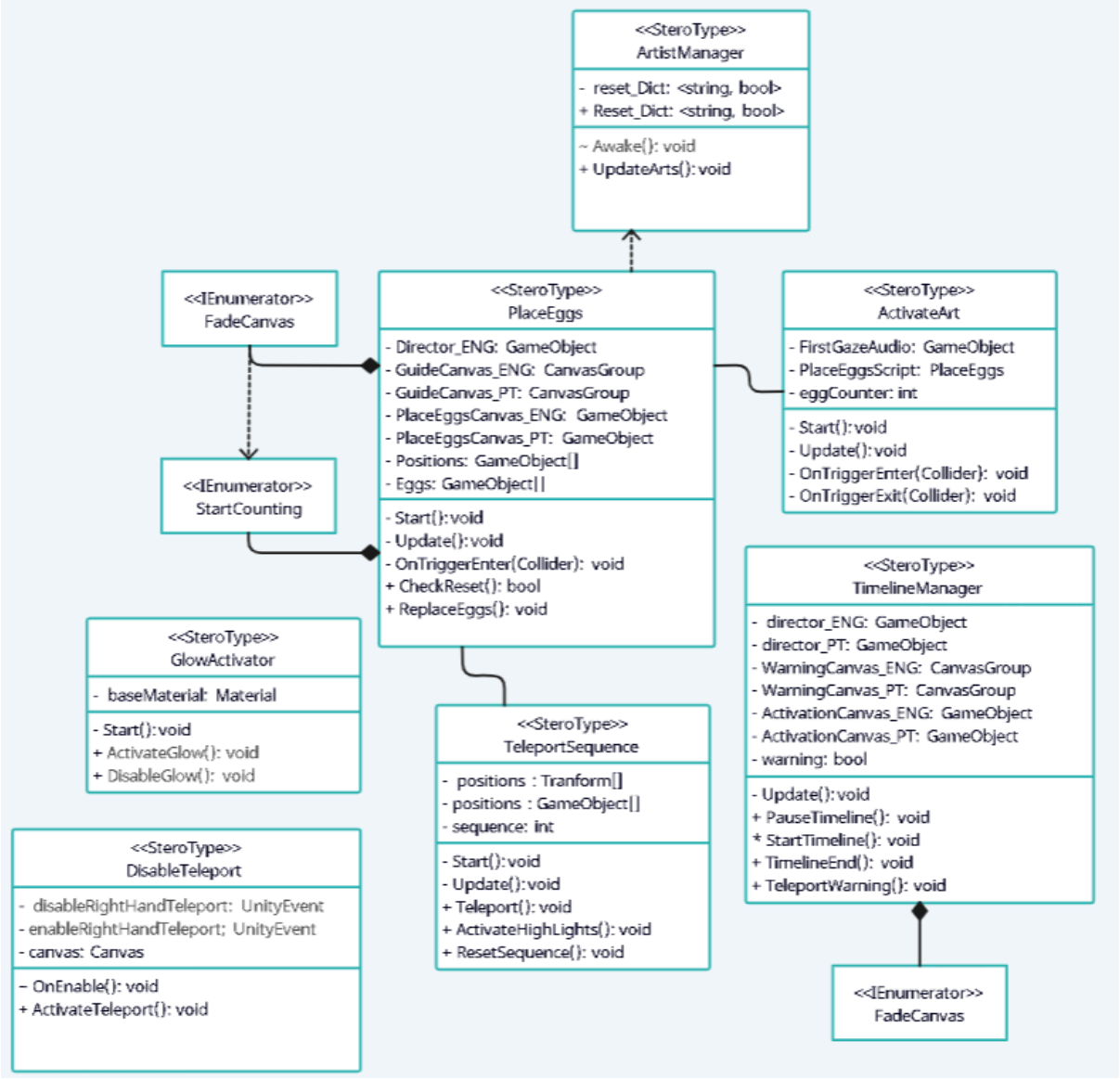

Figure 18. Architecture of all classes used for Deogracias artpiece.

I. First Part

The first part of the art piece (placing the eggs in the nest) is structured around the PlaceEggs class (see figure 18). This class manages the following features of Deogracias's installation:

a) The user interface, primarily the menu prompts that guide the player throughout the experience.

b) The restart feature, which includes:

I) Resetting the positions of the eggs.

II) Refreshing the colliders associated with this section.

III) Signaling the restart activation to other classes responsible for the second part of the installation.

Additionally, the PlaceEggs script implements a timer feature to ensure that every user can access the second part of the artwork. This feature is executed through a Coroutine (see 5.1) that controls two IEnumerators: FadeCanvas and StartCounting.

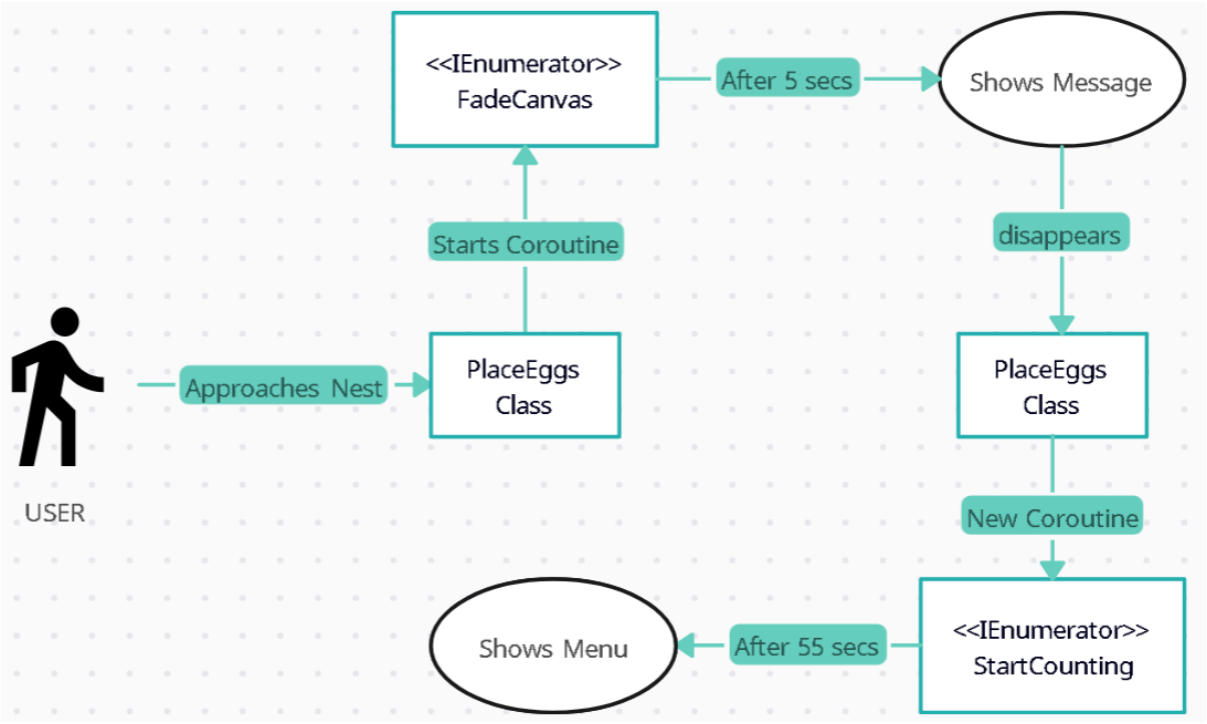

Figure 19. Flowchart of the implementation of the timer feature.

As can be seen in figure 19, when the user approaches the nest the *PlaceEggs* class starts this *Coroutine*, playing first the *FadeCanvas* IEnumerator. This Consists in waiting 5 seconds, after the user approximation was detected and displaying a message to the user afterwards (message instructs the user to place the eggs in the nest). After this message disappears the *StartCounting* IEnumerator starts playing. This IEnumerator is responsible for displaying a menu that provides assistance in placing the eggs in the nest (see figure 20), after 55 seconds of waiting.

Figure 20. Menu activated after 60 seconds of approximation to the nest. If pressed YES all eggs are placed inside the nest automatically, starting the second part of the artwork. If pressed NO the menu disappears (nothing happens).

The *ActivateArt* class is responsible for advancing to the second half of the artwork by verifying every frame, using Unity innate *Update* method, the *state* property of the *PlaceEggs* class and verifying the amount of eggs that are currently placed in the nest. This *state* property has two values: *true* or *false.* The value changes to *true* only when all the eggs are inside the nest or when the user presses "YES" on the menu used by the *PlaceEggs* class (see figure 20), when proven *true* the *ActivateArt* displays the first *Highlight* area (see section II.), marking the start of the second part.

The use of the *PlaceEggs state* property in this class is necessary for sharing information regarding the start of the second half, because it can be started in two ways (using the menu or placing the eggs manually). With the use of the same property for both scripts, the *ActivateArt* class can activate the second part efficiently with both scripts' internal verifications.

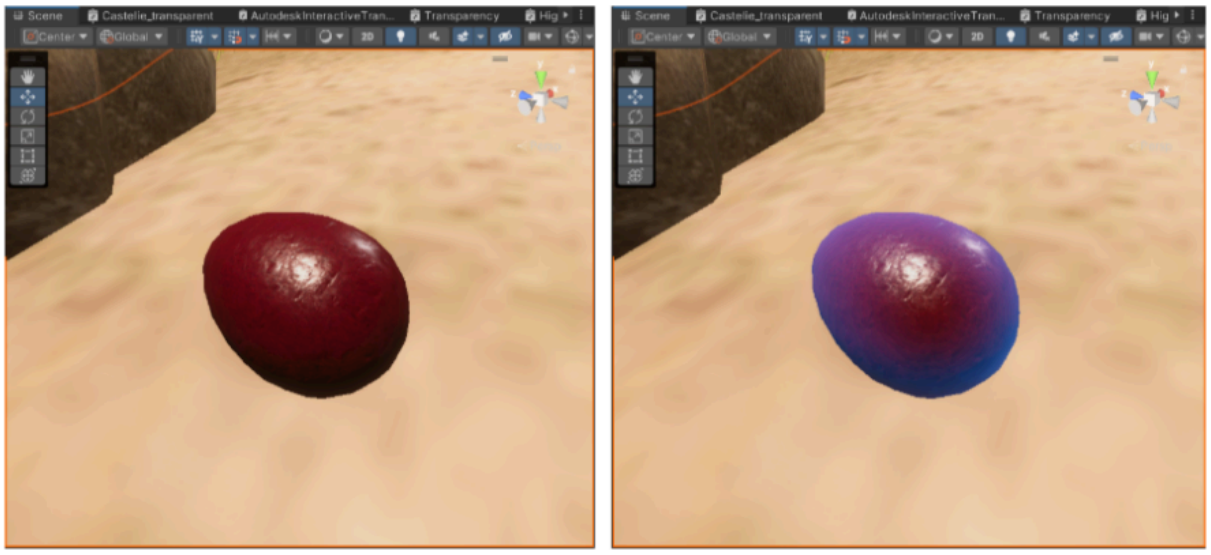

Figure 21. Showcase of the glow effect on the egg.

Finally, to inform the users that they can interact with the eggs a highlight feature was developed. This feature displays a highlight effect around the egg (see figure 21), activating when the user is near the egg (if far away the egg goes back to normal). The GlowActivator class is responsible for this process, controlling the values of a property called *_Glow*. This property represents the emission value of the shader (see 5.1) of the egg, changing between 0 and 1 (no emission and with emission respectively), depending if the user is in range of the egg or not. This effect, seen in figure 21 was achieved with the use of the *Fresnel Effect* on the emission property of the shader. According to Unity Technologies (2024) the Fresnel Effect is "the effect of differing reflectance on a surface depending on viewing angle, where as you approach the grazing angle more light is reflected".

II. Second Part

The second part of the art piece (mockumentary section) is structured around the implementation of a *timeline* (see 5.1). This *timeline* plays the audios for the mockumentaries and their respective subtitles according to time (see figure 22). In total there are two

timelines, one in Portuguese and another in English, the *timeline* used depends on the language chosen by the user in the beginning of the application. For the purposes of clarity, the implementation of the timeline was divided into different processes: How to start the *timeline*; And Pausing/Replaying it.

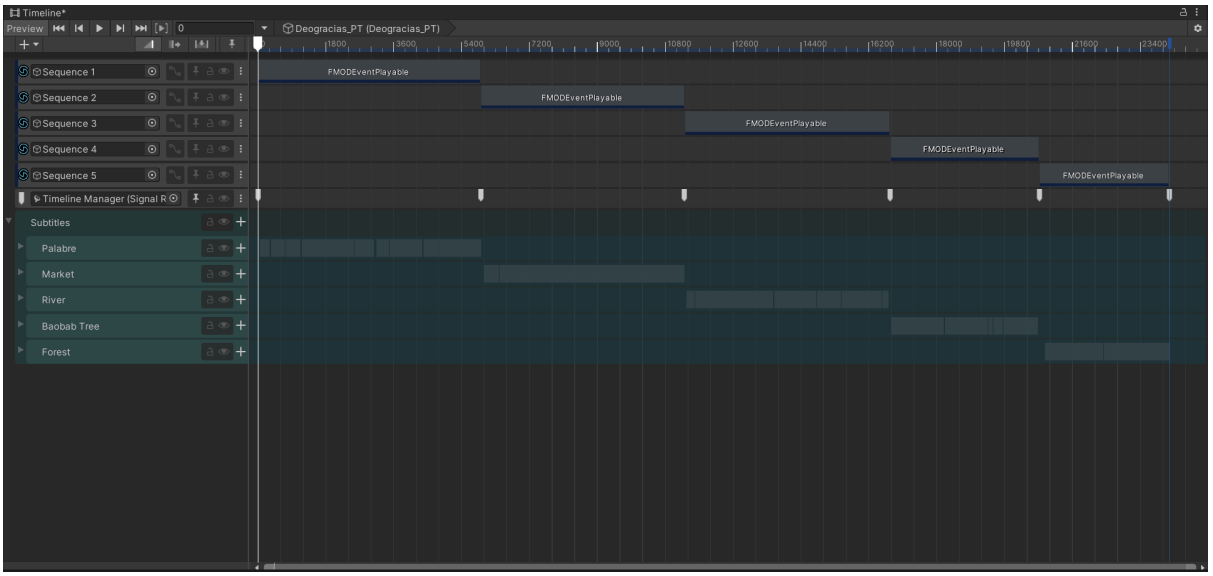

Figure 22. Portuguese Timeline. Containing 5 sequences each with a different audio file (mockumentary) and their respective subtitles (the row in "blue").

Figure 23. Highlighted area in the painting.

To start the second part, play the mockumentaries, it's required to look at a specific area of the painting, this creates the necessity to ensure the user is able to see this area and

verify when it's looked at. Given these requirements *Highlighted* areas were created, they consist in a *GameObject* (see 5.1) with the form of a glowing line around a selected area of the painting, as demonstrated in figure 23.

The *CameraView* class is responsible for this verification process. This class verifies every frame if the user is looking at a *Highlighted* area, when proven true the script starts playing the *timeline* (the mockumentary). The technicalities of this verification consist in the use of a *Raycast*, a 20 meters invisible straight line that starts from the camera point of view. When this line contacts a *GameObject's collider* (see 5.1) it flags a collision with that *GameObject,* sharing all its properties in the process (transform, collider, material, layer, etc). This detection by itself occurs with all the *GameObjects* the user sees in the scene.

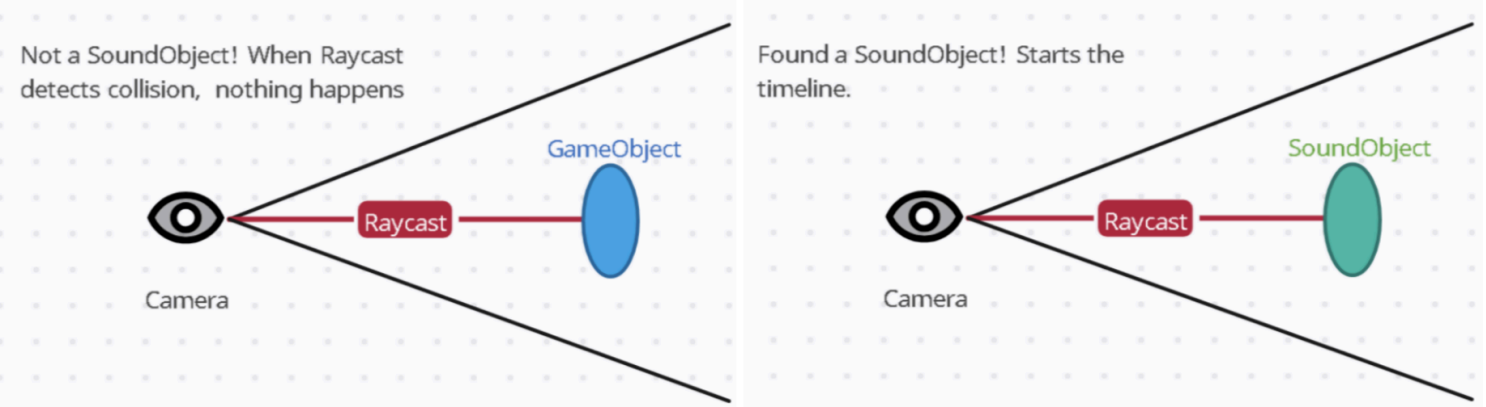

Figure 24. Visual confirmation of objects containing the SoundObject layer using the Raycast approach.

For the purposes of only detecting the *Highlight* area and not all objects present in the *scene* (see 5.1), a layer called *SoundObject* was created. This layer forces the verification to prove true only when the user looks at *SoundObjects,* finally ensuring the start of the mockumentaries when the user looks at the correct place. This process is exemplified in figure 24.

The *TeleportSequence* class is responsible for all the translocation and sequencing during this part. The main functionality of the class is to manage in what sequence of the mockumentary the user currently is, teleport to the corresponding location and activate the associated highlight area (disabling the previous one in the process). To achieve this the script uses a variable called *sequence* to register where the user is currently in, and stores in two

separate arrays, the teleport locations and the all *Highlight GameObjects*. In addition, this class is also responsible for applying the restart feature for this part. Using *PlaceEggs* class to indicate if the feature was activated, this class disables all *Highlight GameObjects* and changes the *sequence* variable to its starting value. By combining this process—which effectively restarts the second part—with the PlaceEggs class's own restart implementation (see section I.), Deogracias's installation is completely reset.

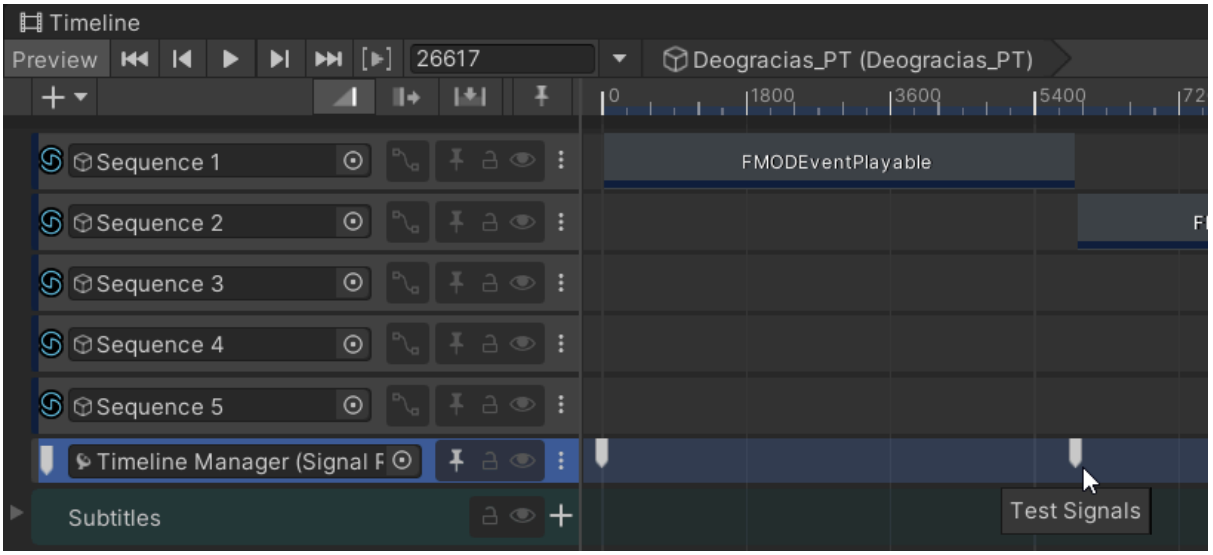

Figure 25. Application of signal receiver inside the timeline.

For stopping and replaying the *timeline,* the *TimelineManager* class was implemented. This class is responsible for managing all the interactions and functionalities of the timeline, such as stopping, playing, or marking the end of the artwork. All these functionalities are triggered by the timeline itself with the use of stamps placed in the *timeline,* called *Signal Receivers*, that trigger a function when the timer reaches them (see figure 25). Two *Signal Receivers* were implemented:

The *Test Signals* receiver (test name, not changed later in development), responsible for pausing the timeline. When this receiver is activated it stops the *timeline* and shows a menu asking the user if he wants to continue the artpiece. If pressed "YES" the menu disappears and the user is teleported to the next location of the sequence, utilizing the *TeleportSequence* class. In case the user presses "NO" the menu also disappears and the sequence is restarted (enabling the user to start again, by going to the first *Highlight* area), utilizing the *TeleportSequence* restart feature.

Finally the *TimelineEnd* receiver, charged with ending the art piece. Thus consists of: **a)** Notifying the user about the end of the artwork, with the use of a disappearing message (fades away after some time). **b)** restarting this part displaying the first *Highlight* area in the

painting. This process allows the replayability of this artwork without the need of going through the first part again (see section I.).

Chapter 6

Results

Introduction

During the interactive development of the application, three prototypes were established as key milestones - playtest prototype, exhibition prototype and the final prototype. In this section we will discuss the goals of each milestone and the observations gathered during the testing.

6.1 Playtest Prototype

The playtest prototype was focused on the environment and immersion of the virtual Panorama. This first iteration of the application consisted in the virtual representation of a classic panoramic exhibition. Providing a proof of concept for the main features present in a panoramic exhibition: Mockup of the full painting, the first iteration of the *faux terrain* and the central viewing platform (see figure 26).

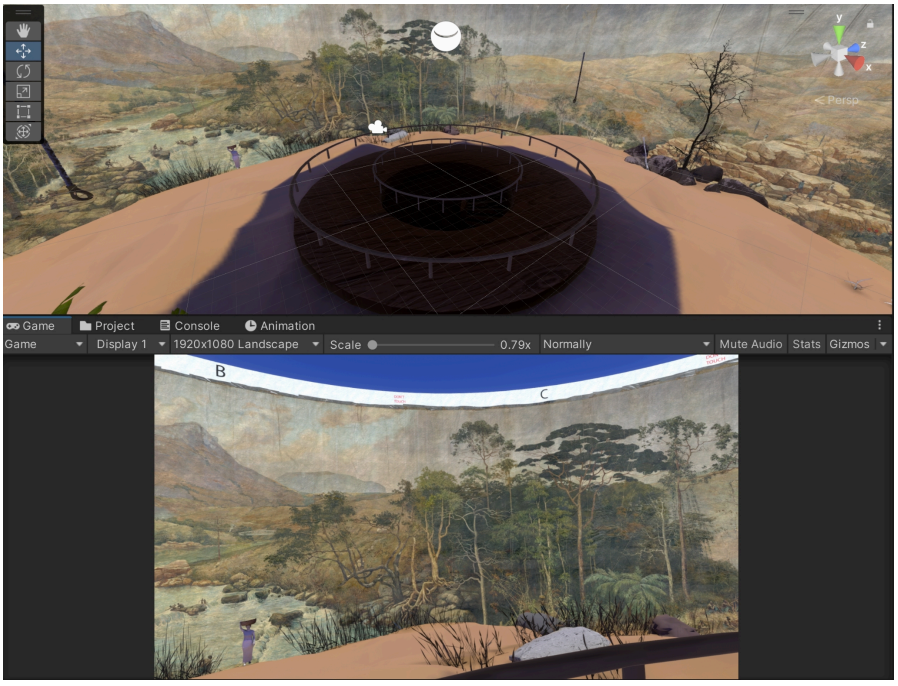

Figure 26. Playtest Prototype Environment.

This prototype was tested during a virtual reality seminar at Lusófona University using the Oculus Quest 2 headsets. The playtesters were acquainted with virtual reality applications, making it possible to test the goals of the prototype without requiring a detailed tutorial. All necessary assistance was provided by the project team in case of difficulties. This iteration meant to test the following focal points:

1. The scenery with the picture;
2. The immersive value;
3. The quality of the fully digitalized Panorama in a virtual reality environment;
4. Movement via Teleportation;
5. Stress test the application;

For a small demonstration of the prototype, a recording was made showing the environment and painting around the viewing platform (see annex 14).

6.1.1 Observations

The results gathered are the observations made regarding the main objective of the prototype, testing the applications performance, viability, usability and accessibility to the users.

During playtesters time with the prototype, the application runned smoothly without any crashes or bugs and the playtesters were able to understand how to use/move around the application without any problems. After the session was over the playtesters were asked if they felt immersed and their thoughts on the experience, their answers proved positive having felt impressed and immersed with the scenery. Some feedback was given regarding the *faux terrain*, with users reporting holes in the rocks and deformities in some objects. The movement via teleportation using the headset controllers was effective, it avoided collisions with other people/objects and provided a quick and motion sickness free form of transportation around the experience. This prototype proved successful in tackling the focal points established, showing signs of promise.

6.2 Exhibition Prototype

The exhibition prototype was focused on testing the application in a museum environment. This iteration of the application improved the quality of the setting (with the addition of new models, textures, lighting, *faux terrain*, etc…), implemented the full panorama image in a sliced format (see 5.3), added a tutorial segment and introduced the first sound implementations via interview snippets. The tutorial consists of an introduction to the theme of the application, and an introduction on how to move and interact in the virtual experience (see annex 15).

Figure 27. Speakers icons indicating the interview snippets, The grey one representing an already played audio.

The snippets of the interviews were audio files that would play when the user approached them (see figure 27). Only one audio could be played at a time, if the user wanted to play another interview he needed only to approach a different snippet, canceling the previous one in the process. These snippets were placed all around the *faux terrain*, to incentivise exploration (see figure 28).

Figure 28. Top view of the Exhibition prototype (numeration indicating the position of each audio snippet).

This prototype was played on the Oculus Quest 2 using the device's default controllers. The Oculus Quest system requires defining a *Guardian*—a safety feature that creates a virtual boundary to prevent users from moving beyond a safe physical area. If a user steps outside this area, the application is automatically paused to ensure safety. This feature is especially important in public or unsupervised environments.

The prototype was open to the public audience in an exhibition at the *Bordalo Pinheiro Museum* for one month. The main goals of this prototype was to evaluate the performance of the application in an unsupervised exhibition, test the effectiveness of the tutorial, test the sound implementation for an museum exhibition environment and evaluate the improvements made for the goals in the previous iteration (see 6.1).

During the exposition time frame, the public was able to give us their feedback and thoughts on the prototype, using a questionnaire. This optional questionnaire was accessible by using a QR code in a pamphlet of the exhibition. The questionnaire aims to understand the user satisfaction using a open questions format, containing the following questions: if they felt comfortable during the experience; if they felt the subject of colonization presented; if they were able to hear the audio snippets, and they thoughts on it; what's their thoughts on the painting presented; and some feedback in technical details or general suggestions;

For a small demonstration of the prototype, see annex 16.

6.2.1 Observations

On the first two days of the museum opening, the development team was present to assist with the exhibition—providing maintenance, accessibility, and guidance to visitors as needed. During this time, the following observations were made:

Guardian System Disruptions

Several users unintentionally left the Guardian-defined safe area while using the VR headset. When this happened, the application was automatically paused (for safety reasons), and users were prompted to create a new safe area. This process disrupted the carefully prepared exhibition setup and often caused confusion. In some cases, visitors required assistance from the development team to restart the application and resume the experience.

Audio Headset Usability

Given the expected noisy museum environment, audio headsets were provided for the installation. However, users had to place these headsets on top of the VR glasses, which proved to be cumbersome and often required assistance. This proved to complicate the setup for playing the application. Some users preferred not to wear the headsets, experiencing the application without sound. In addition, at the end of the exhibition, one of the headsets was found damaged.

Tutorial Ineffectiveness

The tutorial was not effective. Users frequently skipped reading the instructions and started the application immediately, leading to multiple issues as many could not teleport or move around effectively within the application. This required consistent assistance and guidance from the development team.

Audio Snippet Playback Issues

Several bugs were identified in the implementation of the audio snippets. The issue was related to the detection area for playing the audio. If the user was positioned at the edge of the detection zone, the audio would constantly restart, making it difficult for users to listen to the interview and creating confusion.

Painting Visibility

For the painting, a small texture problem was detected. During the connections/borders of the slices, a visible line appeared, making the image appear fragmented rather than one cohesive painting. However, regarding the resolution of the images, no issues with frame rate drops or crashes were observed.

6.2.2 User Perception

As mentioned previously a questionnaire was made for the users to give us feedback while the prototype was in the exhibition. Because of being an optional questionnaire only a small sample was gathered during the time of the exhibition (see annex 17). The results gathered from this questionnaire were analyzed and filtered into a quantitative value, as shown in figure 29.

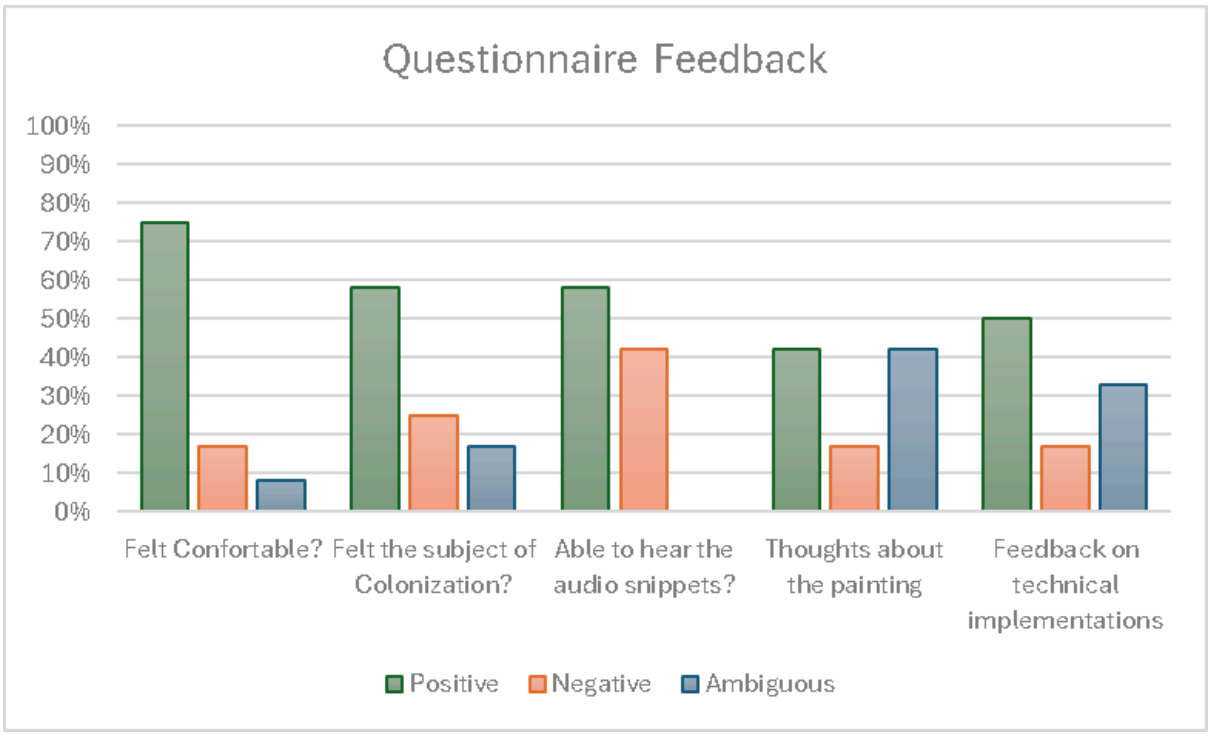

Figure 29. The feedback gathered into a positive or negative perspective. The ambiguous results represent unanswered questions or feedback that could not be taken into a quantitative value.

Most of the negative feedback observed, as shown in figure 29, referred to the application not working. This issue was caused by previous users turning off the VR

headsets, making it impossible for the next person to use the application. Without supervision, this problem often left the installation non-functional for extended periods.

According to the data gathered, the majority of users gave positive feedback about the prototype—they felt comfortable, were impressed by the painting, and understood the topics addressed. However, a significant issue was reported with the audio: nearly half of the respondents (42%) said they were unable to hear the audio snippets. This may be partially explained by the technical problems described in the previous section (see 6.2.1).

Regarding technical feedback, most of the negative responses focused on the inability to start the application due to the powered-off headsets. Other feedback pointed to bugs in the environment, such as floating *faux terrain* objects and inverted speaker positions. Additionally, some users reported feeling lost or unguided in the experience and were unable to understand the connection between the painting and the interviews—highlighting a gap in the narrative design of the prototype.

6.3 Final Prototype

This prototype represents the final milestone of the Virtual Reality application developed for the CONGO-VR project. It includes all the features and implementations discussed in Chapter 4. During the development of this iteration, the artists finalized their concepts for the installations, made possible through the project's iterative and collaborative process. A decision was made to separate the two main goals of the project (see 3.2) into distinct applications—an archival version and an artistic version (see 4.1)—both of which were presented in the final exhibition. This exhibition took place at the *National Museum of Natural History and Science* in Lisbon from February 24 to June 16, 2024 (see figure 30).

Figure 30. VR installation in the National Museum of Natural History and Science exhibition (24/2/2024).

Different from the other prototypes, the Final prototype was played on the computer instead of the VR glasses themselves to allow the maximum quality of performance possible. In other words, the VR glasses were used only as a medium to display the application, while the processing was done by the computer. This change was made because using this application with the high quality image plus all the artworks in the same environment could prove to be a very heavy load on the VR glasses. The use of the computer processing power allowed us to overcome these limitations and provide a more pleasant experience. The glasses used for this exhibition were the Quest 3, providing a more comfortable experience and having better speakers for sound clarity, allowing the users to hear the application clearly in the exhibition without the use of audio headsets, a solution to fix the sound problem observed in the exhibition prototype (see 6.2.1). Additionally, this version employed hand tracking instead of the VR controllers, this change was made in consultation with the curatorial team, which believed that hand tracking would provide a more intuitive and engaging experience to visitors.

Figure 31. Setup of the computers for the exhibition, computers are inside the central box of the installation, as shown in figure 30. Top row computers contain the Artistic version and the other row the Historical version.

The installation used four computers (two running each version), stored inside a box, with the four Quest 3 headsets placed on top (see figure 31). The box remained closed during the exhibition, only opened for maintenance or at museum opening and closing hours. Ventilation holes were added to prevent overheating. Besides the VR headsets, a pamphlet was provided to guide visitors on how to use the headset and interact with the application. Each headset was labeled with a number that corresponded to a matching number on the top of the box. This system was designed to help users return the headsets to the correct location, minimizing the risk of collisions and confusion. The ground also had a dot to indicate where the users should place themselves before starting the application (see figure 30).

6.3.1 Observations

As mentioned previously, this dissertation focuses on the Artistic Version of the application. Therefore, only observations regarding this version and its installation will be discussed here. Given that this prototype represents the final version of the application, no additional feedback questionnaire was created. By this point, most usability and design issues

had already been addressed in earlier iterations. The primary goal of this stage was public presentation rather than further evaluation. Additionally, it is worth noting that the author did not have direct influence over decisions related to exhibition curation and public evaluation strategies.

On the exhibition's opening day, the author and other team members assisted the public with using the application, maintained the installation, and resolved any technical issues. During this period, the following observations were made:

I. Installation-related Issues

- **Lighting Conditions and Hand Tracking**

The installation was placed in a very dark room, which significantly interfered with the VR headset's hand tracking. As a result, many users struggled to complete the tutorial—especially during the teleportation section. The darkness made the teleport input difficult to perform correctly, leading to user confusion and frustration.

- **Headset Placement and Cable Management**

Although each headset was labeled with a number to correspond to a specific position on the installation box (as described previously), this system proved largely ineffective. Most users returned headsets to whichever location was most convenient, which caused the headset cables to become tangled. This not only restricted movement but also created confusion about which headset belonged to which version of the application (artistic or historical).

- **Hardware Stability and Crashes**

Several instances were observed where the application stopped working entirely. These crashes were traced back to the physical cables connecting the headsets to the computers. Users would occasionally disconnect the cables accidentally during gameplay, or certain head movements appeared to trigger the issue.

II. Application-related Issues

- **Hand Tracking & Interaction Challenges**

Hand tracking remained a significant issue during user interaction. Users frequently encountered problems teleporting, grabbing objects, and pressing buttons. These difficulties were likely a combination of the poor lighting conditions and the public's general inexperience with VR. Notably, when the author tested the application in the same space,

these issues were not consistently reproducible—except in areas with particularly poor lighting or awkward hand orientation.

- **Tutorial Effectiveness**

The updated tutorial design proved generally effective: users were no longer able to skip it with a single button press, which encouraged them to read instructions and attempt each interaction. However, some difficulties remained. Users struggled most with the point-based teleportation and teleport menu sections, often misunderstanding the instructions provided.

- **Sound and Visual Performance**

All users were observed to complete the experience without encountering audio issues. The panorama painting was successfully digitized and implemented in a sliced 28-panel format at 16K resolution (see 5.3), with no texture problems, frame drops, or application crashes.

III. Artist-specific Observations

- **Deogracias's Artwork**

Only one user was observed reaching the second half of Deogracias's piece during the entire opening day. The transition between the first and second parts was not clearly understood by the public, suggesting a gap in narrative clarity or interaction design.

- **Hadassa's Artwork**

The diagram included in Hadassa's installation did not appear to draw attention. Most users either overlooked it or did not engage with it meaningfully, implying that its communicative value was limited in the current setup.

- **Castélie's Artwork**

Castélie's piece functioned as expected. No major issues were observed, and users experienced the performance as intended.

Chapter 7

Conclusion

This dissertation discusses the development of a VR application aimed at curating and digitizing the Congo Panorama. Through collaboration with Congolese and diaspora artists, as well as the project team, the application was designed to engage the public with historical themes and provide an immersive experience through virtual exhibitions.

The playtest prototype, built using the Unity real-time engine and the Oculus Quest 2, validated the application's performance and accessibility. A group of experienced VR users participated in playtesting, and the results demonstrated that the prototype was both accessible and immersive.

The exhibition prototype, featuring audio and the digitized painting, demonstrated the application's resilience in a real-world setting at the "Museu Bordalo Pinheiro." An optional questionnaire was provided to the public to assess user satisfaction, usability, and overall experience. The results showed that, while the prototype engaged the public with the intended themes, there were areas for improvement, particularly in sound implementation.

The final prototype, which integrated the Congo Panorama with contributions from Congolese and diaspora artists, created an engaging and immersive virtual exhibition at the National Museum of Natural History and Science in Lisbon. The VR installation provided an impactful experience for visitors while identifying challenges in both technical and practical areas for future work.

Throughout this project, my primary contribution was in the development and technical implementation of the VR application. This involved addressing performance issues, hardware integration, and ensuring a smooth user experience. While the broader project's thematic and artistic elements shaped the overall experience, my focus remained on ensuring the technical aspects met the project's objectives.

In summary, the developed application achieved its core objectives and laid the groundwork for future developments in the preservation and restoration of panoramas. The integration of VR technology, Unity engine, and collaboration with artists allowed the project

to be both informative and engaging, contributing to the evolving narrative of the Congo Panorama.

7.1 Future Work

Future work could improve upon the artists' implementation according to the issues observed. As a possible solution to the problems indicated, for Deogracias's work, part 1 and 2 could be separated and not be dependent on each other to run, allowing for more accessibility. Additionally, in Hadassa’s table, a proposition to make a video or an interactive graph could be a better way to engage users with the diagram.

Further, the system implemented to increase the quality of the painting in consideration of current VR devices' limitations (see 5.3) could be improved. The approach suggested was not tested in a real scenario with all other artistic installations at work. Future work could test the approach and solve foreseen challenges in its implementation. These challenges include the possibility that the application may not run properly due to the rendering process of a plethora of images simultaneously. This investigation could improve the future development of VR panoramic applications, increasing their detail and levels of immersiveness while maintaining a stable and engaging experience.

Bibliography

Rheingold, H. (1991). *Virtual Reality*. Simon & Schuster.

Ch'ng, E., Li, Y., Cai, S., & Leow, F.-T. (2020). The effects of VR environments on the acceptance, experience, and expectations of Cultural Heritage Learning. Journal on Computing and Cultural Heritage, 13(1), 1–21. https://doi.org/10.1145/3352933

UNESCO. (2024). *Culture*. https://www.unesco.org/en/culture

Dewey, J. (1938). Experience and Education. New York: Macmillan Company.

Theodoropoulos, A., & Antoniou, A. (2022). VR games in Cultural Heritage: A systematic review of the emerging fields of virtual reality and culture games. *Applied Sciences*, *12*(17), 8476. https://doi.org/10.3390/app12178476

Ali, M. (2024). Fostering Cultural Heritage Awareness through VR serious gaming: A study on promoting Saudi heritage among the younger generation. *Journal of Infrastructure, Policy and Development*, *8*(3). https://doi.org/10.24294/jipd.v8i3.3084

Costa, S. S., Miranda, B. M., Orichuela, S. de, Ramos, E. A., Bessa, O. F., & Souza, A. M. (2024). XILOVR: Preserving Cultural Heritage through a virtual reality-based woodcutting simulation. *Symposium on Virtual and Augmented Reality*, 234–241. https://doi.org/10.1145/3691573.3691589

Flores, V. Engelen, L. (2022) Pilot 2 CONGO-VR Application Form FilmEU_RIT. https://drive.google.com/file/d/1brc0HqLpJUCMMVxAcW2moRa6zZ7UChY1

Sanders, D. H. (2014). Virtual heritage: Researching and visualizing the past in 3D. *Journal of Eastern Mediterranean Archaeology and Heritage Studies*, *2*(1), 30–47. https://doi.org/10.5325/jeasmedarcherstu.2.1.0030

Antunes, R. F. (2024). *Visiting a neighborhood of medieval Silves using virtual reality and non-player characters*. Mimesis Journal, 13(2), 457–470. https://doi.org/10.13135/2389-6086/9931

Antunes, R. F. (2024). *Visiting the ghosts of mediaeval Silves: Virtual reality experience of 3D urban reconstruction of the past*. In *Advanced Research and Design Tools for Architectural Heritage: Unforeseen Paths* (pp. 275–293). Routledge. https://doi.org/10.4324/9781032637396-12

Parry, R. (2019). How museums made (and re-made) their digital user. In T. Giannini & J. P. Bowen (Eds.), *Museums and digital culture: New perspectives and research* (pp. 275–293). Springer. https://doi.org/10.1007/978-3-319-97457-6_15

Saroka, V. (2024). The role of sound in the immersive experience. *Avant*, *14*(3). https://doi.org/10.26913/ava3202406

Unity Technologies. (2024). *Coroutines*. Unity Manual. https://docs.unity3d.com/Manual/coroutines.html

Unity Technologies. (2024). *Shaders*. Unity Manual. https://docs.unity3d.com/Manual/Shaders.html

Unity Technologies. (2024). *Introduction to timeline*. Unity Manual. https://learn.unity.com/tutorial/introduction-to-timeline-2019-3#

Firelight Technologies. (2024). *Glossary: Event*. FMOD Studio Documentation. https://www.fmod.com/docs/2.01/studio/glossary.html#event

Unity Technologies. (2024). *SystemInfo-MaxTextureSize*. Unity Manual. https://docs.unity3d.com/6000.0/Documentation/ScriptReference/SystemInfo-maxTextureSize.html

Unity Technologies. (2024). *Fresnel Effect Node*. Unity Shader Graph Documentation. https://docs.unity3d.com/Packages/com.unity.shadergraph@6.9/manual/Fresnel-Effect-Node.html#top

Annex

1. List of tasks done for the application: https://docs.google.com/spreadshee
2. Historical version showcase: https://youtu.be/RjxWZwyAKxU
3. Application tutorial: https://youtube.com/shorts/i-J1khlz50Y
4. Point based teleportation demonstration: https://youtube.com/shorts/Sn5Z0Si0
5. Menu teleportation demonstration: https://youtu.be/AAHCoIX15v8
6. Hadassa's table shake effect: https://youtu.be/3L_W2CUBgAk
7. Promotional Leaflet : https://drive.google.com/file
8. Castélie´s dance: https://youtube.com/shorts/0YxFgfbag8k
9. Character grow effect: https://youtube.com/shorts/C3e6iUO8t6E
10. Egg and nest interaction: https://youtu.be/bMUCnimCM6o
11. Mockumentary sequence: https://youtu.be/scVz05J3pUs
12. Github Project Repository: FilipeVillarDEV/CongoVR_Codebase_Thesis
13. Slicing script: https://drive.google.com/file
14. 360º view of Milestone 1 environment: https://youtu.be/dzwTVwfcRBo
15. Milestone 2 tutorial: https://youtube.com/shorts/zs_M6atQOOc
16. Milestone 2 prototype showcase: https://youtu.be/6EGMBWuVxGA
17. Questionnaire: https://docs.google.com/spreadsheets/d

Universidade Lusófona – Centro Universitário de Lisboa
Escola de Comunicação, Arquitetura, Artes e Tecnologias da Informação
Lisboa
2025