DEPARTMENT OF
COMPUTER SCIENCE

NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

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Bachelor in Computer Science and Engineering

SPATIAL AND TEMPORAL DIGITAL DOCUMENTATION PLATFORM WITH GAME CONCEPTS

MASTER IN COMPUTER SCIENCE

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I dedicate this work to my family, you are my rock.

Acknowledgements

Foremost, I would like to express my sincere gratitude to my adviser, Professor Rui Pedro da Silva Nóbrega and my co-advisor, Professor Nuno Manuel Robalo Correia. I am thankful for the opportunity to work on this project and all the support, attention, patience and motivation they provided throughout the development.

I am highly in debt to NOVA School of Science and Technology | FCT NOVA and its community for providing the necessary space and environment for both this project development but also my whole university curriculum.

To all my friends, in and out of the FCT-UNL, and people with that I have crossed paths on this journey, I am grateful for having the opportunity to meet you and for the experiences we have been through together. A special thanks to Rafael Gameiro, for the friendship we share, for the continuous support he has given and continues to give, and for making me someone better.

Finally, I would like to thank my family, my parents - Maria Ferraz and António Ferraz – for supporting me in all this process and for all the hard work that allowed me to achieve this milestone and my sister who provided me with a happy environment to rest outside my research.

"The first step is to establish that something is possible; then probability will occur." (Elon Musk)

Abstract

With the constant development of 3D graphics systems and game engine editors, growth in the use of digital and visualization technologies for documentation and preservation of cultural heritage content followed. It has become more important to improve these solutions and bring to the users an interactive and immersive experience enhancing cultural knowledge acquisition.

New technologies such as 3D reconstruction and 360º photography introduce a new way of preserving objects or even entire buildings and cities at a computer graphics level. At the same time, tools such as Unity allow the development of software, for example games, that simplify the creation of a virtual environment and build attractive and interactive approaches for the user to participate.

Using the Trafaria stronghold as a use case, this dissertation focuses on the creation of a digital documentation platform that can preserve both the physical site, through the recreation of a 3D environment, and the intangible historical and sociocultural elements through game concepts building an interactive experience for the users.

The result of this thesis is a framework to allow a more structured method for building applications with similar components as the one developed in this thesis, applications relying on a 3D environment and allowing its mutation as well as implementing media visualization tools. In addition, the creation of a prototype that allows the user to explore a 3D environment while observing the recreated structures of the stronghold based on 3D models, and the development of interactive methods to promote the visualization of historical content placed in the environment. The prototype also allows the evolution of the system, making it possible to rearrange the environment into different setups.

The system went through an evaluation process where users tested the diverse features and the results express a positive response towards the usability of the platform, as well as a positive opinion on the virtualization of the historical site and the interactive methods for content visualization.

Keywords: 3D Graphics & Interface, Games, Cultural Heritage

Resumo

Com o constante desenvolvimento de sistemas gráficos 3D e motores de jogos, seguiu-se um crescimento no uso de tecnologias digitais e de visualização para documentação e preservação do conteúdo do património cultural. Tornou-se mais importante aprimorar essas soluções para trazer aos utilizadores uma experiência interativa e imersiva que também possibilite a aquisição de conhecimento cultural.

Novas tecnologias como econstrução 3D e a fotografia 360º introduzem uma nova forma de preservar objetos ou mesmo edifícios inteiros e cidades a nível da computação gráfica. Ao mesmo tempo, ferramentas como o Unity permitem o desenvolvimento de softwares, como jogos, que simplificam a criação de um ambiente virtual e constroem abordagens atrativas e interativas para a participação do utilizador.

Utilizando o Presídio da Trafaria como caso de uso, esta dissertação foca-se na criação de uma plataforma de documentação digital que visa a preservação tanto do património físico, através da recriação de um ambiente 3D, como dos elementos históricos e socio-culturais intangíveis através da construção de métodos de gamificação construindo uma experiência interativa para os usuários.

O resultado desta tese visa uma *framework* que permita um método mais estruturado de construir aplicações com componentes similares à desenvolvida nesta tese, aplicações que utilizam ambientes virtuais 3D, que permitam a sua mutação e que implementem ferramentes para visualização de media. E também a criação de um protótipo que permita ao usuário explorar um ambiente 3D observando as estruturas recriadas o Presídio com base em modelos 3D, e o desenvolvimento de métodos interativos para promover a visualização de conteúdos históricos presentes nesse ambiente. O protótipo também permite a mutação do sistema, possibilitando rearranjar o ambiente em diferentes configurações. Para alcançar um resultado satisfatório o protótipo passou por um processo de avaliação onde os utilizadores testaram as diversas funcionalidades para avaliar a versão final do protótipo, resultando numa resposta positiva relativamente à usabilidade mas também em relação aos metodologias desenvolvidas para os diferentes tipos de interação.

Palavras-chave: Gráficos 3D & Interface, Jogos, Património Cultural

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1 Introduction

The desire for the preservation of culture has been a constant in our society, promoting work towards the development and enhancement of solutions to preserve cultural heritage and its meaning. The methods vary in different areas of knowledge, from handwritten documentation to cultural artifacts such as structures, paintings, and objects. As we witness a big evolution in technology, more areas make use of these advancements and culture is not an exception. Especially in the computer graphics department, the ability to recreate the real world in 3D allows the design of more realistic and immersive tools.

The development of technologies for the creation of Virtual Environments (VE) and/or Virtual Worlds (VW) introduces new possibilities for the work in the preservation and documentation of cultural heritage. These technologies introduce the ability to partially or completely recreate an entire environment that allows the immersion in the cultural values that are being represented. As an example, the recreation of a city and its artifacts allow for its preservation even if they deteriorate in the future. Even more immersive experiences are achieved when these environments are exposed through virtual or augmented reality simulating an experience closer to the reality for the user.

On another note, enhanced immersion and engagement are also achieved when these environments are experienced through an interactive system using the same building blocks and logic of 3D games aiming for a simulation of the real world that is relevant to the user.

The current work developed in the maintenance of cultural heritage through the usage of 3D tools and virtual environments has been very concrete, as the majority of these projects [43, 32, 33] aim at a specific museum or historical site, usually not including any reconfiguration processes or mechanisms.

1.1 Motivation

The motivation of this work is to be part of the current development of new ideas and projects with the goal to preserve cultural heritage. Past projects have tried to integrate cultural heritage content databases with a 3D visual environment, creating an interesting and specialized visualization experience for users to enjoy and explore historical sites [12, 33]. Since games have also been increasing in popularity and are an entertaining approach to presenting knowledge, game methodologies and techniques have also been used to enhance these projects.

This work is integrated in the T-Factor project. T-Factor is [1] is a project taking place across Europe with the mission to employ a change and rerouting urban regeneration. The main idea is to make use of historic urban areas such as vacant buildings, plots, and other unused spaces to instigate their use for co-creative experimentation, cultural initiatives, and social and entrepreneurial activities. Not only through the regeneration of buildings and infrastructures, but T-Factor also wants to explore other ways to expand the frontiers of culture and heritage with product transformation and digital-driven innovation.

In partnership with Almada Municipality, there is a strategic project in the requalification of the city of Trafaria to promote economic development and stimulate public space recovery. This initiative aims at the transformation of an area in the NOVA IAT to serve as the main catalyst for the development mentioned above.

Instituto de Arte e Tecnologia (NOVA IAT) will be installed in the *Forte de Nossa Senhora da Saúde da Trafaria*, and intends to create and be a center for art and technology and contribute for the intertwine of these two concepts. Through the development of instruction, research, innovation, and the provision of services it will aim at the creation of products and services that mix the aesthetic and design dimension with the uprising technologies. IAT's mission will also try to confront contemporary challenges, like social justice, sustainability, and human development, while studying the relationship between social sciences, art, and technology.

To accomplish this objective the Trafaria old prison (Figure 1.1) will be used as a case study. This site will soon be renovated to accommodate NOVA IAT and therefore makes an excellent candidate for a digital transition. The renovation allows a great opportunity to create a digital platform to save and preserve this site's cultural value and heritage. As the stronghold is still in rather good conditions there is the possibility of using photography to recreate 3D models of the buildings existent on the site and build a virtual environment that represents the buildings and surrounding area in the future.

This thesis project is then motivated to achieve a digital platform showing a virtual environment based on Trafaria that follows the IAT objective to mix art and technology and create an interface for sharing and dissemination of the cultural heritage values of the Trafaria area.

1.2 Research Questions

Based on our day-to-day context and following the thesis motivation several ideas but also questions arise. In this thesis we aim to research solutions for **(1)** the challenges

[1] T-Factor European project, https://www.t-factor.eu/, last access: 2021

Figure 1.1: Trafaria's *Forte de Nossa Senhora da Saúde da Trafaria*

of replicating a real heritage site in an explorable virtual world, **(2)** integrating a media storage with cultural heritage content with a digital platform, **(3)** how to visualize the artifacts and documents that are related with said site. The research questions that this thesis will be looking to answer are the following:

- **RQ1 -** How to design and build a platform that combines the need for preservation of digital documentation while offering a spatial and temporal experience ?

The main question we want to answer in this thesis is whether it is possible to build a digital platform that can represent the real Trafaria stronghold site or other historical sites and connect this digital representation with game elements and methods that display historical documentation and media. We want the platform to accurately represent the historical site and its cultural characteristics while providing an appealing experience to the user.

- **RQ2 -** Can we create a digital documentation media platform that allows its mutation and configuration?

In this dissertation, one of the key elements is the ability to document and store documents and media. Therefore, one of the features to be explored is the possibility to create a platform that can integrate the stored documentation into the platform and be configurable or changed over time. Allowing the possibility of adding new content at a later stage without compromising previous work, avoiding the complete restructure or even the recreation of the project.

- **RQ3 -** What methods or possible techniques can we develop to achieve an educational and immersive experience while providing documented cultural heritage content?

With the importance of cultural heritage, we intend to bring the documented and archived content to the users, the goal is to explore various possibilities and methods that can display the media to the user, through game elements or media visualization techniques.

- **RQ4 -** Is there a difference and preference in the usage of 2D and 3D interactions?

Given the implementation of different approaches to media visualizers allowing the user to interact with the historical content present in the platform database, one of the challenges is to create entertaining and interactable solutions for the user. The various implementations arise the concept of distinct interaction modes, 2D and 3D interactions. As there are various implementations of media visualizers one of the questions will be towards the hypothesis of a preferred mode by the users.

1.3 Objectives

In the pursuit of a possible solution and answer to the previous questions/problem, this thesis will focus on the development of a configurable virtual environment, with an integrated cultural heritage archive. The following objectives were defined to conduct the research work:

- Create a virtual environment: The base of the thesis project is the creation of a 3D environment anchored on the recreation of the Trafaria stronghold, the environment will be used as a site for exploration and immersion, but also as the ground for the presentation of the cultural content.

- Allow information/media input: One important feature required will be the creation of a methodology to allow the insertion of data/information into the archive, for example, the addition of media, such as the archive will work as a database.

- Build content presentation techniques: Presentation of content is the key element to bring the media to the user, it being historical knowledge or media, there for several techniques will be developed to take this information to the user, such as displaying old images on surfaces to be visualized.

- Environment exploration: The project aims to be a tool that can be used by the user to explore the 3D environment, which means there is a push towards working in different approaches which can be used to do this exploration.

- Reconfiguration support: This project intends to sustain the evolution of the system avoiding the loss of meaning of the content over time, to fix this issue, one of the objectives is to support reconfiguration and mutation of the platform.

With the following objectives in mind, to accomplish our goal in this thesis, we will study past projects and approaches that have accomplished similar results to the desired solution as well as the concepts and methodologies followed.

1.4 Solution Overview

Following the stipulated objectives, to answer the previously stated Research Questions, the work developed throughout this dissertation can be divided into four different stages: development of the virtual environment and user exploration, media content players implementation, system configuration, and user tests.

In the first stage, a virtual environment was designed to virtualize the real-world site and create an immersive user exploration experience. 3D model reconstruction was used to recreate the historical site alongside the implementation of systems allowing user movement and exploration.

The implementation of the media content players explored the integration of media files with interactive visualizers, both with a 2D interaction using HUDs and interface menus, and a 3D interaction allowing the user to interact with 3D objects in the virtual environment itself. The two implementations allowed for different behaviours and interactions between the user and the media players with the same type of media files.

After achieving a stable prototype implementing both the exploration and interaction features, the goal in the third stage was system configuration, conceiving tools within the application and system files syntax to allow the reconfiguration of parts and features in the platform.

Finally, to study the user behaviour with tasks within the platform as well as its performance, a user study was designed and created to collect data on the user interactions. Subsequently, the data was sorted and analysed to conclude the results on the research questions stipulated.

1.5 Contributions

The main contributions that can be drawn from the work developed throughout this dissertation are the following:

- Configurable virtual environment: The design and implementation of a virtual environment with a configurable system able to support changes to fit user needs.

- Media content players: The achieved prototype implemented a wide range of media content players that support various types of media files, developing an experimental site for media content load in application runtime.

- User study results: A user study elaborated with 25 participants both with and without experience with virtual museums and games, offering insights that can help future work implement virtual environment applications with similar concerns.

- Paper: A short paper was submitted and accepted to the 20th Eurographics Workshop on Graphics and Cultural Heritage (GCH 2022) [18].

Additionally, the project has also been presented and demonstrated in the 3rd Conference on Testing and Experimentation in Civil Engineering and in the presentation ceremony of the NOVA IAT architecture project.

1.6 Document Structure

The remainder of the document will have the following structure: Chapter 2 explores the existing state-of-art and refers to the related work developed in the past decades that correspond to the dissertation subject; Chapter 3 aims to present an overview of the system design, going through its requirements, features and also a preliminary prototype; Chapter 4 elaborates on the system development, starting by listing the technological tools used in the implementation process. The different features in the application are explained in more detail, and finally the configuration tools; Chapter 5 covers the evaluation phase, starting with the protocol and user tasks used in the testing session, concluding with the data analysis and discussion of the results; Chapter 6 finishes the document with the conclusions that can be drawn from the work accomplished with this thesis and proposing new avenues for further investigation.

2

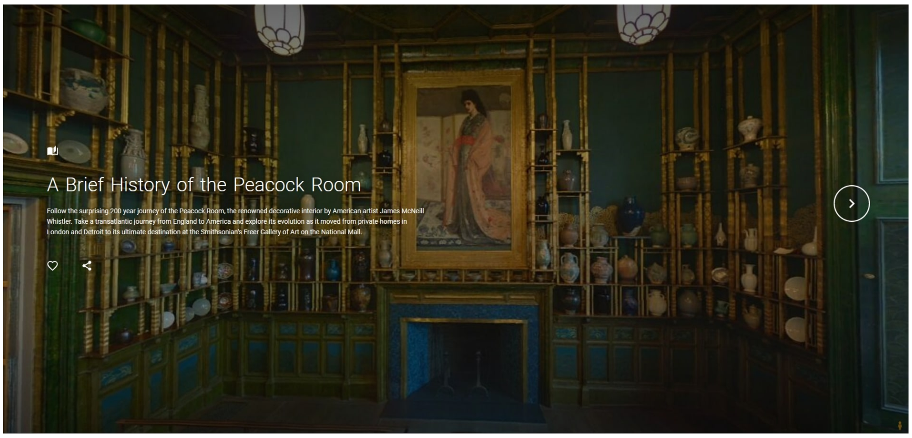
State of the Art

The state of the art is composed by three main sections, Cultural Heritage (Section 2.1), Interface & 3D (Section 2.2), Games (Section 2.3 and a final section (Section 2.4) with a summary of the content presented through this chapter. The first section will introduce cultural heritage and its connection to technology and more concretely virtual environments, second section will present several projects with diverse implementations of virtual environments and 3D interfaces within cultural and historical context and finally games section exposes games as an implementation of virtual environments and cultural heritage, since the thesis includes the usage of game elements.

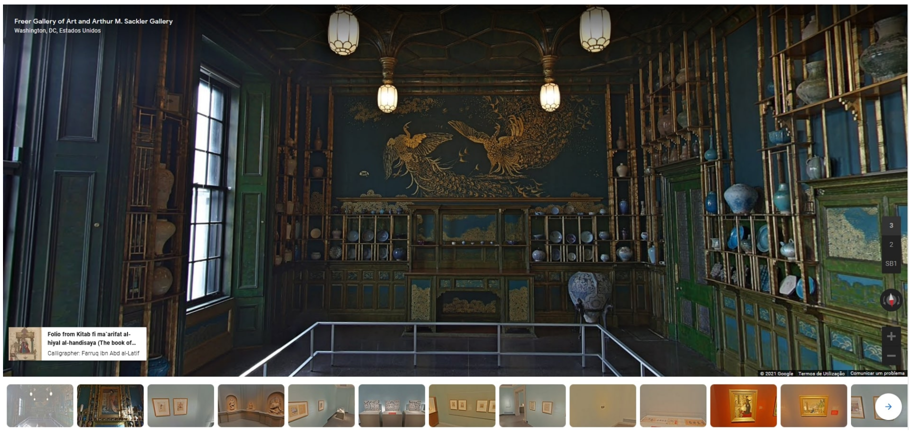
2.1 Cultural Heritage

Cultural heritage can be seen as the indicators and values that characterize a society or a community and its presence. According to Vecco [40], cultural heritage can be partitioned into two different categories, tangible culture and intangible culture, as the given names represent, the first one stands for heritage that can be physically objectified as for example monuments or artefacts' second one as defined by UNESCO focus more on non-physical culture for instance "oral traditions and expressions", "performing arts", "social practices"or "traditional craftsmanship".

As expected, cultural heritage has predominately been used when referring to tangible heritage since traditionally intangible heritage hasn't been getting much attention as it is an harder process to correctly maintain it with the technologies available. Mah et al. [24] highlights that have been few the works towards the creation of interfaces that were able to assimilate both tangible and intangible aspects of cultural heritage. One of these initiatives, Google Arts and Culture an online platform where exhibits of museums, galleries and institutions worldwide are made accessible to the public, has the tangible and intangible aspects on their website kept disparate in terms of virtual tours (Figure 2.1(b)) and interactive storyboards (Figure 2.1(a)).



(a) Interactive Storyboard



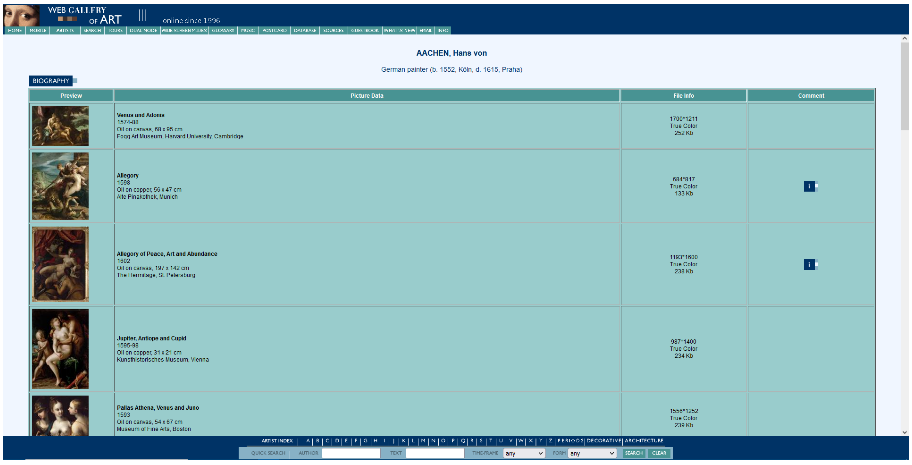
(b) Virtual Tour

Figure 2.1: Google Arts and Culture

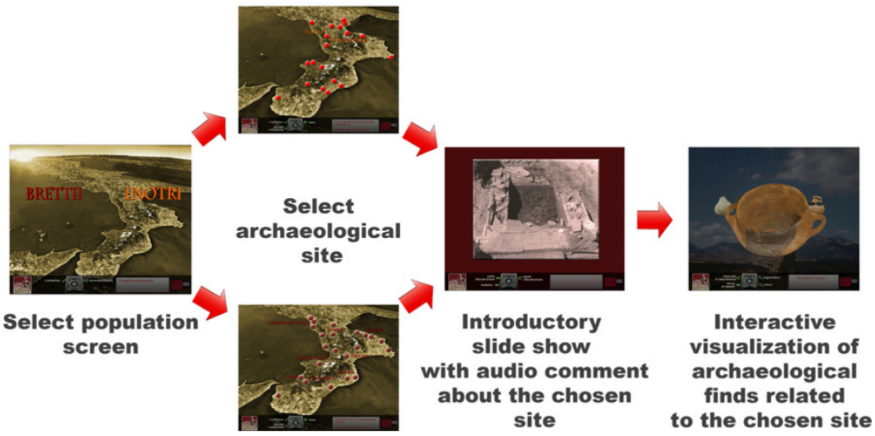
2.1.1 Cultural Documentation And Preservation

Since the main goal towards cultural heritage is keeping its authenticity and values through the passage of time, it is important to correctly implement its documentation and preservation. As mentioned before tangible heritage associates with physical objects so its preservation can be achieved by the storage of these items, but this could provoke the inability for people to observe/experience such items. In the case of intangible its preservation methods were more focused in visual and audio recording since the capture of the contextualization is very important. UNESCO defines that the points, validity, inclusivity, representativity, temporality, sensitivity and community are key factors to take in consideration when developing software that intents to work with intangible heritage.

Approaches such as Web Gallery of Art were of the first projects with the finality to document and preserve cultural content, in this case paintings and music, by developing a digital database system to gather this information into one system (Figure 2.2(a)). But in recent decades with the shift of technology and the development of techniques ranging from laser scanning, 3D point clouds to digital photogrammetry allow the creation of more advanced methods to document tangible cultural heritage and contextualize them with intangible cultural heritage elements. Bruno et al. [12] developed a virtual exhibition system, which presented 3D models of tangible artefacts and overlaid these with an audio samples, picture galleries and movies of the artefact complementing with its intangible heritage contextualization (Figure 2.2(b)).



(a) Web Gallery of Art



(b) Bruno et al.[12] Software Application Map

Figure 2.2: Digital Database Projects

2.1.2 Storytelling

Several techniques and systems are used to create cultural heritage experiences, and one of the most common now are the interactive digital storytelling (IDS) systems which is recommended by Athena Plus to the institutions that pretend to transmit cultural heritage information. B. Alexander [1] showcase five defining parts for the elaboration of digital stories, compelling narration of a story, provide context for the story being told, use imaging to transmit emotions found in the narrative, make use of sounds to reinforce ideas and invite the audience to reflection moments.

Although being the recommended approach it faces several challenges exposed in Schoenau-Fog [34], being the main issue, the so called narrative paradox [5], defined as the clash between the freedom that can be given to the user and which actions are allowed, and what constraints can be enforced on the user to preserve the main course of the story [34]. Reoccurring problems related to the narrative paradox are for example when a portion of the story is connected to an object or a part of the environment that can only be accessed by a trigger activated by the user [35]. Users might miss finding these triggers and not perceiving important information as a result. Thus, narrative paradox solutions are significant contributions to an IDS methodology. Several works have taken different approaches on a solution to these challenges [23], for example, emerging narratives where the stories are connects with elements which the user interacts with through out the main game-play, or the construction of a 360º video environment where the user has the freedom in what order they want to choose the stories. When it comes to the methods to preserve intangible cultural heritage Selmanović et al. [35] suggest using virtual environment and Web-based methods since they provide a better solution for immersion and reality.

2.1.3 Narrative Paradox

The narrative paradox is one of the challenges in designing and developing virtual story worlds. This challenge reflects on how to reconcile the needs of the user who is now potentially a participant rather than a spectator with the idea of narrative coherence — that for an experience to count as a story it must have some kind of satisfying structure. In between the possible solutions to solve this issue is moving the focus to user-as-director instead of the initial user-as-participant, by giving the user more freedom and decision making.

Aylett [5] highlights 2 different issues with the solution above, first is if we are building a narrative how far can we relax the pre-determined narrative without losing its narrative nature, and second how much freedom can we give the user in the virtual environment to participate as an actor and not as a spectator. To achieve a reasonable solution there are a lot of works towards the use of emerging narratives as a solution. These are presented in the form of stories that emerge from the players' interaction with the gameplay governing systems. Emerging narratives have 2 important ideas, the first, emergent narrative is essentially physically and temporally contingent, meaning it happens in a specified place and time frame and the second, what dictates 'the narrative' since it depends on the final goal and the developer. With this there is also a study on the role of the user since the user is gaining more 'freedom' in the environment or at least give the impression of freedom to the user. Taking this into consideration if then important to create a system to aid the user if this goes into the 'wrong' position and guide them or at give the user hints and nuances on where to go and what to do to keep the narrative going.

The author Aylett [5] does another study in Louchart et al. [23] where they try to solve the narrative paradox carrying out a study on RPGs, concluding that a medium term on guidance from the system (in case of the study the Game-Master) and the allowance of freedom to the players is an acceptable solution to the narrative paradox since it provides some degree of freedom and results in enjoyment by the players.

2.2 Interface And 3D

Virtual reality has as its primary finality to create a computer-generated environment experience and at the same time provide the users an immersive and fulfilling experience of the virtual world. An important note is that the term "virtual reality" is loosely used when talking about pretty much any applications/ installations using or containing 3D graphics. For cultural heritage but also for cultural propagation Bartley et al. [7] discuss about the advantages of reconstructing cultural sites in the form of virtual tourism. The reality-virtuality continuum focus on the span between real and virtual environments, and then Augmented Reality (AR) closer to the real and Augmented Virtuality (AV) closer to virtual reality Milgram et al. [28] This continuum is show in the diagram of Figure 2.3. Augmented reality can be defined as "a system that combines real and virtual content,

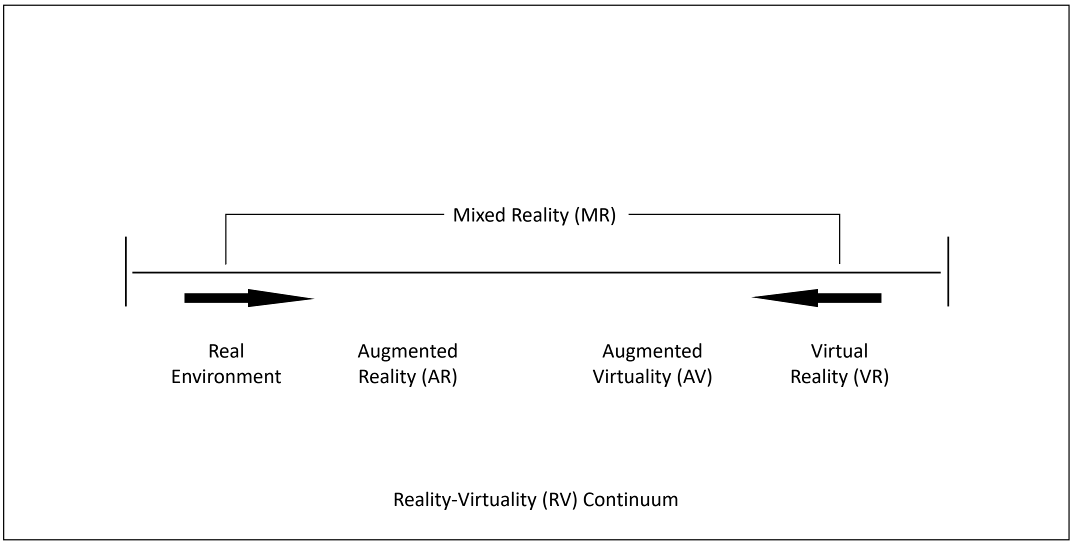


Figure 2.3: Real Virtual Continuum

provides a real-time interactive environment, and registers in 3D." by Azuma [6] since studies have been showing AR as a system that with the complementation of virtual and computer generated information enhances the view we have of the real world, in a short mode and according to Milgram et al.[28], it completes reality without replacing it. AR commonly has some characteristics Azuma [6] (i) It combines real-world and virtual objects, (ii) runs in real time, and (iii) allows interaction between users and virtual objects, although these characteristics can also be found in the other reality-virtuality continuum application. Also Azuma [6] extends AR with systems to potentially remove objects from the real environment using graphic overlays, but here literature classifies it as Mediated Reality. Both these concepts focus on the mix of virtual information with the real environment to enhance perception and built intuitive interaction metaphors. On the other side of the spectrum, we find Virtual Reality (VR) which does not make use of the real environment or lets the user see it, VR tries to completely immerse the subject in a synthetic world through a representation creation in a computer. Since there is no interaction with the real environment VR tries to re-create synthetic content in a way that visual, hearing and touch senses feel like an actual environment. A mid-way approach in the continuum is AV in which lives scenes taken from a real environment are taken into a virtual world to possibly enhance it and augment it. Between AR and AV there is a whole area that tries to blend and mix AV and AR in various ways called Mixed Reality (MR). A simple definition of the the several approaches in the continuum is Bekele et al. [8]:

- Augmented Reality: aims at enhancing our perception and understanding of the real world by superimposing virtual information on our view of the real world.

- Augmented Virtuality: aims at augmenting the virtual world with scenes from the real world.

- Virtual Reality: aims at enhancing our presence and interaction with a computer-generated environment without a means to interact with or see the real world.

- Mixed Reality: aims at blending real and virtual environments.

AR in cultural heritage has its focus centred in three major application areas enhancing visitors' experience, heritage reconstruction, and heritage data management and exploration. VR has technological and immersive aspects that allow several definitions since it's a complex technology complex technology that creates a digital environment with which users may interact and which they feel completely immersed within, Bhouri [10]. Although VR intent is to enhance the user experience in a virtual environment through its interaction and immersion does not mean that the digital environment is a fictitious world, in the CC domain there has been exploration in VR and 3D data acquisition techniques so its possible to build a variety of CH purposes, such as virtual museum, virtual reconstruction, virtual exploration, and Cultural Heritage education. Mixed reality is the in between real and virtual where both exist and can be interacted in real time, it is the consequence of the merge of augmented and virtual reality. “MR is not just an alternative to augmented or virtual reality. Rather, it is a unique perspective that enriches humans' perception of both real and virtual environments.” Bekele et al. [8] . Some systems developed with mixed reality in mind with the goal to transmit the feeling of immersion to the users but also enhance their real world perception in the CH subject are Mura et al. [29] and Okura et al. [30]. Beke et al. [8] refers the following aspects as essential in AR, VR and MR applications:

- Tracking and registration, although tracking is not a must in VR, both the latter and AR seek to track the users viewpoint. AR needs to track its user so it can correctly superimpose the built virtual content over the reality and VR in some cases might want to track the user so it can correctly adjust the perspective of the displayed virtual content. This tracking is usually camera based, sensor based or hybrid based.
- Virtual environment modelling, "process of simulating real objects and their state in a digital space, the behavioral rules that the objects obey, and the relationships and interactions between them" Zhao [44]. To build the virtual environments different techniques can be used like the 3D scanning or using photography to reconstruct real world structures and objects or even mathematical models and abstractions that are used to represent the real world in digital space.
- Computers, display, and devices for input and tracking, to build and use these applications and system devices like computers are needed for development and even display, and others like cameras and input devices are needed for interaction with the environment created.
- Interaction interfaces, Interaction is the main concern in VR since is a cumulative effect of immersion, the sense of being surrounded by a virtual environment, and interaction, the possible range of users' interaction with the virtual environment. There are several types of interfaces tangible, collaborative, device-based, sensor-based, hybrid, and multi modal interfaces.

2.2.1 3D Virtual Environment Applications

In Bekele et al. [8] research it concluded that the usage of virtual environment applications in CC and CH has been primarily for virtual museums and then for education, reconstruction, and exploration purposes. The study goes in depth revealing that these applications for the most part are not at all fully-immersive but most of them semi or non-immersive in their categorization since they do not use tracking methods but are more based on presentation and usage of device-based interface. There for they categorize these applications in Non-immersive, applications that employ desktop screens for displaying the virtual content, and use device-based interfaces, not using tracking methods. Semi-immersive, applications that sometimes use tracking for the pose of the users, but here these applications tend to use interaction devices, also for presentation back-projects screens or 3D stereo displays are used. Finally, Fully Immersive applications where CAVE and HMD display are and option and used to provide a fully immersive experience to the user.

Table 2.1: Applications presented

Application	Purpose	Interface
Virtual Heart of Central Europe [43]	Virtual Museum	Web
Mostar Bridge Diving [35]	Reconstruction	Web / Application
Vrouw Maria [32]	Reconstruction	Application
MayaArch3D [33]	Education	Application
Virtual Exploration of Underwater Sites [21]	Virtual museum	VR Application

2.2.1.1 Virtual Heart Of Central Europe

Virtual Heart of Central Europe (VHCE) [43] is an EU project with the goal to present 4 historical architecture monuments spread around 4 cities across Europe, Bratislava, Graz, Maribor and Prague. The motivation of the project was to make a digital reconstruction of the selected buildings and build an application on the web make use of hyperlinked structures and using a multimodal approach. This project took interesting design and implementation choices since they made use of different servers, one for data storage and one for the application itself, as well as making it so the data components are described in XML notation allowing a flexible and transparent data management, this approach encourages the development of a predetermined notation when working with systems such as this one where there is some importance in the data management. The project implemented a variety of presentation techniques giving the user multiple options to experience his own exploration, implementing the usage of images, videos and also VRML scenes.

(a) Image of presentation video (b) A VRML scene

Figure 2.4: Images from Virtual Heart of Central Europe Project [43]

2.2.1.2 Mostar Bridge Diving

This project [35] takes as reference an Old Bridge in Mostar, a town in Bosnia and Herzegovina, famous bridge built over the Neretva River in the 16th century, destroyed by Croatian military forces in 1993 and later rebuilt in 2004. The aim of the project is to present through VR storytelling and virtual diving the history of the bridge and cliff diving tradition. The project is an example and an application of the 360º video environment, being the whole application in 360º there was also developed the implementation for the usage of a HMD. It is structured as 5 360º videos an introductory video that shows in the beginning and then 4 stories that can be watched and re watched by the user in any order, after there is a quiz to assess if the knowledge was acquired and if positive feedback the user is taken into a cliff diving simulation of the bridge.

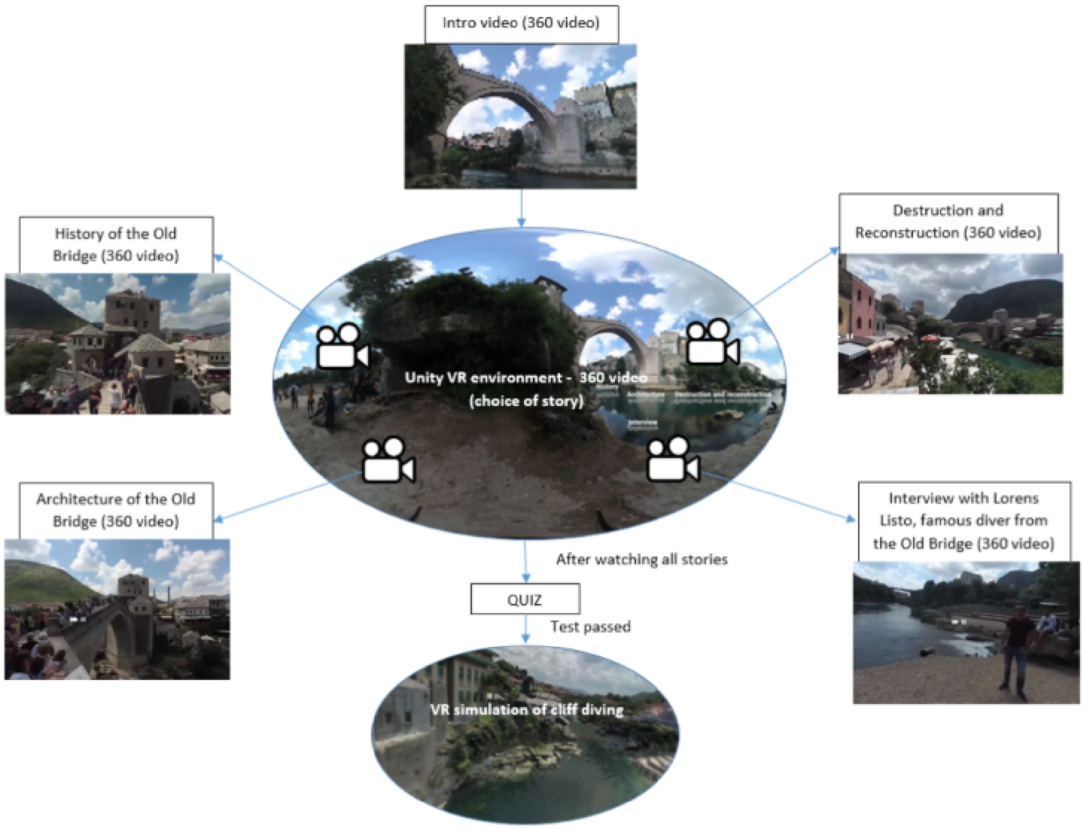


Figure 2.5: Mostar Bridge Application [35]

A WebGL version of the application with the same content was created for the users with no access to HMDs, this rose the extra work of implementing the interaction and navigation of the application with mouse and keyboard, which was a case study in the project and a comparison was built on top of it. In the project the authors explored the 2 selection types of interaction highlighted in Interaction section by implementing the local interaction in the final simulation making so the user has to interact with the ladder to climb and the at-a-distance interaction in the quiz but also in the main interface where the user interacts to pick the stories he pretends to watch. The menu interaction was accomplished by the implementation of a floating 2D menu in the canvas, one of the solutions purposed in the Menu Interaction section, The implementation was mostly done by creating Button UI existent in Unity being able to be clicked and giving feedback to the user when clicked, for example, when clicking to watch one of the stories and after watching it, the button changes colour from white to green. As mentioned before a case study was taken on the comparison between the VR with HMD version and the WebGL version of the application through the medium of the UTAUT to investigate the affect on usability and accessibility for the context of preserving intangible cultural heritage. The result of the study was that VR was the superior medium when compared to WebGL a more traditional method to support intangible heritage applications and doesn't negatively influences the easy of use.

2.2.1.3 Vrouw Maria

This project [32] take as reference the Dutch 18th-century merchant ship Vrouw Maria that sank near Nauvo, Finland while it was doing the travel from Amsterdam to Saint Petersburg. Since the wreck lies at a depth of 41 meters where the visibility conditions are poor and only reachable way is through experienced diving. Taken these conditions and the fact the ship might not ever be able to be retrieved a virtual tour was the only option to conceive a visit. The installation had some interesting core features:

- Reconstruction of the site based on real images and measurements.
- Immersive sound that varies with depth

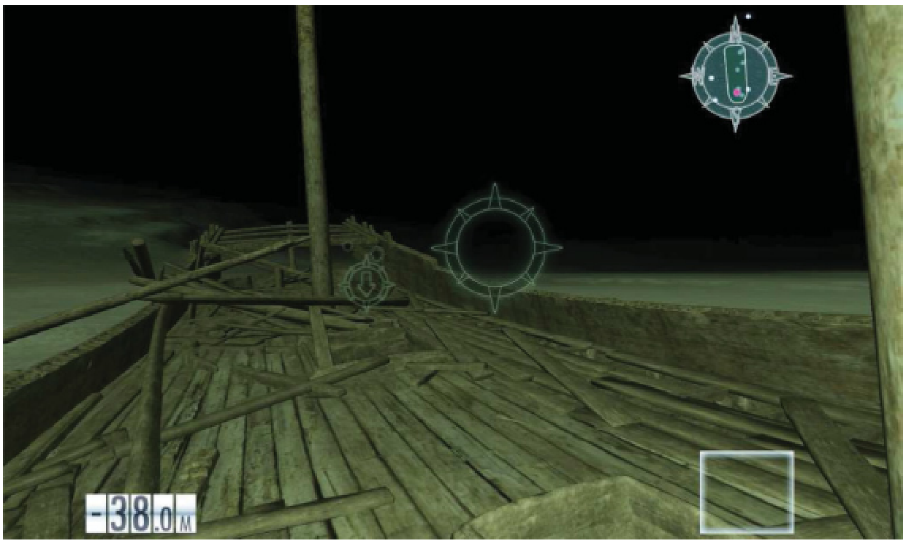


Figure 2.6: Vrow Maria Project [32]

The technical implementation of the Virtual world is relevant since interesting efforts were taken to achieve some immersion aspects. The game engine Unity was used as the base technology but there were used the plugins Ocean and Unisky to create water, waves and sky effects enhancing the experience of the user with the ambient. The authors also tried to recreate the fish and their behaviour around the shipwreck by implementing simple flocking AI behaviour based on the Boids algorithm.

2.2.1.4 MayaArch3D

MayaArch3D [33] is a project that began in 2009 and exploring both device-based and natural systems for education and research of the historical Maya city of Copan in Honduras. Since Copan became a UNESCO World Heritage Site it has seen a lot of tourism in it's archaeological park, but since a great part of the ancient city doest make part of the park boundaries the whole cultural heritage context isn't accessible to the visitors.

With this issue in mind the project aimed at the exploration of 3D digital tools and Geographic Information Systems (GIS) and develop a 3D WebGIS tool, called QueryArch3D. This tool was conceived to allow archaeologists to use a back-end database feature and also provide a simple user interface where several actions could be executed like the usage of search queries such as "show me all excavated temples", turn on and off layers of information and illustrate different environmental interpretations, use sliders that change the environment with time and allow the access of more information like text, images, maps when interacting with the 3D models.

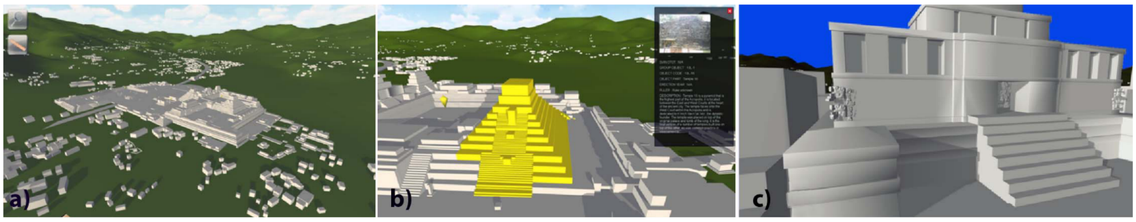


Figure 2.7: QueryArch3D Tool [33]: a) aerial view b) queries on geometric models and c) model with interior walls/rooms

2.2.1.5 Virtual Exploration Of Underwater Sites (VENUS)

"The main goal of the VENUS project is to provide scientific methodologies and technological tools for the virtual exploration of deep underwater archaeological sites."[21] The construction of the virtual environment is divided into 3 principal steps, Seabed meshes are loaded from an XML file containing 3D vertices and texture information, an initial request to the database is per-formed to retrieve artefacts parameters such as location, orientation, status and artefacts models. Then, registered artefacts and markers 3D models are loaded, finally these elements are placed in the virtual environment, and navigation and interaction managers are started. The interaction manager handles inputs and eventually sends queries to the database. Figure 2.8 shows the VR system architecture build for the VENUS project.

Although this project is using a VR system, and not simply a 3D application as this thesis intends, its architecture and implementation of the virtual environment can be used as inspiration as it defines a very structured and cohesive system.

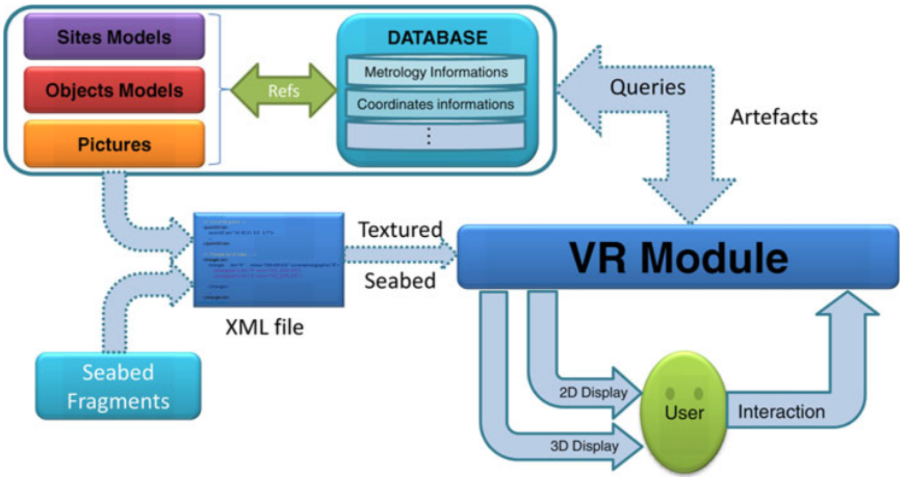


Figure 2.8: VR System of VENUS [21]

2.2.2 360º Video Environment

360º video has been introduced in recent years as an innovative form of experiencing immersions in VR and on implementing virtual environments. It's a promising technology that offers enhanced realism and can be produced using computer generated virtual environments but it's a resource intensive and expensive process. Applications using this idea/technology focus on free viewpoints videos and allow the viewers to navigate in the 3D virtual world by interactively change their viewpoint in the scene Smolic et al. [37] while in traditional video the viewpoint is chosen by the director. In these applications studies reckon that in 360º videos users like and enjoy the possibility of picking which stories and in what order they prefer. This allows a higher level of immersion and in Subsection 2.2.1.2 presenting the bridges of Sarajevo users reported that they would feel like they would be actually walking on the real bridge. Argyriou et al. [4] Talks about some challenges and implications that come with the use of 360º degree videos, mainly related to the video itself that is used as the main game scene of the virtual space and lacks depth so the user can navigate, since conventionally a user can navigate in 3D geometric reconstructed real spaces. To try and solve the challenges Argyriou et al. [4] built a framework to be used as a basis to create 360º degree gamified applications. Often 360º degree video environments incorporate quizzes as a education gamification technique to offer more engaging experiences and increase the level of user's immersion. An example of this is Selmanović et al. [35] and Argyriou et al. [4] that use quizzes in order to solidify the knowledge acquired through the usage of the application but also as learning methods sometimes only allowing the progression of the user to the next phase after successful progression of these questions.

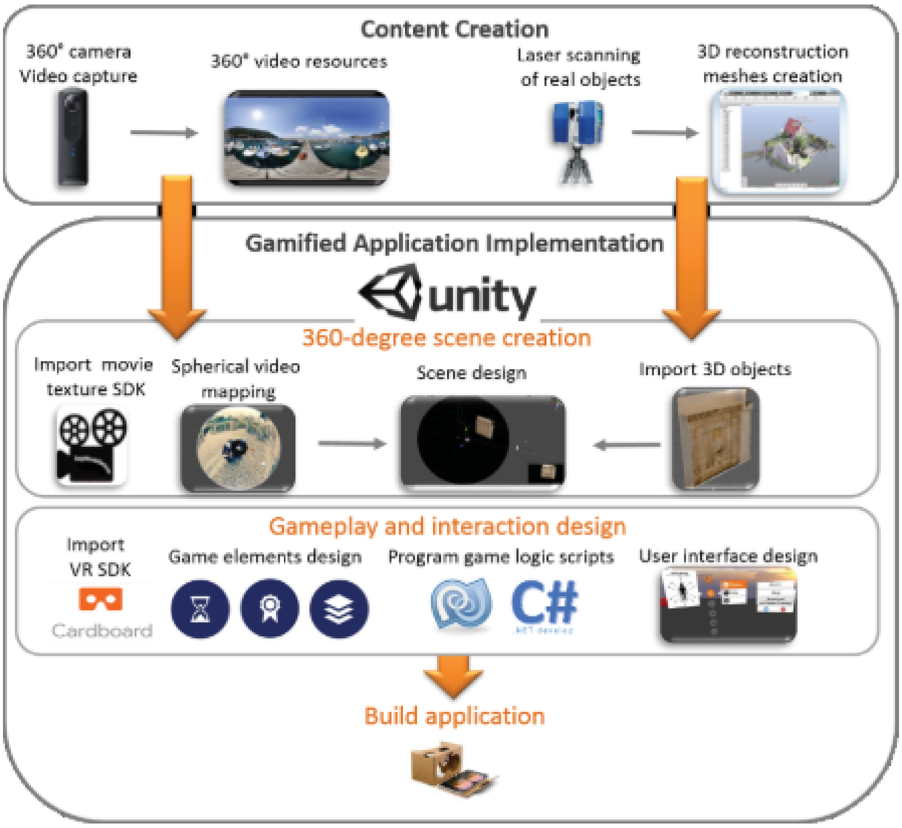


Figure 2.9: 360-Degree Gamification Framework [22]

2.2.3 Interaction

Selmanović et al.[35], Steuer [38] and Sims [36] study the concept of interaction and get to the conclusion that it is one of the key points connected to immersion, being the main feature of a system that wants to create a sensation of presence to the user. They partition the modes of interaction into five different modes:

- Navigation & Locomotion: Movement and navigation is the interaction that allows the user to explore the environment but also guide him through it;
- Selection: Interaction that allows picking the virtual object to further interact with;
- Scaling: Interact with the scale of the environment allowing to scale up or down, giving new opportunities such as the reaching previously unreachable places. but also objects being able to reach details in smaller objects.
- Manipulation: Mode that allows the user to change an objects position and angle and access it fully;
- Menu interaction: Menus introduce the ability to give the user the access to perform various activities such as replay ability.

Selection has 2 key elements, identification and actual selection, first related to the how a systems knows which object to select and second that represents the command or action executed to actually select the identified object. Selection can also be locally if the object is in reach range or at a distance if the object is out of reach of the user, this latest one can be achieved with laser beams, spotlights and through voice for example. Mendes et al.[27] proposed a selection taxonomy that includes cardinality - the number of objects that can be selected simultaneously and gradual refinement-gradual sub selection among multiple larger groups of initially selected objects.

2.2.4 Navigation And Menu Interaction

Navigation and menu interaction are the 2 principal interaction modes, as the former is directly connected to the movement of the user in the virtual environment and the latter allows or restrains the user from using certain functionalities.

Navigation interaction can be divided into 3 different categories:

- Free exploration - Navigation can be implemented though the allowance of the user to have total control over it, being he the one deciding what to do and when to go in the environment, usually represented by the ability of the user to "walk"to a certain destination, an example is Subsection 2.2.1.3 where the user can freely navigate in the ship deck but also in the sea bed.
- Viewpoints/Click-and-go - Navigation can be an in between freedom and system locked, where the possibilities of what and where the user can go are predetermined, but this user still his given the control over in what other he wants to explore the available content.
- Automatic - Navigation can be fully or almost fully automatic when the user is only responsible for the management of the speed at how he experiences the content, for example sequential videos.

Menu interfaces are a key point in interactive systems since they allow the addiction of new and extra functionalities or the alteration of already existing features as well as changing options. Although these interfaces are so important they haven't been deeply studied for when it comes to virtual environments. One of the most common approaches stands in using 2D menus in the 3D environments attaching the menu to the view port of the camera. This menus are usually accessed by pop-ups and pull—downs reached by pressing buttons or clicking interact able objects in the environment. Another approach that has been getting more and more attention are the 3D "physical" menus, such as spin and ring menus usually attached to the user hands.

Nonetheless the decision on what menu interface to use, depends on the goal of the application being developed and on what interaction is intended for the user. Dachselt et al. [16] makes an intensive study on several 3D menu options and builds a comparison between the possible options and discusses a taxonomy for them.

2.2.5 Evaluation

When evaluating the use of a new technology, the researching field relays on the usage of the technology acceptance model (TAM) proposed by Davis Davis [17] to evaluate user attitude and behavioral intent towards the technology in study. A basic version of TAM can be separated into two constructs, perceived usefulness (PU) and perceived ease of use (PEU). PU being "the degree to which a person believes that using a particular system would enhance his/her job performance" and PEU "the degree to which a person believes that using a particular system would be free of effort".

A later version of the TAM was defined by Venkatesh et al. [41] where the attitude toward use and intention to use was replaced by the behavior intention (BI) being this the factor that influences user behaviour. Venkatesh et al. [42] presented an unified theory of acceptance and use of technology (UTAUT) that has four predictors of the behavior of the user: PU involved in performance expectancy (PE), PEU in an effort expectancy (EE) construct, and new predictors of the user behavior: social influence and facilitating conditions. Figure 2.10 shows the UTAUT block diagram.

For SG according to (ISO/IEC-25010 2011) there are some main qualities to be assessed when doing evaluations, these include game design and interfaces, user satisfaction, usability, efficacy and performance, learning outcomes and others. Calderon et al. [14] identify educational effectiveness as the main quality to be accessed in evaluation if the goal is to measure knowledge acquisition followed by user's experience and usability.

As for the methodology for the evaluation, questionnaires and surveys are the preferred method both for measuring technology acceptance and user behavior research [35] but also for the evaluation of SGs[14]. Although surveys are the common method, there are some variations and other approaches to these evaluations, for example in Andreoli et al. [3] the authors experimented the mix of the usage of tasks with a fixed amount of time to be completed followed by a questionnaire to evaluate the degree of involvement and enjoyment of the user.

The implementation of the questionnaires often goes through the usage Likert scales with between five and seven points for the rating of each question, and verbal anchors like Strongly Agree and Strongly Disagree, or Very Low and Very High. An example is the System Usability Scale (SUS) questionnaire which is present in the literature as a reliable tool for measuring the usability [11].

2.3 Games

Video games are a large part of the entertainment industry and have been a part of people lives, in fact, a great part of people in the USA (59% of the population) plays games Hamari et al. [20]. The popularity of games within the younger people over the last ten years games have also solidified themselves as more than leisure, they have also become a tool for education, information systems and cultural dissemination Malegiannaki et al.

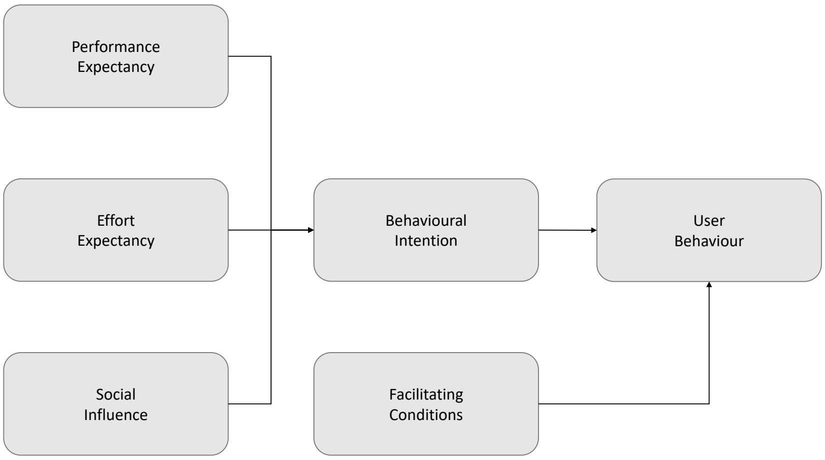


Figure 2.10: UTAUT Block Diagram

[25], Mayer [26]. With video games success game development has been enhanced by the huge advances in computer graphics hardware which also leads to higher quality of real-time computer graphics and increased realism in computer games Anderson et al. [2].

2.3.1 Games In Cultural Heritage

Games are design having in mind the entertainment and the pleasure of players but in recent years we have been seen the use of games to support use of games to support cultural heritage purposes, such as historical teaching and learning, or for enhancing museum visits [2]. "The use of games in various learning environments is supported by their motivational and repetitive character, the engagement and flow they induce, the interactivity and feedback they offer, and their functioning as safe environments to experiment."Malegiannaki et al. [25]

According to Bellotti et al. [9] experience model, students can only recall 10% of what they have read but they can remember close to 90% when performing a task, games can fit these model as they can incorporate a variety of tasks embedded with environment exploration to allow knowledge acquisition. With this in mind a different category of games arises, the Serious Games(SG), defined as “a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives”, thus being games that have educational and informative intent. Since the thesis goal is towards exposing cultural heritage and provide information SGs will be the games category in focus, as they are a "class of games whose primary goal is not entertainment"and with the latest technologies of simulation and visualization immersive situations can be achieved. Anderson et al. [2] makes a further categorization of Serious Games in three types of computer-game-like applications (Figure 2.11):

- Prototypes and Demonstrators - projects that use visual reconstructions of historical sites in order to train and educate their users, usually used for academic studies, an example is the game 'Rome Reborn' (Figure 2.11(a));
- Virtual Museums - interactive museums using gaming technology trying to give the users a digital representation of the cultural heritage sites and at the same time give an entertaining and educative experience. These projects include virtual museums that also exist as real museums but have their digital variation, an example is the game 'New Kingdom Egyptian Temple' (Figure 2.11(b));
- Commercial historical games - games that have their main goal to entertain the player but at the same time make so the player partakes in an historical event, usually battles and wars. These games are usually inserted in the 'documentary game' genre, and example is the game (Figure2.11(c)).

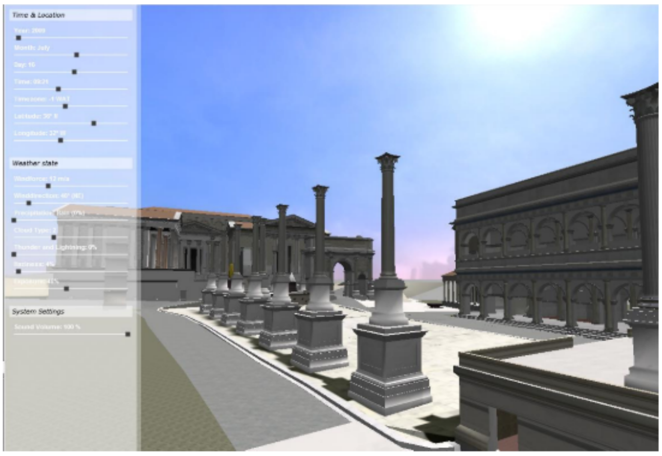
2.3.2 Build Games For Cultural Heritage

As mentioned previously the more suited games for cultural heritage are SGs,but even then there are some considerations to be taken into account while designing and building them. On one hand it's important to represent immensity and immersive when the players are re-experiencing the past, and on the other it's important to understand that when playing an educational game people can allocate different kinds of cognitive processing Mayer [26]. The latter can be divided in Extraneous processing (does not serve for educational purposes and usually caused by distractions), Essential processing (needed to mentally represented the relevant material) and Generative processing (aimed at trying to make sense of the material and caused by player's motivation). The main goal is to design a game that minimizes extraneous processing, walks through essential processing and foster generative processing.

In Andreoli et al. [3] a framework is conceived with the goal to help the creation of SGs for cultural heritage, it consists in 4 major steps, Preliminary Phase, Conceptual Phase, Development phase and Evaluation phase.

A quick overview of each phase is, the preliminary phase aims at a high-level reasoning on the whole SG To be developed, the targeted users, some initial design decisions and others. The conceptual phase is the main phase of the system where the decisions on what and how are the mechanics and resources of the game are going to be used and implemented, the development phase is as the name directs the phase where the development of the decisions made in the previous phase happens and lastly the evaluation phase where tests take place to validate the game.

Reunanen et al. [32] exposes an interesting concept, the interaction matrix which is defined by a final step in the conceptual development where the information that wants to be brought into the game is broken into the several scenes and follow the following properties:



(a) 'Rome Reborn'

(b) 'Egyptian Temple'

(c) 'Great Battles of Rome'

Figure 2.11: Serious Games types

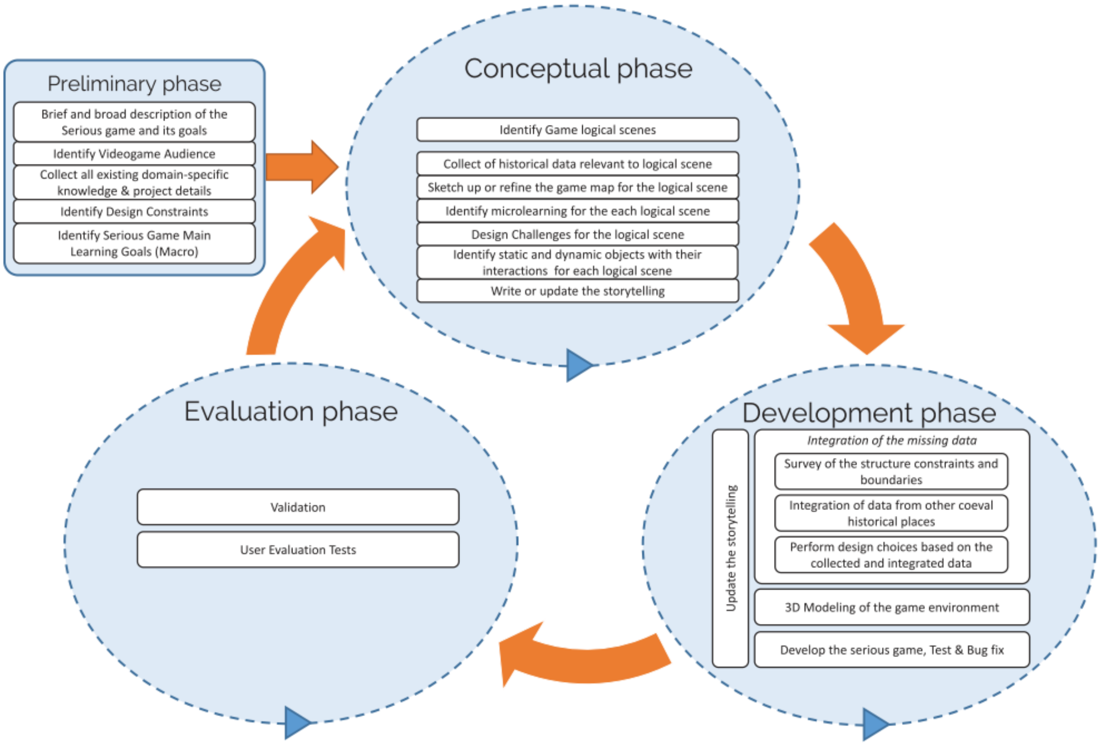


Figure 2.12: Framework for Serious Games

- General description of the location
- Possibilities for user interaction
- User view
- Available extra content, such as videos and photos
- Duration (in the case of chronological events)
- Transition to the following event or location

Further more Bellotti et al. [9] the creation of a model to develop serious games that in rough terms consists in 2 parts, a concrete spatial virtual world where knowledge is distributed and tasks dispersed in this virtual world, tasks that embody units of knowledge and are simple activities that the user can discover and play to gain this knowledge. This can be crossed with the earlier work in Andreoli et al. [3] when in the conceptual phase since its important to build game mechanics to bring the historical value and knowledge to the players. An example of it could be a simple puzzle game in Figure 2.13.

2.3.3 Game Engines

Game engines can be defined as a collection of modules of simulation code [22], with the goal to abstract and simplify game development. Usually the engine includes modules for

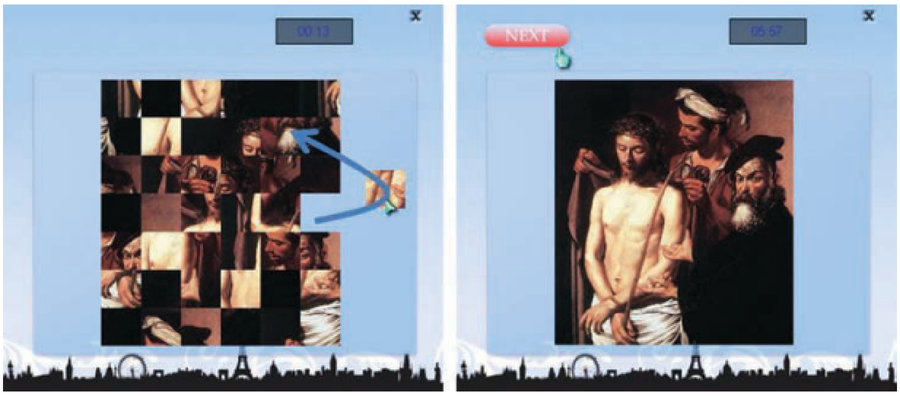


Figure 2.13: Ecce Homo - Puzzle Game

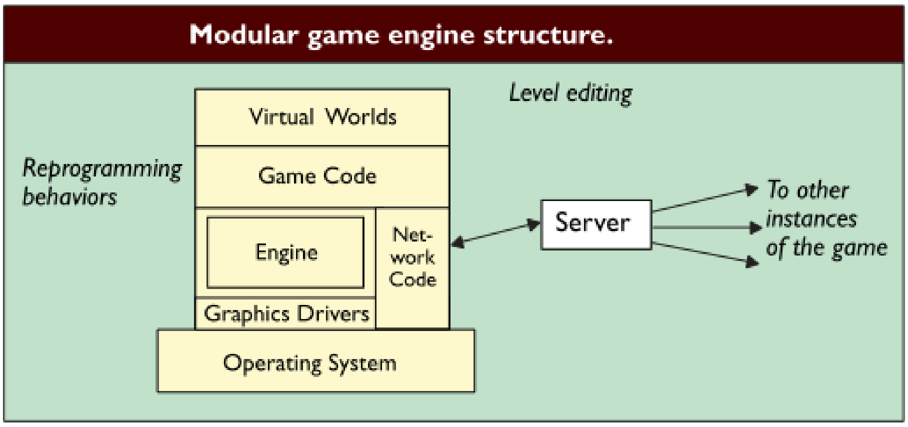


Figure 2.14: Game Engine structure [22]

graphics, physics, sound, input and output handling[22]. Figure 2.14 shows the modular representation of a game engine suggested by [22];

Due to the various needs when developing games there are several options of game engines to pick from, which means several dilemmas arise at the time of choosing the right tool. These dilemmas can be related to its usage as for example if it allows a faster or slower development, how user friendly the game engine is and if it requires a vast knowledge in programming skills. But also how powerful the game engine is, meaning if it allows 3D and 2D graphics, how good is the online and networking support or how good are its physics support. Vasudevamurt et al. [39], Pavkov et al. [31], Gregory [19]

[39] does an in depth comparison of several game engines (Unreal Engine, Cry Engine, Unity, Game Maker Studio, Adobe Flash) providing a good ground work for deciding on what game engine to use on a specific project.

2.3.3.1 Unity

Unity developed by Unity technologies first released 2005 and now being one of the most used engines is a game engine suited to create and develop cross-platform 2D and 3D games but also virtual reality and computer simulations. It allows the development of high quality games through its three dimensional manipulation and simulation through functions defined using programming languages [13]. Some of Unities key features are Craighead et al. [15]:

- Documentation: Unity engine provides a complete documentation for its API allowing a more efficient development and productivity.
- Community: There is a big and online developer community around the Unity engine that aids new users and community features are taken in consideration by the developers becoming an actual feature in some cases.
- Editor: Unity editor is rather easy to use and user friendly since it allows a drag-n-drop feature and separating the objects of the environment in a separate tree. Scripts can also be easily assigned to this object using this feature.
- Physics: Unity provides full support to add physics properties to objects like mass and collision.
- Multi-platform Distribution: Game engine runs on almost all operative systems and the projects developed can be compiled into a normal application but also into a web application.

2.3.3.2 Unreal Engine

Created and developed by Epic Games, Unreal engine is the leading engine when it comes to realistic visualization, vegetation and terrain creation. This engine is generally used for medium to large projects lacking the focus on mobile development although it is supported. Unreal offers visual scripting with a blueprint system, which are graphs composed of connected blocks that create the game logic instead of written scripts.

2.4 Summary

The first section tried to contextualize what is cultural heritage and how it can be defined, gathering evidences that it can be tangible or intangible, depending on whether its connected to a physical place or building or if it is non-physical culture. To carry culture heritage over the time there is the option to document it or preserve it, being the latter more difficult to achieve but more rewarding in the sense of transmitting its cultural context. Bringing this concepts closer to recent technology, we find the Interactive Digital Storytelling Systems which are a common via of cultural heritage transmit and the possible approach of this thesis project. Although being common and a good approach these systems find challenges, like the narrative paradox, that determine the function of the system and the user experience.

The second section explored the concepts of interface and 3D by initially understanding the real-virtual continuum and then focusing on the virtual environment subject as it is the thesis purpose. It is taken a look at several 3D environment applications within the cultural heritage context in order to take a look at the different implementations but also the acknowledged challenges when building these applications. The later chapters discuss the interactions that the 3D applications should be worried of developing to allow a good experience to the user and a final section, discussing some evaluation methodologies to access some factors like usability and easy of use.

Finally there is a final section related to games, an implementation of applications for cultural heritage but with the intuit to be more didactic and incentive the users knowledge acquisition through gamified options which are after more appealing to the user. Its also discussed a framework and a groundwork described the step necessary to build games that aim at the use and showcase of cultural heritage and a later chapter given an insight in some of games engines available today and how they work.

Table 2.2 compiles a table with all the applications showed in this chapter with a brief description of its features.

Projects / Applications	Web App	Pc App	3D	Images	Video	GIS	VRML	Free Exploration
Google Arts and Culture	X		X	X	X			
Web Gallery of Art	X			X				
Software Application[12]		X	X					
VHCE [43]	X		X	X	X		X	
Mostar Bridge [35]	X	X	X	X	X			
Vrouw Maria [32]		X	X					X
MayaArch3D [33]	X	X	X	X		X		X
VENUS [21]		X	X					
Rome Reborn		X	X	X				
Virtual Egyptian Temple		X	X					X
Great Battles of Rome		X	X					

Table 2.2: Projects presented in State-of-art chapter

3

Analysis and System Design

This chapter will elaborate on the analysis of the Research Questions presented in Section 1.2 and the system designed as an answer. For starters, a Requirements section concerning the several requirements identified both in the research questions and the conceptualization of the project, followed by the Case Study exposing the study case on which the project is based to cover such requirements. Next, the Feature Design section is composed of the several idealized features to be implemented in the projected system, followed by the System Design section dedicated to the presentation of its outlining design. Finishing the chapter, a preliminary prototype was conceived in the early stages of the project development, refining the project direction and feature implementation focus.

3.1 Requirements

Recalling the research questions presented in Section 1.2, this section will define the main requirements for the design and implementation of the projected system. Following the research questions, a platform was designed that can offer both a spatial and temporal virtual experience as well as a digital documentation site. Therefore, it was essential to design a system that would support exploration and interaction, plus content storage and system reconfiguration. In summary, the requirements can be divided into categories: content requirements, user requirements, visualization requirements and interaction requirements.

Content Requirements: As the project wants to provide support for a digital documentation component, one of the key elements is which content can the desired platform support and store. Therefore, the platform needs a database component, able to be accessed by the system and able to store the supported content: text, media (images and video), audio, files, and possibly 3D artefacts.

User Requirements: After the initial conceptualization of the platform, two user types were identified as the users that will interact with the platform to be developed. An "editor"user, knowledgeable about the technical implementation of the platform, being able to adjust its configuration files resulting in changes on the platform. As well as a second user, the "normal"user, making use of the platform as a visualization and exploration tool.

Visualization requirements: To bring the documented content onto the platform and consequently, to the user, the project intends to implement and present different visualization methods. These methods can either be, 3D media objects placed on the 3D environment itself, such as pictures on walls, or making use of other visualization modes such as object manipulation or 2D HUDs to perform various actions.

Interaction requirements: As the platform supports several visualization options it will need the implementation of different interaction approaches as a result. These include user movement allowing movement around the virtual environment, object interaction in which the user can select specific objects in the scene, and menu interaction by creating menus that provide a set of functionalities accessible to the user.

3.2 Case Study

A case study covering the previous requirements was established to create a virtual environment using as a basis the building of *Presídio da Trafaria*. The complex was built in 1565, used as a space to provide for storage of materials and a place for merchants, and later used as a prison in the 20th century. The complex suited the project perfectly as the building's condition is deteriorating and will soon be renewed, also it holds a very interesting cultural value for both the local history as well as the country. The focus is the recreation of the site in a VE promoting a realistic and immersive experience to the user while integrating visualization and interaction tools to enhance the learning experience about the historical heritage of the site. To achieve this goal, a set of interactions were designed to allow the users to; move and explore the VE, navigate between locations, interact with objects, and reconfigure the VE. The experiment would consist of having the user perform several tasks that include the different features built into the system, and evaluate the outcome.

3.3 Feature Design

Following up on the analysis of the requirements, feature design is the next phase with a discussion and idealization of the several concepts to be part of the project, as an answer to the planned requisites. In the next Chapter 4 we will present the features that implement these concepts and describe their implementation in more detail.

For better organization of the section, the features will be divided into three categories; exploration, which identifies the features intended to allow the user to experience the VE; digital documentation, including all the features having the concern to present the media content existing in the media database to the user exploring the VE; and system configuration, features that intend to allow the reconfiguration of several aspects on the platform.

3.3.1 Normal User Vs Editor User

Our platform wants to offer to the user a didactic experience but also tools that allow the modification of the platform itself. The user can use exploration tools in the Virtual Environment, which represents a virtualization of the real world, and experience different media content improving its learning experience about the historical heritage site. At the same time, the platform allows the user to modify and reconfigure it as one main concern is the temporal validity of the content, allowing new or more adequate content to be added, removed or replaced over time.

Supporting the two types of interactions resulted in considering two different types of users, the normal and editor users.

The normal user has low to no technical knowledge about the application implementation. He or she interacts with the application as an entertaining or learning tool. This user will be using the application to explore the VE area and interact with the various media items, to obtain the historical heritage knowledge attached to the site.

As for the Editor User it corresponds to a user who has some degree of technological knowledge and has been introduced to the workflow and implementation of the system, being able to make use of a new set of features aiming at the modification of the platform. This user is also able to use of the application in the same way as the "normal user"although having additional features that allow platform reconfiguration from inside the application environment, such as re-positioning of the interactive content within the virtual environment. At the same time, this user is also knowledgeable about the application system file configuration, being able to change the configuration files to further reconfigure the platform.

3.3.2 Exploration

One of the key aspects of this project is the importance of the historical value and the recreation of the real world in a VE, therefore it is important to give the user the ability to move and explore the VE as if he was in the real counterpart of this prebuilt scenario. To achieve this system, two exploration concepts will be implemented, free exploration and auto/assisted exploration.

Free Exploration – This concept involves developing a system that will be able to give the user a mechanism to explore the environment in a self-sufficient way, mimicking the behaviour of a real person when exploring an unknown area or for example in a museum, allowing movement and interactions without interference from the application system.

Auto/assisted Exploration – In contrast to the free exploration, the auto or assisted exploration conceptualizes the creation of various systems that offer exploration methods in which the application system interferes or takes total control of the user. Guided exploration and Auto exploration are included in this concept, the first developing a system that recreates a practice already existent in reality, the guided tours in for example museums, in which the user will be oriented and led to specific locations that might be relevant in the Virtual Environment experience, and the second in which the system takes the user to particular parts of the Virtual environment, in this case, the exploration is fully controlled by the system.

Navigation – In addition to the different types of exploration and since the project wants to virtualize a big space area and several buildings which can be explored by the user arises the reflection on the implementation of the concept of navigation. Navigation that allows quick movement of the user in between points of interest or areas of the virtual environment, avoiding long periods of time with the user not experiencing any interaction.

3.3.3 Digital Documentation

Alongside the virtualization of the real world Trafaria site allowing its exploration, there is the objective to create tools to virtualize media content and make it accessible to the user through different approaches. On this note, the second bundle of features focus on the different forms to integrate the media content in the application database into the virtual environment, allowing different view modes and interactions.

The virtualization of content and the idea of bringing this content to the user arose many approaches to make this possible, as there were variables such as which contents would be able to virtualize and the different visualization modes. The contents envisioned to be supported were various media such as images, video, audio, 3D objects, written documents and pure text.

Figure 3.1 represents the concept of virtualization of media content onto the platform, as a picture or a *.pdf* file would be recreated in the virtual environment, and later interacted with by the user.

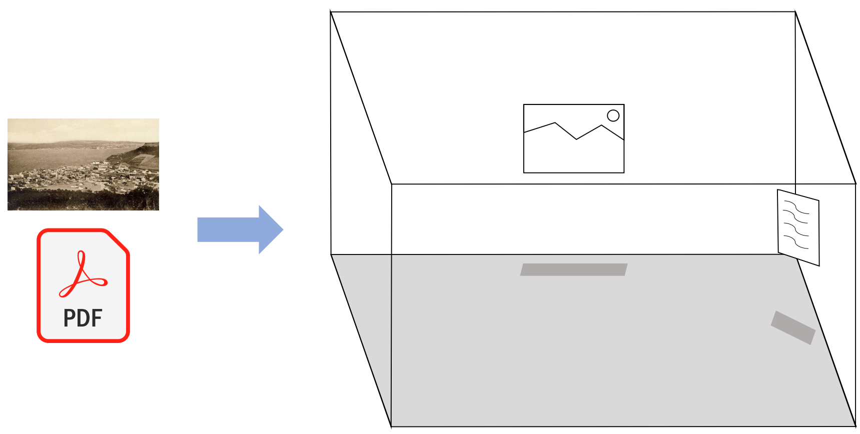


Figure 3.1: Virtualization of media content

Following up there is an overview of the content featured to be able to be virtualized to the platform, and a baseline of operations envisioned to be able for the user to execute.

Image – Image player that allows the visualization of one or multiple images, giving the user the ability to switch in between the several images which one is being presented at a time.

Video – Video player that allows the visualization of a video clip and permits several actions to interact with the video such as play, pause, restart.

Áudio – Audio player that allows the visualization of an audio clip and permits several actions to interact with the audio such as play, pause, restart.

Objects – Object player that allows the visualization of the 3D object and the interaction with such object such as rotating the object.

Files – File player that allows the visualization of a text file such as pdfs and performs actions like zoom in, zoom out, change page.

As the design of these concepts progressed, emerged the possibility to go even further when developing different modes to interact with the virtualized content, resulting in the creation of 2D and 3D interaction concepts. The first corresponds to a more usual approach to content presentation where is made use of interface menus allowing the user to use the mouse to click on the various buttons and actionables, although this interaction mode prevents the user to continue the environment exploration as it locks the user in place. On the other hand, 3D interaction envisions the creation of media players that allow user interaction while avoiding breaking the user engagement with the virtual environment.

3.3.4 System Configuration

In addition to creating a virtual environment to be explored and implementing different ways to allow the user to interact with the content existing in the media database, the project wants to add the possibility of recreating and reconfiguring some parts of the system, allowing the platform mutation over time. To reach this goal and in the context of this project, the main re-configurable parts of the system that we wanted to achieve are related to the exploration modes and the media content present in the virtual environment. The system configuration was planned through two different approaches, features in the application itself and configuration through system files. Both plan to allow more and less expert users on the system to be able to configure the application through the approach they feel is the easiest.

3.3.4.1 Application Configuration

One of the proposed ways to allow the configuration of the platform will be by adding configuration functions within the application itself. These functionalities intend to allow the user to have a more interactive and intuitive manner to reconfigure the virtual

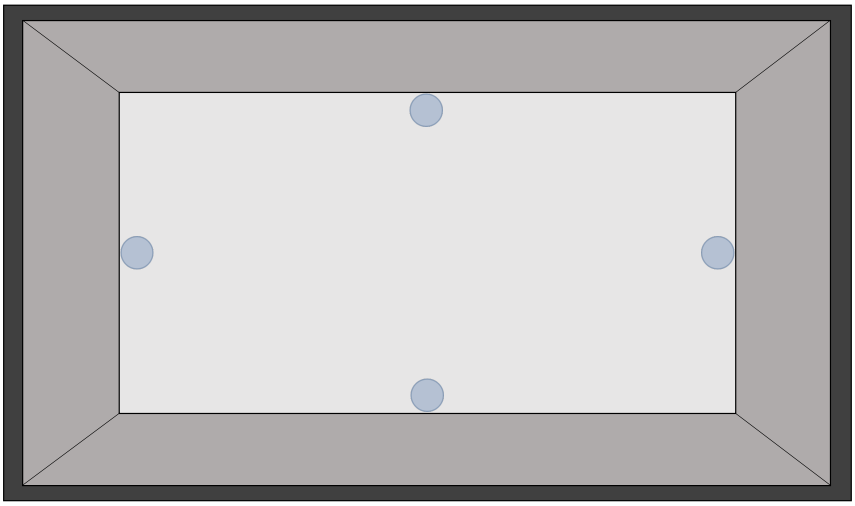


Figure 3.2: Media Room concept with 4 pinpoints to add media

environment. This concept will be referred to as editor mode throughout the rest of the document and the following were the idealized features for it.

Media Players The media players are the core content of the platform as they represent the content visualizers with which the user can interact. These fundamental pieces can vary between different versions of the application, which means one important concept to work on is the ability to modify these media players. The editor player should be able to place and remove the media players, but also change their place to be able to create different setups of the areas in the virtual environment, allowing for the mutation of the platform accordingly to the final goal.

Media Rooms With the introduction of the media players' mutable design, the concern for disorder within the application emerged leading to the concept of media rooms, this concept comes as a solution to organize the media players into a structured system. The user would be able to create and remove these media rooms characterized by a label and add or remove media players to them. The room would also have a placeholder structure with markers where a media player could be placed, to maintain the same structure for the several rooms created by the user.

Figure 3.2 represents the concept of the media room, in which 4 circles appear representing the locations where a media players could be added.

3.3.4.2 System Files

On the other side of the spectrum, the project also wants to provide the possibility for reconfiguration of the system through a more technical approach such as the use of configuration files. These types of configuration avenues often offer a more simplistic approach to a system's core functions and features, removing the complications of UIs or unnecessary actions within the application itself, allowing the possibility of mutating the system without being in runtime.

Guided and Auto Exploration Since guided and auto exploration are 2 features with their core functionality attached directly to the system, it seemed logical to allow the editing of the behaviour of these features through the system configuration files. The configuration of these features could potentially be through the indication to the system of the several checkpoints in the exploration paths.

Media players To allow the virtualization of the media content onto the platform, a system syntax has to be structured and created to build the connection between the media database and the application itself. This concept results in the idea of some sort of configuration file translating the media content into media player objects usable by the application system.

3.3.5 Additional Features

On top of the discussed features, some other arose in the feature design concerning interesting concepts although not representing crucial components of the desired platform. These features are seen as add-ons to the already existing features, not being a priority to the development process as well as not making part of any particular system exposed previously.

Archive - With the possibility of having a big amount of media content and different types of it, there is the possibility of a feature able to gather the information on all the content present in the database. An archive feature is idealized in order to create a centralized font of information inside the application. This feature is envisioned to be able to give the user access to more information on the media content than on the virtual environment itself, as well as giving a possibility to the user to have a filtered and organized way to get to specific media content.

Save Files - As the application can be used by multiple users and its context user may vary, the ability to save the user session or progression could be a concern. As a result, there is the idea of a saving file feature, where several users can access the same application, while being able to return to the place they left the last time they used the application.

Rebuild of the surrounding area - As the virtual environment envisioned intends to recreate a historical site, it could be interesting the extension of this environment recreation to include the adjacent area to further integrate the context of the area in which the site is situated, allowing even more exploration possibilities to the users.

3.4 System Design

Following what is presented in Chapter 1 and trying to answer the problems identified, the solution includes the creation of a configurable platform to present and document cultural heritage content.

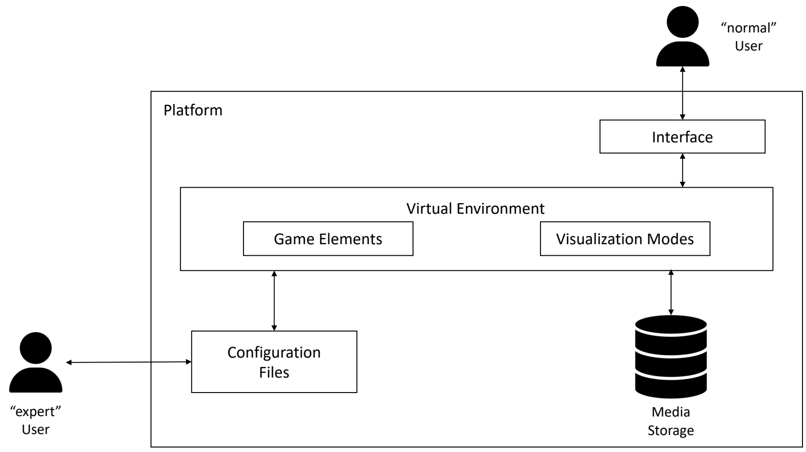


Figure 3.3: System Design

The system design, illustrated in Figure 3.3, can be divided into several components that are intertwined to build a concise and functional platform. The main components of such platform can be divided into the virtual environment built as the recreation of the physical space in Trafaria, the process of the initial configuration of the database/storage of content to be presented in this virtual environment, the techniques built for the exploration of the virtual environment and lastly the visualization modes to present the database and cultural content on this virtual environment. A further explanation of each component of the project is presented below:

- Input configuration files system: Create a system that following a predefined syntax can configure the elements, data and properties of the virtual environment
- Virtual environment: Build a virtual environment based on the recreation of a physical space aided by prebuilt 3D models of some of the buildings and the surrounding environment with mapping tools.
- Visualization modes: Create ways and methods to display the cultural heritage content that will be diversified and gamified to attract the user's interest.
- Virtual environment interface: Achieve different types of exploration of the environment.

Taking into account the architecture presented previously, Figure 3.4 illustrates the dissertation development workflow that will be followed to achieve the solution.

3.5 Preliminary Prototype

In the thesis preparation phase, there were some advances in the project elaboration getting to some prototype milestones. The selection of the technologies to be used in the

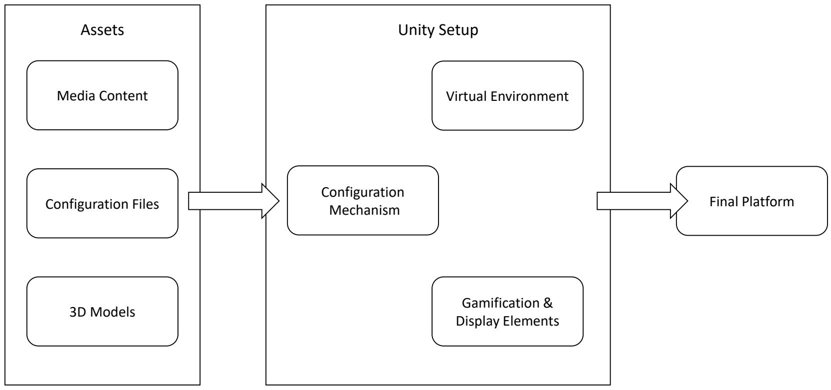


Figure 3.4: Project workflow

project was one of the important early decisions being Unity the choice of main technology since there was previous experience with it and revealed to be a good tool for what wants to be achieved. There was an initial development of a system that was able to read files with a predetermined syntax containing some of the configuration, these files provided the system with some of the environment configuration such as where some elements would be placed and what type of element it is. The goal of this system is to create a default syntax to be used in the project but also allow a flexible reconfiguration of the system in the future. For example, the following JSON file has the configuration of an object that is then placed in the virtual environment represented in Figure 3.5.

As stated in the previous section building the virtual environment is the key point of this project, as it will be where the user will spend all its time within the application as well as being the factor that will allow a better immersion in the cultural heritage to the user. The correct construction of this environment will dictate whether or not the user will have a good or bad experience. In Figure 3.6 we can see a prototype version of this world with some of the 3D models placed.

In these early stages, some experimentation's were also made on the visualization of the media content, as other than the virtual environment other cultural content will be displayed, within these experiments there is the simple display of pictures on the walls of the 3D models 3.7(b), and the creation of interactive objects that are placed in the world 3.7(a).

```json
{
    "objects":
    [
        {
            "objectType": "Display Image",
            "media": "Image1",
            "x": 1,
            "y": 1,
            "z": 1
        },
        {
            "objectType": "Display Image",
            "media": "Image2",
            "x": 2,
            "y": 2,
            "z": 1
        }
    ]
}
```

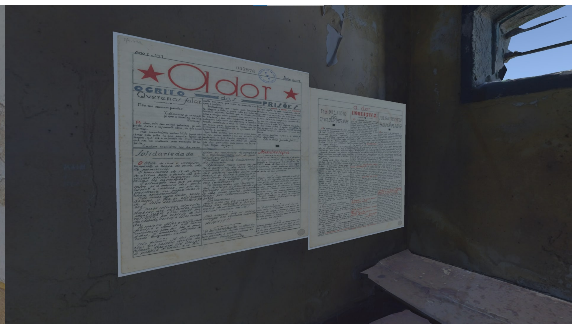
(a) Json Description

(b) Pictures on wall

Figure 3.5: Json to environment object

Figure 3.6: Interactive exploration tool of the 3D models obtain through photogrametry

(a) Document floating in the air in the cell



(b) Pictures on wall

Figure 3.7: Content display examples

4

Implementation

In this chapter, we will go in-depth on several aspects of the system implementation. Starting with an overview of the technologies used to build the project alongside software pieces that enhanced or supported the implementation of several features. Afterwards, each feature implementation will be explained in better detail, including the virtual environment and its exploration, media content players, database component, and system configuration.

4.1 Technologies and Assets

The experimental environment built required several software components, this section discusses the main tools to develop the virtual environment scenes and extra assets that further allowed the ability to implement loading the several types of media in run time into the application.

Unity: Unity was the software picked to implement the system designed as it is a cross-platform game engine and a development environment with a vast base API. In between the possible game engine platforms such as Unity or Unreal Engine, the former was picked as there was previous knowledge on how to work with the platform, also the abundant information, assets and documentation available took a big part in the choice.

AudioImporter: AudioImporter is a package that enables the import of audio files at run time into Unity, loading the audio file into an AudioClip, which is a default type for audio sources in Unity and easier to work with. The package features Asynchronous importing, file browsing and supports Windows, Android and IOS. An optional package to achieve the import of Audio in run time could've been Bass Importer.

Runtime OBJ Importer: Runtime OBJ Importer is a package that enables the import of OBJ, allowing the loading of 3D objects in runtime. The package features load of OBJ files from stream, MTL file loading, texture loading and Triangle, Quad, and Ngon import.

PDF Renderer: PDF Renderer is a package that enables the import of PDF files in run time into the unity application ambient allowing its reading and visualization. On top of the feature features, Open and visualising PDF at runtime, C# API, Render PDF pages to Texture2D, the package is also extensively documented and supports different sources of the PDF files.

4.2 3D Virtualization And Data Colletion

In order to achieve a platform for allowing an exploration experience of a historical site and the creation of visualization mechanisms for the introduction of media content, an initial setup was necessary. This setup was conducted in two phases, firstly a data collection phase gathering the necessary media and models and later a 3D Virtualization phase in which the gathered data was transitioned to a 3D environment using the curation system. The data collection was an important stage as it created a database with relevant media content for later use. In this project, as we wanted to use the historical site as the base environment for the application it was necessary to model the several building structures digitally. To achieve this, cameras were used to capture and scan the buildings present on the site creating several 3D models of the buildings. This process was viable through the usage of the Matterport, using the Matterport Pro2 3D Camera imaging with high-quality 3D was captured and then processed with the Matterport software resulting in the files containing the 3D models. The other step at this stage was the collection of the different media content to later be used in the system, images and videos both from the present and from the past of this historical site, audio media such as music about the city, historical documents (texts, scanned documents, images) and also a compilation of relevant information about the site.

Figure 4.1: Virtualization of the historical site

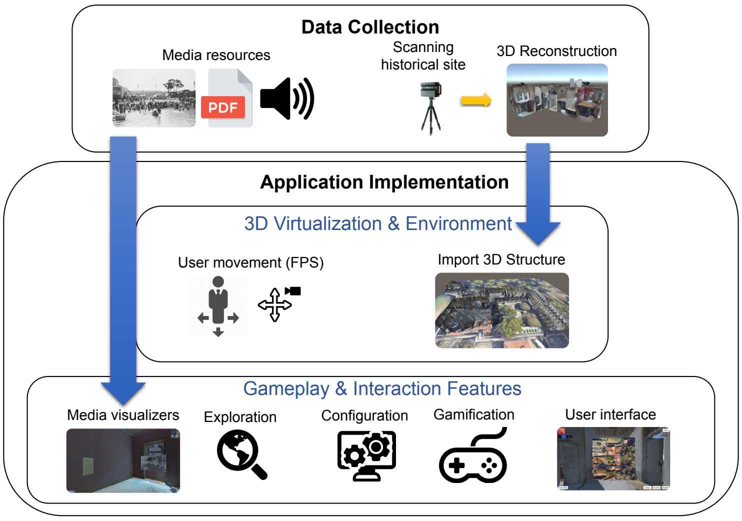


Figure 4.2: 3D environment application framework

The 3D Virtualization phase is characterized by the development and implementation of the graphic system using a game engine. After the conversion of the real structures into the 3d models by the photogrammetry process in the data collection, these were imported with the help of a game engine, in this project Unity, and based on information about the site these models were rearranged to achieve the same layout as the actual site. Figure 4.1 shows the transition from the real historical site to the virtualized counterpart.

Following the import of the 3D models into the virtual environment, we then proceeded to iterate on the basic movement and control systems that would allow the usage of the application by a user. To reach this goal we developed a camera and character movement similar to the ones found in First Person Shooters, as it seemed the more appropriate to implement interactions to provide an immersive experience for the users.

In Figure 4.2 we present and propose a framework to allow a more structured method for building applications with similar components as the one developed in this thesis, applications relying on a 3D environment, that allow the application mutation and implement various media visualization tools. In summary, a first step of data collection needs to occur to gather the necessary resources to build the environment, followed by the implementation of the virtual environment through a game engine, and finally the integration of the various features that will provide the user with the designed interactions.

From this section onwards will be presented the implementation of the features that compose the final prototype and overviewed in Section 3.3. Starting with the final prototyped version, reviewing all the implemented systems and the major differences since the initial prototype.

4.2.1 Final Prototype: Overall Description

The final prototype can be seen as an extension and an update of the preliminary prototype as some of the core features remained on the same basis.

Figure 4.3: Initial Main Menu

To implement the separation of the application usage between the normal and editor user, there was the creation of an initial main menu, Figure 4.3, allowing the start of the application in any of the two different modes. In this initial menu, the user can select the explore option to enter the environment as a normal user, and the edit option to enter the environment as the editor user. In addition, there was the preoccupation for the user to be able to have a concept of session being able to return to a previous session, to accomplish this behaviour when entering the normal user session, the user can either start a new exploration session or load a previously saved file through a code, Figure 4.4.

Figure 4.4: New exploration and Load Exploration

The virtual environment in the preliminary prototype had the possibility for the user to experience a scene with a map with all the buildings (Full View Map) and the possibility to explore one of these buildings (Building 6). The final prototype in addition to the Full

View Map and the exploration of Building 6 also implemented the exploration of all the other buildings, allowing the user to explore all 3D reconstructions of the *Presídio da Trafaria* site. Figure 4.5 shows the inside of two other buildings, 5 and 2 respectively, and Figure 4.6 shows the menu which the user can access to switch in between buildings.

(a) Building 5 (b) Building 2

Figure 4.5: Building 5 & 2 Exploration

Figure 4.6: Main menu

The user can freely explore using the movement controls, but can also make use of the guided and automatic experience in the buildings, where this feature was implemented. In these buildings there is a guide, represented by a yellow light that the user can follow, leading the user to specific locations and in some cases leaving notes, which the user can read and get information related to the *Presídio da Trafaria* context. Figure 4.7 shows an example in user exploration where the user is following the guide represented by the yellow light.

Figure 4.7: Guide system

Figure 4.8: Video media Players
A: 3D Objects that represents 2D interaction video player
B: 3D Interaction video player

In the final version, the application was configured with several buildings to be composed by various media players, so in the testing sessions and also in demos, users can interact with the different media content and experience the features implemented for the media. As a result of the feature design process, there was the creation of 2D and 3D media-players interaction concepts.

The 2D version corresponds to a more usual approach to content presentation where it uses interface menus allowing the user to use the mouse to click on the various buttons and action icons. In this mode, the user approaches the media player (seen in A in Figure 4.8) and then it opens the 2D player seen in b) of Figure 4.14. This interaction mode prevents the user from continuing in the environment exploration, as it locks the user in place while in the menu interface.

On the other hand, the 3D players (seen in B in Figure 4.8) allow the user to interact with them while avoiding breaking the user engagement with the virtual environment, as it allows the user to keep exploring the room. The 3D buttons can be activated directly

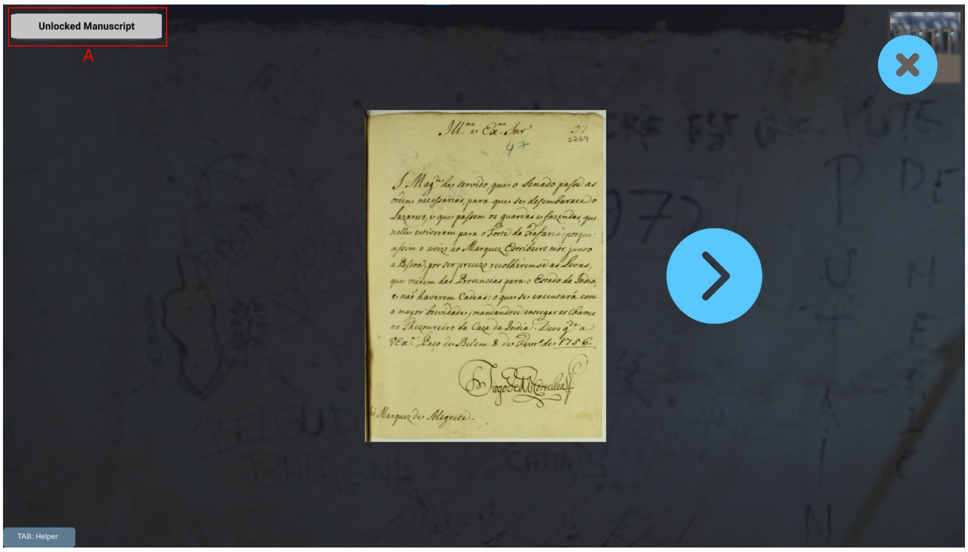


Figure 4.9: Manuscript media player being unlocked
A - Unlock pop-up

in the 3D player. Each player has a unique set of actions that translates into different functions according to the corresponding media.

On top of adding several media players to engage the user even further with the system, a reward logic was built such as the users would feel motivated to explore the environment and engage with the various media players. This system works just like an achievement system in games where after completing a certain task the user is rewarded, in this case, each time the user interacts with a media player for the first time a text pop-up appears on the screen letting the user know he unlocked that media-player in the archive, Figure 4.9, a storage in the application that can be accessed to investigate more about the various players.

4.2.2 Movement And Controls

In order to implement an intuitive movement and control system for the player, that could offer simple controls while allowing the usage of the different features and menus, a mixed approach based on MMO and FPS games system was created. For the player movement was used the default AWSD or Arrows giving the possibility to move in all directions and for the camera movement the usage of the mouse to achieve a rotation equal to First person games where the player can rotate the camera just like it would in real life.

Figure 4.10 presents the overall controls and keys used across the whole system, and Table 4.1 shows the action of each button, actions will be further explained in the rest of this section.

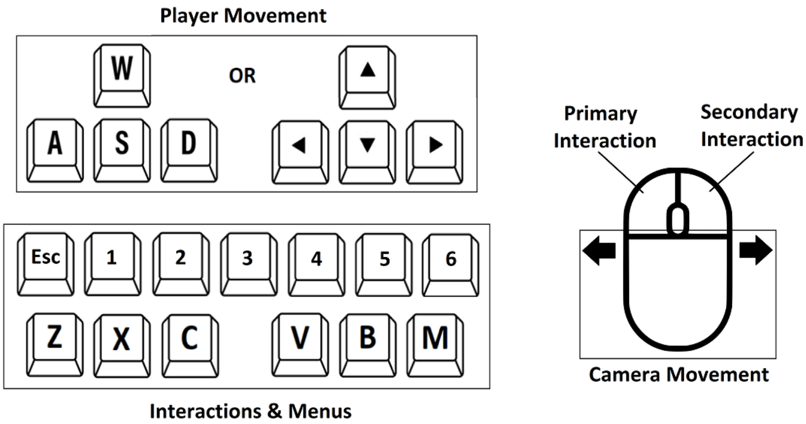


Figure 4.10: System Controls

Table 4.1: Key Actions

Key	Action
Escape	Open Main Menu
Numbers [1 - 6]	Change to Building [1 - 6]
Z	Leave Object View Mode
X	Change Floor
C	Change To/From Editor Mode
V	Change To/From Top View Mode
B	Open Editor Menu
M	Open Map HUD

4.2.3 Exploration And Navigation

As planned in Chapter 3 we wanted to develop systems that allow the user to be able to explore and experience the recreated space. Therefore we developed three different exploration methods that can be used in order to experience the space recreated and a navigation feature to improve the quality of the user movement allowing the latter to more easily change in between scenes.

Free Exploration – The user can explore the environment at free will. Similarly to several 3D games and other 3D exploration applications the user can make use of the movement controls to explore the environment in a self-sufficient way, mimicking the behaviour of a real person when exploring an unknown area or for example in a museum, allowing the user to decide where to go and with that to interact without any interference from the system. This was implemented by giving the user the various movement controls, both for the character positioning with the keyboard and the character camera through the usage of the mouse, this way the user can reach the various parts of the virtual environment on his own.

Assisted Exploration – In contrast to the free exploration, the assisted exploration offers an exploration where the system takes partial or full control of the movement. This feature aims to allow the user to focus more on the content being presented rather than

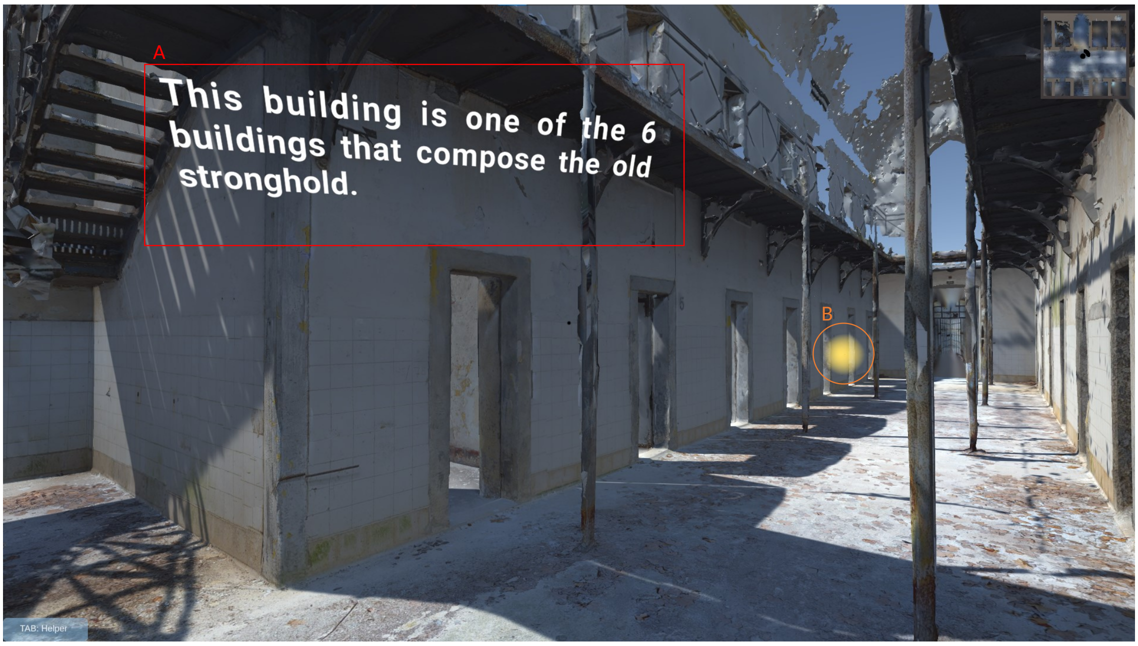


Figure 4.11: Guide system
A: Text left by guide at checkpoint
B: Object (light) representing guide in the next checkpoint

sharing the focus with the movement component. Assisted exploration (and Auto exploration) were developed to achieve this exploration type. The Assisted Exploration recreates what already exists in reality, the guided tours in museums, in which the user will be guided and led to a set of specific locations and given certain instructions that are part of the previously created tour. The implementation of the guided exploration was achieved by creating a guide in the virtual environment that would move through several checkpoints, guiding the user to the several points of interest. In addition, at each checkpoint reached by the user, the guide could leave a message which can be read by the user to add more information to the whole tour. The Figure 4.11 shows an example in user exploration where the user is following the guide represented by the yellow light (Guide is signalled by B), and a note left by the guide (Note is signalled by A). The checkpoint system can also be changed through the editor mode as well as through the configuration, these will be explained in more detail later in this Chapter.

Automatic Exploration - The Auto exploration implements a system that totally takes control of the movement component from the user and similarly to the guided exploration feature brings the user to a specific set of locations previously defined, although in this case the user only experiences the content shown throughout the whole tour. In the implementation of this feature, the system contains a list of locations in the environment that compose the auto exploration path and moves the user slowly from one point to another without user intervention. As the feature doesn't require user interaction we thought it appropriate to be a feature to be automatically activated when recognizing an idle behaviour from the user. Meaning that this feature only activates when either the user is not interacting with the application or when he purposely wants to make use of the automatic exploration feature. In summary, the system automatically starts moving the user if he does not move in the environment after some time.

In addition to the different types of exploration and since the project virtualizes a large space area and several buildings which can be explored by the user, it increased the need for improving the navigation. To implement an easy navigation system, a map menu was created which can be accessed by the user at any point and allows to pick in between the several buildings that can be explored, upon selection the user is automatically moved to the destination. Figure 4.6 shown before presents the map menu with the building's buttons that can be selected to change the building.

4.3 Digital Documentation

This section will focus on the implementation of all the media content players developed to support the various content types. As mentioned previously in the design of the features, one of the goals was to explore different types of interaction between the user and media content so, consequently, there was the implementation of a 2D and 3D interaction version for the same content type, in some cases.

For the 2D image players, a standardisation was followed so that all 2D players would follow the same implementation pattern, all these media players are an implementation on the UI although a subsystem was created so that the user could interact with them. The 2D players are represented in the virtual environment by a 3D object rotating on itself, the user collision with these objects triggers the correct UI to be visible on the user screen.

Table 4.2 compiles the different extensions for each media content type that are supported by the visualizers implemented in the platform.

Table 4.2: Supported Media

Content Type	Supported extensions
Image	.png / .jpg / .svg
Video	.mp4 / .mkv
Audio	.mp3
File	.pdf
3D Object	.obj

4.3.1 Image

Image is the first content type supported by the media players, and both a 2D and 3D interaction media player version was implemented. Starting with the 2D Image player, following the standard created for the 2D media players, the object representing this player in the virtual environment is a 3D representation of a manuscript, shown in Figure

(a) Image 2D Object (b) Image 2D HUD

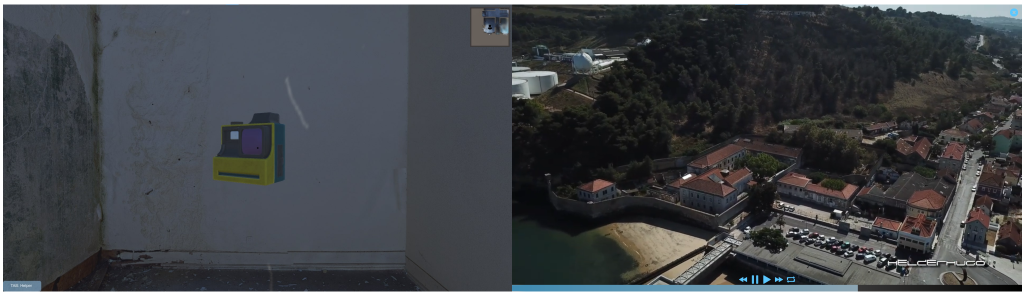
Figure 4.12: Image 2D media player

(a) Image 3D Player (b) Image 3D Player with menu

Figure 4.13: Image 3D media player

4.12(a). When interacting with the manuscript the 2D Image media player HUD becomes visible to the user allowing the usage of the media player functionalities, the Image HUD can be seen in Figure 4.12(b). The Image media player is very simplistic, as it allows the user to move in between images (if the media player contains several images) through the arrows, Left arrow moves to the previous image, while the Right Arrow moves to the next image and to close the media player HUD through the X button on the top right corner.

The 3D Image player, similarly to the 2D allows the user to canvas between one or several images. This media player requires an initial interaction, as the user must first use the primary interaction (Left Click) to open the player menu, this will trigger the appearance of both an arrow on the right side and another on the left side of the media player. The former allows switching to the next image and the latter to switch to the previous image. The user can also use the primary interaction (Left Click) on the media player itself to go to the next image or the secondary interaction (Right Click) to go to the previous one. The Image 3D player before and after the first user interaction can be seen in Figure 4.13(a) and Figure 4.13(b), respectively.



(a) Video 2D Object (b) Video 2D HUD

Figure 4.14: Video 2D media player

4.3.2 Video

Video is the next content type supported by the media players implemented in the system and similarly to the Image, there was implemented a 2D and a 3D version of the media player. The object in the virtual environment which identifies the 2D video media player is a camera, triggering the Video 2D HUD to become visible when interacted with by the user.

The Video player HUD has 5 buttons on the bottom centre identifying several actions, from left to right, Skip Backwards, backtrack the video to 15 seconds earlier; Pause, pause the video; Play, play the video; Skip Forward, advance the video 15 seconds; Restart, resetting the video to the beginning. In addition to these controls, was also implemented the progress bar allowed the player to be aware of the video length and permitted to skip to a specific point of the video. To close the HUD the player simply has to click on the X button in the right top corner.

The 3D Video player, like the 2D, allows the player to be able to experience and watch video content but instead of being focused on the HUD and not being able to do other things, it allows the user to interact with the different media player buttons while the video can continue playing, or even interact with other media players. The 3D player offers all the same functionalities as the 2D through buttons next to the 3D player but the progress bar one, in addition, the player can use the primary interaction (Left Click) on the video player itself to start playing or the secondary interaction (Right Click) to stop playing.

4.3.3 Audio

Audio alongside the Image and Video is the last content type to which a 2D and a 3D version of the media player were implemented. For the Audio 2D player, the 3D object found that suited the media player thematic was a Cd, therefore this is the object found in the virtual environment which when interacted with will trigger the opening of the Audio HUD. In order to follow a similar implementation across the HUDS, the same buttons as the Video HUD were implemented to perform actions over the audio clip,

(a) Video 3D Player (b) Video 3D Player with menu

Figure 4.15: Video 3D media player

(a) Audio 2D Object (b) Audio 2D HUD

Figure 4.16: Audio 2D media player

Skip Backwards, Pause, Play, Skip Foward and Reset. The progress bar implementation was also used to allow more freedom of interaction with the player. Since audio content doesn't have a visual component attached, an audio bar equalizer was implemented so the user would have some kind of visual feedback when using the media player.

The Audio 3D player is a very simplistic version when compared with its 2D counterpart as it only supports playing and pausing the audio clip through the primary interaction, and the reset of the clip through the secondary interaction.

4.3.4 Raw Text

With information being able to be taken to the user through imaging, video or audio the last content type to be implemented is text itself. The implementation of text directly into the application was done by integrating the text into a 3D quad, achieving this way a "wall of text", which can be placed into the virtual environment and read by the user throughout his exploration.

Figure 4.17: Audio 3D media player

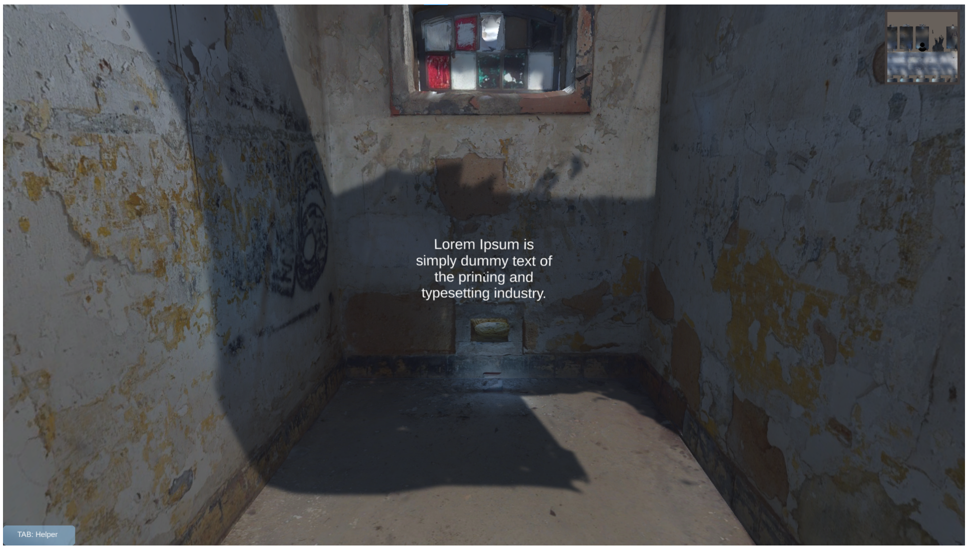


Figure 4.18: Text placed in the 3D environment

4.3.5 PDF Files

As an extension to raw text, the implementation to support a text file media player was introduced. Since the visualization of text files is more intuitive if the user can concentrate on the reading itself, it seemed like a better implementation to do a HUD file reader similarly to how reading a PDF works. Therefore, similarly to the other 2D media players, to access the file HUD, the user has first to interact with an object in the virtual environment, this time a newspaper.

(a) File Object (b) File HUD

Figure 4.19: File media player

(a) Object before interaction (b) Object after rotation

Figure 4.20: Object media player

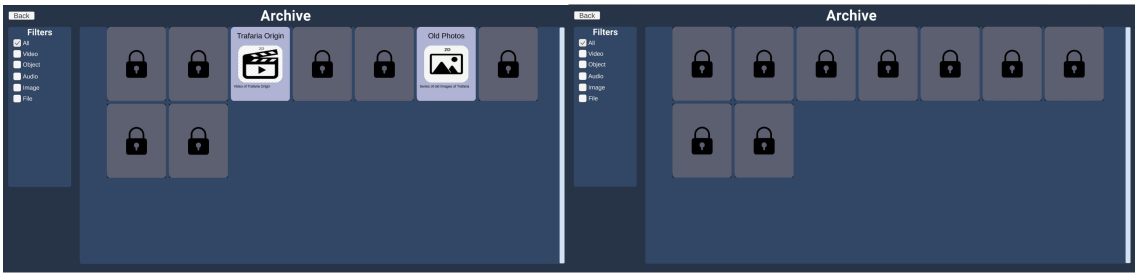
4.3.6 Objects

One interesting yet challenging content type that was implemented on the system was 3D objects, in a didactic environment like a museum although visual content like images, video and text or even audio are great learning tools, objects are also a great source of insight of the era and time spawn they are originated from. The implementation achieved was the actual recreation of the 3D object obtained from the source file in the virtual environment in run-time. The implementation is not perfect, since the system is not able to alongside the object load a texture file to support the colouring of the object, resulting in a complete white object, as well as not being able to resize the objects to an accurate reality reference, resulting in abnormal size when importing objects in certain occasions.

4.3.7 Archive

The archive is a function implemented to aggregate all the media content inside the application, this menu can be accessed to visualise and search for the different contents.

Implementing an achievement like system behind the feature when a "normal user" accesses the archive, the unlocked content depends on which media players the player already had interacted with, as the archive only shows the entry for certain content when



(a) Archive state with no media players interacted with

(b) Archive state after two media players were interacted with

Figure 4.21: Archive system

it's accessed in the virtual environment first. If the archive is accessed by a user using the editor mode feature, then the archive is fully unlocked.

Figure 4.21(a) shows the archive menu at the start of the application when the user hasn't interacted or discovered any media player, and Figure 4.21(b) presents the archive after the user did some exploration and found some media players.

4.4 System Configuration

In order to implement some of the system configuration functions mentioned in Section 3.3 and to achieve platform-like behaviour, the section first addresses the various functions that enable the reconfiguration of the system within the application itself, i.e. functions that allow the user to modify the application from the virtual environment. Later in this section, we will go into the functions that allow the management of different parts of the application via tools outside the virtual environment, i.e. the configuration is done via the configuration files I in the file system of the application. Both features are implemented so that future users can have different experiences from those who used the application before it was modified.

For a better understanding of the overall configuration through the system files, the Figure 4.22 shows the file system tree of the application. The application folder is the root directory, where the executable and data folders are located and where the files that form part of the overall system configuration are. The Config Folder holds the object configuration file that includes all the objects that can be found in the virtual environment, a general configuration file and a folder for each building. Within each building folder, there are two configuration files 1 for the media rooms configuration and one for the exploration configuration. On the data folders, there is also a media folder containing all media content used by the media players and a save folder holding several users' save files.

```
Trafaria 3D/
├── App.exe
├── Data/
│   ├── Config/
│   │   ├── Objects.txt
│   │   ├── Config.txt
│   │   ├── Building 1
│   │   ├── Building 2
│   │   ├── Building 3
│   │   ├── Building 4
│   │   ├── Building 5
│   │   └── Building 6
│   ├── Media
│   ├── Saves
│   └── ...
└── ...
```

Figure 4.22: Project file system tree

4.4.1 Media Database

As mentioned earlier, the developed and implemented application may contain different types of content such as images, audio, videos, etc.

Over time the users might want to make changes to the existing content on the application and to enable these types of actions such as adding, removing or changing content, a database system had to be implemented. Since it was not possible to use a real database system, a simplified approach based on the use of the file system was implemented. This database component consists of two important core elements, the Objects Config file and the Media folder.

The Objects Config file serves as an index containing all the media players that can be added to the virtual environment and contains the information about each media content, it's a JSON with a list of all the media players and each one is composed of a title, a type, a description and its media content. The title or name for the media player is the name that will be seen in the lists of media players when using editor mode to add known media players to the virtual environment. The type decides what type of media player so that the application instantiates and knows which player to instantiate at runtime. The description is a small descriptive text that can be added and later displayed in the archive menu, and finally, the media corresponds to an array with all the media to be presented within the media player in the application. This array contains the path for the media and can either be the full path if you are using personalised content allowing the user to use media from all files on the computer system, or the name of the media with the file extension, and in this case, the system looks for this media in the media folder of the

```
{
    "mediaPlayers":
        [
            {
                "type": "image3D",
                "name": "Old Photos",
                "description": "Series of old Images of Trafaria",
                "media": ["Image1.jpg", "Image2.jpg", "Image3.jpg"]
            },
            {
                "type": "image2D",
                "name": "Manuscript",
                "description": "Pages of an old Manuscript",
                "media": ["Manuscript1.jpg", "Manuscript2.jpg", "Manuscript3.jpg"]
            }
        ]
}
```

Figure 4.23: Objects Config file

application.

The Figure 4.23 exemplifies an use case in what the database has 2 media players.

4.4.2 Editor Mode

To answer the implementation of the application configuration within the virtual environment itself was developed the editor mode. This mode is accessible when launching the application being an option from the main menu. Editor mode is composed of all the features existent for the normal mode, being able to use all of the exploring or interaction features, and also the access to a whole new set of features for configuration purposes.

The user is now able to switch between normal mode and editor more, changing to editor mode the virtual environment will also change accordingly, instead of the content media players, there will be objects that represent these players, allowing the user for a more simple approach to the features, will also be able to see the several media rooms and the checkpoints which compose the guide path.

In the editor mode, the user has access to the normal bottom view mode but also a top-down view mode, giving the editor different ways to interact with the editor tools in the virtual environment of the application. Some editor tools are only available in the bottom view mode and others are only available in the top view mode.

Guide edit tool If the user is in editor mode and the current building has a path created for the guide, several spheres will be visible in the virtual environment reflecting the various guide checkpoints in the guide path. The user can interact with the checkpoints on the path and change the text that is displayed as the user reaches these checkpoints in normal exploration mode. The user is also able at any time to add a new checkpoint to this pass or start a guide path if there is none by pressing the J key. Figure 4.24(a) shows the spheres part of the guide path and Figure 4.24(b) the UI for the text change when interacting with the checkpoint sphere.

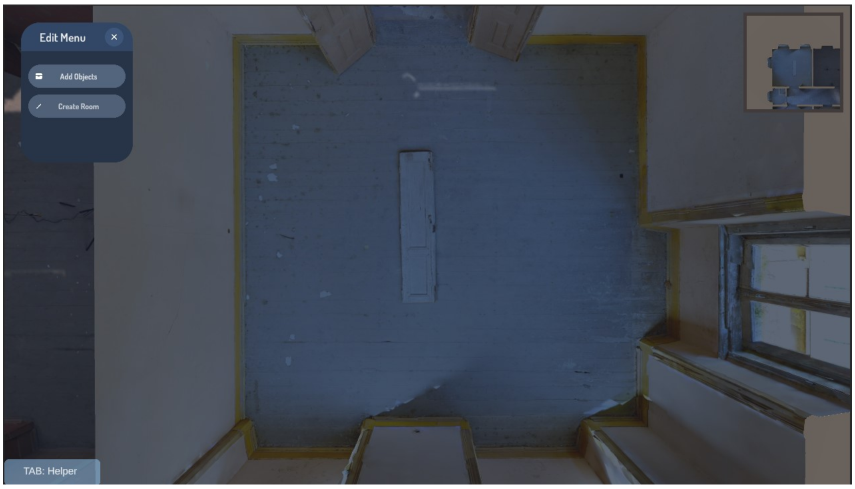
Media room tool To structure the addition of media players to the virtual environment there is a prerequisite, media players can only be added to media rooms. This way

(a) Guide path checkpoint (b) Object after rotation

Figure 4.24: Guide system in editor mode

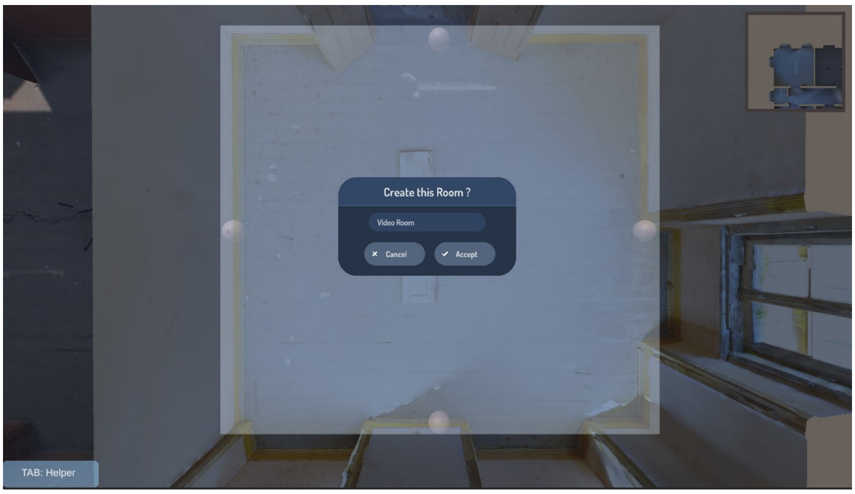
the whole application configuration follows a single structure allowing for configuration files to be implemented more easily. In the editor mode, the user must first create a media room, user has to be in the top view mode and then open the editor menu, choosing to create media room option. After it must click and drag until it reaches the desired area for the room, concluding the workflow by either accepting or cancelling the action. The media room will then be instantiated with four snap points to which the user will be able to at and correctly position the media content players. The Figure 4.25(a), Figure 4.25(b) and Figure 4.25(c) show an overview on the create media room feature workflow.

Media player tool Media players can be inserted into the virtual environment through the editor mode menu, via the add media players tool. By pressing this functionality, the user is given a list with all the available media players in which the user can select which object to add to the virtual environment. Upon the selection of the desired media player, the user must now place it in the virtual environment making use of the snap points of the different media rooms, for correct placement. The user can also move after positioning the object to reorganise the media rooms into a more desirable configuration, this implementation allows the user to reorganise the buildings for different purposes. These media players can also be removed at any point by making use of the secondary interaction action on the media player itself. The Figure 4.26(a), Figure 4.26(b) and Figure 4.26(c) show an overview on the add media player feature workflow.



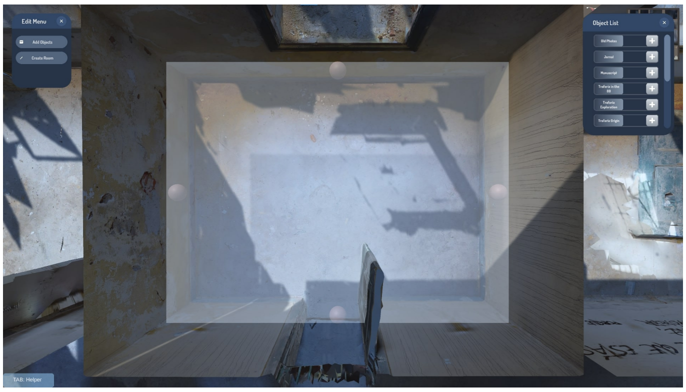
(a) Editor menu

(b) Selection of the room area, after selecting create room option



(c) Input of room name

Figure 4.25: Create media room workflow



(a) Editor menu with object list, after selection of add object option

(b) Placing media player on top snap point

(c) Media player placed, viewed in normal mode

Figure 4.26: Create media room workflow

5

Evaluation

To answer the research questions presented in Section 1.2 and achieve the validation of the system developed throughout this thesis, a user study was conducted to evaluate the user interaction of the diverse system features. This chapter will overview the protocol used to guide the user studies, what kind of data was collected and how it was recorded and the conclusions that were later withdrawn. Therefore, the first part of this chapter includes the detailed protocol and each task that took place in the user test as well as the several questions related to each task, it also includes an explanation of the questionnaires applied at the end of the testing session. The second part covers the results and analysis that were consequent of the user tests, with the presentation and evaluation of the results for the several tasks and questions. The end of the section is dedicated to a more general discussion of the results.

5.1 Protocol

The test sessions required two people to be physically present in the same room, the researcher, and the test subject. The experimental session began with the test subject reading the informed consent, and the rest of the session would continue after the subject agreed and signed the consent form.

The researcher started the session by introducing the system and its goal to the subject, explaining that the session would have 2 parts, the first in which the user would be representing and doing tasks related to the "normal user" and a second one in which he would represent and do tasks related to the "editor user".

After the introductory period, the subject was then asked to explore the application and execute several tasks. The tasks were one or a series of actions the user is asked to make within the virtual environment application. For each task, the researcher completed a form with small observations and once the task is completed the subject was asked some questions related to the task finished previously.

Next in the section, there are the tasks executed by the subject in the testing session as well as the questions and observations for each task in more detail, the data was collected manually either by the researcher or by the subject himself.

The research questions stated in Section 1.2 and that we want to answer with the following user test are:

RQ1 – How to design and build a platform that combines the need of preservation of digital documentation while offering a spatial and temporal gamified experience of such documentation ?

RQ2 – Can we create a digital documentation media platform that allows its mutation and configuration ?

RQ3 – What methods or possible techniques can we develop to achieve an educational and immersive experience while providing documented cultural heritage content ?

RQ4 – Is there a difference and preference in the usage of 2D and 3D interactions?

5.1.1 Task A – Initial Exploration And Controls

In the first task, the user has to complete is as said previously an introductory task for the user to get familiar with the system of the "normal user". The user is instructed to make use of the character and camera movement controls to freely explore the virtual environment. After some time (1 minute and a half), this user has to make use of the menu UI to change the building where it is and continue to explore. In this task, no indications of the controls since the adaptability and how intuitive the controls are one of the observations being tested.

At the end of this task the user answers the following questions:

AQ1 – The player movement controls were intuitive? The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

AQ2 – What was the level of difficulty in using the menu to move between buildings? The answer is a Likert Scale from 1 to 5, being 1 Very Easy and 5 Very Hard, respectively.

Within the task, the observations taken by the researcher are:

AO1 – The user was able to use movement controls? The answer can be Yes, Yes with help.

AO2 – The user was able to use menu controls? The answer can be Yes, Yes with help.

AO3 – The user was able to find the hidden object? The answer can be Yes or No.

5.1.2 Task B – Guide Exploration Vs Free Exploration

In this task, the user will be introduced to and use two different types of exploration existent on the system, guide exploration and free exploration. This task is used to find a contrast between the exploration of the virtual environment by the user while being held by hand and being pointed where to go and an exploration where the user decides where and how to move. In addition, since the guide has the feature of leaving text behind at certain checkpoints, this task also evaluates how a museum-like guide feature is acknowledged by the user.

At the end of this task the user answers the following questions:

BQ3 – The user understood how to follow the guide. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

BQ4 – What is the name of the building presented by the guide notes? The answer is *Presídio da Trafaria* .

BQ5 – Which exploration method did the user prefer? The answer is 1 choice of 3 options, Free exploration, Guide exploration or No preference.

Within the task, the observations taken by the researcher are:

BO1 – The user was able to identify the guide? The answer can be Yes, Yes with help.

BO2 – The user was able to follow the guide to the final room? The answer can be Yes, Yes with help.

BO3 – The user was able to find the final room with content in free exploration? The answer can be Yes or No.

BO3 – Time until the user was able to find the final room. The answer is time in seconds.

5.1.3 Task C – Different Media Usage

This task is the last task of the set of task-directed to the "normal user" functionalities and intends to directly respond to research question four, as it aims at evaluating the different user interactions with the media players implemented. The task is composed of the interaction between the user and 6 media players three with 2D interaction and three with 3D interaction. Since several media players were being interacted with, to achieve a feasible study, the various conditions were counterbalanced by the usage of a Latin-square assignment by using a different order of players to be interacted with to allow a full permutation in the first 4 players. For better understanding, the 4 media players used to achieve the different orders were, A – Image 2D, B – Image 3D, C – Video 2D, D – Video3D, and the permutations in which the user group test was divided into were ABCD, BADC, CDAB, DCBA.

At the end of the task the user answers the following questions:

CQ6 – What colour was the title of the newspaper in the Image 2D media player? The answer is red.

CQ7 – How many pages did the manuscript have in the Image 3D media player? The answer is 3.

CQ8A – Which media player did the user like the most? The answer is between Image 2D and Image 3D.

CQ8B – Which media player did the user like the most? The answer is between Video 2D and Video 3D.

CQ8C – Which media player did the user like the most? The answer is between Audio 2D and Audio 3D.

CQ9 – The user was able to interact with the Image 2D player the way he intended to. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

CQ10 – The user was able to interact with the Image 3D player the way he intended to. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

CQ11 – The user was able to interact with the Video 2D player the way he intended to. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

CQ12 – The user was able to interact with the Video 3D player the way he intended to. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

CQ13 – The user was able to interact with the Audio 2D player the way he intended to. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

CQ14 – The user was able to interact with the Audio 3D player the way he intended to. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

Within the task, the observations taken by the researcher are:

CO1 – The user was able to understand how to open the HUD for the 2D players? The answer can be Yes, Yes with help.

5.1.4 Task D – Exploring Editor Mode

With task D the second set of the task begins, as now the tasks intend to focus on the "editor user" system functionalities. Just like in the first set this first task is an introductory task where the user is asked to make use of the several hotkeys to switch between editor and normal mode, move around the virtual environment with the different modes and explore the new menus. There is no question asked to the user after the completion of the task.

Within the task, the observations taken by the researcher are:

DO1 – The user was able to change to editor mode? The answer can be Yes, Yes with help.

DO2 – The user was able to change to the editor to view mode? The answer can be Yes, Yes with help.

DO3 – The user was able to find the editor menu in top view mode? The answer can be Yes, Yes with help.

5.1.5 Task E – Create Media Room

In Task E the user is asked to make use of the menu existing in the editor top view mode to create a media room. The user is told to try to create a media room in one of the building rooms but first cancel upon the name chosen and then told to create the room again and this time, create with the name Media.

At the end of this task the user answers the following questions:

EQ15 – The user was able to create the room correctly. The answer is a Likert Scale from 1 to 5, being 1 Disagree and 5 Agree, respectively.

EQ16 – What was the level of difficulty of using the create room tool? The answer is a Likert Scale from 1 to 5, being 1 Very Easy and 5 Very Hard, respectively.

5.1.6 Task F – Add Media To Media Room

Finally, the last task involved the user making use of the menu existing in the editor top view mode to add media players. The user is told to add several media players into the media room and then asked to return to the bottom view mode and delete the video 3D media player from the room.

At the end of this task the user answers the following questions:

EQ17 – What was the level of difficulty of using the add media player tool? The answer is a Likert Scale from 1 to 5, being 1 Very Easy and 5 Very Hard, respectively.

EQ18 – What media player did the user have to remove during the task? The answer is Video 3D.

5.1.7 Questionnaires

After the users performed all the required tasks in the testing session, they were asked to fill out some paper post-session questionnaires to evaluate different aspects of the system they just finished using. Firstly the participants filled out a characterization questionnaire that gathered information to characterize the population, to later be cross-checked with the results to evaluate whether characterization factors correlated with the participant's performance. The questionnaire inferred gender, complete education level, age, frequency of play over games, experience with first-person shooter games, experience with virtual museums and regularly used devices. Finally, the participants also filled out a System Usability Scale (SUS) questionnaire, which consists of ten questions that the user must answer by assigning to each question a value between one and five, meaning Strongly Disagree and Strongly Agree, respectively. This questionnaire was used as it is used as a standard questionnaire to measure a system's usability.

5.2 Results And Analysis

This section will go over the results and insights consequent from the user tests. Starting with the presentation of the demographic data of the participants of the user study, followed by the analysis of each task results independently, Annex I. After the individual analysis of each task, there will be a more broad analysis of some of the tasks taking into account other factors like population characteristics, or other tasks. Concluding the section there will be the presentation of the results of the SUS questionnaire and an overall discussion about interesting data points.

5.2.1 Population Characteristics

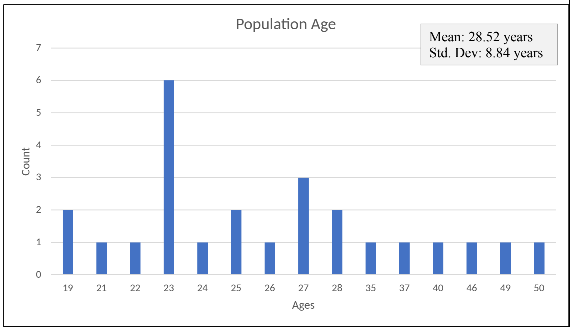
The population was composed of 25 participants, which demographics are presented in Figure 5.1 and Tables 5.1 and 5.2. Participants' gender is presented in Table 5.1 and their age range from 19 to 50 with a median of 25, Chart 5.4(a). The education level within the participants varies with a 60% of the group having completed some level of higher education, Table 5.2. The majority of the participants have played games and/or play them somewhat frequently 72% although only 48% of the total group has had previous experience with first-person shooter games, Chart 5.1(b) and Chart 5.1(c). Only a small percentage, 32% of the total participants had a previous experience with virtual museums, Chart 5.1(d).

Table 5.1: Participants Gender

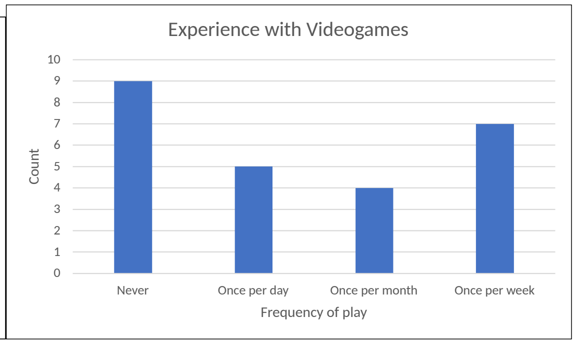
Gender	Participants(#)
Male	15
Female	10

Table 5.2: Participants Education Level

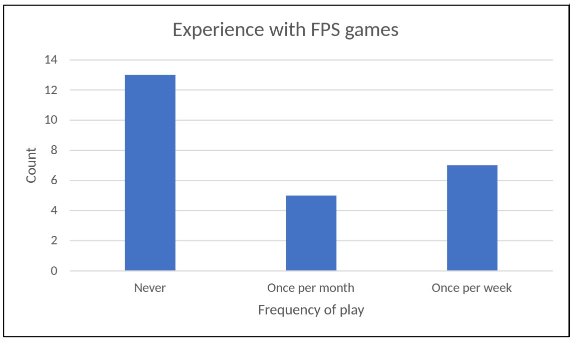
Education Level	Participants(#)
High School	10
Bachelor's	10
Master or More	5



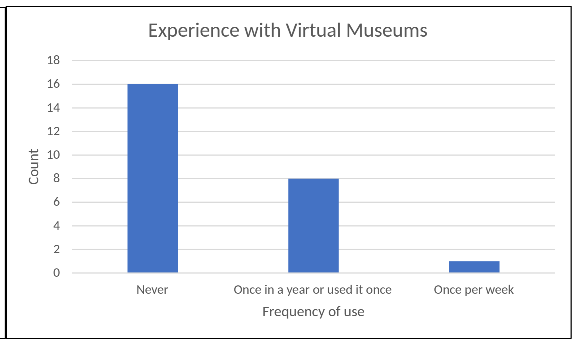
(a) Population age



(b) Frequency of play games



(c) Frequency of play fps games



(d) Experience with virtual museums

Figure 5.1: Population demographics graphs

5.2.2 Tasks Results

Task A was an introduction to the whole system and intends to allow the user to be familiarized with the controls, there is no specific sequence of actions as the user's only task is to make use of the controls to explore the virtual environment. The user is being observed in terms of the ability to adapt to the controls without any help, to determine how intuitive is the system.

Chart 5.2 shows the user's answers to the Questions AQ1 and AQ2, revealing insight into the user experience with the system controls.

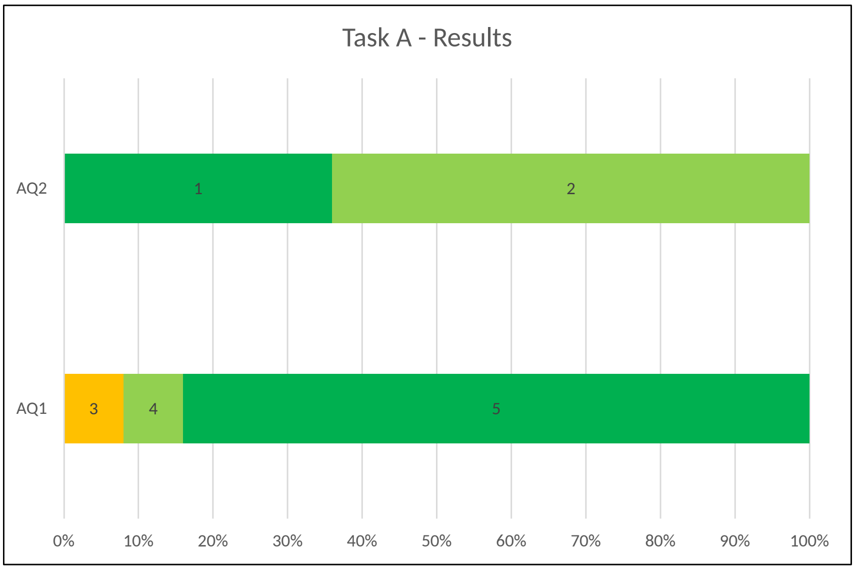


Figure 5.2: Task A questions results
For AQ1 the scale is 1 - Disagree to 5 - Agree
For AQ2 the scale is 1 - Very Easy to 5 - Very Hard

Table 5.3: Task A observation results

AO1 - Movement Controlls	Participants
Yes	19
Yes with help	4

AO2 - Menu Controlls	Participants
Yes	17
Yes with help	8

AO3 - Found Object	Participants
Yes	16
No	9

In comparison with the observations throughout the task, we can conclude the movement control system and menu navigation are rather intuitive since the majority of the users were able to move both the character model and the character camera without any help, as well as finding the menu to move to a different building. Although some users had to get a help tip when understanding that they had to click on the menu map to move to a different building. As for the hidden object that was aimed at testing whether the users would be able to quickly adapt to the controls and explore the various rooms of the building a high percentage of the users was able to find it, as 64% of the users were able to find the object while exploring. The observation results for Task A are summarized in Table 5.3.

Task B aimed at helping to provide an answer to the third research question, it evaluates the user preference towards a type of exploration, similar to a museum visit where the user can decide on a guided or solo experience. The Chart 5.3 presents the answers for the questions BQ3 and BQ5, and Table 5.4 for question BQ4, providing information on the user perception of the exploration modes.

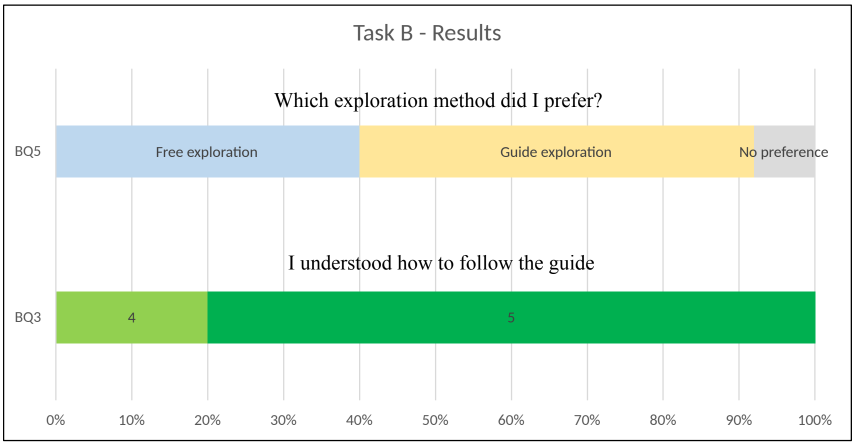


Figure 5.3: Task B questions results
For BQ3 the scale is 1 - Disagree to 5 - Agree

Table 5.4: Task B questions results

BQ4 - Name of Building	Participants #
Correct Answer	25
Wrong Answer	0

The user answers reveal the guide system implemented was simple and understandable since there was not a majority of votes towards a specific exploration method, as well as a good tool for learning purposes as all users were able to respond correctly to the question that evaluated the awareness of the guide notes, and there was no preferred exploration mode. The observations during the task, back up the graphs results as no help was necessary to explain to the users how to use the guide system. It was also confirmed that there was no preference in which exploration mode to use, as all users found the media room with and without the guide, although almost all users picked one exploration method over the "No preference". This brings the conclusion that the preference for one exploration mode over the other might be related to personal preference and not the feature implementation.

Task C was planned to directly respond to the fourth research question and together with Task B the third. In this task all users were evaluated and inquired about the several media players after their testing, the users were divided into several groups with different interaction sequences to rule out a predetermined outcome of results.

The first two questions on this task aimed at understanding if different interactions would affect the awareness and focus of the user on the content being displayed, the Tables 5.5 compiled these results. The outcome of these two questions arise the conclusion that both implementations of media player can provide the user with the necessary information and allow good visualization of the media content since in both cases almost all users were able to respond correctly.

Table 5.5: Task C questions results

CQ4 - Image 2D question	**Participants #**
Correct Answer	20
Wrong Answer	5
CQ5 - Image 3D question	**Participants #**
Correct Answer	20
Wrong Answer	5

The Charts 5.4 present the result related to the preference of a media player over another, as well as the overall feedback on each media player.

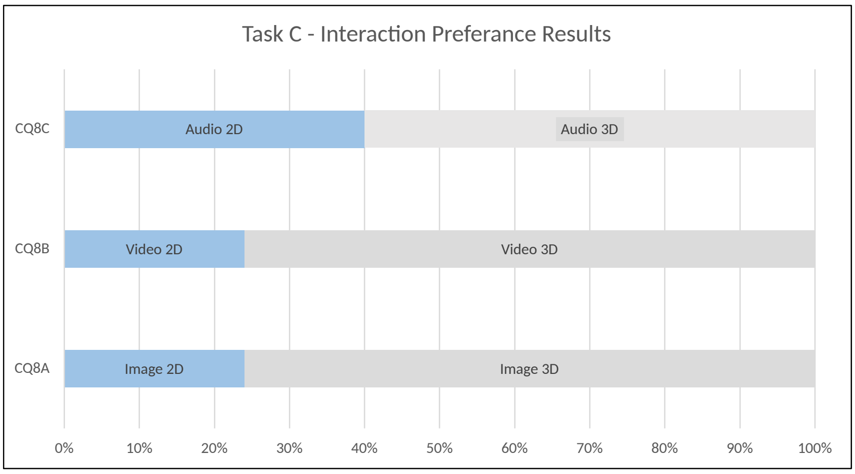
In general, the users did not have any major problems when interacting with the different media players, as they were able to perform the interactions they intended to, which is also supported by the user's answers in the questions Q9 to Q14. Although there was a discrepancy in the media player interaction preference, in all three comparisons visible on Chart 5.4 a), the majority of users preferred the 3D interaction media player. This outcome might be related to the fact that about one third of the users had to be informed on how to prompt the 2D interaction players, as these required the user to trigger the UI by colliding with the rotating object in the environment, Table 5.6.

Table 5.6: Task C observation results

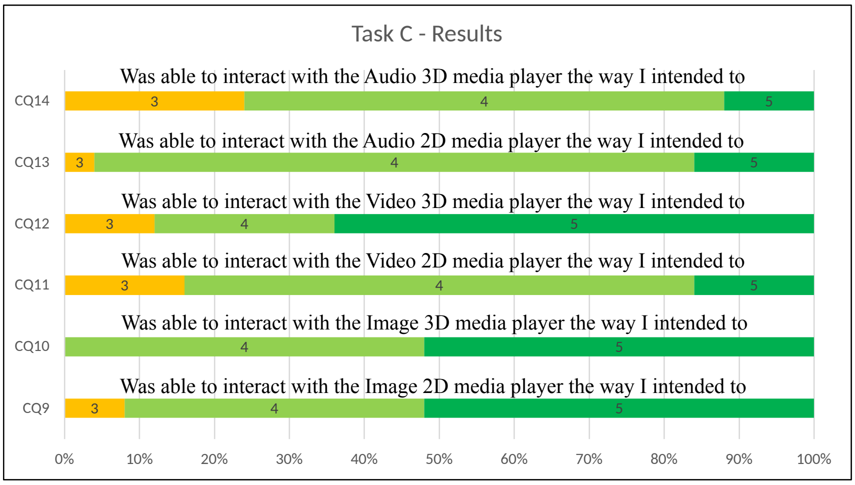
CO1 - Open 2D media players	**Participants #**
Alone	17
With help	8

Task D System configuration and the editor mode are the features implemented as an answer to the second research question and introduced in Task D, starting with a simple task to establish the starting point for the user to test the following features. The user is asked to explore the editor mode and its functionalities as well as menus.

The observations that resulted from this task focus on understanding the behaviour of the user when introduced to the new features and how this reacts to the differences between the normal and the editor mode. Overall the users seemed to understand the concept of media rooms with media player objects and that the different view modes would allow different actions. The observation results are summarized in Table 5.7.



(a) 2D vs 3D Interaction results



(b) Task C Likert Scale results

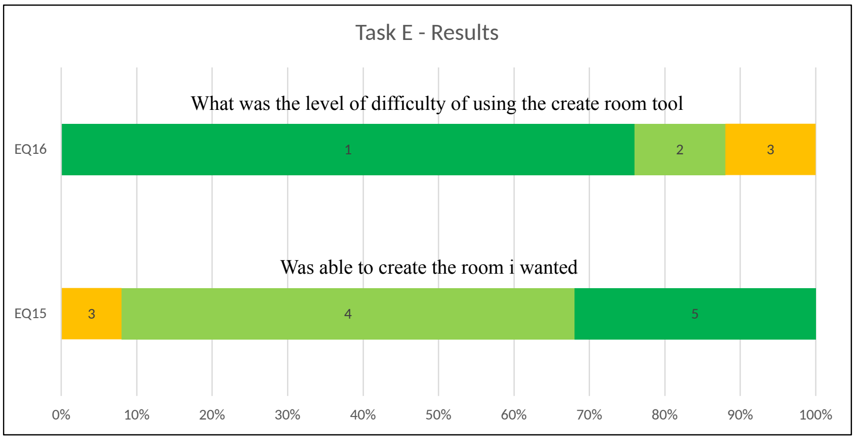
Figure 5.4: Task C questions results
The scale is 1 - Disagree to 5 - Agree

Table 5.7: Task D observation results

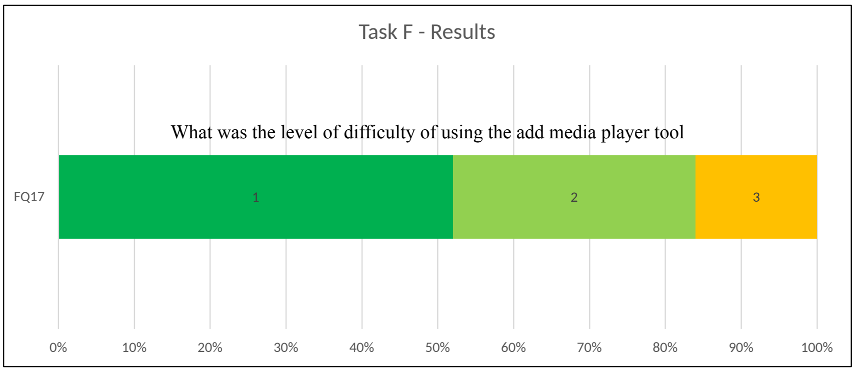
DO1 - Change to editor mode	**Participants #**
Yes	17
Yes with help	8
DO2 - Change editor view mode	**Participants #**
Yes	16
Yes with help	9
DO3 - Open editor menu	**Participants #**
Yes	17
Yes with help	8

Task E & F The last two tasks, E & F, evaluate the user interaction with the implementation of the core functionalities of the editor mode, revealing whether the system is or not easy to use, and if it allows the configuration and reconfiguration of the system according to the user expectancy.

The Chart 5.5 show the results of the questions for tasks E and F, respectively.



(a) Task E questions results



(b) Task F questions results

Figure 5.5: Task E & F questions results
For EQ16 the scale is 1 - Disagree to 5 - Agree
For EQ15 and FQ17 the scale is 1 - Very Easy to 5 - Very Hard

Although the user's answers to the task questions suggest that the editor tools are simple to use, a bit more than half of the users had to be given some sort of help at some point during each task as they were unable to fully complete the task on their own. From these results, we can conclude the editor mode tools are features that as expected will require some technical knowledge of the application workflow, but also there might be the need for some sort of tutorial or tooltip, in the next system iterations. During these two tasks, the time was measured from the moment the researcher finish the explanation of the task until the conclusion of each task for further analysis of the task results.

5.2.3 SUS Questionnaire

This section discusses the SUS questionnaire results. The questions used in the questionnaire can be accessed in Annex II, since here the questions were shortened for visualization purposes, the results data can be seen in Table 5.8. For a better analysis of the results, the answers are grouped in 2 Charts one for the odd questions and another for the even questions, Chart 5.6(a) and Chart 5.6(b), respectively.

An easier way to interpret the results is to keep in mind that the higher the answers for odd-numbered questions and the lower the answers for even-numbered questions the better. In SUS questionnaires a methodology is applied in order to normalize all the answers to be between zero and four. For odd items: subtract one from the user response, For even-numbered items: subtract the user responses from 5 and finally add up the converted responses for each user and multiply that total by 2.5 converting the range of possible values from 0 to 100 instead of from 0 to 40. Based on previous research, scores above 68 can be considered above average, and since the normalized scores obtained in our SUS questionnaire were 75 points, it reveals a positive conclusion on the usability of the system.

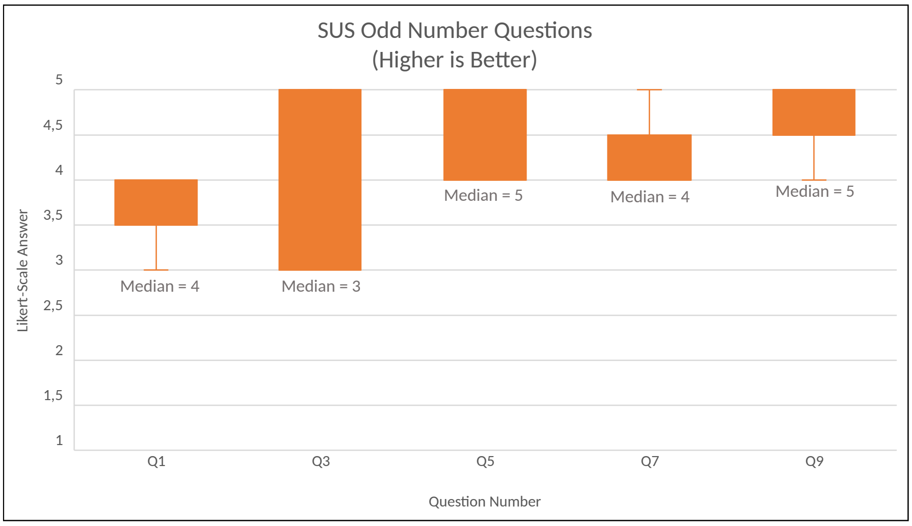
Table 5.8: SUS questionnaire results

Questions	Med	1st Q	3rd Q
1. I would use the system frequently.	4	-0.5	+0
2. The System is complex to use.	2	-0.5	+0
3. The System is easy to use	3	-0	+2
4. I would need technical support.	2	-1	+0
5. The system has well integrated functions.	5	-1	+0
6. The system is inconsistent.	1	-0	+0.5
7. The system is easy to learn.	4	-0	+0.5
8. The system cumbersome to use.	2	-0.5	+0.5
9. I felt confident using the system.	5	-0.5	+0
10. I needed to learn a lot beforehand.	2	-1	+0

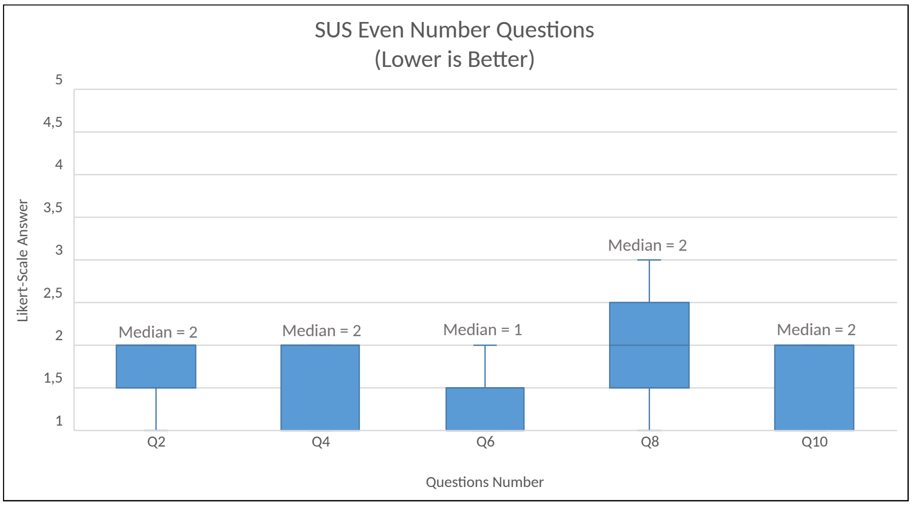
5.2.4 Discussion

Previous sections only focused on the results and analysis of each task, without no correlation between data, for example, the user profiling or other tasks results, to further study the outcomes of each task. This section will focus on aspects such as the influence of previous experience with games on movement and interface interaction as well as a tendency for relevant results.

Throughout the several tasks, we could study the outcome for the RQ1 with each task leaning toward the positive hypothesis of the development of a platform that indeed can conjugate the ability to preserve and present digital documentation while offering an immersive experience of such documentation. The editor mode tasks, Task D, E and F, showed that RQ2 was achievable and that a platform like the one developed can



(a) Odd-numbered questions



(b) Even-numbered questions

Figure 5.6: Boxplot of both SUS questions.

allow mutation and configuration. The feature development and implementation phases proved to be insightful on the possibility of techniques developed to digitalize media content and show it in a virtual environment. This contributes to the response to RQ3 to which we can conclude that each media content type should be handled with a unique implementation although similar baselines can be used, as well as different interaction methodologies can be integrated to achieve diverse engagement by the user. As for RQ4, we could conclude there was a clear preference towards the 3D interaction, which can be correlated to the ability to offer more engagement freedom when compared to the 2D interaction counterpart.

In the following paragraphs, some insights will be revealed when cross-comparing the data resulting from the various tasks and the demographic data extracted on the population characteristics step. Firstly, a discussion over how the experience with games

Table 5.9: Games experience influence on free exploration

Experience with games	Users #	Found object	BO4 Completion Time	T-Test (CI = 95%)
Some	16	87.5%	28.75 ± 7.44	t(25) = -6.669
None	9	0%	48.78 ± 5.86	p <0.00001

affected the adaptation to the controls using as baseline the first set of tasks, as these might have been impacted by the user being familiar or not with the type of controls used in the implementation. Drilling down on the interaction preference on the different types of implemented media players, an analysis on how experience with games but also virtual museums can affect a certain preference for a specific type of media player with either 2D or 3D interaction. Lastly a look over the last two tasks completed by the users evaluating the configuration tools in order to understand whether past experience with virtual museums or games affects the completion time of these tasks.

Games experience influence on control adaptation Table 5.9 shows a resume table on two observations, first whether or not the users were able to find the hidden object when completing the task A, and second the completion time of the task BO4 as the user is asked to find the media room, without the help of the guide. Although the hidden object wasn't an obligatory task to the user, was used to measure how quickly the user would adapt to the controls since users that adapted faster do the controls would usually end up exploring more and eventually find the object within the duration of the first task. Additionally, a two-sample t-test was performed on the task BO4 where the user was instructed to fin the media room on his own to once more focus on the possibility of previous experience with games would affect the time the user would take to move around and explore, this time with an objective. As a result, the users with experience some experience in games showed the ability to find the hidden object while the users without experience were never able to find it. Considering a confidence interval of 95% there is evidence that previous experience in games has a significant impact on the performance on completion of the exploration task, indicating that indeed users with previous experience are prone to adapt quicker to the controls.

Games and virtual museums experience influence on media players preference As inferred in the task C results analysis the 3D interaction players resulted in the most preferred for the users overall 3 comparisons, image, video and audio media content. The tables 5.10, 5.11, 5.12, 5.13, 5.14, 5.15 show now the data obtained when crossing the preferences of each user to their experience with both games and virtual museums, in an act of finding whether any of these statistics influence the dispersion of the data. As expected neither the experience with games or virtual museums affects this preference as the majority of users continue to prefer the 3D interaction media players, only in the cases of no experience do the results happen to float around the equality. This can be related to the fact that the users with experience in games might be used to the 3D interactions leading them to prefer the 3D player.

Games and virtual museums experience influence on reconfiguration tools Task E & F evaluated user performance on the usage of the editor mode configuration tools

Table 5.10: Games experience influence on Image players

Experience with games	Users #	Image 2D	Image 3D
Some experience	16	17.85%	81.25%
No experience	9	33.3%	66.7%
Total	25	24%	76%

Table 5.11: Games experience influence on Video players

Experience with games	Users #	Video 2D	Video 3D
Some experience	16	17.85%	81.25%
No experience	9	33.3%	66.7%
Total	25	24%	76%

Table 5.12: Games experience influence on Audio players

Experience with games	Users #	Audio 2D	Audio 3D
Some experience	16	31.25%	68.75%
No experience	9	55.5%	45.5%
Total	25	40%	60%

Table 5.13: Virtual museums experience influence on Image players

Experience with virtual museums	Users #	Image 2D	Image 3D
Some experience	6	50%	50%
No experience	19	15.79%	84.21%
Total	25	24%	76%

Table 5.14: Virtual museums experience influence on Video players

Experience with virtual museums	Users #	Video 2D	Video 3D
Some experience	6	50%	50%
No experience	19	15.79%	84.21%
Total	25	24%	76%

Table 5.15: Virtual museums experience influence on Audio players

Experience with virtual museums	Users #	Audio 2D	Audio 3D
Some experience	6	33.3%	66.7%
No experience	19	42.1%	57.9%
Total	25	40%	60%

developed in the application. These tools are not as intuitive as the normal exploration controls, therefore it seemed important to analyse the past experience of the users with games and virtual museums to understand if these would influence the user performance. The tables 5.16, 5.17, 5.18, 5.19 compile the performances of the users for each task according to the experience with games or virtual museums, the usage of two-sample t-tests considering a confidence interval of 95%, concluded that neither previous experience reflected significant impact on the completion times.

Table 5.16: Virtual museums experience influence on reconfiguration tools - Task E

Experience with virtual museums	**Users #**	**Completion time Task E**	**T-Test (CI = 95%)**
Some experience	6	90.67 +- 14.27	t(25) = 0.50793
No experience	19	94.68 +- 16.76	p =0.616336

Table 5.17: Virtual museums experience influence on reconfiguration tools - Task F

Experience with virtual museums	**Users #**	**Completion time Task F**	**T-Test (CI = 95%)**
Some experience	6	187.83 +- 23.73	t(25) = 0.61456
No experience	19	194.26 +- 20.65	p=0.544877

Table 5.18: Games experience influence on reconfiguration tools - Task E

Experience with games	**Users #**	**Completion time Task E**	**T-Test (CI = 95%)**
Some experience	16	92.50 +- 15.36	t(25) = -0.48127
No experience	9	95.89 +- 17.62	p=0.634873

Table 5.19: Games experience influence on reconfiguration tools - Task F

Experience with games	**Users #**	**Completion time Task F**	**T-Test (CI = 95%)**
Some experience	16	192.88 +- 24.18	t(25) = 0.04588
No experience	9	192.44 +- 16.02	p=0.963803

6

Conclusions And Future Work

Virtual environments and the virtualization of the real world are exceptional fields to develop research. With the constant advancements in technologies such as game engines like Unity, allowing the recreation of the real world into scenarios that can be explored and also interacted with, allowing for the creation of timeless applications that can give users an immersive experience despite the mutation of the real world. Photogrammetry and 3D scanning are innovative tools that help achieve a more precise recreation of the real-world objects into 3D representations later used in these virtual environments to enhance the user experience.

Using virtual environments to help create platforms that allow the possibility to bring the real world and its cultural heritage to users, is a prime subject to explore, as one of the big concerns all across time has been the documentation of the cultural heritage. In the following context, using *Presídio da Trafaria* as a case study scenario, this thesis focused on exploring the creation of a virtual environment withholding cultural heritage content and introducing interactive elements to provide an entertaining experience as well as permitting a change of the environment, so that the platform can be updated throughout time.

The research started as an idea based on previous work on virtual environments with cultural heritage components, virtual museums like google museum, 3D applications with a real-world site as a base such as Vrouw Maria and even games, as an example Rome, as well as different types of interactions and user interfaces for enhanced user interactions, all presented in Chapter 2. A plan was then conceived to develop a platform using a configurable virtual environment where a user would be able to interact with different types of media content throughout Chapter 3, including a system and feature design. During Chapter 4 the features and system design were implemented, exploring the various decisions and capabilities of the platform. In order to evaluate the prototype achieved, Chapter 5 overviews the various phases of the testing session executed by the participants, as well as analysis and discussion of the data withdrawn. Chapter 1 presented the research questions that guided the work, the motivations and expected contributions for this thesis.

The work developed throughout this dissertation resulted in a functional prototype - Trafaria 3D - a configurable virtual environment with interactable media content, able to offer its users a spatial and temporal experience within the virtual environment and allowing the preservation and dissemination of the cultural heritage present in the media content that the users can interact with on the different features. As mentioned in Section 5.2, the data and feedback from the users throughout the testing sessions, support positively the first 3 research questions, indicating the users were able to enjoy the experience created in the platform and the digital content (RQ1). The users successfully changed and mutated the platform through the implemented mechanisms (RQ2) and the platform was capable of providing different approaches to the documentation and presentation of the cultural content (RQ3). As for the last research question (RQ4), there was a clear preference from the users towards a more UI free interaction, being able to interact with objects in the virtual environment itself through the 3D media player versions.

Both the prototype and the research unveiled the possibility of applying the platform to a different context and environment, to another historical site. The current work does not allow the full transition to a totally different place without doing some hands-on work on the project core files. The major barrier that prevents this possibility is the change of scenery, as of right now the platform is unable to load and change the 3D building structures that compose the historical site in run-time, so to use the platform and adapt to a new site it would be necessary make use of the Unity editor. Although the current project would need this initial step for adaptation to another site since the features developed do not require a specific 3D structure, they would be able easy to incorporate into the new project. The system and configuration syntax through the usage of JSON files allow for simple integration of the media database, guided and auto exploration modes, as well as the media room arrangement. As the media players implemented for the various media types are "game objects" which can be imported into the Unity editor it allows for the usage of these without complications. Finally, the editor mode and system also integrate the media database and allow the usage of its functionalities without the need for extra setup when using the developed project as a baseline.

6.1 Future Work

The framework concept achieved and the resulting Trafaria 3D project prototype, although functional and in insight successful implementation of the conceptualized system and application, can be greatly extended and improved, as more features could be added allowing different interactions and existing features reiterated adding support for different content.

Media Content Support various and different types of media content is an important part of the project since one of the main features is the ability to present and allow the users to interact with the various content through media players. Although the project prototype offered support for a lot of different types of content, it lacks in allowing more file extensions of the same type to be supported. For future work on this segment of the project more files could be tested and implemented to expand even further the amount of content supported by the platform.

Media players New techniques and improvements will be created to build UI and even 3D UI in virtual environments, and with the possibility of the addition of new file types, the existing media players would become obsolete. It would be interesting deeper research on improving the different media players and the creation of new ones to accommodate both the new and old content, but also to allow a more enjoyable and entertaining way for the users to interact with such players.

Configuration Although Trafaria 3D allows a big part of its core to be configurable and mutated, there is room to expand the concept and allow more customization of the platform. It is possible to study the achievement of a platform to fully customize a virtual environment in which the media players could be added, import both the 3D model of the historical site and maybe its surrounding area as well as all the media content to be added to the final application.

Gamification The system is designed to have some gamification aspects such as the achievement mechanism only allowing the user to be able to access a certain content after its interaction with the virtual environment, or the movement and menu implementation, but an extra step could be achieved but implementing more. The idea of adding gamification interactions such as minigames or riddles, even hiding secrets with rewards on discovery could be implemented to enhance the user interactions within the application and boost the interest of users in the application usage.

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I

Annex 1 - Tasks and Post-Session Questionnaires

I.1 Task A

Q1 – The player movement controls were intuitive

Disagree				Agree
1	2	3	4	5

Q2 – What was the level of difficulty in using the menu to move between buildings

Table I.1

Very Easy				Very Hard
1	2	3	4	5

I.2 Task B

Q3 – I understood how to follow the guide

Table I.2

Disagree				Agree
1	2	3	4	5

Q4 - What is the name of the building presented in the guide notes?

Q5 - Which exploration method did I prefer?

- ☐ Free exploration

☐ Guide exploration

☐ No preference

I.3 Task C

Q6 - What color was the title of the newspaper in the Image 2D media player?

Q7 - How many pages did the manuscript have in the Image 3D media player ?

Q8 – Which media player did I like the most
Image 2D vs Image 3D

☐ Image 2D

☐ Image 3D

Video 2D vs Video 3D

☐ Video 2D

☐ Video 3D

Audio 2D vs Audio 3D

☐ Audio 2D

☐ Audio 3D

Q9 – Was able to interact with the Image 2D media player the way I intended to

Disagree				Agree
1	2	3	4	5

Q10 – Was able to interact with the Image 3D media player the way I intended to

Disagree				Agree
1	2	3	4	5

Q11 – Was able to interact with the Video 2D media player the way I intended to Q12

Disagree				Agree
1	2	3	4	5

– Was able to interact with the Video 3D media player the way I intended to

Disagree				Agree
1	2	3	4	5

Q13 – Was able to interact with the Audio 2D media player the way I intended to

Disagree				Agree
1	2	3	4	5

Q14 – Was able to interact with the Audio 3D media player the way I intended to

Disagree				Agree
1	2	3	4	5

I.4 Task E

Q15– Was able to create the room i wanted

Very Easy				Very Hard
1	2	3	4	5

Q16- What was the level of difficulty of using the create room tool

Disagree				Agree
1	2	3	4	5

I.5 Task F

Q17 – What was the level of difficulty of using the add media player tool

Very Easy				Very Hard
1	2	3	4	5

Q18 - What media player did I remove during the task ?

I.6 User Profile

Gender:

- ☐ Male
- ☐ Female
- ☐ Other

Completed Education Level:

- ☐ Less than High School
- ☐ High School
- ☐ Bachelor's
- ☐ Master or More

Age:

Frequency of play over games:

- ☐ Once per day
- ☐ Once per week
- ☐ Once per month
- ☐ Once in a year or played it once
- ☐ Never

Experience with First Person Shooter games:

- ☐ Once per day
- ☐ Once per week
- ☐ Once per month
- ☐ Once in a year or played it once
- ☐ Never

Experience with virtual museums:

- ☐ Once per day
- ☐ Once per week
- ☐ Once per month
- ☐ Once in a year or played it once
- ☐ Never

II

Annex 2 - SUS Questionnaire

1. I think that I would like to use this system frequently

Strongly disagree				Strongly agree
1	2	3	4	5

2. I found the system unnecessarily complex

Strongly disagree				Strongly agree
1	2	3	4	5

3. I thought the system was easy to use

Strongly disagree				Strongly agree
1	2	3	4	5

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

Strongly disagree				Strongly agree
1	2	3	4	5

5. I found the various functions in this system were well integrated

Strongly disagree				Strongly agree
1	2	3	4	5

6. I thought there was too much inconsistency in this system

Strongly disagree				Strongly agree
1	2	3	4	5

7. I would imagine that most people would learn to use this system very quickly

Strongly disagree				Strongly agree
1	2	3	4	5

8. I found the system very cumbersome to use

Strongly disagree				Strongly agree
1	2	3	4	5

9. I felt very confident using the system

Strongly disagree				Strongly agree
1	2	3	4	5

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

Strongly disagree				Strongly agree
1	2	3	4	5