NOVA SCHOOL OF
SCIENCE & TECHNOLOGY

DEPARTMENT OF
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NELSON MIGUEL JOEIRINHO FARIA

Bachelor in Computer Science and Engineering

WEB INTEGRATION OF VIRTUAL MUSEUM TOURS AND 3D MEDIA VISUALIZATION

MASTER IN COMPUTER SCIENCE

NOVA University Lisbon
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Web Integration of Virtual Museum Tours and 3D Media Visualization

This document was created with the (pdf/Xe/Lua)LaTeX processor and the NOVAthesis template (v7.0.3) [**novathesis-manual**].

To my mom and grandmother.

Acknowledgements

First and foremost, a special thank you to my advisers, Rui Nóbrega and Nuno Correia, for giving me the opportunity to conclude my academic life with a dissertation on topics I was eager to work on and explore, and for their trust and support along the way. *Enriching* would be the word I'd use to describe this journey, and I owe much of that to their guidance during this last chapter of my studies.

To NOVA LINCS for funding my research, along with its team and collaborators.

To *Faculdade de Ciências e Tecnologias da Universidade Nova de Lisboa* and all the teachers I met during these years.

To *Academia das Ciências de Lisboa* and all the collaborators I had the chance to work with. Thank you for the availability and support, which greatly facilitated the development of this project.

To anTUNiA, for teaching me things that no school could teach, and all the friends I made along the way that made my academic life much more than what it would have been if I haven't stepped in that rehearsal room for the first time.

To my mother Cristina and my grandmother Rosa, to whom I owe most of who I am today. Thank you for teaching me the value of hard work.

To Rita, for always supporting me through the ups and downs of these past years, and all the words of encouragement.

”

“The difference between ordinary and extraordinary is that little extra.”

— Jimmy Johnson

Abstract

This thesis explores the intersection between cultural heritage preservation, 3D virtual environments and user experience design for website development in order to present the design, implementation and evaluation of a system focused in showcasing cultural heritage objects and spaces.

This dissertation, made in collaboration with *Academia das Ciências de Lisboa*, contributes to the digital preservation of cultural historic sites and artifacts, as well as providing a way for the public to access, explore and engage with the museum's collection digitally. To make it possible, several means of 3D scanning and visualization techniques were explored, in order to implement a solution using state-of-the-art 3D scanners and modern website development technologies, focused on efficiency and user engagement.

To evaluate this success of this project, a user study was performed (N=30) on subjects with different background and characteristics. Known questionnaires, such as the User Experience Questionnaire (UEQ) and the System Usability Scale (SUS), were administered. The results of these tests were positive, supporting the thesis that such a website can be engaging and informative.

The major contribution of this dissertation is a virtual tour website for the *Academia das Ciências de Lisboa*, already live online. Additionally, it offers a set of guidelines on how to create such a platform, based on the work developed. Finally, the positive results of the user study are also presented, supporting the value of this system.

Keywords: Cultural Heritage, Virtual Museum, 3D Scanning and Visualization, Web Development

Resumo

Esta tese explora a interseção entre a preservação do património cultural, ambientes virtuais 3D e o design de experiência do utilizador no desenvolvimento de websites, com o objetivo de apresentar o design, implementação e avaliação de um sistema focado na exibição de objetos e locais de património cultural.

Esta dissertação, realizada em colaboração com a *Academia das Ciências de Lisboa*, contribui para a preservação digital de locais e artefactos históricos, além de proporcionar ao público uma forma de aceder, explorar e interagir digitalmente com a coleção deste museu. Para realiza-la, foram exploradas várias técnicas de digitalização e visualização 3D, com o intuito de implementar uma solução utilizando scanners 3D de última geração e tecnologias modernas de desenvolvimento web, com foco na eficiência e no envolvimento do utilizador.

Para avaliar o sucesso deste projeto, foi realizado um estudo com utilizadores (N=30) de diferentes origens e características. Questionários conhecidos, como o User Experience Questionnaire (UEQ) e o System Usability Scale (SUS), foram aplicados. Os resultados destes testes foram positivos, sustentando a tese de que um website desta natureza pode ser envolvente e informativo.

A principal contribuição desta dissertação é um website de visita virtual para a Academia das Ciências de Lisboa, já disponível online. Adicionalmente, oferece um conjunto de diretrizes sobre como criar uma plataforma semelhante, com base no trabalho desenvolvido. Por fim, são também apresentados os resultados positivos do estudo com utilizadores, que reforçam o valor deste sistema.

Palavras-chave: Património Cultural, Museu Virtual, Digitalização e Visualização 3D, Desenvolvimento Web

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1 Introduction

The preservation and documentation of cultural heritage plays a crucial role in our society. Ensuring that the transmission of knowledge and experiences is passed down intact throughout generations is fundamental, not only to keep the history, but also for countries and individuals to understand their origins and have a sense of identity. Numerous efforts have been made throughout the years in order to ensure that the necessary activities regarding this matter are performed, with its roots starting with the legal rules defined in the Congress of Vienna, in 1814 [13]. From there on, with an even greater necessity of cultural heritage preservation after two world wars, entities with responsibilities in this matter took bigger steps in suggesting measures for the safeguarding cultural heritage, such as UNESCO's Convention on the Protection of Cultural Property, in 1954 [1].

With the development of technologies over the years, new ways of preserving and conserving cultural heritage have taken their place. Technologies such as scanning, modeling and visualization have reach a point where performing such activities are not only easier, but also effective in keeping and visualizing documentation of this matter [26]. Such technologies allow the creation of digital twins of artifacts, sites or structures to be kept for years, even if the physical object suffers any damage, either by natural events (floods, earthquakes, etc), wars or by natural degradation [5]. However, with the advent of the Internet and the accessibility it brought to our society, it is now possible to share these digital twins to the world, and allow people to connect to new cultures, learn about them and see cultural heritage in ways that were not possible to experience before. Nothing compares to the experience of being in an actual site and explore a different culture, but with technology it is now possible to create a virtual environment on which someone can, in the comfort of their home, travel to another part of the world and be presented with a different culture in a engaging way, as close as possible to what the real life experience would be.

1.1 Context and Motivation

Preserving cultural heritage is a matter of extreme importance, as it tells the history of territories, artifacts and culture. As a society, it is important to understand our past in order to progress into the future, and cultural heritage preservation and conservation plays an important role in keeping our past intact and protected, so that future generations can access it. Allowing people to have access to different cultures not only enriches that individual, but also helps the culture itself to not be forgotten. Therefore, there are two main motivations on which this dissertation will revolve around.

Firstly, the main point of preserving cultural heritage is making sure that if something happens to the physical entity – either it being an object, artifact, site or building –, it will be possible to have access to some record of it, in the future. An artifact can be affected by numerous reasons, ranging from natural disasters to vandalism, so making sure there's a digital copy of it is the first motivator factor.

With the technology available now, it has never been easier to share and learn. The Internet has been having its role on the process of globalization, and culture sharing is happening as a consequence. Therefore, it is now possible to share different cultures and their rich content, in the form of artifacts and histories, to anyone living in a different part of the world, which otherwise probably would never have access to it. This is the second great motivator to this dissertation, since it has a positive contribute to our society, allowing individuals to know about different cultures and the culture itself to be recognized as part of our history.

This thesis was developed in a partnership with *Academia das Ciências de Lisboa*. This academy, founded in 1779, was a teaching institute focused on science, social science and humanities studies until the end of the XIX century. Nowadays, it stands as a relevant institute dedicated to the promotion and disclosure of scientific culture, as well as a mark in Portugal's history as a teaching institute that demonstrated the relevance of sciences and letters studies to the development of the country. This academy contains a wide range of cultural heritage artifacts, connected to science and human history, and the goal is not only to make digital twins of these relics but also to present them to the public in an interesting and engaging way, focusing on knowledge transmission.

1.2 Objectives

Given that this dissertation was carried out as part of a project in partnership with the *Academia das Ciências de Lisboa* and addresses their needs for a platform focused on showcasing its cultural content, the main objective of this thesis is:

- Create a platform aiming to provide a virtual tour for the *Academia das Ciências de Lisboa*, presenting its spaces and cultural heritage objects in an engaging and informative manner.

In order to successfully achieve this objective, some research work must be conducted in order to come up with a solution that follows the current state-of-the-art technologies while going through testing phases to be validated. Additionally, from the work developed throughout this project, it is also expected to gather some insights into how these systems can be created and generalized for similar cases. Therefore, the following additional objectives for this dissertation arise:

- Research on the current state of presenting media in the context of virtual tours for museums, including the current technologies in 3D scanning, modeling and modern website development;
- Explore different available visualization options in the context of a digital platform for the selected media content;
- Establish a set of guidelines for the creation of similar platforms, gathered from the work developed during this thesis;
- Evaluate the finalized version through user studies, in order to analyze the effectiveness and overall quality of the platform.

1.3 Research Questions

The presentation of a museum's content can vary greatly, depending on its type and the available methods to support this presentation digitally. It is of crucial consideration to choose how to present this content, as it can significantly impact user's engagement and knowledge intake. Moreover, the user's experience must be efficient and smooth, so the chosen technologies must run efficiently within a browser. Lastly, it is important to consider that the presented content can be modified and expanded.

Therefore, in order to guide the research work, the following research questions arise:

- **Q1** – Is it possible to create a digital platform, focused on cultural heritage presentation, that is engaging and informative?

This question focuses on measuring the success of the creation of such a platform, as the main goal is to create something that successfully engages the user and transfers information. This measurement can be done by asking the user the overall feeling of engagement with the platform and how much information he managed to acquire.

- **Q2** – Can this platform ensure that all types of chosen media run efficiently and smoothly in the browser?

This question focuses on how the platform will be built and how effectively the necessary tools for implementing and presenting the chosen media types perform in a browser. Factors such as the size of the 3D models, media content and the implemented

features to interact with the digital world can have effects on the performance of such a platform when it's used online. Loading times, smooth navigation and interaction greatly depend on the technologies used in this project.

- **Q3** – Can this project be generalized for implementation in other museums?

This research question explores whether the methods, findings and outcomes of this project can be applied to other museums or similar systems. By addressing this question, we can determine if the project's framework is flexible and scalable enough to be implemented across a diverse range of museums or if it may be more suitable for specific contexts only.

1.4 Implemented Solution

To satisfy the objectives of this dissertation, a website for a virtual tour of the *Academia das Ciências de Lisboa* was created using modern frontend and backend technologies. This website contains information about the Academy's spaces and cultural heritage objects and offers interactive ways to visualize them. This website, pictured in Figure 1.1, and it's available in the following url: https://visita3d.acad-ciencias.pt/.

Visitors can access pages related to the Academy's rooms, which provide an initial presentation with an audio guide while the user automatically navigates between relevant points in the space using a 3D viewer. Upon finishing the presentation, users can navigate freely in the space and explore at will. This 3D viewer is accompanied by annotations on relevant objects within the room. When clicked, these annotations provide additional information about the artifact through text and images. Items that belong to the visited room's page appear in an interactive gallery that, when clicked, opens a detailed presentation window. This information panel contains high-quality images of the objects,

Figure 1.1: The *Academia das Ciências de Lisboa* virtual tour website.

descriptive information, and, in some cases, a 3D viewer of the object. For some books and manuscripts, a direct link to the full content is also provided.

This website is fully responsive, so it can be accessed by every type of devices. Additionally, the website is available in English, so it can be accessible by an international audience.

1.5 Contributions

The primary of this dissertation is the creation of a platform for a virtual tour for the *Academia das Ciências de Lisboa*. The developed website provides an interactive and user-friendly way to access information about the Academy's spaces and its cultural heritage objects. With the knowledge gathered during the development of this project — not only by the research done about the related topics but also by direct contact with the Academy's stakeholders and the iterative development process —, this dissertation provides a structured approach for the developing such a platform, with some guidelines on how to create an effective virtual museum experience.

Additionally, the users tests that were conducted with some subjects being museum experts and historians, in order to evaluate this system in different aspects, represent another contribution, as they offers results and provide insights about the user's experience that might be useful for similar projects.

1.6 Document Structure

This chapter aims to introduce the context and motivation of this work, by giving a starting point to what this project is about and the necessity behind it.

In Chapter 2 the state of the art is presented, where relevant topics to the research work will be discussed and from which conclusions about the implementation of this project will be derived. This chapter will be focused on Cultural Heritage, 3D Virtual Environments, User Experience and Design, and lastly, Web Development and Design. Chapter 3 will be focused on the System's Analysis and Design, specifying the requirements, the applied methodology, the various versions of the developed website, the final system's architecture and guidelines for creating a website for a museum virtual tour. The next chapter (Chapter 4) describes in more detail the implementation of this platform, stating the chosen technologies for development and describing the creation of the website itself and its features. Chapter 5 will present the evaluation phase, where the user tests protocol were described in detail and their results are provided, culminating in a general analysis and discussion of the data gathered. Lastly, Chapter 6 concludes this dissertation, providing interesting future work possibilities to be continued in this system.

2

State of the art

This chapter will introduce the key themes associated with this thesis, analysing related work and understanding the state-of-the-art of each of them.

Cultural Heritage and its Preservation is the basis of this thesis and the first subject to be reviewed. This topic will focus on what Cultural Heritage is and dive into what is being done regarding its preservation and conservation, both very important endeavors aimed at safeguarding and maintaining cultural artifacts, sites, and objects for future generations. Creating digitalizations and proper documentation are two ways to achieve the goal of keeping cultural heritage preserved, and a few examples of initiatives regarding this matter will be presented. Those digitalizations often occur in the form of 3D scannings with the final goal of creating **3D Virtual Environments**, that allow an easier access for people around the world to see those artifacts. The way these digitalizations are presented to the public is very important, as it can be very hard to mimic the experience of a real-life visit to a museum, so **User Interaction and Experience** concepts need to be applied in the virtual accessibility of such artworks. In the end, the goal is to present these digitalizations in a web page, so it will be relevant to dive into the world of **Web Development and Design**.

2.1 Cultural Heritage

Cultural Heritage refers to the body of knowledge, traditions, artifacts and practices that are passed down from one generation to the next [33]. It encompasses both tangible and intangible aspects of human history and culture. Cultural Heritage establishes a connection between the past and the future with the application of particular approaches in the present. Due to its value for specific groups or societies, cultural heritage is maintained in the present and holds great value for the benefit of generations to come. It can be split into three different components, with the first one being Tangible Cultural Heritage, which includes physical artifacts, monuments, buildings, artworks, manuscripts and archaeological sites. This type represents the material manifestations of human culture and history. Another type is Intangible Culture Heritage, which encompasses

traditions, rituals, languages, folklore, oral histories, music, dance and other non-material aspects of culture. It reflects the social and cultural practices of a community. The last one is Natural Heritage, where some definitions also include natural sites and landscapes that hold cultural significance, such as sacred natural sites, ecosystems, and natural features tied to cultural traditions [37].

2.1.1 Preservation and Conservation

Cultural Heritage preservation and conservation are essential to ensuring that the wide range human history and culture is passed down intact to future generations. This complex endeavor encompasses a wide range of practices, each with the goal of safeguarding both tangible and intangible aspects of cultural heritage. Unfortunately, despite their varied nature and composition, artifacts are inevitably exposed to numerous risks. War and armed conflicts are a few of those risks, and many laws and protocols have been put in place in order to prevent damage of cultural heritage. One example of such effort it's the 1954 UNESCO's Convention on the Protection of Cultural Property in the Event of Armed Conflict, that suggested protective measures for the safeguarding of cultural property [1]. However, such actions are not enough to cover all the risks regarding Cultural Heritage damage. Environmental factors, such light, temperature and relative humidity; anthropogenic causes like vandalism, pollution and wrong restoration interventions; natural disasters, biocontamination, and climate changes, all contribute to threaten the preservation of cultural heritage and its transfer to future generations [5]. Therefore, other preventive measures of preservation of Cultural Heritage need to be applied, and with advances of technology over the last years, many of those come in the form of new innovations that even though they do not help directly with the physical conservation of buildings and artifacts, they do work for keeping digital information of these for many years, no matter the current state of the physical object.

To achieve such level of preservation, there are various techniques and new technologies being used. However, to focus on the scope of this thesis, it will only be presented those that involve some sort of spacial scanning, such as 3D scanning [36] and photography [32].

2.1.2 Digitalization and Documentation

Digitization has emerged as a critical tool in the preservation and dissemination of cultural heritage. It evolves the creation of digital records and representations of artifacts, documents and other heritage items. This process is executed using technologies such as 3D scanning, high-resolution imaging and digital archiving. An example of a 3D scanner, Leica RTC360, can be seen in Figure 2.1.

The digitization process involves creating high-quality digital records of artifacts, historical documents and other heritage items. This enables cultural heritage institutions to have accurate and detailed representations of their collections. High-resolution imaging

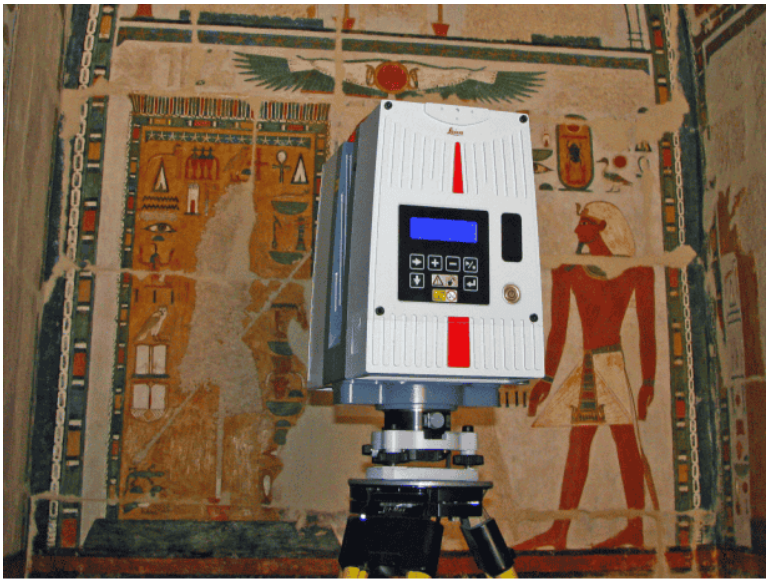


Figure 2.1: Leica HDS 6000 scanner mounted on tribrach, used in the scanning and modeling of the upper terrace of the Hatshepsut Temple in Deir el-Bahari as an example of architectural heritage documentation for restoration purposes [31].

techniques capture intricate details, colors and textures, ensuring that the digital copies closely mirrors the original artifacts.

Traditional methods of gathering cultural heritage data involve field surveys, mapping and photos. These results have become a crucial foundation for heritage preservation [26]. Novel and advanced technologies, such as digital photogrammetry and spectral imaging, are becoming mode widely employed in heritage science and are often used to comprehensively record, understand and protect historical relics and artworks. Some examples of these advances include the use of drones to obtain high-resolution images and using the data for 3D modeling; using 360 degrees panorama technology to obtain panoramic photos; or using terrestrial laser scanners to obtain point clouds [10].

2.1.2.1 Europeana

One example of an on-going successful digitalization project is Europeana[1]. Europeana is a European digital platform that provides access to millions of cultural heritage items from across the European continent. It was launched on 2005 and open to the public on 2008, with the goal of serving as a vast repository of digitized materials, including artworks, books, manuscripts, photographs, and historical artifacts [61]. Europeana's mission is to bring Europe's rich cultural heritage to a global audience, making it accessible to people from all walks of life, including researchers, educators, students, and the general public. When navigating the Europeana's website, the user will be able to see two types of search options: by collections or by stories. When choosing the search by collections, the user will then be able to filter the results by themes, topics, century or specific museums or

[1]Europeana (Last Access: 9/2024) -https://www.europeana.eu/pt/stories

organizations. The view of a specific gallery or exposition is quite simple, with either a slideshow of photos being displayed or a video or audio file being played. When searching by stories, the user will be presented with online blog's posts or expositions, with a richer storytelling and presentation of the information regarding the chosen topic. Another interesting feature of Europeana is the possibility of an user to share its own data. Europeana helps individual contributors or institutions with the propagation of its data within its platform and can even help share it among others.

2.1.2.2 Google Arts & Culture

Google Arts & Culture[2] is a digital platform and initiative developed by Google that focuses on making art and culture accessible to people around the world, and has become a prominent online resource for exploring and learning about art, history, and cultural heritage. It started with partnerships with a few prominent cultural institutions and museums, which then led to Google Art Project, also launched in 2011 [7]. Over time, the Google Cultural Institute expanded its focus beyond visual arts. In 2016, the initiative was rebranded as "Google Arts & Culture" to encompass a broader range of cultural content, including history, heritage, and artifacts. For interiors of museums, Google adapted the Google Street View technology, by putting a camera on a "trolley" system for an easier scanning. For paintings, there were taken high resolution picture with great detail, allowing to zoom those pieces of art into a "brush-level" detail on images of several gigapixels. Regarding the virtual museum tour experience, the navigation works as Google Street View as this was the basis for this application. An example of its interface can be seen on Figure 2.2, of *Museu da Marinha*[3] exhibit.

However, Google Arts & Culture exceeds itself when it comes to providing useful resources to the users, besides virtual tours and high-detail images of artwork. More than just providing access to cultural heritage in the form of virtual environments, to create a better virtual tour experience to an user the story surrounding an object or even a whole exhibition must also be replicated as if the user was in a physical museum with a guided tour. This is called storytelling and it's a very important factor to take in consideration when there's a goal to keep the user engaged in the virtual tour experience. Many techniques and media can be used, with some of them being used in video-games, but can be easily adapted to work well in adaptations for digital museums [48]. Google Arts & Culture applies this techniques in a specific way of displaying piece of art or a whole exhibition called *Online Exhibits*[4]. There are several at the platform, and their goal is to replicate as close as possible what it would be like to have a real world guide with

[2]Google Arts & Culture (Last Access: 9/2024) - https://artsandculture.google.com/

[3] Google Arts & Culture - *Museu da Marinha* (Last Access: 9/2024) -https://artsandculture.google.com/partner/museu-de-marinha?hl=pt-pt

[4]Google Arts & Culture: Online Exhibits (Last Access: 9/2024) -https://artsandculture.google.com/project/exhibits

Figure 2.2: The interface of Google Arts & Culture virtual tour experience, at the entrance of *Museu da Marinha*.

the user, by presenting a storyboard that a user can follow, displaying text, images, videos and audio files, and even allow the user to input their own interactions.

Another interesting feature of Google Arts & Culture is that it has integrated Gamification [43] elements into its platform to engage users, make cultural exploration more interactive, and enhance the educational experience. Gamification in this context refers to the use of game-like features to encourage user participation and learning. For example, *Art Selfie*[5] allows users to take a selfie, and the platform's image recognition technology matches their facial features with famous artworks from the platform's collection. Users can see which historical or artistic figures they resemble, adding an element of fun and personal engagement. It also offers various educational games and activities that are both entertaining and informative. This can incentive users to explore more content and engage with the platform.

2.1.2.3 Matterport

Matterport[6] is a company that is known for its 3D scanning and spatial data capture solutions and systems, with it's primary focus being on creating immersive 3D experiences of physical spaces. Their technology allows users to capture real-world spaces in high detail, converting them into 3D models which then allows the creating of virtual tours and other interactive applications. Although it is not directly connected with digitalization and documentation of cultural heritage, as it can be used for many situations, it is still relevant to observe as their display techniques are quite interesting and different from the previously mentioned platforms.

The company offers many software and services, most of them requiring a paid

[5]Google Arts & Culture: Art Sefie (Last Access: 9/2024) -https://artsandculture.google.com/camera/selfie

[6]Matterport (Last Access: 9/2024) -https://matterport.com/

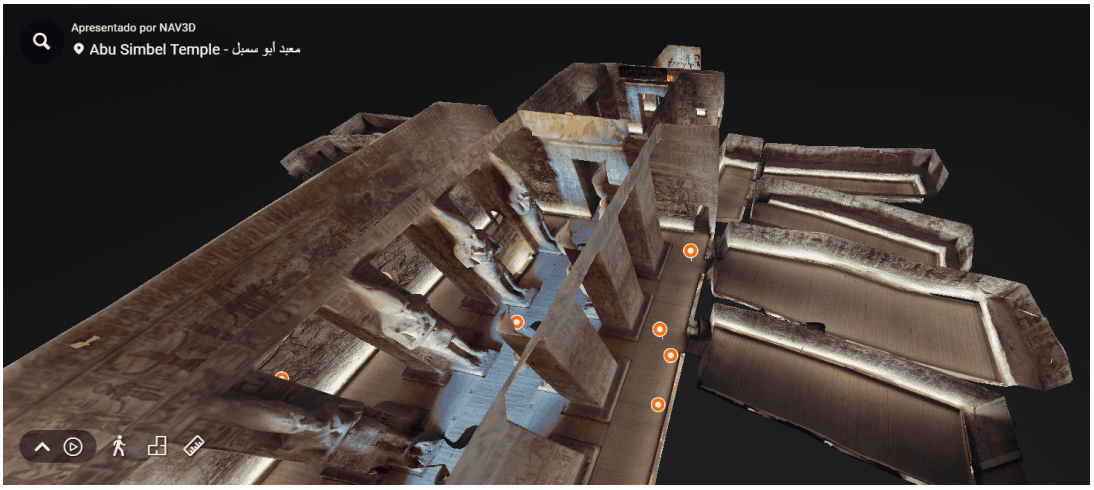


Figure 2.3: The "Dollhouse" view in Matterport of the Abu Simbel Temple 3D Model.

subscription plan, but there is a free plan where a user can create his own 3D environment by using his mobile phone camera or supported 360° cameras for scanning. However, for the use of more advanced 3D cameras, which the company also sells, and more advanced features, a paid subscription is required.

As mentioned, the focus of the company is not cultural heritage 3D environments, but more about creating a marketing tool [51], as it allows the creation of a digital twin of anything the user wants. For example, an architect could create a 3D replica of its new building, which would allow an interested buyer to take on a virtual tour before committing to a physical tour. However, the company still provides a large offer of interesting virtual environments, some connected to art and cultural heritage. For example, the Abu Simbel Temple[7] will be used as a case study. Upon entering the environment, the user is presented with a rich interface with different options to choose from. It is possible to select two different types of views: Dollhouse (see Figure 2.3), which is basically an "aerial" view of the 3D model, allowing the user to navigate with the mouse buttons to change its location in the space; and the first-person view, which works like Google Street View used in Google Arts & Culture virtual tours. In both views, clickable notations are also presented, allowing the user to get to know more information about relevant objects presented in the tour. Upon clicking on a note, a side bar is shown containing more detailed information about the object of interest.

Another interesting feature that hasn't been mentioned in the previous studied platforms is the existence of a measuring tool. With this tool, the user can draw a line between two points in the 3D model and get the distance between them. This is possible because the scanning with Matterport cameras create a truly 3D point cloud model, unlike what is seen in Google Arts & Culture, for example, where it is mostly 360° imagery. Therefore, it is possible to calculate exact measurements and observe the real distance between two

[7] Matterport - Abu Simbel Temple (Last Access: 9/2024) - https://artsandculture.google.com/entity/abu-simbel/g1214g7hh

points.

2.2 3D Virtual Environments

With the evolution of computer processing power, graphics hardware and gadgets that allow a greater immersion experience, 3D Virtual Environments are becoming a very interesting and discussed topic over the past years [18]. Those can be defined as a being a real or created digital worlds where users can navigate and interact with, for many purposes ranging from leisure and gaming to learning. There are many ways these worlds can be created and navigated in, such as computers, mobile phones or devices like virtual and augmented reality glasses, but for the scope of this thesis the focus will be web browsers, as the main mean of presentation of such environments. Therefore, it's crucial do get a deeper understanding of how such environments are created, and how we can visualize them.

2.2.1 3D Scanning

The creation of digital worlds can be done through different ways, but the utilization of 3D scanning has become a prevalent method for recording and preserving a multitude of objectives. It's inherent that 3D models offer a more comprehensive representation of the physical realm, encompassing both form and surface attributes, surpassing the limited perspective of 2D images. This advantage extends to a wide array of applications, spanning industrial assessments and e-commerce presentation to the digitization of museum collections and the documentation of archaeological findings [19]. There are different methods to acquire a 3D scan of the real world, and the most used will be listed below.

2.2.1.1 LiDAR – Light Detection and Ranging

A very common used 3D scanning technology to acquire 3D models is LiDAR. It's operation principle is simple: a scanner using the LiDAR technique will emit laser pulses at the speed of light towards a target, to measure the time it takes for the emitted laser beam to bounce off an object and return to the sensor. By precisely measuring the time delay and the speed of light, LiDAR systems calculate the distance to the object. LiDAR also employs multiple laser beams to capture data from different angles. A diagram of this how a LiDAR system works can be seen in Figure 2.4. This type of scanning is often used to capturing detailed 3D information over large areas, such as buildings, archaeology sites and other infrastructures, as it cover long distances effectively [45].

However, depending on the goal of the scan, LiDAR is not usually enough as the laser sensors are only able to capture geometric data, and not color, for example. Therefore, when necessary, it is normal to complement LiDAR scanning with other types of techniques.

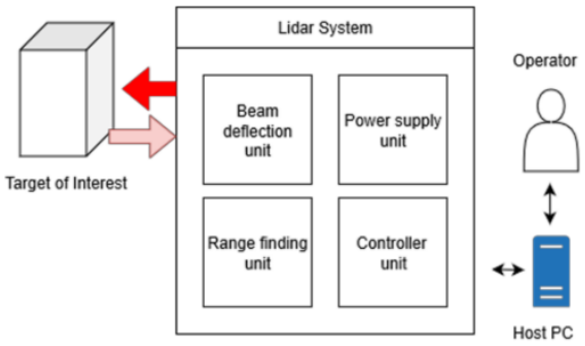


Figure 2.4: Block diagram of light detection and ranging (LiDAR) system [45].

The main purpose of including other complementary systems is to acquire different information about the objects, like color and texture. Some 3D laser scanners, like Leica RTC360 [8], have the capability to capture color information along with 3D data. In addition to the LiDAR technology that captures the 3D geometric information using laser pulses, the RTC360 is equipped with high-resolution imaging sensors and cameras that allow it to capture color and visual texture information. This color data is overlaid onto the 3D point cloud, resulting in a more realistic and visually informative representation of the scanned environment or objects. Leica RTC360 generates a massive and rich point clouds and high-definition images with comprehensive data and rich details [29]. An example of the result of a scan using Leica RTC360, a scanner employing LiDAR technique, can be seen on Figure 2.5.

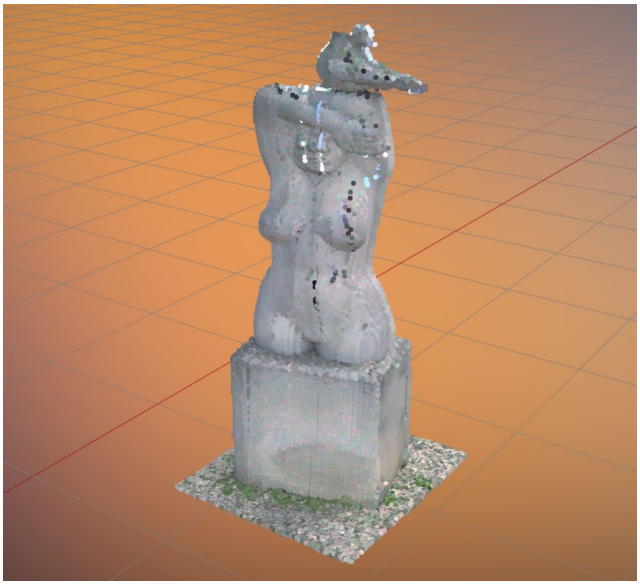
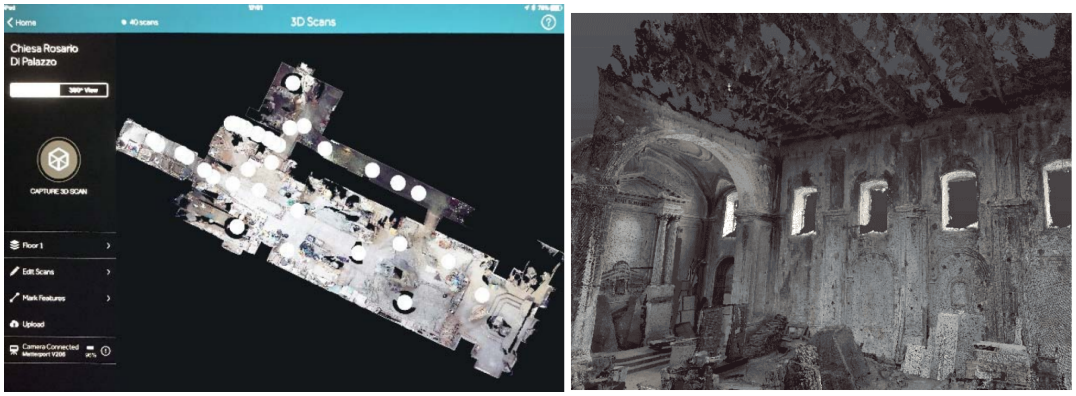


Figure 2.5: Visualization of a statue at School of Science and Technology captured with the scanner Leica RTC360.

[8] Leica RTC360 (Last Access: 9/2024) - https://leica-geosystems.com/pt-br/products/laser-scanners/scanners/leica-rtc360



(a) Sky view with shot's locations. (b) Generated 3D model.

Figure 2.6: Indoor view of the Matterport Pro2 3D's point cloud obtained from multiple shots inside the Church of Rosario di Palazzo [44].

2.2.1.2 Photogrammetry

Another well known and used technique is Photogrammetry [39]. This technique involves capturing 3D data from photographs. It is a method that uses multiple 2D images of an object or scene from different viewpoints to create a 3D representation. Multiple high-quality images of the object are captured from different angles using digital cameras, or even cellphone pictures. These images should overlap to ensure full coverage of the subject. Then, with the use of proper algorithms, a point could is created out of the 2D images after merging them together, with eventual manual cleanup after this process. This technique extracts very useful information such as distance, color, specular reflections, amongst other [53]. Photogrammetry as a means of 3D modeling has increased because of its efficiency in regard to cost, time and accuracy, as it offers a much lower-cost solution and more accessible. [47]. For example, Matterport offers a feature in its app where the user can take photos using his own smartphone camera, and the app will generate a 3D model of the captured object [12]. Ít also allows the use of compatible 3D cameras to create 3D models. For example, as seen in Pulcaro et al. [44] case study, a Matterport Pro2 3D camera was used to create a 3D model of the Church of Rosario di Palazzo. By taking several shots of the inside of the church, and then processing those shots in the Matterport app, a final 3D model was generated. which can be partially seen in Figure 2.6.

The combination of laser scanning techniques with photogrammetry usually provides the best way to scan and digitally reconstruct objects of any size, capturing most of the essential information that's necessary to obtain the final 3D model [32].

2.2.1.3 Structured Light Scanning

Another technique used to create reliable 3D models of objects is Structured Light Scanning [15]. The principle is different from the previous techniques: this scanners employ the projection of a light pattern onto the object and subsequently detect how this pattern

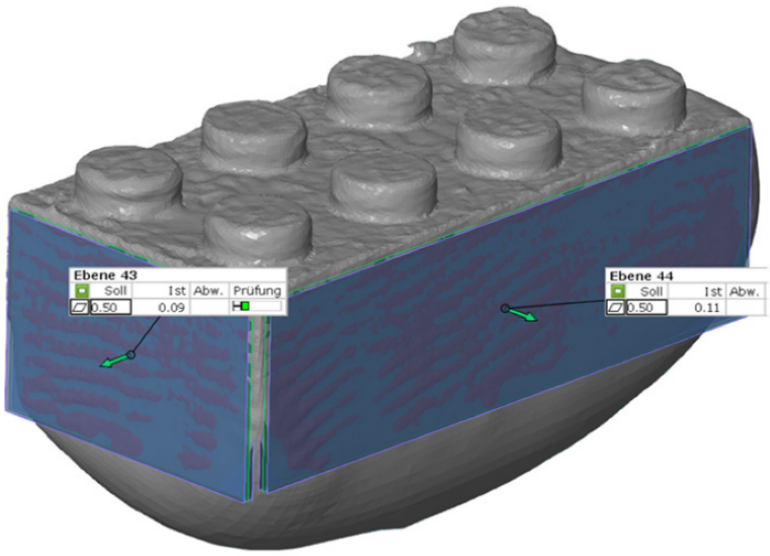


Figure 2.7: A Lego piece scanned with Artec Space Spider [59].

deforms when it interacts with the object. This pattern can take the form of either one-dimensional or two-dimensional structures. For instance, a one-dimensional pattern may be represented as a line. The scanner projects this line onto the object using either an LCD projector or a scanning laser. Positioned slightly offset from the pattern projector, a camera records the shape of the line from an angle alpha. To calculate the distance to each point along the line, a method akin to the triangulation principle is employed. In the case of a single-line pattern, the line is systematically swept across the field of view, gathering distance information one strip at a time. An example of a two-dimensional could be a grid or a pattern consisting of line strips. A camera serves the purpose of capturing the deformation of this pattern, and an algorithm is used to calculate the distance at each point in the pattern. Structured light 3D scanners, however, offer the significant advantage of speed. Rather than scanning a single point sequentially, these scanners have the capability to simultaneously scan multiple points or even the entire field of view in a single instance. This feature serves to diminish or altogether eliminate the challenges associated with distortions resulting from object motion [38].

An example of such a scanner is the Artec Space Spider[9], developed by Artec 3D. This scanner is designed for capturing 3D data from a variety of subjects and is particularly suitable for capturing medium to large objects and even people. An example of a scanned object can be seen in Figure 2.7.

[9] Artec Space Spider (Last Access: 9/2024) - https://www.artec3d.com/portable-3d-scanners/artec-spider

2.2.2 3D Visualization

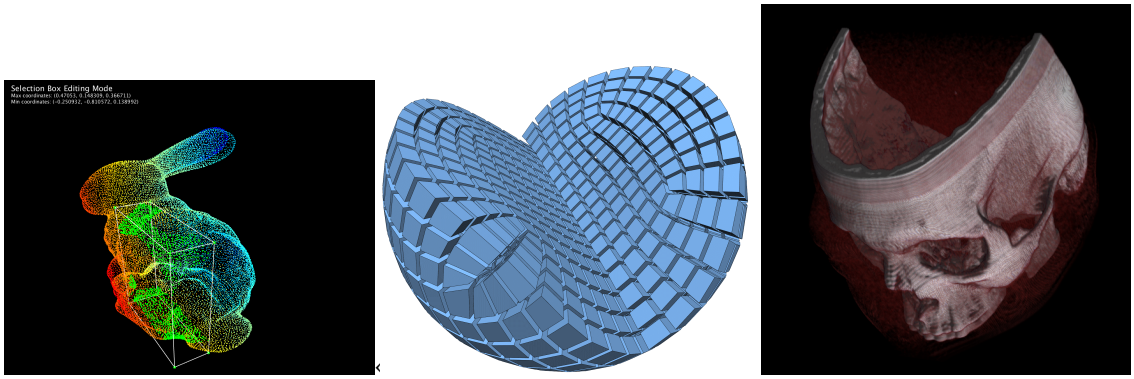
Three dimension visualization involves the creation of three-dimensional representations of objects, spaces, or data for various applications, including entertainment, design, engineering, medicine, and science. The visualization of objects and scenes in 3D provides not only a more aesthetically appealing design, but also a better understanding and memorization of a visualization, as well as favors the perception of the human visual system [55]. Therefore, 3D visualization has been successfully applied in different situations, for example, design studies, movie's animations, video games, virtual reality scenes and many more. Considering the theme of this thesis, this topic be focusing on data representation for 3D models, techniques and technologies and provide a few examples of what's being done in the recent years.

2.2.2.1 Data Representation

The efficacy of representing complex information relies heavily on the nuances of data representation. In the realm of 3D environments, there are different ways to represent 3D models, each one with its advantages and use cases.

Point Cloud [49] is one of those ways, where discreet points are collected in the 3D space, defined by their coordinates. This type of representations lacks a predefined structured like the one found in geometric data, since these points are unorganized in sets that may not be explicitly connected to form surfaces or volumes. LiDAR cameras, like Leica RTC360, usually outputs a representation of what was captured in a point cloud fashion, as this format is one of the most used for 3D scanning and computer vision. This representation is particularly valuable when capturing and representing the detailed geometry of real-world objects, terrains and spaces, as they are versatile in applications like 3D modeling, reconstruction and analysis. In this thesis this type of data representation will be largely used, and it is necessary to do some post processing steps to work it it. This post-processing usually involves the following steps [34]:

- **Data Registration** – When it is necessary to combine data from different scans, multiple point clouds or scans are aligned into a common coordinates system;
- **Noise Removal** – In order to enhance accuracy and reliability of the point cloud, it is often necessary to eliminate noise points that may arise from sensor inaccuracies or environmental factors;
- **Downsampling** – Reduce the density of points in areas that don't require the amount of detail, without sacrificing the overall quality. This is often performed in large datasets.
- **Outlier Detection** – Identify and eliminate points that significantly deviate from the expected patterns.



(a) Points cloud. (b) Geometric data. (c) Volumetric data.

Figure 2.8: Visualizations of Points Cloud, Geometric Data and Volumetric Data.

- **Smoothing** – Apply filters or algorithms to smooth the point cloud surface, in order to reduce irregularities.
- **Colorization** – Assign color to points based on additional data sources, like images.
- **Surface Reconstruction** – Generate surfaces or meshes from the point cloud data, in order to create a more visually interpretable representation.

Geometric Data [3] is a different way of representing data, by representing shapes, surfaces and volumes formed by connecting points in a structured manner. Common examples include representations of 3D models using polygons, triangles or other geometric primitives. This kind of representation is frequently employed in computer-aided design (CAD), computer graphics and other engineering applications where a structured representation of shapes is important.

Another way to represent 3D environments is **Volumetric Data** [22]. In this type of data representation, information is distributed in a 3D space, often in the form of a 3D grid or voxel data, where each voxel contains information about the properties of the volume at that specific location. It has a continuous structure and often represents properties like density, temperature or other attributes within a volume, being visualized using techniques like volume rendering. In this process, the attributes of data are mapped to colors and opacities, creating a visually interpretable representation of the internal structures. It is often used in medical imaging (CT scans, MRI), simulating fluid dynamics in scientific research and analysing physical processes in engineering. Examples of visualizations of these data types can be seen in Figure 2.8.

2.2.2.2 Visualization Techniques

Having an understanding of how data is represented in the context of 3D environments, it is fundamental to be able to present that data to the user in the most appealing, useful and efficient way, always considering the purpose of the visualization. Therefore, many visualization techniques are used to transform raw data into meaningful representations.

(a) Ray-Tracing off. (b) Ray-Tracing on.

Figure 2.9: Comparison of the same scene in Cyberpunk 2077 with Ray-Tracing off and on. (*source:* https://www.youtube.com/watch?v=Xf2QCdScU6o).

One of the most basic forms of visualization is **Point Rendering** [25], where each point from the points cloud is individually displayed on the screen. There are no surfaces or planes, so the display of this data is pretty straightforward. However, when dealing with large or noisy datasets, some challenges arise in the form of processing complexity.

A different technique that is largely used it's **Rasterization** [21]. This rendering technique involves converting vector or geometric shapes into a raster image composed of pixels on a grid. In other words, rasterization involves projecting the vertices of 3D models onto a 2D plane, creating a set of 2D coordinates. These 2D coordinates are then used to determine which pixels on the screen are affected by the corresponding 3D geometry. Therefore it usually works with geometric data, like vertices, edges and faces, and not with point cloud representations. This technique is used for many purposes, such as real-time graphics, interactive applications and video games, where most of today's games use it [4]. One example of a video game that primarily uses rasterization for rendering graphics is Cyberpunk 2077[10], developed by CD Projekt and released in December 10, 2020. This game was highly anticipated for its ambitious visuals, and advancing visual effects, including **Ray Tracing** [62].

Ray Tracing is another visualization technique that is used to simulate the way light interacts with objects in a virtual environment. This sophisticated approach to rendering generates photo-realistic and high-quality images by simulating the physical behavior of light rays as they travel through a scene, delivering advanced lightning effects, reflections in wet surfaces and detailed global illumination. An example of the difference this technique brings to the visual aspect of games can be seen on Figure 2.9. This technique is been increasingly used in gaming and in the film industry, where in the latter it is a standard technique for rendering realistic CGI (computer-generated imagery). Ray tracing can be computationally demanding, specially when displaying complex scenes with many light interactions.

Cyberpunk 2077, as well as many other modern games that place the player in a broad open world also implement a technique called **Level of Detail** (LOD) [28]. This technique

[10]Cyberpunk 2077 (Last Access: 9/2024) -https://www.cyberpunk.net/pt/en/

varies the level of detail based on factors such as distance from the viewer, aims to enhance performance by reducing the complexity of distant objects.

2.3 User Experience and Interaction Design

In an increasingly digital world, the User Experience (UX) and Interaction design have become a foundation for the success of digital products and services. As technology develops and user expectations evolve, the need for well-designed, intuitive and engaging interfaces has never been more demanded. The User Experience design considers all the overall experience that users have when interacting with a system and encompasses a user's perceptions, emotions and responses to the given interface. On the other hand, the Interaction Design focuses on the development of the graphical and interactive elements that users interact with in digital interfaces to ensure intuitive and efficient user experiences [52].

This topic has its roots back to the early days of human-computer interaction and the emergence of graphical user interfaces. However, the term "user experience" got more focus when Donald Norman introduced this term on his book "The Design of Everyday Things", which was first published in 1988 under the title "The Psychology of Everyday Things". Jakob Nielsen's work on heuristic evaluation, defining a set of 10 usability heuristics also have contributed significantly for the definition of User Experience and Interaction guidelines [40].

User Experience and Interaction Design is fundamental to this thesis, since that in a given virtual museum or site of cultural heritage, it is crucial that the interaction between the user and the system is as smooth, engaging and easy to understand as possible, if the goal is to create an experience as close as possible to a real life museum experience. Therefore, it is relevant to study User Experience and Interaction Design to correctly build a rich and appealing system for the user.

2.3.1 Foundational Principles of UX and Interaction Design

From common practices widely recognized in the field of UX and Interaction Design, a few principles can be derived. These principles have been developed and refined over several decades by industry experts, researchers, and practitioners in the realm of human-computer interaction, usability, and user experience [17].

- **Usability** – A foundation of User Experience, the usability involves designing interfaces that are easy to use, efficient and free of errors. Key components such as learnability, efficiency, memorability, error prevention and user satisfaction make part of it. Usability testing is a common practice in the field, where designers observe user interacting with a system to identify and correct usability issues [42].

- **Affordance** – this refers to the perceived action possibilities of an object or interface element. A well-designed interface makes it clear how users should interact with it. For example, a clickable button affords the action of clicking. Understanding and utilizing affordances is crucial for creating intuitive interfaces [14].

- **Cognitive Load** – refers to the mental effort required to process information and make decisions. Minimizing cognitive load is a key principle in UX design. Simplifying complex tasks, providing clear instructions, and reducing distractions all contribute to a lower cognitive load and a more user-friendly experience [54].

- **User-Centered Design** – User-centered design (UCD) is an overarching philosophy in UX and Interaction Design. It emphasizes involving users throughout the design process, from initial research and prototyping to testing and iterative improvement. UCD ensures that products are tailored to meet the needs, preferences, and behaviors of the target audience [2].

Focusing on this last principle, User-Centered Design, an optimal approach can be derived when designing of new interfaces. This approach starts, as the term suggests, with a deep focus on the user part of the design. It is critical to get a better understanding of who the user is and how he thinks, in order to develop the best possible interface, so a user research is done in the very first phase. This methods include surveys, interviews, focus groups, and ethnographic studies. These techniques help designers gain a deep understanding of users, their behaviors, motivations, and pain points. The creation of user personas, which represent archetypal users, is a common outcome of user research. Characteristics such as age, gender and technological aptitude are established and together with other tasks to be performed and how often they will be performed, the designers will have a better understanding of who the user is and design the interface accordingly.

Based on this research, the designers will create initial concepts and prototypes, crucial for testing and defining ideas before investing extensive resources in development. These prototypes will allow the usability testing phase, which involves observing users as they interact with this prototypes and empirical measurements are taken. These measurements provide information about the user behavior, including user paths, engagement metrics, conversion rates, time to finalize tasks, errors and questions from the users. These tests must be performed with all the users expected to use the system, and those empirical measurements should always be taken. According to Jake Nielsen [41], early testing should be performed with at least five people, given that with such a sample dimension, it could be possible to find at least 75% of all usability issues.

Since the process to create a new interface is an interactive one, the measurements taken during user testing should be analysed and corrections to the interface must be made, and then the process should repeat with a new interaction of user testing for the updated design. When a stable version has been found, i.e, when the obtained measurements are

positive in regards to the user experience and interaction with the system, the process is over and the interface is complete if it matches all the established requirements.

For this thesis, this methodology should be applied when thinking about and designing the interface for a virtual museum or any interactive display of cultural heritage artifacts, as the user's experience and overall satisfaction, as well as the information transferal, will be depending on the quality of the implemented system's interface.

2.3.2 Cultural Heritage Exhibitions

The proper use of carefully designed interfaces that take in consideration UX and Interaction principles is of utmost importance in virtual exhibitions of Cultural Heritage artefacts or museums, since the overall satisfaction of the user will depend on how its experience with the system was and how the information was passed to him [30]. A very important factor to take in consideration, in case of a virtual museum tour, is the users movement. For an optimal experience, the user should be allowed to move through the space as he wishes, just like in a real life visit to a museum. For example in Google Arts & Culture virtual tours, the user could move by either pushing the WASD keys, the arrow keys or point and click with the mouse. However, the target location of those movements were only those where the 360° images were taken. That means that in those types of virtual environments, based on 360° imagery, the movement is usually limited to a few locations in the space.

However, in cases where the 3D imagery is done with scanners that can actually obtain a 3D model of the space, like Leica RTC360, it is possible to create a 3D virtual environment

Figure 2.10: Example of Google Arts & Culture's virtual tour – even though the user has the mouse where the arrow is, if the user click on the mouse to move he'll land where the X is. It is also visible the floor levels on the right of the screen, and the navigable points at the bottom.

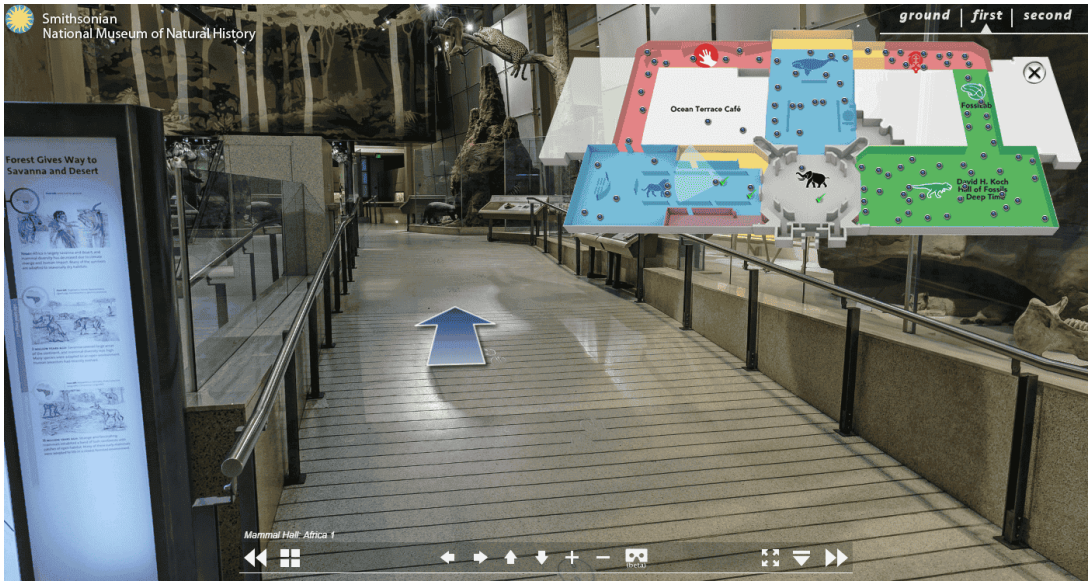


Figure 2.11: Smithsonian National Museum of National History - virtual tour interface.

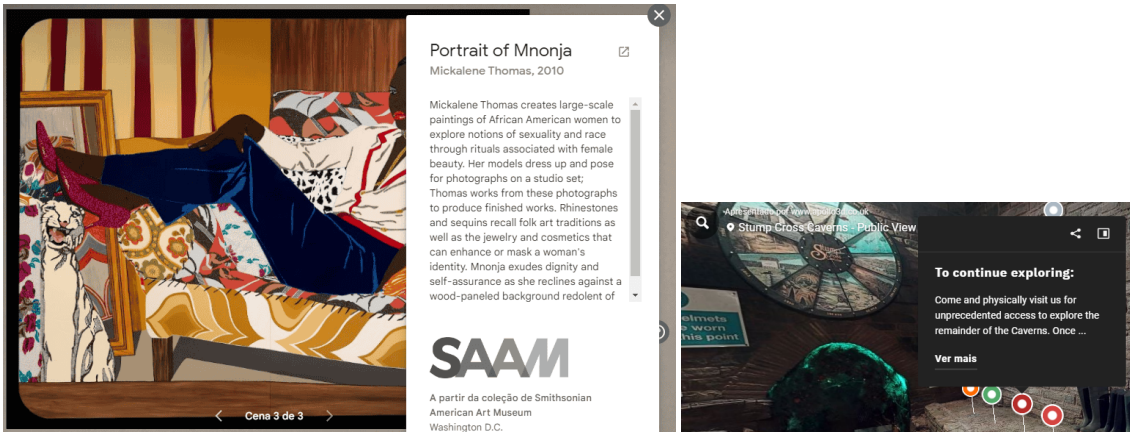
where the user moves around just like in a game. This creates a more fluid and realistic experience to user, by giving him the sensation of actually being able to move around the museum, just like if it was the real physical space.

On a broader view of movement through space, an important feature is to allow the user to move between the space without having to walk all the way. Either it be changing the position on the same floor, or between floors, it's crucial for the user's experience to be able to quickly teleport to another place in the space. On Google Arts & Culture virtual tour, the user can select the floor by clicking on buttons on the side of the screens indicating the floor level, and then quickly move to points in that same floor by choosing one of the snapshots at the bottom of the screen, as seen on Figure 2.10.

An interesting approach to this particularity is the one made at the Smithsonian National Museum of National History[11] virtual tour, as seen on Figure 2.11. On the right-top corner of the screen, there's a menu with the available floors and below it there's a plant of the space with some points marking where the user can click and teleport to. It also shows the current position of the user and where he's looking at. Such feature allows not only a better understanding of the space by the user, but also a more rich way of interacting with the space.

Another interesting feature to take in consideration is media visualization in the form of clickable tags. In some situations, the 3D imagery has enough quality to display some artefacts and sites, but sometimes it can be really difficult to real some labels or information that's displayed in the physical space, since by zooming on that text it can become blurry or too small, and then unreadable. A way to solve this issue is by integrating clickable annotations on every artefact that deserves a closer look at and its information in the virtual environment itself, and not be depending on the imagery gathered for the 3D

[11] Smithsonian National Museum of National (Last Access: 9/2024) - https://naturalhistory.si.edu/



(a) Google Arts & Culture tags. (b) Matterport tags.

Figure 2.12: Comparison of Google Arts & Culture tags display with Matterport's.

model. Google Arts & Culture has a special type of exhibitions called *Pocket Galleries*[12], where the user is taken into a 3D virtual environment of a specific gallery and, just like in the normal tour, move around the space, but can also click on a specific piece of art and a side pop-up will appear, showing some information about the object. It also contains a button that when clicked will send the user to a new page containing more detailed information about it. This type of annotation system is ideal, since the user can click on every object that exists in the tour and be presented with detailed information on request.

On Matterport, the user sees tags placed on top of surfaces or objects and by hoovering over it, the tag will open and a short description will be presented. Both Matterport's and Google Arts & Culture Pocket Gallerie's ways are effective in allowing the sharing of information throughout the tour while making it more interactive for the user. A comparison between the two tagging systems can be seen in Figure 2.12.

A different tag system can be seen on London's The National Gallery's[13] virtual tour. Here, the user can move around the space and click on a artwork, just like on Google Arts & Culture's Pocket Galleries, which will open up a panel next to the object in a way that it appears to be in three-dimensions, existing in the same space as where the user just clicked. This panel has the usual "Know more about" button which will send the user to a more detailed page about the artwork, but also has another two buttons with interesting features. The one with a "Play" button allows the user to listen to the text that it's in the panel describing the artwork. This is a useful feature that not only improves the accessibility of the tour, but also the way information is presented to the user. The middle button, with "3D" icon, will open another panel which will contain a 3D model of the artwork, making it possible for the user to rotate around the object and zoom on it, seeing it in more detail. Figure 2.13 presents these last two visualizations.

There are a few other new features that can be included in a museum virtual tour system,

[12]Google Arts & Culture: Pocket Gallery (Last Access: 9/2024) - https://artsandculture.google.com/project/pocket-gallery

[13] The National Gallery (Last Access: 9/2024) - https://www.nationalgallery.org.uk/

(a) Side panel (b) 3D Object Viewer

Figure 2.13: The National Gallery's virtual tour

that when done properly can augment the user's overall satisfaction of the experience. For example, in B. Gocket et al.'s presentation of VMUXE [24], there was an analysis about the Charterhouse's church of Villeneuve-lès-Avignon interactive 3D virtual museum, where the overall experience was evaluated by the proposed approach. In this virtual tour, there was an interesting feature where the user was presented with a slide bar at the bottom of the screen. This slide bar allowed the user to see the integration of the site's reconstruction over the current state of the church, which was captured by real cameras on the site. When the bar was at the left position, the user could only see the real picture taken at the

Figure 2.14: Charterhouse's church 3D virtual tour – the use of a slider to increasingly show a 3D reconstruction of the site over the picture of it's real state [24].

Figure 2.15: Google Arts & Culture Story - a different way to display exhibits and deliver information.

present time, and by sliding the bar to the right, the 3D reconstruction of the site would increasingly be overlaid, allowing the user to compare the differences between the past and the present (as seen in Figure 2.14).

Another interesting way of showing exhibits it's what Google Arts & Culture did with their Story[14] mode. The presentation is quite simple, consisting only on images and corresponding text descriptions. In the beginning, the user is displayed covering the entire screen and some text with the exhibit's title in the center. As the user scrolls down, a new image slides on top of the last one and some text appears next to it, telling a story and describing the image and may include audio support as well. This way of presenting content is different than the virtual tours through the space that has been the main focus of this topic, but it's simplicity comes with a more subtle way of delivering information and an engaging way to tell a story. Figure 2.15 shows an example of a presentation of a Story page.

The implementation of a good interface with interesting features in the scope of this thesis is very important as the satisfaction of the user will depend greatly on how well the User Experience and Interaction principles are applied.

2.4 Web Development and Design

Back in 1989, the English computer scientist Tim Berners-Lee invented the World Wide Web (WWW) [6], at CERN, with the goal of finding a better way to store, update and find documents and data files, as well as allowing outside collaborators to have access to them. During the 1990's, the WWW was as simple as possible, made of heavy-text and static pages. However, the introduction of the Mosaic browser in 1993 marked a

[14]Google Arts & Culture: A Walk Around the Park (Last Access: 9/2024) -: https://artsandculture.google.com/story/_AWhFCErxjMByw

significant leap, as it allowed for the integration of images with text, starting the shit from a purely text-based web to a more visually appealing and engaging experience [58]. A few years later, in 1995, Netscape introduced JavaScript, which revolutionized the dynamics of web pages by enabling client-side scripting. This new language allowed the developers to create dynamic pages with interactive elements, which contributed significantly to a greater development and growth of the web, propelling it into a new era. The final factor which contributed to the rise of the web to the state that is familiar nowadays was the creation of Cascading Style Sheets (CSS), in 1996. This last improvement provided a standardized way to control the visual presentation of web pages, by separating style from structure [11]. From there on, the development of technologies focused on creating web pages and apps has been growing and evolving, allowing the existence of around 1.13 billion websites on the internet in 2023[15].

2.4.1 Website Development

In an effort to improve the efficiency, scalability and maintainability of web applications, the separation of backend and frontend development is a fundamental paradigm that has been evolving over the years. This separation guarantees the need for clear distinctions between client-side and server-side functionality and responsibilities, allowing specialization of developers and a modularity of the system. Therefore, it is worth to dive into this technologies.

2.4.1.1 Frontend Technologies

A factor that contributed significantly for the rise of web development was the advancements in frontend technologies. The use of modern frameworks facilitate the creation of dynamic and responsive user interfaces, providing developers with efficient tools for building modern interactive web applications. As of 2023, the most popular frontend frameworks are ReactJS, Angular and Vue.js[16].

ReactJS[17] is an open-source library developed by Facebook that allows developers to make immense web-applications web apps using a component-based architecture. The tools provided by ReactJS to ease the process of building interfaces contribute for a better development of applications, as Rawat et al. states: "The brilliant thought of React moreover makes arranging UI reliable and takes a huge weight off from programmers so they could focus on more huge limits and business reasoning."[46].

Angular[18] is a open-source framework developed by Google. Just like ReactJS, it has a component-based architecture with internal state, but differs in the architecture by

[15] Forbes, Top Website Statistics for 2023 (Last Access: 9/2024) - https://www.forbes.com/advisor/business/software/website-statistics

[16] Imaginary Cloud, Top 10 best front end frameworks in 2023 (Last Access: 9/2024) - https://www.imaginarycloud.com/blog/best-frontend-frameworks

[17] React's website (Last Access: 9/2024) -https://react.dev

[18] Angular's website (Last Access: 9/2024) - https://angular.io

allowing changes with a model-view controller pattern[23].

Lastly,**Vue.js**[19] is a progressive JavaScript framework developed by Evan You, described as a flexible and approachable framework that allows developers to incrementally adopt its features[20].

A closer look at the these technologies' features as well as a comparison between them can be seen in the Appendix A.1.

2.4.1.2 Backend Technologies

On the backend, the rise of serverless architectures and microservices has reshaped the development of web applications. Server-side programming languages provide the foundation of building robust and scalable applications that handle server-side operations and management of databases. Although there are numerous available programming languages options, Node.js and PHP are two of the most used nowadays.

Node.js[20] is an open-source, cross-platform JavaScript runtime environment designed for server-side and network applications. Using Chrome V8 engine internally (developed by Google), compiles JavaScript code directly to native machine code for better performance.

Lastly, **PHP - Hypertext Preprocessor**[21] is a widely-used server-side scripting language designed for web development. Even though there are newer technologies around, PHP is still used by 76.5% of all websites W3Techs knows about[22].

More detailed information about these technologies and a comparison between them can be seen in the Appendix A.2.

2.4.2 3D Engines and Libraries

Given the topic of this thesis being the creation of a virtual tour in a website, it is crucial to find the junction between the previous topics regarding culture heritage 3D models and the topic at hands, Web Development. This can be done with the integration of 3D models viewers in a website, and to achieve that goal we'll look further into 3D Engines and Web Libraries that allow such implementation.

A Web Library deserved to be mentioned is **Three.js**[23], which is a popular JavaScript library that simplifies the creation of 3D content for web applications. It is open-source and widely used for building interactive 3D graphics and experiences that run directly in web browsers.which makes it ideal for creating 3D applications to run in browsers.

[19] Vue's website (Last Access: 9/2024) -https://vuejs.org/
[20] Node.js's website (Last Access: 9/2024) -https://nodejs.org/en
[21] Stack PHP's Website (Last Access: 9/2024) - https://www.php.net/
[22] W3Techs, Usage statistics of PHP for websites (Last Access: 9/2024) - https://w3techs.com/technologies/details/pl-php
[23] ThreeJS's Website (Last Access: 9/2024) - https://threejs.org/

Unity[24] is a powerful and widely used cross-platform game engine and development environment. It was created by Unity Technologies and was first released in 2005 as a Mac OS X game engine and has since become one of the most popular game engines globally, with a large and active community of developers. A very important feature about Unity to take into consideration it's its ability to export applications directly to WebGL. In the context of this thesis, this would mean that a user could create its 3D virtual environment of a cultural heritage site or a virtual museum tour and export it to be able to run in a web browser. Some factors, like size and performance limitations need to be taken into consideration, though.

Unreal Engine[25] is a very well known game engine, and was one of the first to ever be developed. Just like Unity, Unreal Engine supports a vast array of platforms, including Windows, macOS, Linux, Android, iOS, PlayStation, Xbox, Nintendo Switch and WebGL. This cross-platform capability allows developers to create games for various gaming consoles, PC, and mobile devices. In the context of preserving cultural heritage, this game engine remains a solid option for computer-based applications. Its visual scripting capabilities facilitate the delivery of engaging storytelling while ensuring the creation of visually pleasing and interactive environments. However, when it comes to building online platforms, this may not be the most suitable solution due to the absence of web application support, like WebGL. Nevertheless, the platform's documentation suggests that for the development of web-based games, users can and should adhere to mobile game development guidelines, as they impose similar restrictions to those found in web browsers.

PlayCanvas[26] is a popular web-based game development platform that allows developers to create 3D games, interactive experiences, and applications that can run directly in web browsers. It's designed to be user-friendly and accessible, making it an excellent choice for both beginners and experienced developers.

The last game engine worth mentioning is **Babylon.js**[27]. Babylon.js is entirely written in JavaScript, making it a suitable choice for web developers who are familiar with the language, and it can be used in conjunction with HTML and CSS to create interactive 3D web applications.

An overall view about these technologies can been seen in the Appendix A.3.

[24] Unity's Website (Last Access: 9/2024) -https://unity.com/pt
[25] Unreal Engine's Website (Last Access: 9/2024) - https://www.unrealengine.com/
[26] PlayCanvas's Website (Last Access: 9/2024) -https://playcanvas.com/
[27] Babylon.js's Website (Last Access: 9/2024) - https://www.babylonjs.com/

3

Analysis and Design

After studying the state of the art on topics related to this project, this chapter aims to provide a comprehensive analysis of the system's architecture and design. Section 3.1 presents the case study, detailing the context for this thesis and outlining the preliminary needs of the system. In Section 3.2, an analysis of the problem is complemented by the system requirements, with the methodology applied discussed in Section 3.3. Section 3.4 reviews the various stages of the solution's development, explaining how the functional requirements were progressively implemented using an Iterative Design methodology. Finally, Section 3.5 offers guidelines for creating a virtual museum tour website, derived from the research and experiences gained during the project's development.

3.1 The *Academia das Ciências de Lisboa* and its Museum

This thesis was developed in collaboration with the *Academia das Ciências de Lisboa*[1]. This Academy, founded in 1779, is one of the oldest national scientific institution in Portugal. Located in the center of Lisbon, this institute was dedicated to the advancement of knowledge and scholarship across a wide range of scientific matters and performed relevant activities of teaching until the end of the XIX century. Nowadays, it's key functions include the promotion of scientific research — by supporting research across various scientific disciplines, providing a platform for scientists to collaborate and share their findings —, organization of educational initiatives, recognition of excellence — by honoring outstanding contributions to science through various awards and distinctions —, and international collaboration.

The Academy of Sciences of Lisbon is a place rich in history, filled with spaces and cultural objects that are incredibly relevant and fascinating to the public. Of such places, one that stands out as central to the Academy's offerings is its extensive library, which can be seen in Figure 3.1, that holds a vast collection of rare books, ancient manuscripts and scientific journals from different centuries. This library is a critical resource for researchers and scholars, preserving the intellectual heritage of past generations. Among its

[1] *Academia das Ciências de Lisboa* website (Last Access: 9/2024) - https://www.acad-ciencias.pt/

Figure 3.1: *Academia das Ciências de Lisboa*'s library

holdings are works of Portuguese and international scientists, illustrating the progression of scientific thought and knowledge over time.

The Academy also features many exhibition rooms that display a diverse range of historical artifacts and scientific instruments. These artifacts, which include antique telescopes, microscopes, and other scientific tools, were used by scientists and teachers at the Academy and exemplify the evolution of scientific methods and practices. In addition to its scientific collections, the Academy's art showcase is of considerable cultural importance. It includes portraits of distinguished founders and intellectuals, as well as other artifacts related to science and art. These pieces not only enhance the Academy's interior but also honor individuals who have made significant contributions to science and culture. The art collection, together with the historical artifacts, books and manuscripts, positions the Academy as a vital repository of cultural and scientific heritage.

3.2 Problem Analysis and Requirements

The project involved the development of a platform featuring a virtual tour and dedicated pages to show the various spaces an cultural objects of the *Academia de Ciências de Lisboa* (ACL). The primary aim is to enhance public engagement with the Academy's rich historical and cultural heritage, making it accessible to a broader audience through a digital platform.

The development of this project was a collaborative effort involving key stakeholders from the Academy, including historians, professors and administrators, alongside external experts working in as a website designer and 3D modeler. The development of this project was supported by funding from *Caixa Geral de Depósitos* with its initiative *Programa Caixa Cultura*[2].

[2] *Programa Caixa Cultura* (Last Access: 9/2024) - https://www.cgd.pt/Institucional/Caixa-Cultura/Pages/Caixa-Cultura.aspx

In an early stage, multiple visits to Academy took place, in order to meet the Academy's team, gather the requirements to discuss initial ideas, as this project is being developed over a iterative design methodology. Those requirements were defined by the working team in this project, where the major stakeholders contributed to the requirements elicitation. Considering the main goal of this thesis, which is to create a digital platform to present cultural heritage documentation of the Academy, it is crucial to explicit the requirements of the end users that will interact with this platform.

The main and more general requirement is that it must be possible for any user to access the website through any web browser, by Internet, and explore it. Users must be allowed to navigate through the website, enroll on the virtual tours with 3D environments and access every page related with the rooms and artifacts of the Academy. It is fundamental that the user experience is as engaging and informative as possible, so User Experience and Interaction principles, discussed in Chapter 2.3, must be applied. For system administrators, i.e, curators and collaborators of the academy, it is required that they have access to an administrator panel where they can not only configure some aspects of the implemented virtual tours and general information of rooms and artifacts, but also create new content if necessary. Considering that this system will have a considerable amount of media, it is necessary that this system has the support of a database. This database will store media content that was created as this system was being developed, but also new media created by curators, as well as user's accounts and information.

Regarding more specific system requirements, it will be crucial that the website is deployed on a web server and be able to efficiently allow users to navigate on it and interact with it. The main requirement related with the implemented techniques and used technologies is that the end user, which will explore the virtual tours and access to 3D models and environments, must have a smooth and efficient experience, performance wise. The 3D models must be of the right size, and the technologies used to visualize these models must be appropriate to run in a web browser.

To consolidate the previous discussed general requirements and proposed features, a mind map presented in Figure 3.2 was developed. This mind map provides a general representation of the identified concepts and potential additional features to be implemented in this project.

3.3 Methodology

The methodology adopted for this project involved a systematic approach to gather requirements, develop prototypes, and iterate towards a final version of the website. The project started with initial meetings with the stakeholders from the Academy. These meetings were pivotal in identifying and defining the project's objectives, scope, and specific requirements.

Following the requirements elicitation phase, described in Section 3.2 and complemented in Section 3.4.1, the project moved into the prototyping stage. This early prototypes

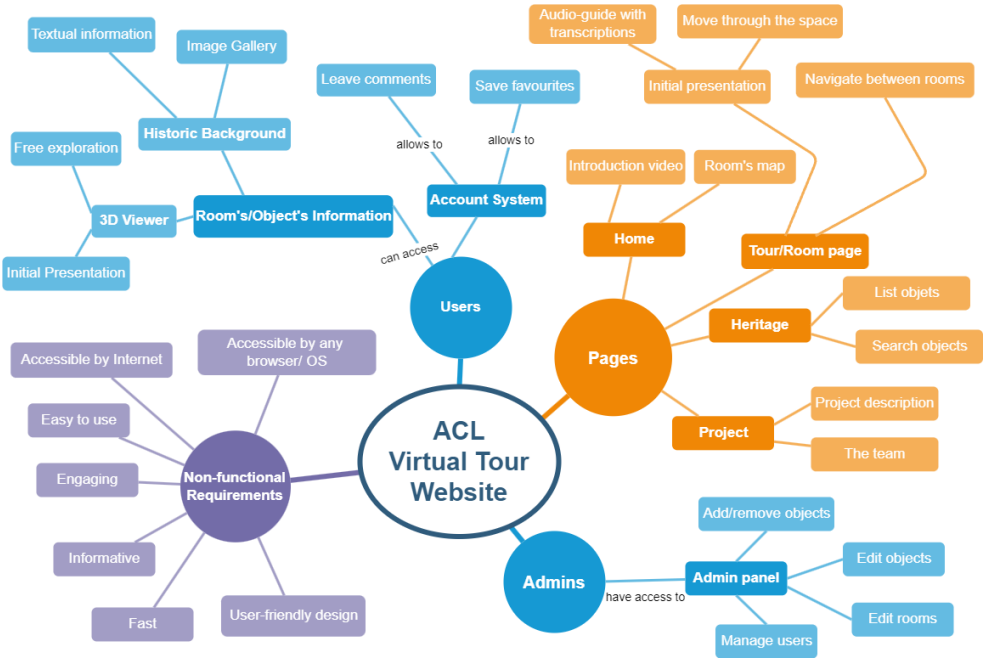


Figure 3.2: Mind map representing concepts, requirements and potential features of the system.

aimed to demonstrate the envisioned functionalities and user interface design based on the gathered requirements. Upon completion of the initial prototype, it was presented to stakeholders. Feedback from these presentations was collected and analyzed, and from there on the development process followed an **Iterative Design** approach as exemplified in Figure 3.3, where subsequent versions of the prototype were improved based on the feedback received. Every new iteration is described in Section 3.4, and each involved incorporating suggested improvements, solving identified issues and upgrades to the user experience and content presentation. Multiple cycles of prototype development, presentation, feedback collection, and refinement were conducted to ensure continuous improvement in order to achieve a final version that met stakeholder expectations and the project's requirements. The testing and evaluation phases can be interpreted as the demonstrations and informal testing of the prototypes to the Academy's stakeholders and their given feedback, considering that the actual testing phase only happened with the final version of the website, as described in Chapter 5.

3.4 Iterative Design Stages

In this section, we go into the the iterative design process approach to develop the website for the Academy. This processes allowed for continuous improvement and enhancement of the system based on stakeholder's feedback and evolving requirements. By systematically planning, prototyping, testing and presenting through multiple iterations, the goal was to create a final version that would meet the requirements and the stakeholders needs.

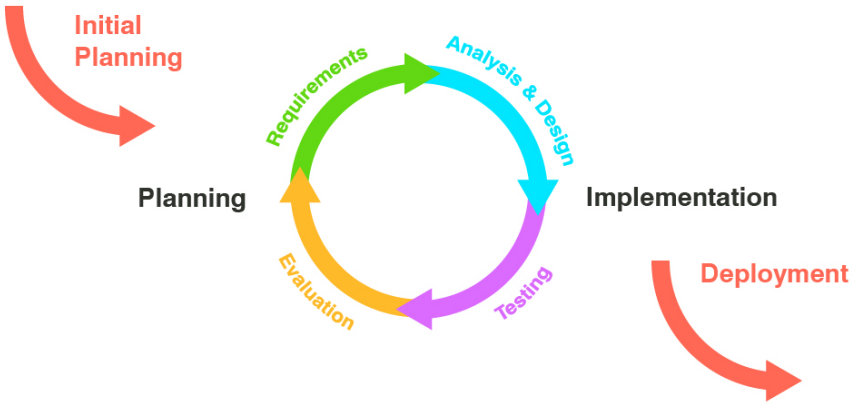


Figure 3.3: Iterative Design Approach.

3.4.1 Initial Planning

The development process began with a planning stage, where initial requirements were gathered through discussions with the Academy's staff involved in this project. During this phase, the following requirements were found:

- **Presentation of the Academy's rooms —** This digital platform should allow the presentation of the Academy's physical spaces. This should be composed of textual information about the room and a list of relevant cultural heritage objects that make part of it. Also, upon entering for the first time in a room's page, a presentation of the room with an audio guide should be available. Preferably, this should be done with the use of a 3D digital environment where the user moves automatically through different places of the room while listening to the audio guide, and where he can navigate through the space freely at the end of the presentation.
- **Presentation of the Academy's objects —** Some relevant objects should also be presented in the room's page it is associated with, with images and eventually a 3D viewer, for certain objects, where the user can explore at will, allowing features like rotating and zooming closely into the object.

To meet these requirements for the presentation of the Academy's spaces and objects, the next step involved acquiring the necessary data. The Academy had previously photographed some of their cultural heritage objects with an high-end camera, so that material was gathered, selected and associated to each of the presentation rooms of the Academy.

To create an interactive and detailed virtual representation of the Academy's spaces and objects, it was then necessary to proceed with the scanning of 3D models. This work was conducted during some visits to the Academy, where both rooms and objects were scanned. The selected rooms were scanned with Matterport Pro3 Camera, which, of many features, allows the upload of these 3D models to their online platform to be used in their built-it viewer, that can be embedded in other web pages. The next step consisted

in scanning some artifacts from the Academy that will be part of the platform, with two different 3D scanners: Artec Spider and Artec Leo (as seen in Figure 4.2). Both of them produce a very detailed 3D model of the scanned object, which usually require some post-processing work that can be done in Artec Studio – a 3D software that has useful modeling and processing tools to improve scanned models.

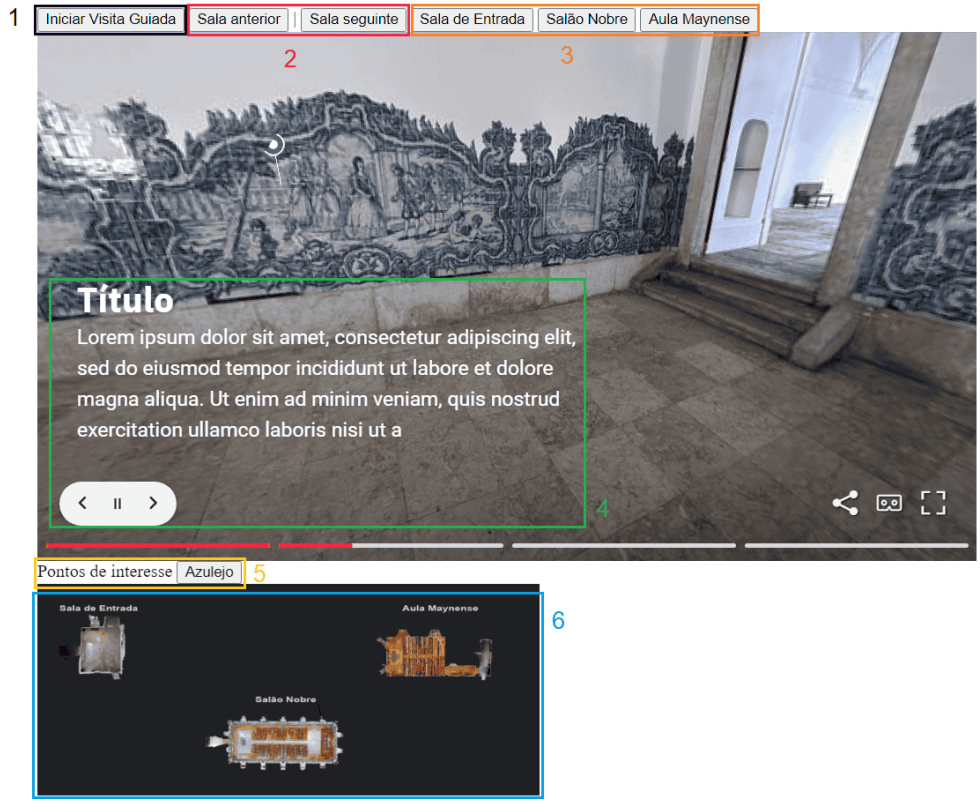
Having collected the essential media files and completed the 3D scanning of the Academy's spaces and objects, the next step was to begin developing the first prototype of the digital platform. This prototype served as a base version, enabling initial testing and feedback collection to guide further development and refinement. To develop this prototype, it was necessary to analyze the requirements and define what would be the functionalities of this system.

Considering that the main idea for this system is to create a virtual tour, some initial ideas arose:

- A **map**, or some sort of **itinerary**, would be useful to the user, so he can be aware of the existing rooms to visit. Clicking on any room of this map would open the presentation page of the selected space;
- The **room's presentation page** would contain a 3D viewer of the space, all the relevant information about the current room and a **list of cultural heritage objects** that belong to it. When entering this page, a presentation of the room should start, which shall move the user between interesting points in the space while an audio guide is playing. In the 3D viewer of Matterport, the tagging feature would also be used, which allowed the creation of tags/labels in certain positions of the 3D model where objects appeared and provide some additional information about them.
- The user should be able to **navigate between rooms**, which would have a predefined route that would start on the entrance of the Academy and go through all the available rooms.

(a) Scanning with Artec Spider. (b) Scanning with Artec Leo.

Figure 3.4: Object scanning with 3D scanners, performed at *Academia das Ciências de Lisboa*.



1 - "Start Guided Tour" button, starts the 3D viewer and the audio guide;
2 - Go to Previous/ Next room;
3 - Change to a specific room;
4 - Matterport's Guided Tour feature - presents some textual information;
5 - Go to specific points of interest in the current room;
6 - Plant view, where the user could click on a specific room to go to.

Figure 3.5: Experiment with a simple web page containing Matterport's viewer and some functionalities.

With the major functionalities identified from the requirements, the next step involved creating a simple prototype to demonstrate these core features. This prototype served as an initial proof of concept, which was presented to the Academy's stakeholders. This was done with a simple interface, consisting on the Matterport's viewer frame, a map of the available rooms and some buttons to control the tour. Upon entering a room, an audio file was played, simulating a guide's voice, and the Matterport's Guided Tour feature would start, going from point to point in the room while displaying some informative text. This experiment was useful to understand how the Matterport's viewer would work when changing between different rooms and to try Matterport's tagging feature, where we could personalize the content inside a tag that was placed on some point in the space. This prototype is presented in Figure 3.5.

By creating and presenting this initial prototype, it was possible to validate the core

functionalities and gather important feedback from the Academy's stakeholders. Following the presentation of the initial prototype, the development process entered an iterative phase. This involved multiple cycles of refinement based on feedback from stakeholders at the Academy. Each iteration aimed to enhance the platform's functionality, usability, and overall user experience.

3.4.2 Version 1.0

Change Log

ADDED

- Top navigational bar
- Home page
- Room's presentation page
- About us page
- Itinerary map
- Mute/unmute background music button
- Mute/unmute audio guide button
- Previous/next room buttons
- Itinerary map

The main goal for the first iteration was to develop a design that matched the Academy stakeholders' vision and requirements. The design of this website should be similar to the design of the main site of the Academy, which should reflect the Academy's prestigious and historical nature, by including a clean, elegant interface, matching the Academy's color pallet. A key aspect of the interface was that it should be intuitive and easy for any user.

At this stage, it was also important to define which pages would compose this website. Considering the needs of such a platform and aiming to keep the structure as simple and user-friendly as possible, the following pages were determined to be necessary:

- A **Home** page (Figure 3.6), where users would land upon entering the website. The main page is designed to immediately capture the user's attention with a visually appealing background image that reflects the essence of the Academy, so a photograph of one of the most impressive rooms of the Academy, the Noble Hall, was chosen. The presence of "Start" button, above the background image, directs users straight to the guided tour, ensuring an easy access to the main feature of the platform. Below the background image, an interactive itinerary map is provided, which allows users to jump directly to a specific room within the virtual tour, offering a quick and intuitive way to navigate the Academy's spaces.

Figure 3.6: Home page in version 1.0.

- The **room's presentation page** (Figure 3.7), which serves as the primary center for detailed exploration of each room within the Academy. It contains an embedded 3D viewer from Matterport that allows users to explore each room in detail, as well as an automatic room presentation upon entering the page. Accompanying the 3D viewer, textual descriptions offer historical and contextual information about the room. Below the textual information, a list of objects within the room is displayed. Users can click on these objects for more detailed information.

- An **About Us** page (Figure 3.8), that introduces the team behind the project and provides context about the initiative.

In every page, a navigation menu will be present, containing four links — *INÍCIO* redirects to the home page, *ROTEIRO* also goes to the home page but scrolls down to the itinerary map, *ACADEMIA* opens the Academy's main website, and *SOBRE NÓS* redirects to the About Us page.

The **room's presentation page** is where the major functionalities of this system are implemented. Upon entering this page, an automatic presentation of the room is started. The Matterport's Guided Tour functionality, available in the Matterport's online platform (seen in Figure 3.9), allows the creation of an overview of the room by positioning the user in different places of the space, while rotating the camera for a few seconds. It also allows

the insertion of textual information on each of this positions, which can be used to give additional information or to transcribe what the audio guide is saying.

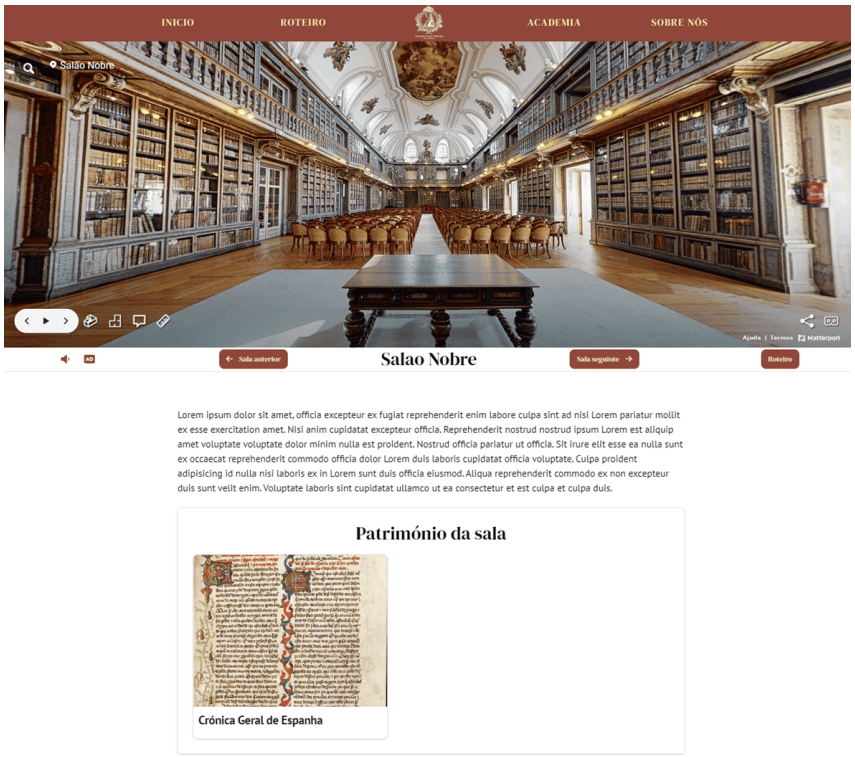


Figure 3.7: Room presentation page in version 1.0.

Figure 3.8: About Us page in version 1.0

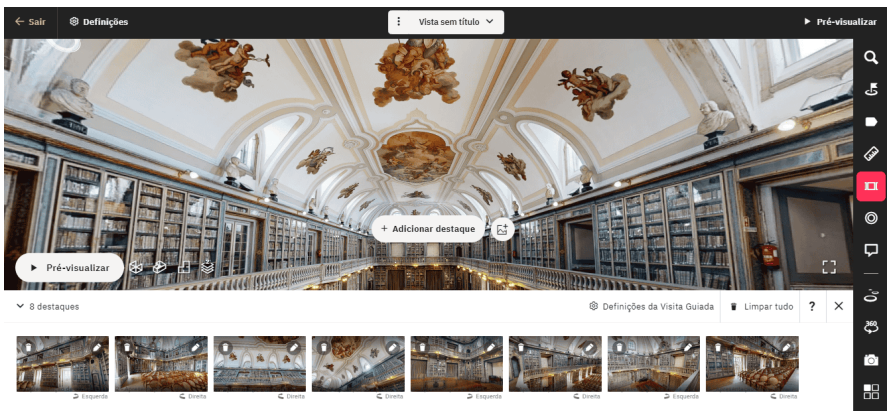


Figure 3.9: Matterport's Guided Tour editor interface.

In the virtual tour interface, users have several interactive options. A button allows users to start or stop the audio guide, and another provides the option to mute or unmute the background music. Two other different buttons allow them to go back to the previous room they visited, or take the user to the next room in the itinerary. On the right side of the panel there's the itinerary button, which will open a window containing the itinerary image and on which users can click in specific rooms to go to their information page.

Bellow the textual information of the space, there's also the list of items that belong to that room. When clicking on an item, a window will appear, containing textual information describing the object and some photographs of it.

Lastly, the **About Us** page is designed to provide information about the project and the team behind it. In the current version, this page serves as a placeholder, with basic details that will be expanded in future iterations.

The proposed design for the website, along with the main functionalities of the virtual tour, was presented to the stakeholders at the Academy. Based on the positive reception and constructive feedback, the stakeholders accepted the proposed design and main functionalities of the virtual tour. This approval marked a significant milestone in the project's development, allowing to proceed to other aspects and functionalities of the website while having a chosen design.

3.4.3 Version 2.0

Change Log

ADDED

- Introdution page before the first room of the museum, with and introductory video and instructions
- Final page after the last room of the museum, with a video expliciting the Academy's events

CHANGED

- Home page - changed the static picture to a background video
- New itinerary map image, with museum sub-level
- New improved scans of some rooms
- Mute/unmute audio guide button improved to reflect its current state

REMOVED

- Background music during the tour

The second iteration of the project introduced several new features and design corrections, aimed at enhancing the user experience and addressing feedback from the

initial prototype. These updates focused on improving the visual appeal, navigation, and usability of the virtual tour platform.

In the **home page**, instead of a static picture, it now features a dynamic background video. This video showcases various spaces of the Academy, providing a more engaging and immersive entry point for users. Right below it, a new and more detailed image of the itinerary was created. This image, which can be seen in Figure 3.10, now includes the rooms of the museum. When users click on the museum, the specific rooms within it appear next to the main image.

Another novelty occurs when the user starts the tour, by clicking in the "START" button that's centered in the background video of the home page. Instead of going straight to the first room of the itinerary, users are first directed to an **introduction page**. This page includes an introductory video that highlights several places within the Academy, setting the context for the tour. It aims to provide users a better notion of what's to come, while building some excitement and curiosity. Right below the introduction video, clear textual instructions are provided to guide users on how to navigate and use the virtual tour effectively, in an attempt to provide users all the information they need in order to properly navigate through the virtual tour and to better understand the available functionalities. Part of this new introduction page can be seen in Figure 3.11. A similar page also exists in the ending of the virtual tour, with an informative video about the Academy's events and initiatives and a goodbye message below it.

During the virtual tour, in the room's presentation page, some alterations and improvements were also made. In the feedback from the previous prototype presented to the Academy's stakeholders, there was a request to remove the background music that was playing while the audio guide was presenting the room, so that the user's attention would only be on the voice of the audio guide. Therefore, in this version, the **background music was removed** together with the button to toggle on and off. The button to control

(a) Normal view of the itinerary.

(b) After clicking in the "Museum", new rooms appear.

Figure 3.10: The improved itinerary map, incorporating the museum's rooms.

Figure 3.11: Introduction page to the virtual tour.

the audio guide was updated to include both an on and off icon, replacing the previous static volume button. This change improves the clarity and usability of the audio guide controls.

Finally, in this version some rooms were re-scanned to address issues of poor quality and reflections that were present in the initial scans. These improvements ensure a clearer and more accurate representation of the Academy's spaces. In Figure 3.12a it can be seen that in some angles of the Noble Entrance room there's a lot of brightness, so new scans were made that took in consideration the light that's coming into the room and the location of the scanner, as shown in Figure 3.12b.

(a) Poor quality scan, with too much brightness.

(b) Improved scan with better quality.

Figure 3.12: Comparison between scans of the Noble Entrance, in the version 2.0 improvements.

3.4.4 Version 3.0

Change Log

ADDED

- Save the current audio guide playing status when changing between rooms
- Automatic transition to the next room if no mouse movement occurs
- Creation of the object's information window

CHANGED

- New layout and font type of the navigational bar
- New improved video in the introduction page before the first room of the tour
- New audio guide voice for the portuguese voice-over
- Matterport's transcriptions synchronized with the audio guide
- Full restructure of the page Heritage

Following the acceptance of version 2.0 by the Academy's stakeholders, version 3.0 introduces several new features and enhancements aimed at further improving the user experience and functionality of the virtual tour platform.

In this new version, there was a request from the Academy stakeholders to change the top menu, so a **new navigation menu** was created. In this new version, that can be seen in Figure 3.13, the logo of the Academy appears on the left with the Academy's name right next to it. Then, the *ACADEMIA* link was removed and replaced with *PATRIMÓNIO*, which will open the page Heritage, that will display all the cultural heritage objects of the Academy. The typeface of the text was also changed to one that better matches the classical and formal nature of the Academy.

In the introduction page, the Academy's **presentation video** was improved. The previous video contained some shots that were poorly captured, had some light reflections or lower quality frames. Those shots were replaced, and some drone footage that captured aerial angles of different rooms in the Academy were added.

In the room's presentation pages that make part of the virtual tour is where most of the improvements were made. Starting with the **audio guide**, a famous Portuguese actress, Dalila Carmo, who's also involved in some works with the Academy, gave her voice to narrate the story about the rooms that make part of this virtual tour. The old recordings were replaced with her voice and this improvement made a significant difference in the

Figure 3.13: New navigation menu introduced in version 3.0.

Figure 3.14: Example of the audio guide transcription using the Matterport's feature.

environment created during the room's presentation.

Still in the topic of the room's presentation, the **transcriptions** provided by Matterport are now **synchronized** with the guide voice, ensuring that users can follow along with the audio guide more easily. What is being said in the audio guide is also being displayed in the 3D viewer, as can be seen in Figure 3.14. This feature enhances accessibility and user comprehension, as it helps users who might have hearing problems or simply prefer to not listen to the audio guide while the room's presentation is happening.

From the feedback that the Academy's stakeholders provided for the version 2.0 of this platform, one of the most needed improvements was regarding the **audio guide persistent playing**. In order to ensure a consistent user experience and to reduce the

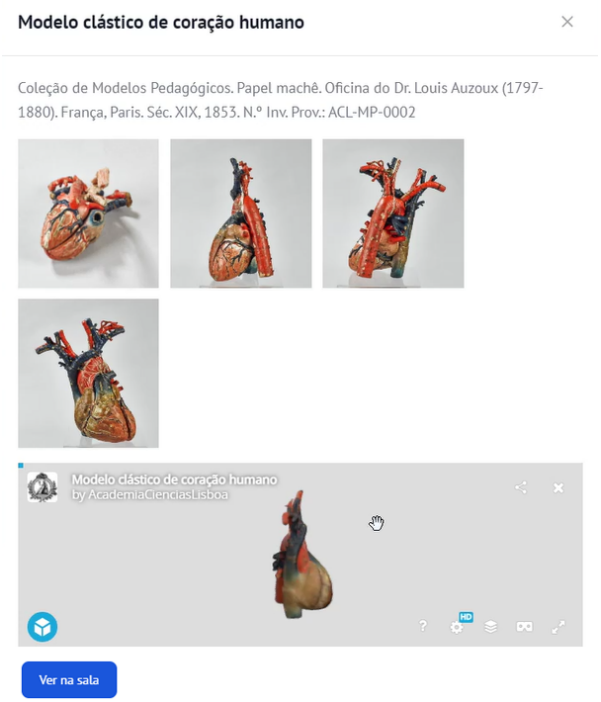


Figure 3.15: Object information's window.

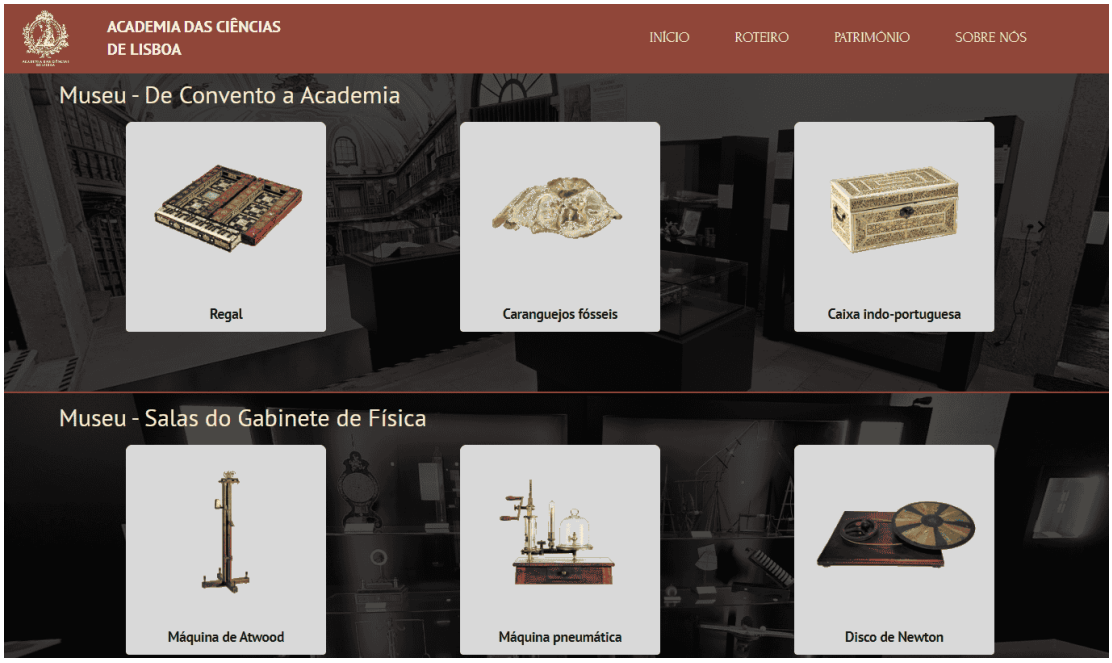


Figure 3.16: Heritage (*Património*) page, displaying all cultural objects.

need for repeated adjustments, in this new version if a user turns off the audio guide and changes to another room's presentation page, this choice is retained on the new page. This avoids the need to turn off the audio guide when entering a new room page, if that was the previously chosen setting.

A very wanted feature by the Academy's stakeholders was the **automatic transition to the next room** after the presentation of the current space. This would keep the tour moving and maintain user engagement, by keeping a continuous presentation of the Academy's spaces without the need for user interaction. Therefore, when a room's presentation is over, the "Next Room" button will show a countdown that will trigger the activation of this button when it reaches the end, if the user doesn't move his mouse meanwhile.

One of the biggest improvements in this version was the **objects information window**, that appears when clicking an object in the room's presentation page. This window (seen in Figure 3.15) contains textual information about the object — for example, it's origins and other relevant characteristics —, a gallery of high-quality images of this object and, eventually, a 3D viewer of the object's model, if it was one of the selected ones to be scanned previously. When clicking in one of the photos from the gallery, a very complete image viewer opens and allows the user to perform actions like zooming, rotation or start a slideshow. The objects that were chosen to be scanned and have their 3D model created will also appear in a viewer, provided by Sketchfab[3], that allows a complete exploration with features like zooming, view with virtual reality glasses, full-screen, among others. This window also contains a button "See in the room" that, when pressed, will move the camera in the room's 3D Matterport viewer straight to the selected object, facilitating the

[3]Sketchfab website (Last Access: 9/2024) - https://sketchfab.com/

discovery of this object in the space without the user having the need to search for it.

Lastly, a new page titled *Património* (available from the top navigation menu) was added, containing all the cultural objects from every room. Clicking on an object provides the same interactive features as in the rooms presentation page, offering detailed information and interactive viewing options in the object information's window. This page, which can partially be seen in Figure 3.16, aims to facilitate the user's search for cultural objects presented in this platform without having the need to go through every room's page.

3.4.5 Final Version

Change Log

ADDED

- Informative message at the end of the room's presentation
- Restart button that appears at the end of the room's presentation
- Creation of a pause menu during room's presentation
- "Play" button on the Matterport's 3D viewer, if the user refreshed the page
- Change the website's language feature
- Audio guide english voiceover using AI-generated voices
- Responsive layout for the mobile version

CHANGED

- Background color from white to sepia
- Itinerary switched places with the instructions section
- *ROTEIRO* button on the navigational bar goes to the new itinerary location
- Improved the quality of the first frames of Matterport viewer during the room's presentation
- Uniform background color and margins of object's images

REMOVED

- "Guided Tour Completed" message at the end of the room's presentation

With the version 3.0 of the website presented to the Academy stakeholders and approved, it was time to move to the last iteration of this process. The final version of the virtual tour platform represents the culmination of iterative improvements, feedback from every prototype presentation and refinement of the overall design and implemented features in order to deliver a ready-to-use product that matches the Academy's needs and wishes.

Starting with the overall website design and layout, the first change in this version was the switch from a **white background to sepia**. This alteration aligns the virtual tour

(a) Poor quality frame. (b) Improved quality frame.

Figure 3.17: Comparison between quality frames of the first position in the Guided Tour.

platform with the original website of the Academy, giving it a more classic and mature look that matches the nature of this institution. In terms of layout, the **itinerary**, initially placed on the home page, **switched places with the instructions section**, originally in the introduction page. So now, the home page has the original background video and, right below, the instructions of the virtual tour. This adjustment ensures that users receive essential information about navigating the tour right from the start. The introduction page, which appear when the user starts the virtual tour by clicking in the "BEGIN" button in the home page, now has the introduction video and the itinerary below it. This change allows users to access the itinerary directly before starting the tour. Additionally, the *ROTEIRO* button in the top navigation menu now redirects users to this updated itinerary section.

Significant improvements have also been made to the virtual tour itself. One of the complaints from the Academy stakeholders was right in the beginning of the room's presentation phase. This presentation, which involves the audio guide playing while the "camera" in Matterport's 3D viewer changes and rotates through different positions using Matterport's Guided Tour functionality, initially suffered from low quality and blurring issues. This problem was likely due to Matterport prioritizing the loading of subsequent frames over the initial position. Since the first camera's position coincided with the first point in the Guided Tour, there was not enough time for the viewer to load the initial frames properly. To address this, the initial position of the space was adjusted so that it did not coincide with the first presentation points. So now, when Matterport loads, the first position is somewhere in the space and the Guided Tour starts a few seconds after, changing the camera's position to the first point in the Guided Tour, giving it time to properly load the frames. This change ensures that Matterport loads the initial position properly, enhancing the visual quality from the start. A comparison of the different frame qualities can be seen in Figure 3.17.

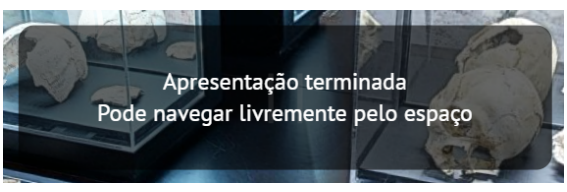
In the previous version, at the end of the room's presentation, using Matterport's

Figure 3.18: Misleading "End of Guided Tour" window that appeared at the end of the room's presentation.

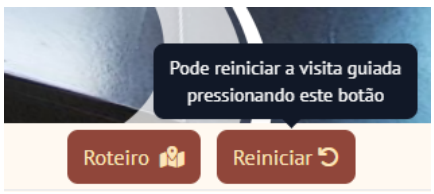
Guided Tour functionality, a window appeared displaying a misleading "Guided Tour Completed" message (which can be seen in Figure 3.18). This message confused users that were led to believe that the whole tour was over, when in fact it was just the current room's presentation. Since Matterport didn't have an option to disable that window, the only solution was to set the Guided Tour as a loop, going back to the first position when it reached the end and repeating the process, and only finishing the tour when the audio guide was over. The audio guide is coordinated to emit an event signaling the end of the tour, which will also triggers a function to end the Matterport's Guided Tour. Instead of the misleading message appearing, a simpler message stating "Space presentation ended. You can now walk freely in this space." appears. Additionally, a restart button also appears now in the tools bar below the 3D viewer, with a pop-up message saying that the user can use this button in order to restart the guided tour. This message and the restart button can be seen in Figure 3.19.

Moreover, in the previous version if the user clicked within the 3D viewer during the presentation, this would immediately stop the tour. This abrupt stop was not ideal, especially if users clicked by mistake, as he would need to restart the whole presentation. Therefore, having the possibility to just pause the presentation was introduced with a pause menu that appears upon clicking, allowing users to pause the presentation. Users can then choose to continue or stop the tour using the available buttons.

Another issue addressed in this version was the audio guide not playing automatically



(a) New message informing that the presentation is over.



(b) Guided Tour restart button with the pop-up message.

Figure 3.19: End of the tour message and restart button - new features of the final version.

(a) Pause menu of the room's presentation.

(b) "Play" button that appears when refreshing a room's presentation page.

Figure 3.20: Pause menu and "play" button - new features of the final version.

if the page was refreshed. This problem arose because most browsers require user interaction before playing any sounds automatically, to prevent spam. Now, when a user refreshes the page, a "play" button appears on top of the 3D viewer, directing the user to start the room's presentation manually. The pause menu and the "play" button features can be seen in Figure 3.20.

In response to issues related to the presentation of heritage objects, several improvements were made to enhance uniformity and visual appeal. All object images were uniformed by creating margins and cropping them to stay centered. The background color for these images was changed to one selected by the Academy's stakeholders from several provided options. This can be seen in Figure 3.21. Additionally, in the object presentation window, two arrow buttons were added to facilitate the transition between objects without the need to close the window and select another object manually.

Another major feature introduced was the implementation of a language switch between Portuguese and English, as the Academy expects that a considerable part of the website's visitors could be non-portuguese speakers. This required translating all textual information, including menu and button texts as well as descriptions of objects and rooms. The guided audio tracks also needed translation, so an AI-generated voice was created using ClipChamp[4]. Special attention was given to the phonetics of Portuguese words to ensure accurate pronunciation in English.

Figure 3.21: New design for the display of cultural heritage objects

[4]ClipChamp (Last Access: 9/2024) - https://clipchamp.com/en/

3.4.6 Final Interface

Having presented the changes that happened over the different iterations, the final version of the website's interface can be seen from Figures 3.23 to 3.29, with all its pages with captions describing the different implemented features. Figure 3.22 presents the website's map, which gives a general view of the website pages and major features.

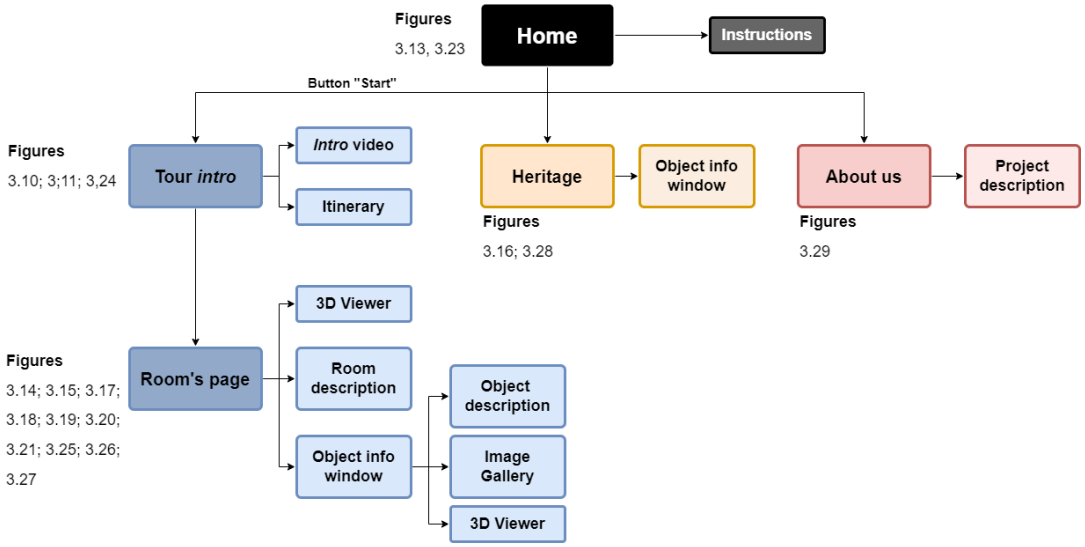


Figure 3.22: The website map, showing its pages and major features.

1 - Navigational bar
2 - Change website's language;
3 - Background video
4 - "Start tour" button
5 - Instructions

Figure 3.23: Final version of the Home page.

1 - Introduction video
2 - "Start Tour" button
3 - Itinerary (accessible by the navigation bar too)

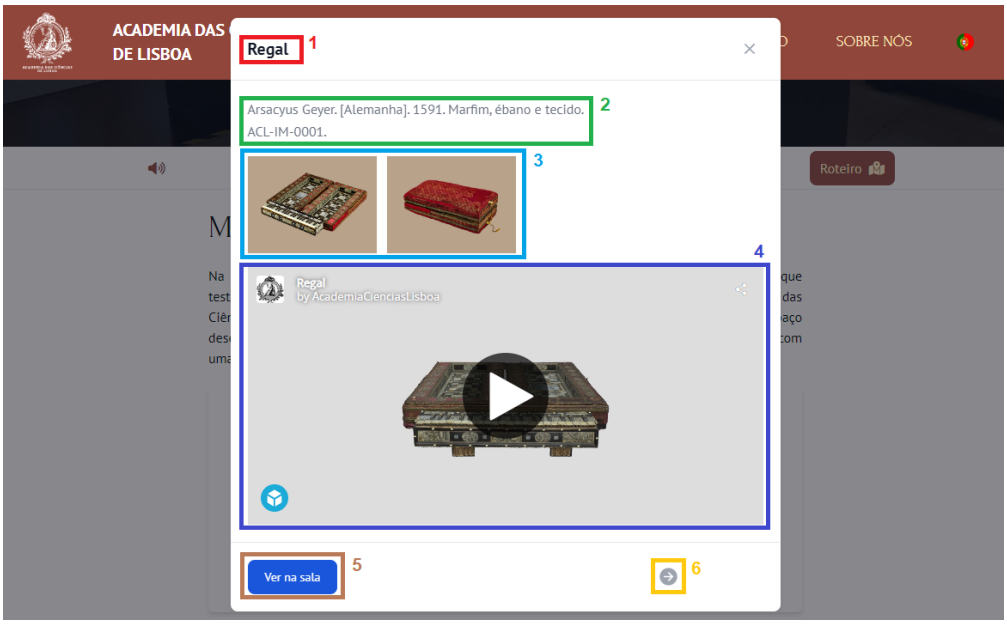
Figure 3.24: Final version of the tour introduction page.

1 - Matterport's 3D viewer
2 - Transcriptions of the audio guide
3 - Mute/unmute audio guide button
4 - Previous/Next room buttons
5 - Itinerary button

Figure 3.25: Final version of the room's presentation page.

1 - Room's description
2 - Heritage section

Figure 3.26: Final version of the room's presentation page (continuation).



1 - Object name
2 - Description
3 - Clickable image gallery
4 - Object's 3D viewer
5 - "See in the room" button
6 - "Previous/next object" buttons

Figure 3.27: Final version of the object's information window.

1 - Room's name
2 - List of objects

Figure 3.28: Final version of the Heritage page.

1 - Project's description
2 - List of stakeholder's and collaborators

Figure 3.29: Final version of the About Us page.

For this final version, the entire website was made responsive to ensure compatibility across various devices, including PCs, tablets, and smartphones. This enhancement guarantees that users can access and enjoy the virtual tour regardless of the device they use. Snapshots of pages in the mobile version can be seen in Figure 3.30.

(a) Home page. (b) Tour page.

Figure 3.30: Mobile version of the website.

One of the last implemented features was the creation of an **admin panel** that would allow the Academy staff to edit the content of the website. Therefore, in this version an administration panel was created (which can be seen in Figure 3.31), which allowed the following features:

- **Edit room's information** — The administrators are allowed to edit some information about the rooms, such as its names, descriptions (both in Portuguese and English), and add or remove objects.
- **Edit an object's information** — They can also change information of a specific object, like their title and description, and upload or remove photographs.
- **Add or remove users** — This administration system will have two types of users: a **superadmin** and a **normal admin**. Superadmins will have the power to remove or create new normal admins and to restore the system back to a previous state.

With the final result of the website ready and approved by the Academy, it was made public in the web, hosted in the Academy's server.

3.5 Guidelines for Creating a Website for a Museum's Virtual Tour

Creating a website for a virtual museum or virtual tour involves a proper planning process to ensure that the end product not only presents the museum's collection effectively but

(a) Edit room's information page (b) Edit object's information window

Figure 3.31: Administrator panel created for the final version

also provides and engaging and immersive experience for visiting users. This chapter outlines essential guidelines for developing such a website, gathered and elaborated from the work developed for this thesis' project. Each of the following guidelines play a crucial role in creating a logical and enriching virtual tour that reflect the essence of the physical museum and its nature, taking advantage of the current state of digital technology to enhance interactivity and accessibility.

3.5.1 Collaborative Work

One of the critical phases in any software development process is the analysis of requirements and the future presentation of prototypes, which involves a substantial collaboration between the development team and the client. Effective communication, clear presentations and and organized workflow are essential to ensure a smooth progress of the project. Based on the experience gained during this project's development, several key principles for a positive collaboration have been pointed:

Initial meetings – This step focuses on listening and fully understanding the client's problems and needs. It's crucial to get to know the company, the team and how they operate, while also beginning to gather requirements and desired functionalities for the project. At this stage, it's equally important to establish how the development team prefers to work — communication channels, frequency of meetings, etc. For example, if specific materials (such as media contents, text files, feedback on prototypes) are required to be sent by the client, clearly explain how they should be organized (e.g. avoid duplicates, categorize by certain criteria). The clients are often not familiar with the process required to ensure a smooth collaboration for this type of projects, specially when their area is quite different from software development, which was the case of the Academy's team. Therefore, establishing this work processes can prevent future problems. Additionally, as much as they need to understand how's the developer team workflow, it's necessary to understand how they prefer to work on specific situations, while trying to find common ground for both parties.

Set clear expectations – From the beginning, it's important to establish clear expectations on both sides regarding the project's features, deliverables and timelines. When it comes to ideas for development, it's good practice to listen to them all first, which helps setting the highest standard for they imagine, and if not everything is possible to develop, clearly explain why. Regarding deliveries and timelines, it's also fundamental that those expectations are defined from the beginning, taking into consideration the schedules of both sides.

Prototype presentation – Presenting prototypes is one of the most important phases. It's essential to go to the meeting with the presentation prepared on detail, considering what will be presented, in which order and at what pace. It's necessary to have notes on every design decision to justify when explaining why certain features work or others may need adjustments. As these meetings become more regular, insights into how the client's team operate are obtained naturally, which allows to structure the presentations accordingly. During these sessions, it is essential to take notes on the feedback provided. However, it's also a good practice to ask the client to document their feedback in writing, as this gives them more time to articulate their thoughts and explain their requirements more clearly.

Communication – Maintaining clear and open communication is vital for keeping all the stakeholders informed. From the beginning, define the communication channels and who's responsible for what on both teams. This ensures that everyone knows where to turn for specific updates or clarifications, preventing time loss due to miscommunication. Keep the communication concise and straight to the point, specially when dealing with feedback documents as these can be considerable long. Regular check-ins and status updates also help maintaining transparency and ensure that everyone is on the same page. When working with a multidisciplinary team - which was the case of this project as there were specific people for specific tasks, such as developers, designers, historians -, it's also important to establish who takes care of what, in order for the communication to be targeted to a specific responsible.

Collaborative work is essential to the success of any project and it's a skill that develops with experience. Each project comes with its own set of challenges, stakeholders and objectives, so what may work well in one situations might not apply in other. Therefore, it's important to approach every new project with flexibility and an open mind, being ready to adapt new strategies and communication methods as needed. The key principles outlined in this guide provide a solid foundation for any project development process.

Figure 3.32: Meaning and mood effects of colors.

3.5.2 Design

A website design refers to the process of **creating visual aesthetics and functional aspects of a website**. It encompasses various elements such as layout, color scheme, typography, graphics and overall user interface design. The goal of website design is to create a cohesive, engaging and user-friendly online experience that effectively communicates the website's purpose and content.

A fundamental aspect of the design it's the **color scheme**. The Academy's website color scheme came from its main website, and it leans more to a classical theme that reflects the Academy's nature, with warm colors being used the most. In Figure 3.32 it's shown the meaning of some colors and how they affect moods. Therefore, when choosing the color palette of a museum's website, one should ask himself what's the nature of the entity and what feelings and moods are the website's trying to evoke. Should it lean more to a classical, modern or arty theme? The chosen theme and color scheme should align with the answers to that question.

Another crucial part of a website's design it's related with **typography**. This is the art and technique of arranging type to make written language legible, readable and visually appealing when displayed. It involves selecting typefaces, point sizes, line lengths, line-spacing and letter-spacing, as well as adjusting the space between pairs of letters. A good typography ensures that text is easy to read and understand, reducing eye strain and creating a more pleasant reading experience. It contributes to the overall look and feel of a design, adding to the visual appeal and professionalism of the website, but also in evoking different emotions and setting the tone for the content.

The most relevant aspect of typography is the typeface, or fonts. They define the

Figure 3.33: Meaning of different font types.

form of the letters users see and, depending on the type, evoke different feelings. On the Academy website, two types of fonts were used. For titles and important buttons (such as the top navigation bar), a Serif font was chosen, as it conveys a sense of tradition, formality, and respectability. This font was selected for the most important elements on the website because those are the feelings we want to evoke in the user. For other textual elements, such as room descriptions and general text, a Sans Serif font was used, as it is more neutral, easy to read, and simple. Figure 3.33 shows the meaning behind different font types.

User Interface (UI) design also plays a crucial role in the overall effectiveness and appeal of a website. It encompasses the visual and interactive aspects that enable users to engage with the website's content and functionality in an easy way. The **layout and structure** ensures that users can navigate the website easily and find the information they need, and encompasses factors like white space — adequate spacing between elements to improve readability and focus — and visual hierarchy — strategically arranging elements to guide the user's attention to the most important parts of the page. An effective **navigation** is essential for user experience, making it easy for users to move through the website. Figure 3.34 illustrates different possibilities for a website's design, depending on the device it'll be shown in. **Consistency** in design elements such as colors, fonts and button styles creates a cohesive and professional look. The Academy's virtual tour website was developed considering these factors, with an attempt to keep the layout and structure as simple as possible, creating user-friendly navigational structure and keeping an overall consistency in the used elements.

Imagery also plays a crucial role in website design by enhancing visual appeal, communicating messages effectively and engaging users. High-quality images, illustrations

and graphics contribute to the overall visual appeal of a website, creating a positive first impression. Imagery should align with the brand's identity, reflecting its values, tone, and personality through color schemes and style. In the Academy's virtual tour website, there are 4 types of images being used:

- The **itinerary** consists of circles with borders matching the website's main color, a background image of the room, and the room's name above it. This design aims to resemble a map without showing the exact physical location of the rooms, for safety purposes.
- **Object's images** that were cropped, resized, and given a background that matches the website's theme, ensuring all images have a cohesive and consistent format.
- **Background images of rooms/spaces** on the Heritage page include their respective objects placed above them to provide context.
- **Entities logos** which were placed in the header, footer and About Us page.

When choosing imagery for a museum's virtual tour website, careful consideration is essential to ensure the images match the website's theme, provide necessary details and look professional. Additionally, images should be optimized for web use, ensuring fast load times and responsiveness across different devices. Figure 3.35 describes the most used image file extensions and some characteristics of each, when used in the web. In the Academy's website, the images of some objects are considerably large as they are very high detailed. However, in order to reduce client's payload, lower quality images are rendered in the objects showcase. Only when the user opens an object's information window these high-quality images are downloaded.

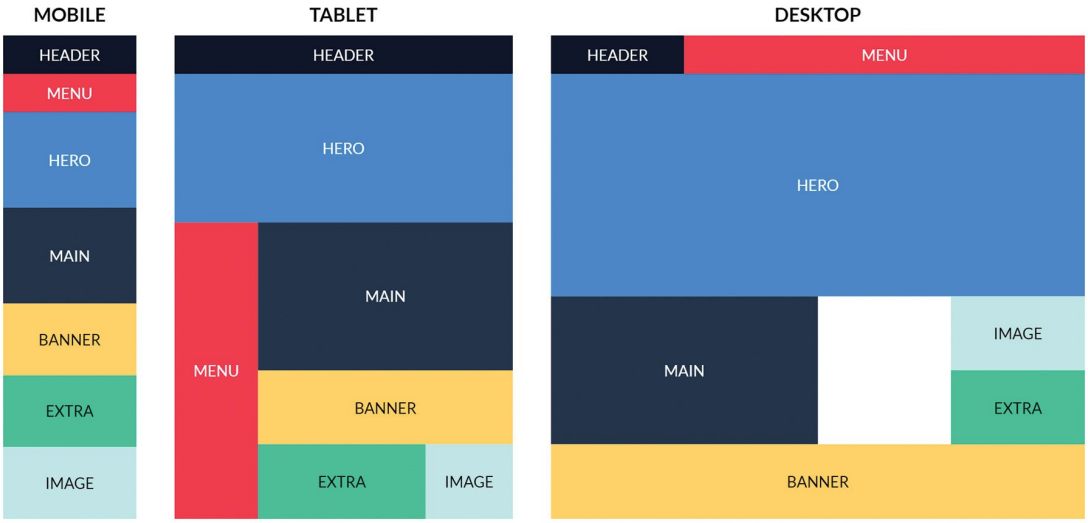


Figure 3.34: Options for different layouts, depending on the device.

3.5.3 Content

Content is the core of the virtual museum, dictating what the visitors will experience and how they will engage with the digital space. It is essential to curate a diverse and rich collection of materials that provide a comprehensive and immersive experience. In this section we'll examine different types of possible contents and how to present them in a website. Figure 3.36 summarizes a few of the ideas listed below.

The **physical spaces** of a museum are more than just buildings; they are often filled with history, reflected in their decorations, architectural details, and the overall ambiance. Capturing and conveying this rich atmosphere in a virtual environment is essential to providing an immersive and authentic experience for online visitors.

To replicate the feeling of being in these historic spaces, a website must contain high quality visual and interactive elements. Photographs can offer detailed views of different areas, highlighting certain details and decorations. Videos can show, in a dynamic way, the museum environment which can be enhanced with sound effects or music.

However, the most effective way to provide an immersive experience is through 3D environments. Using advanced 3D scanning technology, these environments can be created to allow users to navigate and explore the museum as if they were physically present. Visitors can move across rooms, observe exhibits from different points of view and experience the spatial relationships between different areas of the museum.

Showcasing **physical objects** its at the core of any museum. These objects can vary from paintings, sculptures or artifacts and it's crucial to find the best way to present them to the public. When it comes to showcasing **paintings** or other objects that only have one side, **high-quality images** with zooming options are usually sufficient. These images should be of the highest resolution possible to ensure that no detail is missed, allowing viewers to appreciate every stroke of the brush.

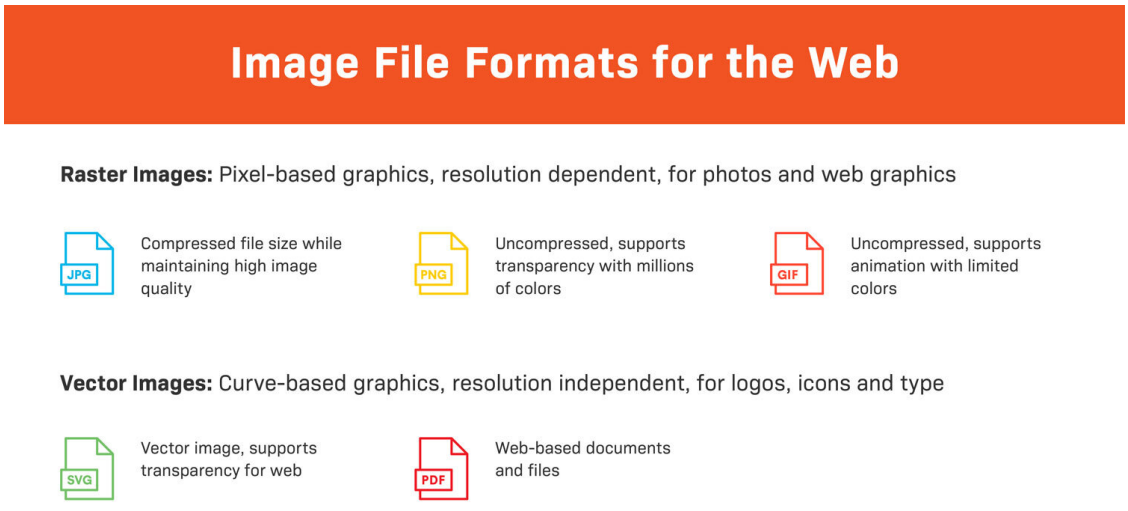


Figure 3.35: Image's file extensions and their characteristics.

However, for three-dimensional objects such as **sculptures or artifacts**, having more than just pictures is beneficial as these objects can be fully appreciated only when viewed from multiple angles. The use of 3D scans is an excellent solution for this, as they allow users to interact with the object and examine it from every perspective. By providing 3D models, visitors can rotate, zoom in, and explore these artifacts in a way that static images cannot replicate. This level of interaction helps to better understand the object's physical presence and details more effectively, offering a richer and more engaging viewing experience. This content can also be organized by theme or chronologically to guide the visitor through different periods or styles.

One of the most valuable relics in some museums are **books and manuscripts**. They offer a direct view into the past, with the power to communicate thoughts, stories and knowledge. Every detail in these documents, from the handwriting and illustrations to the type of paper and ink used, can provide invaluable information and deeper understanding of the historical context.

In a virtual museum, it is essential to present these relics in a way that allows visitors to fully appreciate its details. High-resolution digital versions should be provided and features like checking page-by-page with zooming functionality are usually very appreciated. Additionally, providing some contextual information together with these digital versions can improve the viewer's understanding of the work. This might include historical background, information about the author and the significance of the work within its historical context.

Including **other multimedia** elements can greatly enhance the immersive experience of a virtual museum. **Videos** showcasing some parts of the museum, complemented with a narrator and sound effects can trigger some excitement and curiosity on users to visit the virtual or the physical museum. **Interviews** with some of the museum collaborators,

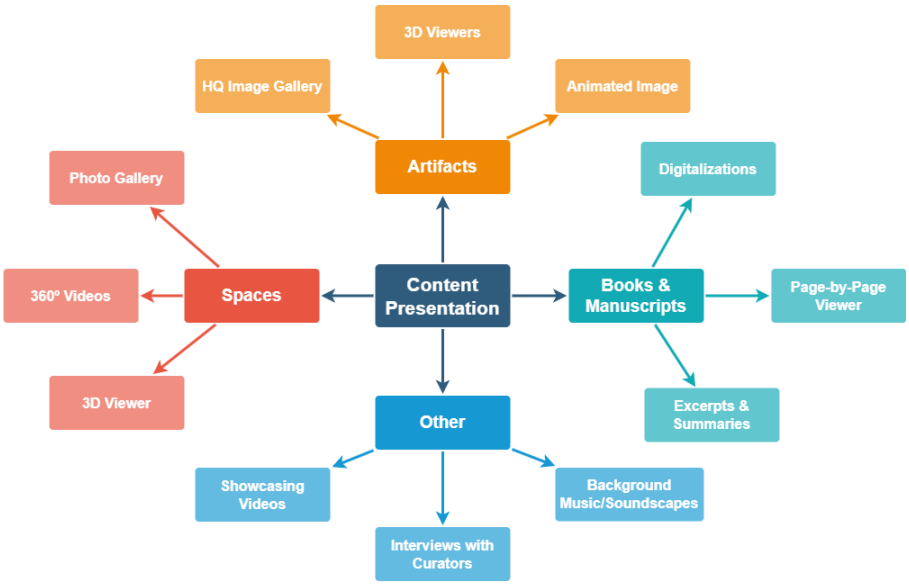


Figure 3.36: Different content presentation ideas.

like curators and historians, can give a deeper insight about some artifacts or the museum itself. **Audio guides** can provide a deeper insights into exhibits. **Background music or soundscapes** can also be used to set the mood and enhance the visitor's experience.

3.5.4 Functionalities

While content presentation is crucial for a museum's website, additional features significantly enhance user experience, engagement, accessibility, and overall functionality. These functionalities can vary from content presentation, viewer features, educational features, user engagement and others. For the Academy's virtual tour website, many features were given thought and consider to be implemented. Due to simplicity and time restrictive factors, only a few of them were implemented. Nonetheless, below it's a list of useful **general features** in a museum's virtual tour website:

- **User Registration and Login** — Enable users to create accounts, log in, and save their progress of seen artwork, favorite exhibits, and other information related with the user;
- **User Analytics** — Track user behavior and preferences to personalize the experience and suggest exhibits;
- **Search Functionality** — Allow users to search for specific exhibits, artists, themes or keywords;
- **Responsive Design** — Ensure that the website works on all types of devices;
- **Multilingual Support** — Offer content in multiple languages to allow visitors from all parts of the world;
- **Accessibility Features** — Features like text-to-speech, colorblind safe color schemes and high-contrast modes;
- **Contact Form and Support** — Provide a way for users to ask questions or report issues;
- **Newsletter** — Allow users to subscribe to updates about new exhibits or events;
- **Social Media Share** — Enable sharing of exhibits on social media platforms.

Content presentation is, as mentioned before, a the core of any virtual museum website. Although some of these features were previously mentioned, this section will recap interesting potential features:

- **High-Resolution Images** — Provide high-quality images of paintings, artifacts, and documents with zoom functionality. Allow easy sharing of these collections with share buttons that send links by email, social media or chat apps;

- **Timelines** — Allow users to access a timeline of the history of the room or object. Offer information about the artifact by year or era, complemented with images for each;
- **Then & Now** — For rooms or objects with historical records in photographic format, allow users to compare the past and present status of the item. One possible implementation is a slider that, when moved, overlays the new photo on top of the old one, showing the changes over time;
- **Detailed Descriptions** — Include comprehensive descriptions and historical context for each exhibit, such as information about the object's origin, materials, and conservation status;
- **Audio Guides** — Offer narrated guides that users can listen to while exploring exhibits. Use voices that match the tone for the type of content being displayed, as it strongly enhances the user's experience;
- **Video Showcases** — Include videos that provide an overview of the museum or specific exhibits, made by professionals;
- **3D Viewers** — Incorporate 3D viewers to showcase rooms, spaces or objects.

The use of **3D viewers** strongly enhances user's experience when visiting a virtual tour website. Besides common functionalities like navigating in the 3D space, a list of other interesting features to this main component is provided below:

- **Zoom and Pan** — Enable users to zoom in on specific details and pan around objects;
- **Annotations** — Incorporate interactive points that provide additional information about specific parts of an object. This can be achieved using labels similar to those used by Matterport, or by highlighting an item when the user hovers over it with the mouse. Annotations may include textual information, photographs, specific 3D viewers for objects, an audio guide dedicated to the object and sharing options. For paintings and similar artworks, annotations can focus on specific parts of the piece, complemented with expert insights on its meaning or the technical skills employed in its creation;
- **Lightning Controls** — Enable users to adjust lighting to see how objects look under different conditions;
- **AR/VR Integration** — Offer augmented reality (AR) and virtual reality (VR) experiences for more immersive viewing;
- **Comparison Tools** — Allow users to compare different objects side-by-side. This can be done either inside the 3D viewer or as an external component that appears somewhere in the information page of the space or object;

- **Map** — While users navigate the 3D environment, a map can display their current location within the space, their current viewing direction and nearby objects labeled accordingly. Users can interact with the map by clicking on specific areas to navigate directly to those locations. Additionally, a floor plan may be included to illustrate different levels or floors within the space;

- **Wayfind Assistance** — Provide virtual paths and guides to help users explore the museum, going to predefined paths of an exhibit, for example.

Educational features are an interesting possibility to be integrated into online museums as they serve to enrich visitors' understanding of the content being exhibit. Incorporating games into virtual tours can enhance information retention, because when users engage actively through quizzes, challenges, or interactive activities related to the exhibits, they tend to retain information better. This active participation not only makes the experience more enjoyable but also reinforces learning by encouraging users to apply the knowledge gained during the tour. Here goes a list of possible educational features to be implemented in a virtual museum website:

- **Live Virtual Tour with a Guide** — The museum can organize live sessions with a real guide who navigates through the space and provides a live presentation. Users can participate by watching the guide's stream and engaging with the content and asking questions in real time;

- **Quizzes and Games** — Including interactive quizzes and educational games related to the exhibits. These activities can be integrated into the virtual tour experience or hosted on an external page. For instance, after exploring a room and its objects, a quiz can appear in a separate window where users can answer questions to earn points and awards, which are then saved to their profile;

- **Dedicated pages to exhibits** — In addition to information pages for specific rooms and objects, the museum can create dedicated pages for temporary exhibits it hosts. These pages can also be organized around specific themes within its collection, providing a deeper exploration and context for visitors.

Allowing users to engage with a website can significantly enhance their experience and benefits others, too. By providing a feature for users to give feedback about exhibits, museums give visitors a chance to gain a better understanding of the content as other users can give their insights and share knowledge about a certain object. Allowing a sense of community within a virtual tour or museum website also contributes positively to the experience, because when users feel connected to a community of fellow enthusiasts, scholars, and learners, it creates a richer environment for sharing insights, discussing exhibits, and exchanging ideas. Here are some ideas for **user engagement** features.

- **Reviews and Ratings** — Allow users to leave reviews, comments and ratings about exhibitions. This can be moderated by the museum's staff to avoid misuse;
- **Discussion Forum** — Provide a space for users to discuss exhibits and share insights;

Administrative features are crucial for the effective management and operation of virtual museums and tour websites, as they enable museum administrators and curators to maintain and enhance the digital experience for visitors while efficiently managing the museum's resources and content. Below is a list of interesting features for administrative work.

- **Content Management System** — Provide an easy-to-use administrative panel for updating content and exhibits.
- **User Management** — Create tools for managing user accounts and permissions. This can involve creating new admin accounts, delete or modify user accounts, delete comments or reviews of users.

3.5.5 Technical Considerations

When developing a virtual museum platform, it's important to have in mind some technical considerations to ensure optimal performance, user experience and long-term sustainability. One of the biggest factors to consider is **performance**. Dealing with heavy content, such as high-resolution images, 3D content and multimedia elements, can lead to slow loading times that results in an negative user experience, therefore one of the primary technical goals is to optimize the website to ensure fast loading times. A strategy used in the development of the Academy's virtual tour platform is the use of thumbnail images to represent the larger images of objects, which are downloaded when objects are being displayed in the gallery, and only when the user clicks on an object, the bigger images are downloaded. The use of Matterport's 3D Viewer helped dealing with the 3D models of rooms, as this viewer is already optimized to efficiently download and run the room's 3D model. For 3D models of the objects, Sketchfab was used, which also has a 3D viewer that can be embedded in an HTML page. However, before uploading the model to Sketchfab, some post-processing had to be done, such as cleaning, mesh refinement and lowering the polygon count.

Another aspect to take in consideration is **security**. Implementing robust security measures is essential to protect user data and the integrity of the website. This includes employing HTTPS encryption, secure authentication mechanisms and user privacy that follow data protection regulations.

Scalability should also be one concern. Designing the website with scalability in mind ensures it can accommodate increased traffic and content growth over time. So, if a website is expected to grow over time, factors such as database scalability and traffic load need to be considered when developing such a system.

4

Implementation

This chapter will focus on the implementation of the project, outlining the development process and providing a detailed description of how the website was created, with each major feature and functionality technically described.

The chapter begins with an overview of the chosen tools and technologies in Section 4.1, highlighting their relevance and advantages for the project. Following this, the system's architecture will be presented in Section 4.2, providing a general overview of the structure and components of the system. Subsequently, the major functionalities are categorized into their part in the system and described in the next sections of this chapter. Finally, this chapter will detail the implementation steps for creating the backend, as described in Section 4.9. This will include a discussion of the key processes involved in backend development, including its implementation and the necessary changes applied in the existing system to accommodate it.

4.1 Development Tools and Technologies

The development of the virtual tour platform involved the use of various tools and technologies to ensure an efficient, interactive and user-friendly experience, to ensure an optimal end result that aligned with the requirements exposed in Chapter 3. Most of these technologies were previously discussed in Chapter 2, where a research to find the state of the art about the topics associated with this dissertation was conducted.

Starting with the 3D scanning technologies, **Matterport Pro3 Camera**[1] was chosen for the scanning of the Academy's rooms and spaces, to generating 3D models. These models formed the basis of the virtual tour experience, together with other Matterport functionalities — such as object's labeling and Guided Tour. Leica RTC360 was considered to be used, but this scanner is more suitable for precise measurements with a millimeter level of accuracy, while the Pro3 Camera is more appropriate for creating immersive 3D tours with just the necessary level of accuracy. For acquiring 3D models of the Academy's

[1] Matterport Pro3 Camera website (Last Access: 9/2024) https://matterport.com/pro3

cultural heritage objects, the scanners **Artec Space Spider**[2] and **Artec Leo**[3] were used. Artec Spider is designed for capturing intricate details and small object, therefore it was essential to scan some of the smaller objects of the Academy's heritage collection. On the other hand, Artec Leo is mostly used because of its ability to scan large objects quickly, so larger artifacts of the Academy's collection were scanned with it. These models were post-processed using the software **Artec Studio**[4], design to work with Artec's line of 3D scanners, providing a set of tools for capturing, editing and exporting high-quality 3D models. When the final models were obtained, they were uploaded to **Sketchfab**[5], an online platform for sharing, displaying and exploring 3D models, with many other features. Sketchfab allows the use of its 3D viewer, with different sort of interesting features, in external web pages by embedding it with HTML code.

Regarding the frontend development of the website, the chosen tool was **Vue.js**[6], because of past experience using this framework. Also, as discussed in Appendix A.1, React.js could have been used, as it is one of the most well known technologies for frontend development, but Vue.js's performance seems slightly better in some cases. Another tool that helped in the development of the frontend was **Tailwind CSS**[7]. This CSS framework is designed to enable developers to build custom user interfaces quickly and efficiently. It provides a set of low-level utility classes that can be combined to construct any design directly in HTML code, making it easier to use.

Lastly, for backend development, the chosen technology was **Node.js**[8]. This technology is one of the most used for developing backend systems and optimal for high performance applications. PHP was also considered, but discarded due to personal preference, considering my past experience using Node.js.

4.2 System Architecture

This section presents the general architecture of the system, in its final version presented Section 3.4.5. This architecture follows a client-server pattern, where the content available to the end users is in the frontend (client side), separating some system functionalities and database access which is defined in the backend (server side). In order to retrieve information, the client side fetches the data from the backend with API calls. This architecture is depicted in Figure 4.1.

The system has 3 types of users: the end user, normal administrators and super administrators. The **end users** will have access to visualization pages of the Academy's

[2] Artec Space Spider website (Last Access: 9/2024) - https://www.artec3d.com/portable-3d-scanners/artec-spider
[3] Artec Leo website (Last Access: 9/2024) - https://www.artec3d.com/portable-3d-scanners/artec-leo
[4] Artec Studio website (Last Access: 9/2024) - https://www.artec3d.com/3d-software/artec-studio
[5] Sketchfab website (Last Access: 9/2024) - https://sketchfab.com/
[6] Vue.js website (Last Access: 9/2024) - https://vuejs.org/
[7] Tailwind CSS website (Last Access: 9/2024) - https://tailwindcss.com/
[8] Node.js website (Last Access: 9/2024) - https://nodejs.org/pt

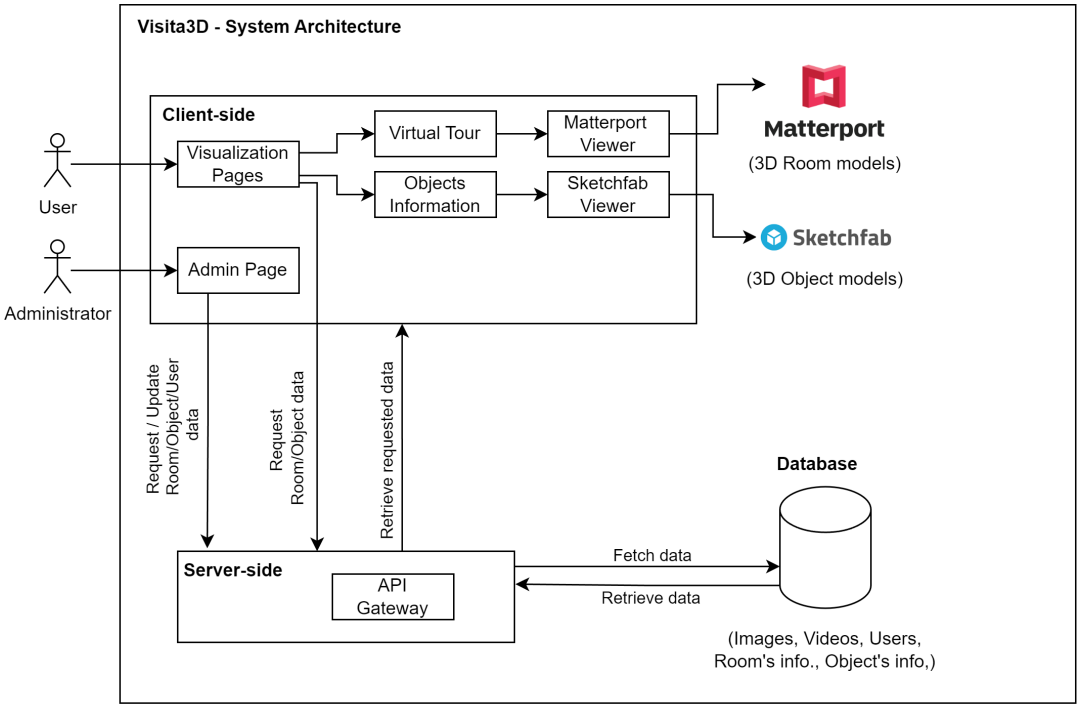


Figure 4.1: System's architecture.

rooms and objects. The necessary information of the **rooms** are stored in the system's database — where textual information about the rooms, such as it's name and description are saved — and in the Matterport's digital platform — where the room's 3D model is found. Regarding the **objects**, their information is also stored in the database — such has it's name, descriptions and images — and, for objects with 3D models, those are available in Sketchfab's system.

The system **administrators** will have access to the administration panel. Both normal and super administrators can modify the content of the database, such as room's and object's information. However, only super administrators can manage administrator accounts, being able to edit its information, create and delete other accounts. The latter can also roll back the system to a previous stage, in case something wrong happened during an update to the database content.

4.3 Room Scans with Matterport

As mentioned in Section 3.4.1, the initial stage of the development started with scanning the Academy's rooms and spaces that would be part of this virtual tour, with Matterport Pro3 Camera.

In order to provide a consistent gap between positions and to get complete coverage and optimal image quality, the scanning process requires the **camera to be positioned systematically across the room**, in a **grid-like pattern**. In Figure 4.2a, the camera is located in one of the positions and everyone present in the room must be hidden. For

(a) Scanning a room, with Matterport Pro3 in the background, inside the circle.

(b) The Matterport Pro3 Camera.

Figure 4.2: Scanning a room with Matterport Pro3.

every room, multiple scans were necessary to capture the entire space accurately. Before beginning the scanning process, Matterport provides two digitalization options:

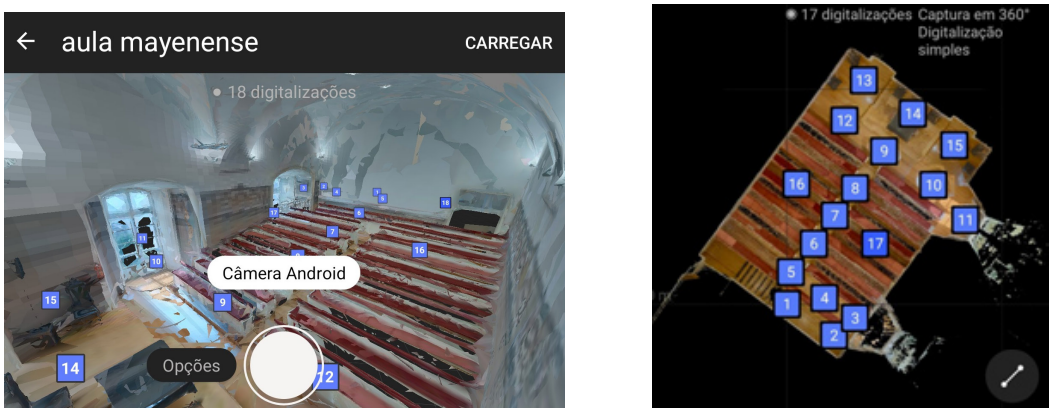
- **3D Digitalization** — This option captures depth data to create a 3D model of the space;
- **360º Capture** — In addition to capturing depth data, this option includes a 360º image, providing a more detailed and immersive view.

For this project, the **360º Capture** option was selected, as it offers images and texture, as it was necessary to present the model with realism.

The Matterport Pro3 Camera requires an external device connection for operation. During the scans, both an iPad and a Samsung Galaxy S24 were used on different occasions to manage the camera and proceed with the scanning, using Matterport's app (seen in Figure 4.3). After completing the scans of a room, the generated model was uploaded to the Matterport platform. This platform offers various customization and configuration options the enhance the presentation of the space.

4.3.1 Initial Viewpoint

One of the configuration options utilized was selecting and **initial viewpoint**. This point is crucial as it sets the first impression, displaying the room's essence when the model is opened. This initial frame is chosen carefully to capture the most representative and visually pleasing aspects of the room.



(a) First-person free view.

(b) Sky view.

Figure 4.3: Matterport's app interface, with the scan of the Academy's *Aula Maynense* room.

4.3.2 Guided Tour

The next step involved creating a room presentation using Matterport's **Guided Tour** functionality. This feature allows the selection of specific scan positions, where the camera will move automatically between and rotate for a chosen amount of degrees. The choice of positions focused on capturing the best views, avoiding irrelevant or less visually appealing angles. Matterport offers three presentation options for the Guided Tour:

- **Highlight Reel** — This option displays thumbnail images of selected positions below the viewer, allowing users to jump to a specific point by clicking on them, or letting the tour automatically go through every point;
- **Guided Tour with History** — Similar to the Highlight Reel, but includes textual information for each position that appears on the bottom of the viewer. This option was initially chosen for the platform, but due to limitations in character count and the use of italics led to the feature being disabled and implemented manually.
- **None** — In this mode, the presentation automatically transitions between positions without allowing users to select points. This was chosen for the final version of the website, as separate a transcription feature was created.

4.3.3 Object Labeling

The final customization step involved using Matterport's **Object Labeling** feature. This allows for the creation of visual labels in the 3D viewer, attached to specific objects within the space. Clicking on a label opens a window with more detailed information about the project, such as a title, description, attached multimedia (images and/or videos) and other embedding — for objects with a 3D scan, the Sketchfab's viewer with the corresponding object model was embedded in this setting. To maintain visual coherence, the labels' color was chosen to match the site's primary color. The editing panel can be seen in Figure 4.4.

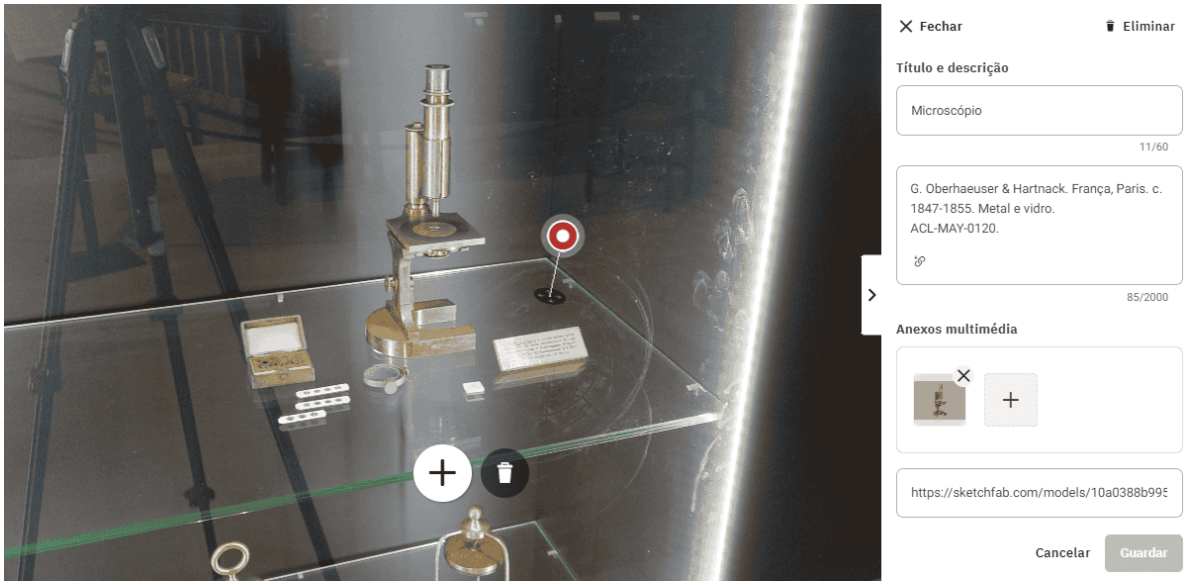


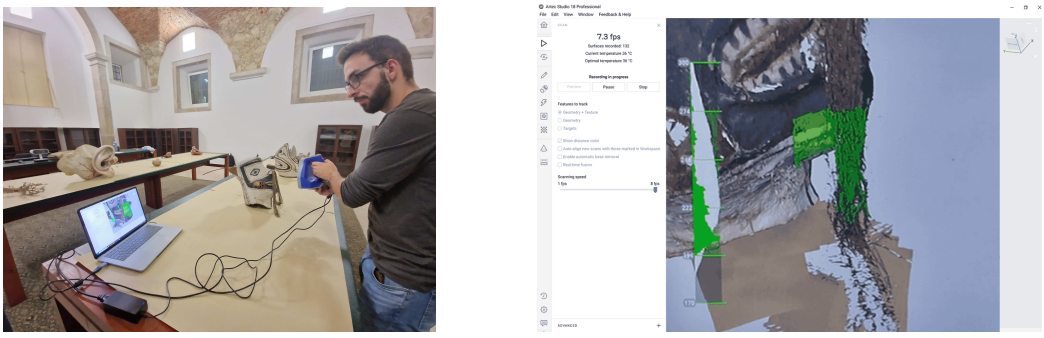
Figure 4.4: Editing an object's label in Matterport online platform.

4.4 Object Scans with Artec Scanners

The Academy's objects were scanned using two different types of 3D Scanners: the Artec Space Spider and the Artec Leo. Each scanner has its own capabilities, suited to different types of objects based on their complexity and detail requirements.

The **Artec Leo** scanner has the advantage of having an internal storage system, so scanned models are stored directly in the scanner and need to be imported to a computer later. This makes Artec Leo completely wireless, which eases the scanning process. It also has an integrated touchscreen display, that allows users to configure the scanning settings and view the scanned model in real-time directly on the device. This scanner was particularly useful for objects with simpler geometries, such as those with fewer curves and holes, due to its ease of use.

Unlike Leo, the **Artec Space Spider** does not have an internal storage system or a



(a) Scanning with Artec Space Spider, connected to a laptop.

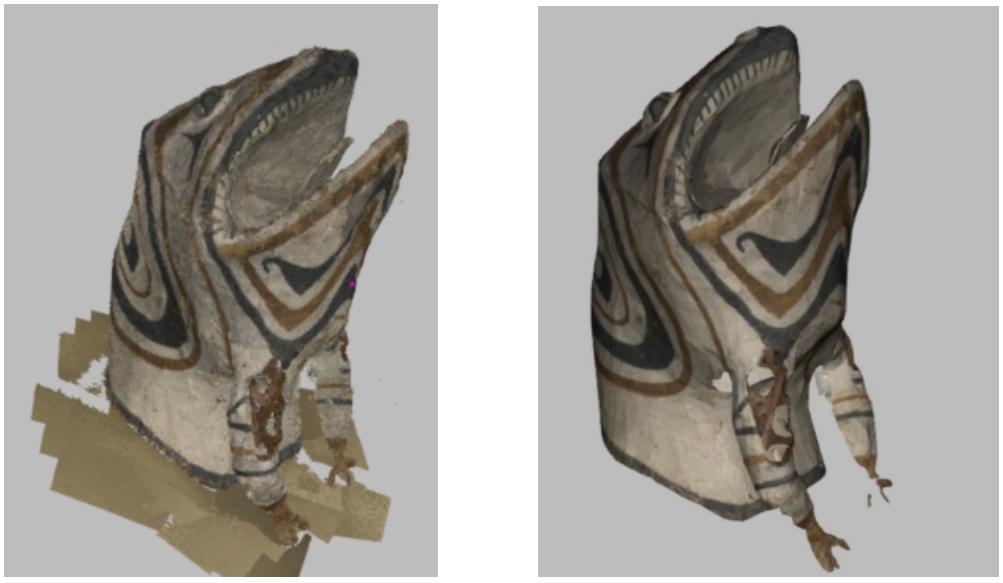
(b) The Artec Studio software displaying the current model being scanned.

Figure 4.5: Using Artec Spider to scan an object.

display screen. Instead, it must be connected to a computer running the Artec Studio software, which is used for visualizing and saving the scan data. Figure 4.6a shows the scanning of an object being made with this scanner, with the results appearing in a laptop, seen in Figure 4.6b. This scanner is ideal fo capturing more intricate details, making it the preferred choice for objects with complex shapes.

For the **scanning procedure**, the objects were placed in a table that would allow the scanner movement without the need to touch or rotate the object. During the scanning process, careful attention was paid to ensure that every detail and corner of the objects were captured accurately. Multiple scans were performed for some complex objects, as an attempt to capture enough models that could be mixed later.

Once the scanning was completed, the resulting models underwent a **post-processing** stage to ensure the highest quality output, using the Artec Studio software. For each object, the process was similar, beginning with merging existing scans in cases where multiple scans had been taken. The next step involved cleaning up the merged model by removing noise and artifacts. Most of the objects, due to their shape, had holes that needed to be filled. This was typically done by placing a black area or a color that matched the surrounding surface of the hole. The next step was mesh smoothing, which involved applying smoothing algorithms to improve the surface quality without losing significant detail. The final step of this process was decimation, which reduced the polygon count while maintaining the essential shape and details to decrease file size and enhance performance. The final result was then exported and validated together with the development team and the Academy staff to be approved. Figure 4.6 shows an example of a cultural object that exists in the website, before and after being post-processed.



(a) Model before processing. (b) Noise removed and smoothing.

Figure 4.6: Comparison of a 3D model of an object before and after post-processing.

4.5 Development Environment and Setup

Having gathered the necessary content for the virtual tour, including 3D models of spaces and objects, and photos provided by the academy, the next step in the development process was to set up the working environment and begin the initial frontend project.

4.5.1 Working Environment

The chosen **Integrated Development Environment (IDE)** for developing the project was **Visual Studio Code (VSCode)**. This IDE offers several advantages, including a lightweight and customizable interface, vast extensions for various programming languages and Git integration. To efficiently work with Vue.js, two extensions were added to VSCode:

- **Vue 3 Snippets** – This extension provides a collection of code snippers for Vue.js 3, allowing developers to quickly initiate components, default syntax and other features, in order to speed up the coding process;
- **Vetur** — This extension includes features such as syntax highlighting, IntelliSense for auto-completion, error checking and debugging capabilities.

With the working environment set up, the next step was to initialize a **GitHub repository** in the project's folder. GitHub was chosen for version control, allowing to keep track of changes and manage different versions of the website. Additionally, **GitHub Pages** was utilized to deploy the website temporarily. This feature enabled the project to be hosted on GitHub's servers, providing a live version of the site that could be accessed by the academy's stakeholders for testing and feedback, while their dedicated server was still being prepared.

4.5.2 Frontend Setup

The next step in the development environment was **setting up a Vue.js project**, as this would be the foundation for the development of the website's frontend. Before starting with Vue, a few prerequisites need to be installed:

- **Node.js and npm** — Node.js is a JavaScript runtime that allows developers to run JavaScript on the server side. Node Package Manager (npm) is bundled with Node.js and is used to install and manage packages for JavaScript projects. These are essential for running Vue's development server and managing dependencies. Both were installed following their documentation pages[9,10];
- **VUE CLI** — The Vue Command Line Interface (CLI) is a tool that helps in setting up new Vue projects quickly. It offers a range of features such as easy project

[9]Node.js Docs (Last Access: 9/2024) - https://nodejs.org/docs/latest/api/
[10]npm. Docs (Last Access: 9/2024) -https://docs.npmjs.com/

```
Vue CLI v5.0.8
? Please pick a preset: Manually select features
ter> to
proceed)
 ( ) Babel
 ( ) TypeScript
 ( ) Progressive Web App (PWA) Support
>(*) Router
 ( ) Vuex
 ( ) CSS Pre-processors
 ( ) Linter / Formatter
 ( ) Unit Testing
 ( ) E2E Testing
```

Figure 4.7: Example of Vue CLI project initiation.

setup, plugins, and configurations for efficient development. This tool was installed following its documentation page[11].

After installing the necessary tools to begin the project, a new Vue.js project was initiated using Vue CLI with the command **'vue create <project-name>'**. Vue CLI guides the installation process and allows multiple configurations to be selected according to the project's needs. For this project, one essential plugin that had to be installing was **Vue Router**, a core library for Vue.js that enables developers to create and manage the navigation and routing of a single-page-application. It allows for the transition between different views or pages within the application without requiring a full page reload. An example of the Vue CLI during installation and selection of the necessary plugins can be seen in Figure 4.7.

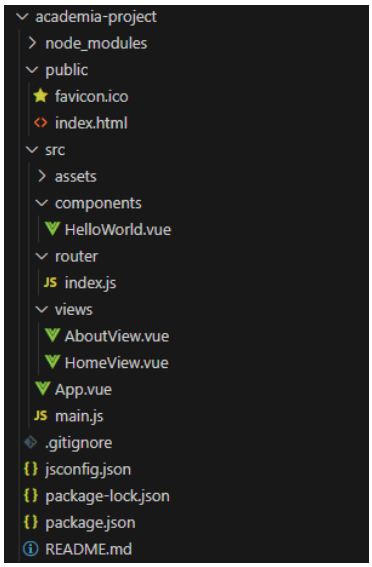


Figure 4.8: Folder structure of a Vue.js project started with Vue CLI.

[11]VUE CLI Docs (Last Access: 9/2024) - https://cli.vuejs.org/getting-started

Once the project installation is complete, the file structure is made visible and is relatively straightforward. Vue CLI automatically generates the initial folders and files necessary for the project, as can be seen in Figure 4.8. The most relevant folders are:

- **node_modules** — This folder is used exclusively during development and contains all the necessary Node.js modules that the project depend on. These are automatically installed and managed by **npm**;
- **public** — This directory is used to store static assets such as images, fonts and other media content that will be directly used in the application;
- **src** — This is the core folder where the most of the development takes place. It contains important subfolders:
  - **components** — This folder is where all reusable Vue components are stored;
  - **router** — All the routing configurations for the application are saved here;
  - **views** — This folder stores the different page views of the application. Each file in this folder typically corresponds to a route in the application, representing the full-page components that are displayed when users navigate to different parts of the site.

With the project installation complete, the next step was to define the **router configuration**. To begin this process, some placeholder components/pages were created to serve as the initial routes. These placeholders provide a basic structure and layout for the different sections of the application, making it easier to visualize the navigation flow and text the routing functionality. The router configuration is primarily managed in the **'router/index.js'** file. This file is where all the routes are defined, associating each route with a specific component or page. A version of this file, where the routes are defined, can be seen in Figure 4.9.

The next step in the initial development was the installation of **Tailwind CSS**, following its documentation[12]. This framework provides a set of classes to build custom designs directly in the markup code. For example, for changing the background color of a ** ** element to red, one can simply write the class **'bg-red'** inside the 'style' markup, such as: **' '**. This greatly facilitates the process of customizing a website's theme. With Tailwind installed, the next step was to configure the theme in the **'tailwind.config.js'** file. Tailwind offers numerous customization options, enabling developers to define global styles and settings that can be reused throughout the project. For this website, three specific customizations were defined:

- **Colors** — A set of predefined colors was established, which can be easily referenced when styling components, ensuring consistency across the website;

[12]Tailwind.css Documentation (Last Access: 9/2024) - https://tailwindcss.com/docs/installation

```
const router = createRouter({
  history: createWebHistory(import.meta.env.BASE_URL),
  routes: [
    {
      path: '/',
      name: 'home',
      component: HomeView
    },
    {
      path: '/tour',
      name: 'tour',
      component: GuidedTourView
    },
    {
      path: '/tour/:id',
      name: 'tourId',
      component: GuidedTourView
    },
    {
      path: '/galeria',
      name: 'gallery',
      component: GalleryView
    },
    {
      path: '/sobrenos',
      name: 'aboutus',
      component: AboutUsView
    },
  ],
  scrollBehavior(to, from, savedPosition) {
    if (to.hash) {
      return { el: to.hash, behavior: 'smooth' };
    } else if (savedPosition) {
      return savedPosition;
    } else {
      return { top: 0 };
    }
  }
})
```

Figure 4.9: Partial content of the router configuration file, where routes are defined.

- **FontFamily** — Two custom fonts were defined in the configuration file. Tailwind allows for easy font customization, making it simple to set global typography settings;
- **Screens** — Breakpoints for different screen sizes were defined under the screens section. This is particularly useful when working with responsiveness, as it allows for the creation of styles that adapt to various devices.

The customizations mentioned above in the **'tailwind.config.js'** file can be seen in Figure 4.10.

After installing and configuring Tailwind, the next step in the setup involved integrating additional external components and plugins essential for the development of some of the website's features. One of the key components added was **Flowbite**[13]. This library offers pre-built components that work with Tailwind, with a wide range of interactive elements like modals, buttons and navigation bars. This was necessary in order to reduce the work involved with creating some necessary components and to maintain consistency in the project.

Another important addition was **vue3-carousel**[14]. This external plugin is a flexible and responsive carousel component specifically built for Vue 3, that allows to create carousels and slideshows easily, with various customization options. This library was used when displaying cultural heritage objects, providing a carousel style showcase that is visually appealing and interactive.

[13] Flowbite Documentation (Last Access: 9/2024) - https://flowbite.com/docs/getting-started/vue/
[14] vue3-carousel Documentation (Last Access: 9/2024) -https://ismail9k.github.io/vue3-carousel/

```
theme: {
  extend: {
    colors: {
      "acad-primary": "#90463A",
      "acad-primary-darker": "#78463a",
      "acad-secondary": "#fce5bb",
      "acad-secondary-darker": "#e6d0aa",
      "acad-bg" : "#fff9f1"
    }
  },
  fontFamily: {
    PTSans: ["PT Sans, sans-serif"],
    DMSerif: ["Forum", "serif"],
  },
  screens: {
    "sm": "640px",
    "md": "768px",
    "lg": "992px",
    "xl": "1280px",
    "2xl": "1550px"

  }
},
```

Figure 4.10: Partial content of the Tailwind configuration file.

The final component installed was **v-viewer**[15]. This library provides a complete image viewer, with support for features such as zooming, rotating and navigating through images. This plugin was essential when displaying cultural heritage object's photos, as it allowed for users to interact with the images, particularly for high-resolution images where examining closer details is important.

```
<template>
  <div class="block">
    <div id="mpViewer" ref="container" class="w-[100%] h-[80vh]"></div>
  </div>
</template>

<script setup>
const sdkKey = "ieap1iedw1xf41q41z1e2m123";

onMounted(async () => {
  await connectShowcase(props.room);
})

const container = ref()

const connectShowcase = async (space) => {
  sdk.value = await setupSdk(sdkKey, {
    container: container.value,
    space: space,
    iframeQueryParams: { qs: 1, lp:1 },
    iframeAttributes: {allow:'xr-spatial-tracking', allowfullscreen : true}
  });
};
</script>
```

Figure 4.11: Partial code of the Matterport Viewer component.

[15] v-viewer Documentation (Last Access: 9/2024) - https://www.npmjs.com/package/v-viewer

Having installed all the necessary external plugins, the last step in the initial setup process was to install the core of the virtual tour features, which was **Matterport SDK**[16]. The Matterport 3D Showcase SDK is a library for third-party developers to integrate Matterport in their applications. It allows a deep customization of the 3D Showcase experience and build entire applications based on Matterport's functionalities. After installing the dependencies following Matterport's documentation, the next step involved creating a Vue component that would exhibit the Matterport's viewer. Using the SDK functions, this process is pretty straightforward, as it only requires creating a ** ** element which will be referenced in the SDK's function **sdkSetup** and initializing parameters such as the ** ** reference, the **space** ID to be loaded (i.e, the room to be displayed), and other optional parameters like **quickstart** or **allow full-screen**. In Figure 4.11, part of the code of the Matterport Viewer component is presented.

4.6 Data Structure

At this stage of this document, it's important to detail how the data is structured in this project. Initially, the website was developed as a static site, meaning all the data was unchangeable. The focus was solely on frontend development, with no backend or database integration, so all media content was directly embedded in the development project, specifically in Vue's **public** folder.

The data that needed to be stored and managed was primarily related to the Academy's rooms and objects. Each room and object required various pieces of information to be accessible on the website, including textual descriptions, images and other media content. To organize and manage this data in an efficient way, a global **rooms.json** file was created. This JSON file served as a centralized repository for all the necessary data that needed to be accessed. In Figure 4.12, an example of one room is displayed. This file stores an array of room objects, and it's worth to explain what do its fields mean:

- **name**— The room's name;
- **desc** — The room's description - textual information to be displayed in the room's page;
- **modelSid** — The Matterport's ID of this room, to be called in the Matterport's Viewer component;
- **audioFile** — The audio file of the audio guide of this room;
- **background** — The path to a wide photo of this room, to be displayed in the *Patromónio* page;

[16]Matterport SDK Documentation (Last Access: 9/2024) - https://matterport.github.io/showcase-sdk/sdk$_{h}ome.html$

- **points** — An array of the cultural heritage objects that belong to this room. Inside each element, the following information is stored for each object:
  - **name** — The object's name;
  - **description** — A description of the object;
  - **images** — A path to the objects images directory;
  - **digitalization** — A link to the book or manuscript full digitalization;
  - **model** — The embedding to Sketchfab's viewer of the object's 3D model;
  - **moveTo** — This object is used for the **View in room** feature, which moves the user in the Matterport 3D Viewer to a specific location in the 3D space, facing the object. Therefore, its necessary to store information such:
    - **sweepId** — Every scanned performed with the Matterport scanner has its own ID. This is necessary to move the user to this specific point;
    - **x, y** — The coordinates to rotate the camera to face the object;
- **transcriptions** — The feature of showing the transcriptions of the audio guide had to be coded since Matterport's transcriptions were limited. This stores an array of objects that contain information about transcriptions, such as:
  - **title** — The transcription title;
  - **desc** — The transcription text of the audio guide;
  - **dur** — The duration of the transcription, in seconds.


```
[
  {
    "name": "Entrada Nobre",
    "desc": "A Entrada Nobre situa-se no Largo de Jesus, na fachada sul, adjacente à Igreja...
    "modelSid": "RhwXTTy3FgY",
    "audioFile": "/sound/guide/1-entrada.mp3",
    "background": "/images/rooms/entradanobre/panoramica.jpg",
    "points": [
      {
        "name": "Painel de azulejos com os fundadores da Academia das Ciências de Lisboa",
        "description": "Fábrica Faiança Battistini, de Maria de Portugal. 1940.",
        "images": [
          "/images/rooms/entradanobre/painel_azujelar/painel_azulejar.jpg"
        ],
        "digitalization": "https://biblioteca.acad-ciencias.pt/mfn=69157&amp;DDB=",
        "model": "https://sketchfab.com/models/322f3a56bd054d26b32354a14b6c5dc6/embed",
        "moveTo": {
          "sweepId": "xea17fthyir0k269ga20iwe6a",
          "tagId": "b0rmqX4bmT3",
          "x": "5",
          "y": "180"
        }
      }
    ],
    "transcriptions":[
      {
        "title": "Fundação da Academia",
        "desc": "A Academia das Ciências de Lisboa foi fundada em 1779. Mantém atividades...
        "dur": 9
      },
      ...
    ]
  }
]
```


Figure 4.12: Partial content of the rooms and objects data file.

4.7 Virtual Tour Functionalities

The virtual tour is the core of this website, that provides an immersive and structured way for users to explore the Academy's spaces and cultural heritage objects. This virtual tour is designed as a sequence of information pages dedicated to a specific room within the Academy. Each page is structured to have, at the top, the Matterport Viewer, followed by textual information about the room and, at the bottom of the page, an area dedicated to showcasing the cultural heritage objects found within the room.

One of its features is the **itinerary**. This is presented as an image, designed to feature circles representing each of the Academy's rooms and connected by path that symbolizes the journey through the Academy. This image is accessed either by the top menu of the website in the *Roteiro* link or directly at the room's information page in the *Itinerário* button. The image itself is a simple **.png** file, but its interactive functionality is accomplished through the use of an **SVG mapper**[17]. This is a tool that overlays clickable areas on top of images, creating an interactive map that, when clicked, can trigger a certain function or redirect the users to a new page, which is the case here. The SVG mapper outputs an HTML code that was saved in as the itinerary component, which was reused in the different areas where this map appears. A part of this component can be seen in Figure 4.13. The clicable areas are defined with the **<rect>** tag, giving the image coordinates for clickable areas and associating a function when they are clicked.

```
<div class="relative mt-4 flex items-center justify-center">
  <svg v-show="!museumCircles" version="1.1" xmlns="http://www.w3.org/2000/svg"
    xmlns:xlink="http://www.w3.org/1999/xlink" viewBox="0 0 2681 3603"
    class="h-[100%] w-[100%] max-w-[1000px]">
    <image
      :xlink:href="locale === 'pt' ? '/images/roteiro/vertical_sem_museu.png' : '/images/roteiro/vertical_sem_eng.png'"></image>

    <rect class="hover:cursor-pointer" @click="handleClick(0)" x="93" y="42" fill="#fff" opacity="0"
      width="697"
      height="706"></rect>

    <rect class="hover:cursor-pointer" @click="handleClick(1)" x="1323" y="189" fill="#fff"
      opacity="0" width="706"
      height="706"></rect>

    <rect class="hover:cursor-pointer" @click="handleClick(2)" x="1962" y="972" fill="#fff"
      opacity="0" width="715"
      height="700"></rect>
      ...
  </svg>
</div>
```

Figure 4.13: The itinerary component created using SVG mapper.

[17] Image SVG Mapper (Last Access: 9/2024) - https://www.image-map.net/

```
onMounted(async () => {
  sdk.value.on(sdk.value.Tour.Event.STARTED, function () {
    emit('tour-started')
  });
})
```

(a) Matterport Viewer component - emitting the 'start-tour' event.

```
<MatterportViewer v-show="hasClicked" ref="mpViewer"
  :room="rooms[currentRoom].modelSid"
  @tour-started="startTour()" />
```

(b) Guided Tour component - catching the 'start-tour' event.

Figure 4.14: Pieces of code exemplifying the handling of the 'start-tour' event.

Moving into the **room's presentation feature**, when a user enters a room's page within the virtual tour, a presentation of the space starts. This presentation takes advantage of the Matterport Virtual Tour functionality, which guides the user through various points within the room while an audio guide is playing. The synchronization of these two elements - the virtual navigation and the audio guide - is crucial to ensure a smooth and engaging tour experience. Therefore, when one starts or stops, the other must do the same.

The presentation begins as soon as the Matterport Viewer fully loads. This automatic initiation is supported by the Matterport SDK, which has been set to start the tour immediately upon loading. Once the Matterport Viewer is ready and the virtual tour begings, the component emits an event to the parent component signaling the start of the tour. This event is captured by the parent component Guided Tour, responsible for all the login of the virtual tour, which then triggers the **startTour()** function. This function starts the necessary elements that belong to the room presentation feature, such as start playing the audio guide. This process can be seen in Figure 4.14

The end of the presentation is determined by the completion of the audio guide. As it reaches its end, it signals the Matterport component to call the **stop()** function of the Matterport Viewer, which causes the Guided Tour to fully stop and allows the user to start moving freely in the space. This can be seen in Figure 4.15.

Continuing the development of the guided tour functionality, users are also given the flexibility to pause or completely stop the room's presentation at any point during the tour. To enable this functionality, an invisible overlay layer was created on top of the Matterport Viewer which, when clicked, it pauses the presentation and displays the pause menu. When the pause menu is triggered, the audio guide is paused using **pause()** function of the audio element. Simultaneously, the Matterport presentation is stopped using the **stop()** function, the same function used to conclude the presentation as mentioned previously.

```
<audio v-show="guidedAudioPlaying" ref="guidedAudio"
  :muted="isMuted"
  :src="rooms[currentRoom] ? rooms[currentRoom].audioFile : ''"
  preload id="audio"
  @ended="stopTour(true)"></audio>
```

(a) Guided Tour component - the **ended** event triggers the **stopTour** function.

```
const stopTour = () => {
  sdk.value.Tour.stop()
}
```

(b) Matterport Viewer component - the **stopTour** function stops the Guided tour.

Figure 4.15: Pieces of code exemplifying the handling of the end of the tour emitted by the end of the audio guide.

If the user chooses to continue the tour, the system resumes from the exact same point where it was left off. The audio guide is restarted using the **play()** function, while the Matterport Viewer resumes the Guided Tour with the **start()** function, which resumes the presentation from where it was paused. However, if the users decides to completely stop the tour, the same functions that are invoked at the natural end of the tour are called again, which stops both the Matterport Guided Tour and the audio guide. Users are then allowed to explore the space freely, and a **restart** button appears on the right side of the options bar which allows them to restart the tour. When a user restarts the tour, the process starts all over again, with both the audio guide and the Matterport Guided Tour starting from the beginning.

During the room's presentation, users are also given the ability to toggle the audio guide volume on and off. The implementation is straightforward, using the **mute()** function of the audio element to enable or disable the sound. When the audio guide is muted, the icon of the toggle button dynamically updates to visually represent that the sound is off. In contrast, when the audio is unmuted, the icon reverts to its original state, symbolizing that the sound is active again.

Another important component of the room presentation feature is the **textual transcription** of the audio guide. This feature ensures that the transcriptions remain synchronized with the audio. Matterport offers a similar feature when designing the Virtual Tour but, due to limitation in characters and special formats such as italics, this feature had to be coded separately.

To achieve this synchronization, the transcriptions are stored in the **rooms.json** file along with the duration for each transcription segment. Initially, the duration of each segment had to be manual inputted, by listening to the audio guide and defining the duration for each sentence. When the audio guide starts playing, the first transcription is displayed immediately. For each subsequent transcriptions, a countdown is initiated using JavaScript's **setTimeout()** function, which executes code after a specified time in miliseconds. This countdown triggers the **nextSubtitle()** function, which updated the current displayed subtitle to the next one in the sequence and sets a new timeout based on the duration of the new segment. This cycle repeats until the audio guide concludes, marking the end of the presentation. However, if the user pauses the presentation, the system must adjust the timing of the transcriptions to ensure proper synchronization. To handle this, each time a new transcription begins, the system records the current system's time in a variable called **transStartTime**. When the user pauses the presentation, the system saves the pause timestamp in a **transStopTime** variable and clears the active **setTimeout()**, stopping the countdown. When the user resumes the presentation, a new timeout is created, with the remaining duration calculated as:

$$newDuration = originalDuration - (transStopTime - transStartTime) \tag{4.1}$$

This ensures that the transcription remains in sync with the resumed audio if the user

pauses the presentation. When the user stops the presentation and restarts it, the whole process repeats itself, resetting the initial transcription and clearing existing values in the time storing variables.

To enable the navigation between rooms within the virtual tour, a **room-changing feature** was implemented with two functional methods.

First, users can manually navigate to the previous or next room by clicking the designated buttons. The second method, provides an automatic transition between rooms: five seconds after the current room's presentation ends, a countdown begins, after which the system automatically changes to the next room in the sequence. However, the countdown stops immediately if the user clicks or moves the mouse within the window, allowing users to take control of the navigation. This countdown feature was implemented using JavaScript's **setTimeout()** function. To detect user interactions, two event listeners were added for mouse movements and clicks using the **window.addEventListener()** function. If any of such events is detected, the active timeout is cleared, stopping the countdown and preventing the automatic room change. Changing room is achieved by updated the **spaceId** in the Matterport component, which when changed, automatically reloads the Matterport Viewer to display the new room and refreshes the page's content.

A feature to **display the cultural heritage objects** for each room is crucial for this website, and it is available both in the individual room pages and on the **Património** page, where similar functionalities are offered. This display is implemented in both locations using the previously discussed **vue3-carousel** component. This allows the creation of card-style elements in a carousel-style format. When a user clicks on one of these cards, a modal window — provided by Flowbite — opens, ofering detailed information and some additional interactive features. Within this modal, the object's name and description are always displayed. For books and manuscripts that have been digitized and are available on the official Academy website, a button is provided for users to access these digital resources directly. Additionally, the **v-viewer** tool is integrated to offer a gallery of high-quality images of the object. Users can click on any image to open in full screen and enabling zooming. For objects that have a 3D digitalization available on Sketchfab, the 3D model is embedded directly within the modal. If an object physically exists within the room's digitalization, a "See in the Room" button is displayed that, when clicked, automatically moves and rotates the camera in the Matterport Viewer to focus on the object in its specific location in the room. Finally, two navigation arrows are provided at the bottom of the modal, enabling users to move easily between the previous and next objects without needed to close the window.

4.8 Website Translation

One of the requirements from the Academy for this website was that it needed to be available in English to encourage non-Portuguese speakers to visit and explore it. Therefore, it was necessary to implement a language switch within the system. There were two main

areas that required separate translation: the rooms and objects information, and the general static website text.

For the rooms and objects translations, the textual information for each item had to be translated into English and stored separately within the **rooms.json** file. When the user switched the language, the system would simply select the English fields and import the corresponding textual information.

However, for the static website content, a different approach was taken. Rather than storing separate translations manually, the solution was to use the **i18n**[18] library, which is a tool for managing translations in applications. For the static website content, two **locale.js** files were created, one for each language (Portuguese and English), where all translations were stored. Each translation is organized as key-value pair, where the key is a unique identifier and the value is the corresponding translation. These can be called anywhere in the website using the i18n's syntax like **$t('key-name')** and the correct value is automatically inserted in place, based on the selected language. An example of this tool can be seen in Figure 4.16.

In the navigation bar of the website, a option was created that allows the selection of the preferred language. When selecting a new language, it changes a variable **currentLocale** in the i18n configuration that's responsible to save the current selected language.

Translations of the audio guides also needed to be provided for the room presentations. To achieve this, AI-generated voices were utilized by using the online video editing platform **Clipchamp**[19]. To create the translated audio guides, the textual content of each room's audio guide was input into Clipchamp's text-to-voice generator. The tool then produced downloable audio files in the chosen language and the selected voice, which were then integrated into the website.

```
"sala": {
    "sala_seguinte": "Sala seguinte"
}
```

(a) Example of a key-pair value in **locale.js** translation file.

```
<p class="hidden sm:block">
  {{ $t("sala.sala_anterior") }}
</p>
```

(b) Referring to the translation using i18n's syntax.

Figure 4.16: Example of how to define and call a key-value pair translation using i18n.

[18] Vue i18n website (Last Access: 9/2024) - https://vue-i18n.intlify.dev/
[19] Clipchamp website (Last Access: 9/2024) - https://clipchamp.com/en/

4.9 Backend

The final stage of the development phase involved creating the backend, which would support an admin panel for the Academy's staff to manage the site's content effectively. The creation of this backend, after the frontend being developed fully static, led to some changes having to be performed in the frontend in order to support API calls to retrieve information. This Section will detail the backend's setup, development, and the necessary changes made in the frontend to accommodate this new aspect of the system.

4.9.1 Setup & API Endpoints

The backend server was built using Node.js and Expres.js. As seen before, Node is a JavaScript runtime environment that allows developers to execute JavaScript code on the server side. Together with Express.js, which is a Node.js web application framework to create web servers, the development of a backend server is a very straightforward process.

Node.js had already to be installed due to other dependencies on this project, but Express.js was installed using **npm**, following its documentation[20].

With the necessary tools installed, the next step was to develop the API that the frontend would interact with. The data previously stored directy in the frontend (i.e, the **rooms.json** file with all the information about the rooms and objects, plus the object's images) were migrated to the backend server's file storage system. Textual data related to the rooms and objects continued to be stored in a JSON format within the backend, while the images were stored in the server's local file system.

After the migration of the data files to the backend server, the next step in the process was to create the API endpoints, which would allow the frontend to fetch data from the backend. The following endpoints were defined:

- **POST /upload** — Allows the uploading of images to the server;
- **GET /api/rooms** — Retrieves all data from the **rooms.json** file, providing a complete dataset of rooms and objects;
- **GET /api/data** — Retrieves data from the **rooms.json** file but filtered by the selected language (either Portuguese or English);
- **POST /api/rooms** — Creates a new room entry in the rooms.json file;
- **GET /api/rooms/objects/images** — Retrieves all images associated with a specific object within a specified room;
- **DELETE /api/rooms/objects/images** — Deletes an image of a specific object;
- **GET /api/users** — Gets all the users registered as administrators;
- **POST /api/users** — Creates a new user dataset;

[20] Express.js website (Last Access: 9/2024) - https://expressjs.com/

```
app.get('/api/data', (req, res) => {
  const lang = req.query.lang || 'pt';
  const filteredData = getData().map(entry =>
    filterByLanguage(entry, lang));
  res.json(filteredData);
});
```

Figure 4.17: Example of defining an API endpoint in Node.js using Express.js.

An example image of how the endpoint **GET /api/data** was created can be seen in Figure 4.17. This endpoint uses an auxiliary function called **filterByLanguage()** which filters the **rooms.json** file only retrieving the fields on the selected language.

4.9.2 Frontend Modifications

With the transition from a static to a dynamic site, several changes were necessary on the frontend to accommodate the new backend integration. Previously, data was loaded directly from static files included within the website. Now, the frontend needs to make API calls to the backend to fetch the required data.

These calls occur in two specific moments when using the website. One is when a user enters a room's information page. At this point, the frontend needs to make a call to the API to retrieve all the necessary data of the room and its objects images. This two calls happen at every new room page the user enters. The second moment is when the user goes into the *Património* page. Here it's necessary to get all the room's objects information and all the thumbnail image of each object. Only when the user clicks on an object, the frontend calls the API to retrieve the high-quality images.

This API calls are used using JavaScripts Fetch API. This tool is built-in JavaScript and allows easy network requests in order to, for example, retrieve data from a server. An

```
fetch('http://localhost:3000/api/data')
  .then(response => {
    if (!response.ok) {
      throw new Error('Network response was not ok');
    }
    return response.json();
  })
  .then(data => {
    rooms = data;
  })
  .catch(error => {
    console.error('There was a problem with the fetch operation:', error);
  });
</script>
```

Figure 4.18: Example of fetching data using the Fetch API.

example of using this API can be seen in Figure 4.18.

4.9.3 Administration Panel

In addition to the API, an admin page was also developed, to allow the Academy staff to manage the content displayed on the website. This page was also developed using Vue.js and some of the other tools used in the main website.

To enter this page, an admin user must login. As stated before, there are 2 types of users: **admin** and **super admin**, with the only difference being that the super admin can manage users and roll back to previous states of the website, while being able to do the other general actions that a normal admin can also do. When logged in, the users have access to configuration pages for rooms and objects. This pages allow the modification of existing content or creating new ones.

When entering the page, the existing data is fetched using Fetch API. This data is kept in a local variable that can be changed in the configurations pages. Only when the user clicks on the **save** button, that data is sent to the API to be uploaded. The textual data is relatively easy to manage as it is all stored in a JSON object, which will be then stored in the **rooms.json** file.

However, to manage images, it was necessary to use a middleware library called **Multer**[21]. This library helps to manage file uploads by adding them to the request objects.

Multer was configured to work as a storage engine in the backend file system. It allows the creation of a variable called **upload** which can be associated with an API endpoint to upload the images. That function easily manages all the uploads of images, such as creating the file in the system, managing duplicates and filenames. This facilitated the development process and allowed for a safe file system management which would have been more complicated if it needed to be coded all together.

[21] Multer documentation (Last Access: 9/2024) -https://www.npmjs.com/package/multer

5

Evaluation

To address the research questions proposed in Section 1.3 and to validate the developed system, a series of user tests were conducted. This chapter outlines the implemented testing protocol, the gathered data and insights into the system's effectiveness and usability. The chapter begins by detailing the testing protocol, including a breakdown of each task, the used questionnaires and the methods used to evaluate user interactions. Following this, the results of the collected data are presented together with a general analysis of each. This chapter concludes with a discussion and deeper analysis of the tests results.

The first phase of this user tests consisted of a series of tasks designed to help the participants become familiar with the website. Once this introductory tasks are completed, additional tasks were presented to evaluate whether they have effectively learned how to navigate and use the website. Following this, participants completed a set of standardized questionnaires to gather feedback on their experience.

After the questionnaires, users were invited to share their opinions about the website, including what they liked the most, what they liked the least and any suggestions for improvements. After that, a section focused on the website's design follows, where users can provide their opinion on different design options. The user test concludes with personal questions and demographic information, to provide context some context about the test subjects that participated in this user tests.

5.1 Protocol

The testing session required both the researcher and the test subject to be physically present in the same room. The researcher first prepared the necessary materials, which included two laptops - one provided access to the website, while the other displayed the test form. Using two computers facilitated the testing process, allowing the test subject to focus on the tasks without needed to switch between windows on a single device.

Once the laptops were set up, the researcher gave a brief introduction of the context of this thesis and outlined the structure of the test. The test subject was asked to be as honest and unbiased as possible in their responses. The session began with the test subject

reading and agreeing to the informed consent form, as show in Annex I. With the consent given, the testing started with the first two phases of tasks.

These tasks involved simple actions such as reading a section of text on the website, navigating to a different page or test a functionality. The tasks were divided into two groups: the first group consisted of simple and straightforward tasks designed to help the user become familiar with the website, while the second group contained more complex and less direct tasks intended to assess how well the user could navigate the site autonomously. Assistance was provided during both phases, but in the second phase the researcher allowed the user more time to attempt the tasks before offering help. Data was collected manually by the researcher during the session.

Following the tasks groups, the User Experience Questionnaire (UEQ)[50] was presented. This questionnaire is designed to evaluate a user's impression of a product's usability and user experience. After the UEQ, participants were given the System Usability Scale (SUS)[9]. This questionnaire is a simple ten-item scale that provides an assessment of overall usability of a system.

Having completed the standardized questionnaires, the test subjects were asked to answer some questions regarding their personal preferences for design options on the website. The final section of the questionnaire gathered demographic information and other personal details about the test subjects.

5.2 Group A - Exploration Tasks

This group of tasks was designed to familiarize users with the website by guiding them through various activities that involved exploring its pages, navigating between them and trying the available functionalities. These tasks also served to assess how easily users can perform basic operations and how long it takes them to do so. For each task, the following observations were recorded by the researcher:

- **AQ1 - Time to completion** The time taken to complete each task, in seconds.
- **AQ2 - Able to complete?** Responses could be *Yes*, *Yes, with help* or *No*;

Assistance was provided whenever necessary to ensure users could understand and complete the tasks. For Group A, tasks were divided into 3 different categories, in order to facilitate the result's presentation. The **Starting Tasks** were labeled as such because they are mostly introductory and simple. The **Tour Tasks** are those related with the virtual tour pages and functionalities. Lastly, the **Navigation Tasks** are related with navigational functionalities and general exploration of the remaining features. The tasks presented in this group are the following:

Task A1 to A4 - Starting Tasks

Task A1 - Read the instructions in the home page – This task aimed to give an overview of the website's functionalities to the test subject and to measure how long does the average user takes to read the whole instructions section.

Task A2 - Start the Virtual Tour – In this task the user had to instinctively press the "Start" button presented at the top of the main page.

Task A3 - Watch the introduction video – This task served to give the user a general overview of the Academy rooms and cultural heritage objects in an engaging way.

Task A4 - Click on the button "Start" – This task started the virtual tour.

Task A5 to A13 - Tour Tasks

Task A5 - Turn off and on the audio-guide – This task presented the user the functionality to toggle off and on the audio-guide.

Task A6 - Pause the room's presentation – In this task the user was asked to pause the initial room presentation, by clicking on the 3D viewer. However, this functionality was not explained previously, so this task aimed to assess if the users instinctively understood how to accomplish it.

Task A7 - Stop the room's presentation – Once the presentation is paused, a menu with a "Stop" button is presented. This tasked aimed to assess if the users understood its purpose.

Task A8 - Navigate freely in the 3D environment – In this task the users were able to explore the 3D space freely and try the available functionalities.

Task A9 - Open the itinerary while being in a room's information page – In this task the user had to open the itinerary map by clicking the existing button under the 3D viewer.

Task A10 - Open the information window of an object while being in a room's information page – This task presented to the user the object's information window functionality.

Task A11 - Open and explore an image in the information window of an object – In this task the user was presented with the image exploration feature of the existing gallery in an object's information window.

Task A12 - Go to the next room – This tasked aimed to introduce to the user the "Next room" button.

Task A13 - Go to the previous room – This tasked aimed to introduce to the user the "Previous room" button.

Task A4 to A23 - Navigation Tasks

Task A14 - Open the page "Itinerary" – This tasked showed the user a different way to access the itinerary, by pressing the button in the top navigation menu.

Task A15 - In the page "Itinerary", go to the "Earthquake" room, in the "Museum" – In this task the user was presented with the multi-level functionality of the museum's rooms, which displays new rooms when clicking in the "Museum" button in the itinerary.

Task A16 - In the "Earthquake" room, find a label of the object "Dice" in the 3D viewer and click on it – This tasked presented the Matterport's object label functionality to the user.

Task A17 - Open the page "Heritage" – In this task the user was presented the "Heritage" page.

Task A18 - Open an object's information window and click in the button "See in the space" – This tasked aimed to introduce the user to the "See in the space" functionality, present in the object's information window.

Task A19 - Enter the room "Museum - Aula Maynense" – This tasked aimed text how the user goes to a specific room, now that he is familiar with the itinerary functionality.

Task A20 - Open the information window of the object "Heart" and explore its 3D model – This tasked introduced the 3D viewer of certain cultural heritage objects.

Task A21 - Click in the button "See in the space" in the "Heart" information window – This tasked showed the user the "See in the space" functionality, which positions and rotates the camera in the Matterport's 3D viewer directly at the object.

Task A22 - Open the "About Us" page – This tasked introduced the "About Us" page to the user.

Task A23 - Change the language of the website to English – This tasked aimed to introduce to the user the language switch functionality.

5.3 Group B - Autonomous Tasks

With the users familiarized with the website, this group of tasks aimed to assess how easily and how long it took them to perform more general tasks. In this group of tasks, assistance was only provided if the users had difficulties in understanding the task. For each task, the following observations were recorded by the researcher:

- **BQ1 - Able to complete?** Responses could be *Yes*, *Yes, with help* or *No*;
- **BQ2 - Time to completion** The time taken to complete each task, in seconds.

The tasks presented in this group are the following:

Task B1 - Starting in the "Home" page, open the information page of the room "Cloister" – This tasked aimed to assess if the users understood the different ways to access a room's information page.

Task B2 - Starting in the "Home" page, open the information window of the object "Atwood's Machine" – This tasked aimed to understand if users know how to find a specific object.

Task B3 - Starting in the "Aula Maynense" information page, go to the "Philosophical Journey of Alexandre R. Ferreira" page – In this it was tested how do users go from one room's information page to another.

Task B4 - Starting in the "Heritage" page, open the 3D viewer of the object "Human Body" – This tasked aimed to assess if the users understood that certain objects had their 3D models available in the object's information window at the "Heritage" page.

Task B5 - With the information window of the object "Human Body" opened, go to the information window of the object "Heart" – In this task the users could go to the next object's information window by clicking in the arrows available at the bottom of the window. This task aimed to assess if users instinctively understood that functionality, since it wasn't presented in the Group A tasks.

Task B6 - In the information page of the room "Earthquake", open the information window of the object "Dice" and do so that, in the 3D viewer, the camera is directed at this object – This tasked aimed to assess if users were aware of the "See in the space" button that was presented previously.

Task B7 - Find the name of the person that did the voice over in Portuguese – This tasked aimed to understand if the users were aware of the "About Us" page and its content.

Task B8 - Find the type of material of the object "Club with Human Figuration" – This tasked aimed to assess if users knew the type of content displayed at an object's information window, more precisely it's description.

Task B9 - Open the "Integral Digitalization" of the work "Atlas of Lázaro Luís" – This tasked aimed to assess if the users could find a specific object and if they could explore the object's information window and find the link to the "Integral Digitalization", since this feature wasn't presented in the Group A tasks.

5.4 User Questionnaires

Once the tasks were finished, participants were asked to complete several questionnaires, which evaluated different aspects of the system. Two standardized questionnaires, the System Usability Scale (SUS) and the User Experience Questionnaire, provide better insights into what the users think about this system in dimensions such as usability, efficiency, novely and others. Other non-standardized questionnaires aim to acquire the opinion of the test subjects regarding matters such as design options, users characterization and personal opinions about the website's design and functionalities.

5.4.1 User Experience (UEQ) Questionnaire

The first standardized questionnaire users had to answer was the User Experience Questionnaire (UEQ). This is a tool used to assess a user's impressions and feelings about a system's usability and appeal. It covers various aspects of user experience, such as attractiveness, clarity, efficiency, dependability, novelty and stimulation.

In the context of this study, the UEQ was used to measure how users perceived the website as a whole, including both its usability and how engaging and satisfying it was to use. This questionnaire is replicated in Annex II.

5.4.2 System Usability Scale (SUS) Questionnaire

The last standardized questionnaire the test subjects were asked to answer was the System Usability Scale (SUS). This questionnaire aims to assess the usability of a system, providing a quick and reliable measure of the overall user experience. It consists in ten statements that users rate on a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree". This statements address various aspects of system usability, such as the ease of use, user's confidence in using the system and complexity. This questionnaire can be found in Annex III.

5.4.3 General Feedback

The test subjects were also asked to provide their personal opinions on the website's functionalities, ranking them by preference and commenting what they liked the most and the least about the website. This questionnaire also invited participants to offer suggestions for improvement. These questions were administered twice, once for the desktop version and once for the mobile version. This feedback was valuable for gaining insight into user preferences and identifying potential areas for further improvements. This questions can be found in Annex IV and in Section 5.5.6.

5.4.4 Design Opinion

Another stage of the user tests focused on gathering feedback on various design options. Participants were presented with different design choices for website elements, such as background colors for images, font styles, and specific aspects of implemented functionalities. This section aimed to collect user preferences on these design variations and assess whether the current design aligns with the overall preferences and expectations of the website's users. This section can be found in Annex V and in Section 5.5.7.

5.4.5 Characterization Questionnaire

The final stage of the user tests involved a characterization questionnaire designed to characterize the participants involved in the study. This questionnaire included questions

about age, educational background, frequency of website usage, frequency of museum visits, and what functionalities they would like to see in a virtual museum tour website. This questionnaire can be found in Annex VI and in Section 5.5.1.

5.5 Results and Analysis

This section will present the results of the user tests, beginning with a characterization of the participant population. Following this, the results of the tasks phase will be presented, followed by the outcomes of the user questionnaires. A general analysis of the results will occur in each section, leaving a more deeper discussion to the next section of this document.

5.5.1 Population Characterization

Demographic data was gathered in order to understand the composition of the test subjects group. The population was composed of 30 participants. Eight participants were collaborators of the Academy, with professions ranging from historians and museum experts to curators and administrative workers. Participants gender distribution is shown in Table 5.1. Most of the participants had ages between 20 and 29, as can be seen in Table 5.2. All the participants in the user tests had a superior education level, as shown in Table 5.3. It's worth to provide some context of the user's background regarding previous experiences with museums and virtual tours. Therefore, Table 5.4 shows that most participants only visit a museum once a year. About 33% of the participants never visit a museum's website, while about 57% of them have engaged in a virtual tour in the past, as can be seen in Table 5.5 and Table 5.6, respectively.

Some additional questions were asked regarding the user's habits related with using digital technologies which can be considered similar to the ones that this website utilizes. From the 30 users, a large majority (86.7%) visits websites using a desktop computer on a daily basis. When it comes to visiting websites on mobile devices, 76.7% of them reported to do it daily. These results can be seen in Table 5.7 and in Table 5.8, respectively.

Table 5.7: Visiting website's habits on desktops

	Participants (#)
Daily	26
Weekly	2
Monthly	2
Annually	0
Never	0

Table 5.8: Visiting website's habits on mobile devices

	Participants (#)
Daily	23
Weekly	5
Monthly	1
Annually	1
Never	0

The use of 3D viewers resemble playing video games in some aspects, so it's expected that users that play them are more proficient in using 3D viewers. Therefore, it was asked

Table 5.1: Gender distribution

	Participants (#)
Male	18
Female	12

Table 5.2: Age distribution

	Participants (#)
20-29	23
30-39	3
40-49	2
50-59	2

Table 5.3: Education levels

	Participants (#)
Less than high school	0
High school or equivalent	6
Bachelor degree	11
Master degree	13
Doctorate	0

Table 5.4: Frequency of Visits to Museums

	Participants (#)
Daily	1
Weekly	1
Monthly	8
Annually	17
Never	3

Table 5.5: Frequency of Visits to Museums' Websites

	Participants (#)
Daily	0
Weekly	3
Monthly	4
Annually	13
Never	10

Table 5.6: Has engaged in a Virtual Tour

	Participants (#)
Yes	17
No	13

how often do users play video games, with 40.3% answering they do it on a regular basis (daily, weekly) while 36.7% of them claiming they never play video games.

Additionally, because using an online video player is somewhat similar to interacting with the 3D viewer, users were also asked how often they watch videos on desktops or laptops. The majority (73%) stated they watch videos daily. These results can be observed in Table 5.9 and in Table 5.10, respectively.

Table 5.9: Video games playing habits

	Participants (#)
Daily	4
Weekly	9
Monthly	3
Annually	3
Never	11

Table 5.10: Watching online videos habits

	Participants (#)
Daily	22
Weekly	6
Monthly	1
Annually	0
Never	1

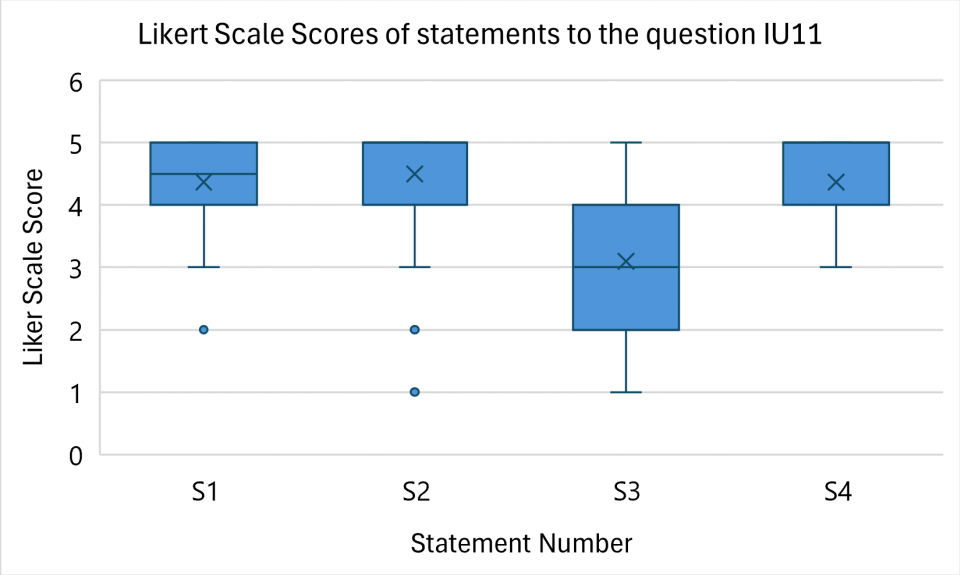


Figure 5.1: Box plot of the results for question IU11.

Lastly, it was interesting to understand what would make a user engage on a virtual tour. Therefore, to the question ***IU11*** - *What would be important for you to engage on a virtual tour?*, the following statements were shown to the test subject, where they had to rate each on a Likert scale, ranging from 1 (Not important) to 5 (Very important):

S1 - Get knowledge about the art

S2 - Get to know the physical space of the museum

S3 - See if a virtual tour compares to a physical visit to a museum

S4 - To see if after a virtual tour, I would be interest in doing a physical visit

The results of this question can be found in Figure 5.1[1]. As can be observed, most users consider the 4 statements important factors to engage on a virtual tour. The statement S3, however, seems to be the least important for a number of the test subjects.

[1]An introduction to the box plot like the one in 5.1 is presented in Appendix B

5.5.2 Group A Tasks

As stated in Section 5.2, the Group A Tasks focused on familiarizing the users with the website's navigation and functionalities. This section will present the results gathered during the execution of this tasks with a general analysis of each.

Task A1 to A4 - Starting Tasks

Table 5.11: Results of tasks A1 to A4.

	Completion Time (seconds)				**Able to complete? (# users)**		
Question	$\overline{X}$	σ	**min**	**max**	**Yes**	**Yes, w/ help**	**No**
A1 - Read the instructions in the home page	58.83	27.54	7	131	30	0	0
A2 - Start the Virtual Tour	2.17	0.46	2	4	30	0	0
A3 - Watch the introduction video	71.00	0.00	71	71	30	0	0
A4 - Click on the button "Start"	2.33	0.80	1	4	28	2	0

Table 5.11 presents the results of tasks **A1 to A4**. These tasks were labeled as "Starting Tasks" because they are mostly introductory and simple. The task **A1** concluded that, on average, users took 58.83 seconds to read the textual information, which is reasonable considering its length and content.

Regarding task **A2**, the results indicate that all users completed it quickly (within 4 seconds), suggesting that the functionality of the "Start Tour" button, located in the middle of the home page, is obvious to every user.

Task **A3** - Watch the introduction video was straightforward, as users only needed to watch it. No relevant data can be gathered in this task.

Lastly, task **A4** - Click on the button "Start" was also completed in under 4 seconds, indicating that the purpose of the "Start" button is clear and effectively serves its intended function.

Task A5 to A13 - Tour Tasks

Table 5.12: Results of tasks A5 to A13.

Question	Completion Time (seconds)				Able to complete? (# users)		
	$\overline{X}$	σ	min	max	Yes	Yes, w/ help	No
A5 - Turn off and on the audio-guide	6.00	5.21	2	24	28	2	0
A6 - Pause the room's presentation	3.60	2.63	1	15	25	5	0
A7 - Stop the room's presentation	4.30	4.71	2	25	29	1	0
A8 - Navigate freely in the 3D environment	13.77	8.32	2	42	30	0	0
A9 - Open the "Itinerary" while being in a room's information page	5.20	6.14	2	35	27	3	0
A10 - Open the information window of an object while being in a room's information page	8.23	3.14	3	18	26	4	0
A11 - Open and explore an image in the information window of an object	5.47	2.64	2	12	26	4	0
A12 - Go to the next room	2.90	1.40	2	7	30	0	0
A13 - Go to the previous room	2.13	0.43	1	3	30	0	0

Table 5.12 presents the results of tasks **A5 to A13**, referred to as "Tour Tasks" due to their focus on the tour's functionalities. In task **A5**, users located the mute/unmute button in an average of 6 seconds, a good response time for the first task on the room's information page. Two users required assistance, mainly to identify the correct button.

For task **A6**, users completed it in an average of 3.6 seconds, with a maximum time of 15 seconds. Since this feature was not explained in the homepage instructions, most users relied on instinct, but five needed assistance, expecting a more explicit button.

Task **A7** involved stopping the room's presentation, following the previous task to pause it. Most users quickly understood the task, though one needed guidance on the button's functionality.

Task **A8** introduced users to 3D navigation, with an average completion time of 13.77 seconds. The relatively small room size contributed to this time.

For task **A9**, users took an average of 5.2 seconds to use the toolbar below the 3D viewer. Three users required assistance, confusing the itinerary button in the navigational bar with the one in the toolbar.

In task **A10**, users needed to scroll to find the heritage section of the room's presentation page, taking an average of 8.23 seconds. Four users required assistance locating this section, which is at the bottom of the page, but can still be considered a positive result, as users were more focused on completing the task rather than exploring the page first.

Task **A11** involved opening an image in the object's information window, with most users completing it in an average of 5.46 seconds. However, four users needed help realizing the images were clickable.

Tasks **A12** and **A13**, involving navigation to the next and previous rooms, were straightforward, as the buttons were easily found in the toolbar. Most users completed these tasks quickly.

Task A14 to A23 - Navigation Tasks

Table 5.13: Results of tasks A14 to A23.

Question	Completion Time (seconds)				Able to complete? (# users)		
	$\overline{X}$	σ	min	max	Yes	Yes, w/ help	No
A14 - Open the page "Itinerary"	4.20	1.79	2	8	25	5	0
A15 - In the page "Itinerary", go to the "Earthquake" room, in the "Museum"	7.60	3.47	3	18	25	5	0
A16 - In the "Earthquake" room, find a label of the object "Dice" in the 3D viewer and click on it	14.50	10.46	3	60	27	3	0
A17 - Open the page "Heritage"	4.13	2.75	2	15	30	0	0
A18 - Open an object's information window and click in the button "See in the space"	5.77	2.28	3	13	30	0	0
A19 - Enter the room "Museum - Aula Maynense"	7.00	2.52	3	13	30	0	0
A20 - Open the information window of the object "Heart" and explore its 3D model	10.23	6.18	4	30	27	3	0
A21 - Click in the button "See in the space" in the "Heart" information window	6.33	3.95	2	16	30	0	0
A22 - Open the "About Us" page	2.87	1.31	2	7	30	0	0
A23 - Change the language of the website to English	2.90	1.40	2	9	30	0	0

Lastly, regarding the Group A phase, Table 5.13 present the results of tasks **A14**

to A23, labeled as "Navigation Tasks" because they are more related with navigational functionalities and general exploration of the remaining features. In contrast to Task A9, task **A14** required users to open the itinerary page. Most users understood they needed to click the "Itinerary" button in the top navigational bar, although five needed assistance with this nuance. On average, the task was completed in 4.2 seconds.

Task **A15** involved clicking on the "Museum" room in the itinerary to reveal its associated rooms. Many users initially searched for the "Earthquake" room without first selecting the "Museum." Those who clicked the correct button took an average of 7.6 seconds to complete this task, which is positive considering there was no prior explanation of the museum room functionality; however, five users required assistance.

Task **A16** asked users to explore the 3D viewer to find a specific object label, resulting in varied completion times ranging from 3 to 60 seconds, with an average of 14.5 seconds. This wide range of completion time reflects the users' ability to navigate in the 3D environment, which can vary according to previous experiences and skills. Three users needed help locating the correct label.

Task **A17** was straightforward, as users were already familiar with the navigational bar from previous tasks. The average completion time was 4.13 seconds.

In task **A18**, users, having already navigated the object's information window, completed the task easily in an average of 5.77 seconds.

For task **A19**, despite having been introduced to the multi-level functionality of the museum's rooms, users took an average of 7 seconds to grasp the task requirement, as most of them were trying to locate the room before opening the museum multi-level.

Task **A20** introduced users to the 3D model viewer for an object, taking an average of 10.23 seconds to complete. Although the 3D viewer of the objects appears bellow the image gallery, some users took some time realizing that they were separate elements. Three users needed assistance due to confusion about the task.

Task **A21**, being similar to a previous task, was completed in an average of 6.33 seconds.

Task **A22** was straightforward, as the "About Us" page was clearly visible in the navigational bar and was the only page not yet visited, resulting in an average completion time of 2.87 seconds.

Finally, task **A23** involved finding a language selector, a common feature on many modern websites, which users completed quickly, averaging 2.9 seconds.

It's also worth presenting the total time statistics per the tasks category, by calculating the total time taken by each user for each category. Those results are presented in Table 5.14. The **Starting Tasks** mainly involved reading the instructions in the main page and watching the introduction video prior to the beginning of the virtual tour. Therefore, the only variable that can produce a significant change here is the time users take to read the instructions, since the rest of th tasks were pretty straightforward. On average, users took 134.33 seconds to conclude this category's tasks. For **Tour Tasks**, users took on average 51.60 seconds. Although there were significant more tasks in this category, most

of them were performed rather quickly, as presented in this Section. Lastly, the category **Navigational Tasks** was completed in an average of 65.53 seconds.

Table 5.14: Results of Group A by categories.

	Results (seconds)			
Categories	$\overline{X}$	σ	**min**	**max**
Starting Tasks	134.33	27.20	83	206
Tour Tasks	51.60	19.36	27	123
Navigation Tasks	65.53	19.81	39	148
All Group A	251.47	51.10	163	447

5.5.3 Group B Tasks

This group consisted in more general tasks with no connection between them, aiming to assess how users perform after being familiar with most of the functionalities available in the website, as stated in Section 5.3. This section will present the results gathered during the realization of this group's tasks.

Table 5.15 presents the results of the Group B tasks. Starting with task **B1**, it aimed to assess whether users knew how to reach the specific room's information page. On average, it took 10.73 seconds for users to complete it, indicating a positive result as they navigated to the itinerary and located the "Cloister" room.

Task **B2** aimed to evaluate users' ability to locate a specific object. It took users an average of 21.57 seconds to accomplish this task, which required navigating through the itinerary page and finding the object within a comprehensive list of the Academy's items. With a standard deviation of 11.67 seconds, these results suggest high variability in how quickly users could locate the object.

Task **B3** focused on whether users understood how to navigate from one room's information page to another. To add complexity, users had to click on a room within the museum to reveal the final destination. On average, users completed this task in 19.57 seconds, although three needed assistance in recognizing that the room was located within the museum's section.

Regarding task **B4**, it involved searching for a specific object on the Heritage page and accessing its 3D model viewer. This task took users an average of 10.33 seconds to complete.

Task **B5** required users to navigate to the next object, the "Heart," from the "Human Body." Users accomplished this by clicking the arrows at the bottom of the object's information window. Since these arrows had not been previously introduced, some users were unaware of their existence. Nonetheless, 26 users instinctively used the arrows,

Table 5.15: Results of tasks of Group B.

Question	Completion Time (seconds)				Able to complete? (# users)		
	$\overline{X}$	σ	min	max	Yes	Yes, w/ help	No
B1 - Starting in the Home page, open the information page of the room "Cloister"	10.73	5.03	3	23	30	0	0
B2 - Starting in the "Home" page, open the information window of the object "Atwood's Machine"	21.57	11.67	5	60	30	0	0
B3 - Starting in the "Aula Maynense" information page, go to the "Philosophical Journey of Alexandre R. Ferreira" page	19.57	10.30	7	47	27	3	0
B4 - Starting in the "Heritage" page, open the 3D viewer of the object "Human Body"	10.33	3.12	4	16	30	0	0
B5 - With the information window of the object "Human Body" opened, go to the information window of the object "Heart"	7.47	8.20	2	36	26	4	0
B6 - In the information page of the room "Earthquake", open the information window of the object "Dice" and do so that, in the 3D viewer, the camera is directed at this object	13.90	7.79	3	31	25	5	0
B7 - Find the name of the person that did the voice over in Portuguese	11.90	7.62	2	30	26	4	0
B8 - Find the type of material of the object "Club with Human Figuration"	20.83	10.51	10	57	27	3	0
B9 - Open the Integral Digitalization of the work Atlas of Lázaro Luís	17.07	9.93	4	35	27	3	0

completing the task in an average of 7.47 seconds. Only four users needed assistance in understanding this task's objective.

Next, task **B6** assessed whether users were aware of the "See in the space" button available in the object's information window for items that exist physically in the room. Users completed this task in an average of 13.90 seconds, with five requiring assistance

primarily to locate the button.

Task **B7** involved accessing the "About Us" page to find the name of the person who did the Portuguese voice-over. Users took an average of 11.90 seconds to complete this task, although four needed assistance in realizing that this information could be found on the "About Us" page.

In tas **B8** users were required to find the object's description in its information window. While this section had not been pointed out directly in previous tasks, users had multiple opportunities to notice it. They took an average of 20.83 seconds to complete this task, and three required assistance to be directed to the description section.

Lastly, task **B9** required users to utilize their intuition regarding the "Integral Digitalization" feature, which had not been previously introduced. This feature could be found in the object's information window, beneath the descriptions of certain literature works available on the Academy's main website. Users took an average of 17.07 seconds to complete this task, with three needing assistance to locate the object's information window.

Regarding the total time of concluding the Group B phase, Table 5.16 presents these results. Although there's a considerable time range between the fastest user to finish this group, in 66 seconds, and the slowest, in 249 seconds, on average users took 133,37 seconds to finish this group. This result can be considered positive, as users were able to try most of the functionalities of the website in around 2.21 minutes.

Table 5.16: Results of Group B total times.

	Results (seconds)			
	$\overline{X}$	σ	min	max
All Group B	133.37	39.34	66	249

5.5.4 User Experience Questionnaire (UEQ)

In this context, the UEQ was conducted to assess the overall user experience of the website and was presented after the tasks phase. The participants were asked to rate their experience by providing responses to 26 questions of pairs of contrasting adjectives, such as "complicated" versus "easy". The responses were in the form of a 7-point scale, ranging from -3 (extremely negative) to +3 (extremely positive). The questions of this questionnaire can be found in Annex II.

The UEQ focuses on measuring the User Experience on six key dimensions:

- **Attractiveness:** General impression of the system. Is it pleasant or not?
- **Perspicuity:** How easy is it to understand and get familiar with the system?
- **Efficiency:** Does the user feel they can complete tasks with minimal effort?
- **Dependability:** How much control and security does the user feel while interacting with the system?

- **Stimulation**: Is the system motivating, fun and interesting to use?
- **Novelty:** Does the system offer innovative and creative features?

This questionnaire does not generate an overall score for user experience. Instead, the results are separated by individual scales, and each scale's mean score should be interpreted independently. The scales range from **-3** to **+3**, and values **between -0.8 and +0.8** should be interpreted as a **neutral** perception of the corresponding scale, suggesting that users do not feel strongly positive or negative about that aspect of the system. Values **above +0.8** indicate a **positive** evaluation of the scale, while values **below -0.8** indicate a **negative** evaluation.

The results can be presented in the form of the mean and variance values of each dimension, as can be seen in Table 5.17.

Table 5.17: UEQ scales results

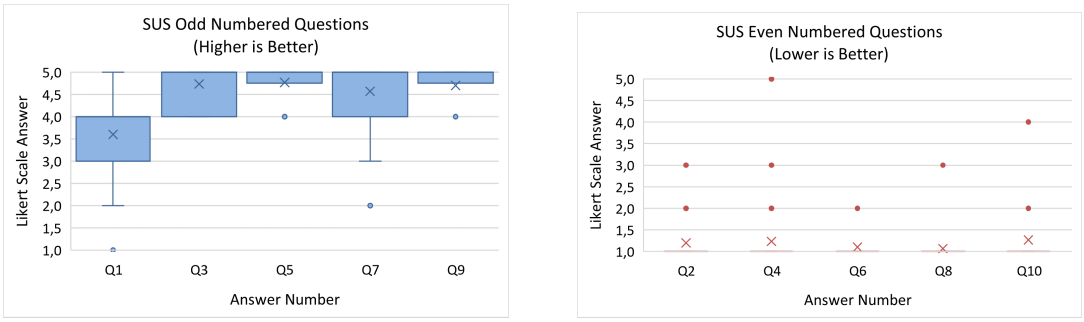
	Mean	**Variance**
Attractiveness	2.63	0.17
Perspicuity	2.39	0.17
Efficiency	2.47	0.24
Dependability	2.07	0.16
Stimulation	2.22	0.25
Novelty	1.30	1.42

As can be observed, overall all dimensions except **novelty** have a very high positive evaluations, above 2, showing that users found the system highly attractive, usable, efficient, dependable and stimulating. The high variance in the novelty dimension suggests a wider range of opinions, implying that users had differing opinions about how novel the system felt. These results suggest that the system is generally very well received, but there might opportunities for improvement on the perceptions of novelty. Figure 5.17 presents two box plots showing the distribution of the results of odd and even numbered questions.

5.5.5 System Usability Scale (SUS)

The System Usability Scale was used in the context of this user tests to get a global subjective assessment of the system usability. The SUS is a ten-item scale where users rate 10 statements on a five-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree". The final score range from 0 to 100, with higher scores indicating better usability. Generally, a SUS score above 68 is considered above average. The statements that users need to rate and that were used during this phase of the tests can be found in Annex III.

The calculation of the SUS score is a straightforward process. For each participant, the score for odd-numbered questions (positive statements) is obtained by subtracting 1 from their score, while for even-numbered questions (negative statements), the score is



(a) Odd numbered questions.

(b) Even numbered questions.

Figure 5.2: Boxplot of even and odd numbered questions.

calculated by subtracting their score from 5. After adjusting the scores for all 10 questions, the total score for each participant is summed and multiplied by 2.5, scaling it to a range of 0 to 100. Finally, the average SUS score for all participants is calculated by summing the individual scores and dividing by the total number of participants, which was 30.

After analyzing the responses from 30 participants, the average **SUS score** for the website is **91.3**. The minimum score found was **70** and the maximum was **100**. This score is a strong indicator of the system's overall usability, with 91.3 being well above the industry benchmark of 68, suggesting that the system is **easy to use** according to participants. As can be seen in Figure 5.2a, most test subjects gave high scores to odd numbered questions, indicating a positive perception of the usability. In Figure 5.2b, it was observed that the boxplot displayed only lines, indicating a lack of variability in the responses. This suggests that the participants had a consistent positive perception of the aspects addressed in these questions, since they tend to be on the lower values.

5.5.6 General Feedback

This section was dedicated to gather user's personal opinions and feedback on the website. The goal was to gain insights of their overall impressions, what they liked and disliked the most, and suggestions for potential improvements. The questions of this section can be found in Annex IV.

The first question was *GFD1 - Rank the following features in order of preference*. In this question users were asked to rank, in order of preference, 10 features that they had tested on the website. Each feature had to be rated from 1st to 10th, reflecting the user's personal preference for each functionality. No feature could share a ranking and each position could only be assigned to one feature. To evaluate the results, a scoring system was implemented: if a feature was ranked 1st, it received 10 points; if ranked 2nd, it received 9 points, and so on, with the 10th position earning just 1 point.

The results of this question can be seen in Table 5.18. As it can be observed, the feature that users enjoyed the most is the free navigation in the 3D viewer, while the one they enjoyed the least is being able to change the website's language.

Table 5.18: GFD1 - Results

Feature	Points
Free navigation in the 3D viewer	269
Visualization of 3D objects	244
Labels with object's information	191
Room presentation with audio-guide	182
High-quality image viewer	178
Face the object with the "See in the space" button	175
Heritage page	166
Audio-guide transcriptions	122
Pause menu during room's presentation	100
Change the website's language	72

The next questions were duplicated for both the desktop and mobile versions of the website, and were open-ended, allowing users to freely express their thoughts. Starting with the **desktop version**, the question *GFD2 - What did you enjoy the most about this website?* had the most frequent response mentioning the 3D navigation in the rooms and the availability of heritage objects directly on the page. This was followed by users highlighting the simplicity and easy flow of the website's navigation. The high quality of the 3D images was also praised, being a frequently mentioned favorite feature. One user stated, quoting, "*(What I enjoyed the most was) the possibility of visiting a historic site at home using a dynamic, efficient, and fun-to-use platform, while also being able to convey knowledge to the user through detailed information, both in text and verbally.*".

For the question *GFD3 - What did you enjoy least about this website?*, the most commonly disliked aspect was the absence of a search feature to quickly locate specific objects or rooms, which could have been placed in the top navigation bar or on the heritage page. The second most criticized feature was the automatic playing of the audio guide. While there is an implemented feature that saves the user's choice regarding the audio guide when switching between rooms, if the user navigates to a different page and then returns to the virtual tour, the audio guide always starts playing. Quoting a user, "*I think that the room's presentation starting automatically instead of on-demand can be inconvenient if the user just wants to read and navigate the page.*" The third most criticized feature of the website was the color scheme, which was considered outdated and not stylish by users.

Question *GFD4 - Do you have any suggestions to improve the user's experience when navigating the website?* generated a wide range of responses. Several users suggested that the website could offer a setting to increase or decrease the font size across the entire site, aiming to improve readability. Following their dissatisfaction with the absence of a search feature and the automatic playback of the audio guide, some users recommended addressing these issues. Other users proposed that the instructions on the main page could be presented more dynamically, incorporating images or even a short video.

For the question *GFD5 - Do you have any suggestions to improve the virtual tour?*, not many users responded. One user suggested the introduction of portals in the existing

doorways of rooms that would lead directly to another room, rather than relying on the "Previous/Next Room" buttons. Another user recommended that the descriptions of objects could be more detailed, providing more historical context.

Regarding the questionnaire for the **mobile version**, most users responded to the questions with the same answers they provided for the desktop version. However, in *GFM2 - What did you enjoy the most about this website?*, some users specifically praised the responsiveness and the simple layout of the mobile version. The question *GFM3 - What did you enjoy the least about this website?* only received answers that repeated the feedback given for the desktop version. For *GFM4 - Do you have any suggestions to improve the user's experience when navigating the website?*, there were only two responses: one suggested reducing the amount of text on the 'About Us' page, and another suggested that, overall, there should be less text throughout the entire mobile version of the website.

5.5.7 Design Opinion

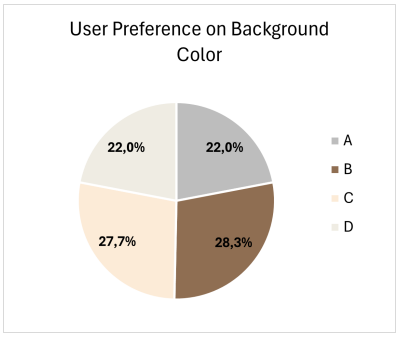
One of the phases of the user testing involved a dedicated section aimed at gathering users' opinions and feedback on various design options. This section was designed to facilitate a comparative analysis between the existing version of the website and several alternative design ideas. To achieve this, a series of questions were presented concerning different design elements. The exact questions with images can be found in Annex V.

Q1 - Image background color – This question presented the user with four different images of a painting featured on the heritage page, each displaying a different background color. The option that matches the background color chosen for the current version of the website is option B. As can be seen in Figure 5.3a, **option B** was chosen as the favorite design option with 28.3% of the votes, followed by option C with 27.7%.

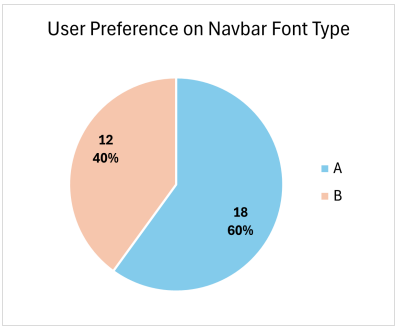
Q2 - Navigation bar font type – This question showed the user two different font types for the website's navigation bar. Option A is the current font type being used in the website and was chosen as the favorite with 60% of the votes, as can be observed in Figure 5.3b.

Q3 - Toolbar design – In this question, users were presented with two design options for the toolbar that appears under the 3D viewer of a room's presentation page. Option A consisted in the current version being used in the website, where the buttons appear with an icon followed by textual information that indicates what does the button do. Option B consisted in the buttons being composed only with icons, with no textual information. **Option A** was chosen as the favorite design possibility with 87% of the votes, as can be seen in Figure 5.3c.

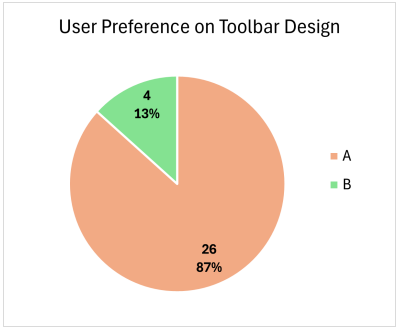
Q4 - Pause menu during a room's presentation – The current version in the website has a pause menu when a user clicks on the 3D viewer during a room's presentation page, which corresponds to option A. It was demonstrated a version of the room's presentation feature where, when a user clicks on the 3D viewer during the showcase, it stops completely, corresponding to option B. **Option A** was the favorite version of this



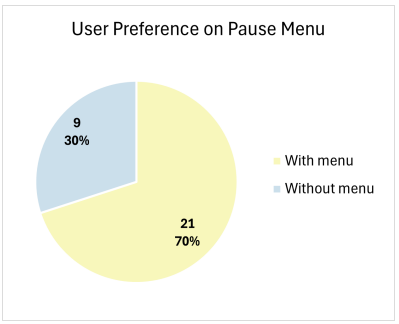
(a) Q1 - Object's background color.



(b) Q2 - Navigation bar font type.



(c) Q3 - Toolbar design.



(d) Q4 - Pause menu during room presentation.

Figure 5.3: Charts of the results of test subject's opinion regarding design elements of the website.

feature with 70% of the votes, as can be seen in Figure 5.3d.

5.6 Discussion

In the previous sections, brief analysis were conducted to present the results of both the tasks and the questionnaires responses. Overall, the performance across both tasks groups showed **positive results**, with all participants successfully competing every task, although with some requiring assistance. Task completion times for both Group A (Section 5.5.2) and Group B (Section 5.5.3) were within acceptable ranges for the complexity of the tasks involved.

The User Experience Questionnaire (UEQ) results, shown in Section 5.5.4, were **positive** across all dimensions measured. The lowest score was observed for the "Novelty" dimension, with a mean value of 1.3, though still being within the positive range. All other dimensions showed strong positive results, reflecting an good user experience.

Similarly, the System Usability Scale (SUS), with its results shown in Section 5.5.5 reinforced these positive findings, with an average score of 91.3. This score is significantly above the industry benchmark of 68, indicating a **high level of usability** for the website. Such a high SUS score is a strong indicator that users found the system easy to use, efficient

and intuitive.

Regarding direct feedback from users about potential improvements, it's important to note that, although user tests on task performance, usability, and experience were positive, there is still room for enhancement. Users shared their thoughts in the General Feedback results in Section 5.5.6, highlighting areas where improvements could be made.

Concerning the various design options, the tests detailed in Section 5.5.7 (Design Options) indicate that users generally prefer the designs presented and that currently exist in the website. However, some users mentioned in Section 5.5.6 (General Feedback) that they did not like the color palette of the website.

This section now aims to present a deeper analysis of the results by looking at them in a broader context, comparing user characteristics such as age and gaming experience with the tasks and questionnaires results. This analysis aim to understand whether these factors influenced task performance and overall system usability.

Age influence on task performance

Age is often considered a significant factor in technology adoption and usability, as younger individuals are generally more familiar with digital interfaces and may navigate them more efficiently. Therefore, in order to understand if age had an influence in task performance, measured as completion times of tasks, two-sample t-tests were performed for Group B Tasks. Participants were divided into two groups, one for individuals under

Table 5.19: Results of T-Test: Age vs. Task Performance.

Time Questions (s)	**Age < 30**	**Age** $\geq$ 30	**T-Test (CI = 95%)**
B1Q1 - From "Home" to "Cloister"	11.35 ±5.21	8.71 ±4.07	$t(28) = 1.22$, $p = 0.23$
B2Q1 - Find "Atwood's Machine"	20.91 ±12.64	23.71 ±8.06	$t(28) = -0.55$, $p = 0.58$
B3Q1 - From "Aula Maynense" to "Jorney"	18.74 ±9.51	22.29 ±13.06	$t(28) = -0.79$, $p = 0.43$
B4Q1 - Find object "Human Body"	9.57 ±2.79	12.86 ±2.97	$t(28) = -2.69$, $p = 0.01$
B5Q1 - "Human Body" to "Heart"	6.13 ±6.82	11.86 ±11.19	$t(28) = -1.67$, $p = 0.11$
B6Q1 - Use the "See in the space" button	13.35 ±7.20	15.71 ±9.93	$t(28) = -0.70$, $p = 0.49$
B7Q1 - Find the Portuguese voice over	12.13 ±6.80	11.14 ±10.49	$t(28) = 0.30$, $p = 0.77$
B8Q1 - Find the type of material of "Club"	19.51 ±8.29	25.14 ±15.93	$t(28) = -1.25$, $p = 0.22$
B9Q1 - Find the "Integral Digitalization"	16.43 ±9.32	19.14 ±12.32	$t(28) = -0.63$, $p = 0.54$

30 years old (sample size = 23), and the other for individuals 30 years old or above (sample size = 7). It's worth to mention that the sample size of the group of individuals 30 years old or above is considerably small and may limit the generalizability of the results. Table 5.19 provides the results, with a confidence interval of 95%. As can be observed, there is a **lack of evidence indicating that age has a significant impact on the results** of task performance, with only one task, **B4Q1 - Starting in the "Heritage" page, open the 3D viewer of the object "Human Body"**, that indicates a significant result.

Gaming habits influence on task performance

Another important explored variable was the influence of gaming habits on task performance. Gaming experience is often linked to a better performance in digital environments, as gamers tend to develop skills related with spatial awareness and interface navigation. In order to assess if gaming habits had any influence in task performance, two-sample t-tests were performed for Group B Tasks. Participants were divided into two groups, one for individuals who claimed to play games (sample size = 11), and the other for individuals that reported that they never played (sample size = 19). According to the t-test results, provided in Table 5.20, there is a **lack of evidence indicating that gaming habits have a significant impact on task performance**.

Table 5.20: Results of T-Test: Gaming Habits vs. Task Performance.

Time Questions (s)	**Play Games**	**Never Play Games**	**T-Test (CI = 95%)**
B1Q1 - From "Home" to "Cloister"	9.36 ±3.04	11.53 ±5.82	$t(28) = -1.14$, $p = 0.26$
B2Q1 - Find "Atwood's Machine"	19.36 ±7.90	22.84 ±13.41	$t(28) = -0.78$, $p = 0.44$
B3Q1 - From "Aula Maynense" to "Jorney"	17.27 ±8.83	20.89 ±11.07	$t(28) = -0.93$ $p = 0.36$
B4Q1 - Find object "Human Body"	11.55 ±2.70	9.63 ±3.20	$t(28) = 1.67$, $p = 0.11$
B5Q1 - "Human Body" to "Heart"	8.82 ±9.73	6.68 ±7.34	$t(28) = 0.68$, $p = 0.50$
B6Q1 - Use the "See in the space" button	15.45 ±7.13	13.00 ±8.20	$t(28) = 0.83$, $p = 0.42$
B7Q1 - Find the Portuguese voice over	8.91 ±5.70	13.63 ±8.17	$t(28) = -1.69$, $p = 0.10$
B8Q1 - Find the type of material of "Club"	21.27 ±10.68	20.58 ±10.70	$t(28) = 0.17$, $p = 0.87$
B9Q1 - Find the "Integral Digitalization"	14.55 ±10.73	18.53 ±9.42	$t(28) = -1.06$, $p = 0.30$

Prior experience with virtual tours influence on task performance

The third explored variable was prior experience with virtual tours and its potential impact on task performance. Being familiarized with virtual tour environments could lead to better navigation skills which would translate into quicker task completion and overall a more intuitive interaction with the website. To examine whether prior experience with virtual tours had any influence on task performance, two-sample t-tests were conducted for Group B Tasks. Participants were divided in two groups, one for individuals who had previously participated in a virtual tour (sample size = 13), and another for those who had no prior experience (sample size = 17). According to the t-test results, show in Table 5.21, there is a **lack of evidence indicating prior experience with virtual tours significantly impacts task performance**.

Table 5.21: Results of T-Test: Prior Experience with Virtual Tours (VT) vs. Task Performance.

Time Questions (s)	**Prior experience in VT**	**No prior experience in VT**	**T-Test (CI = 95%)**
B1Q1 - From "Home" to "Cloister"	12.38 ±4.39	8.00 ±5.27	$t(28) = 1.28$, $p = 0.21$
B2Q1 - Find "Atwood's Machine"	27.15 ±14.68	17.46 ±9.16	$t(28) = 1.98$, $p = 0.06$
B3Q1 - From "Aula Maynense" to "Jorney"	20.92 ±12.28	18.54 ±9.34	$t(28) = 0.44$ $p = 0.66$
B4Q1 - Find object "Human Body"	11.08 ±2.40	9.69 ±3.48	$t(28) = 1.06$, $p = 0.30$
B5Q1 - "Human Body" to "Heart"	9.46 ±8.19	7.00 ±8.09	$t(28) = 1.08$, $p = 0.29$
B6Q1 - Use the "See in the space" button	12.85 ±7.97	15.85 ±7.57	$t(28) = -0.61$, $p = 0.55$
B7Q1 - Find the Portuguese voice over	11.92 ±6.64	13.15 ±8.63	$t(28) = -0.33$, $p = 0.74$
B8Q1 - Find the type of material of "Club"	16.54 ±4.24	22.23 ±12.27	$t(28) = -1.83$, $p = 0.08$
B9Q1 - Find the "Integral Digitalization"	13.85 ±7.91	17.77 ±11.23	$t(28) = -1.36$, $p = 0.19$

Once again, it's crucial to acknowledge that due to the relatively small sample sizes, the results of these prior T-Tests can't be generalized to a larger population. The limited number of participants reduces the statistical power of the analysis, making it difficult to draw definitive conclusions.

Finally, it is important to revisit the research questions proposed in Section 1.3 to evaluate whether the results obtained in this study provide insights into each of them:

- **Q1** – Is it possible to create a digital platform, focused on cultural heritage presentation, that is engaging and informative?
- **Q2** – Can this platform ensure that all types of chosen media and media presentations run efficiently and smoothly in the browser?
- **Q3** – Can this project be generalized for implementation in other museums?

The user test study was more focused in gathering data to provide answers to Q1 and Q2. Starting with question **Q1**, there is data supporting the assertion that this system, a digital platform focused on presenting cultural heritage, is indeed engaging. Specifically, the User Experience Questionnaire measures the dimension of "Stimulation," interpreted as a motivating, fun, and interesting system. The score for this dimension was 2.22, which is considered positive. Given that the aim of presenting cultural heritage also involves conveying information about the objects and rooms featured, combined with the overall positive results from user tests, it can be said that there is evidence to support the claim that this system is informative.

Regarding question **Q2**, all types of chosen media and media presentations are considered by the users to run efficiently in the browser as, once again, the SUS score for dimension efficiency had a positive result of 2.47. Additionally, no users reported any issues related to the efficiency of opening images, watching videos, or exploring 3D models of rooms and objects. On the contrary, in the General Feedback, users praised the smoothness and flow of the website. Therefore, this question can be answered positively.

Lastly, for **Q3**, there is no clear evidence measured during the user tests that could provide a direct answer to this question. However, if this system is valid and serves its purpose for the *Academia das Ciências de Lisboa*, it can be interpreted that such a system may also be effective for similar projects and potentially generalized to other museums. Several reasons support the idea of generalization. First, the platform is designed to showcase cultural heritage, making it adaptable for various types of museums. Other institutions can modify the content to fit their specific collections and themes, and follow the guidelines of Section 3.5 to develop new features. Positive user feedback regarding engagement and efficiency indicates that the design elements and functionalities resonate well with users, which could be valuable for other museums. Furthermore, the system's reliance on widely used technologies for media presentation suggests that it can be implemented in different settings without significant technical barriers, specially if following the steps provided in Chapter 4. Overall, the project shows promise for generalization for museums with similar content to be displayed, which is the case of most.

6

Conclusion

Using technology to safeguard our cultural heritage has become increasingly important and widely practiced. As we face potential threats to our historical sites and artifacts, the fields of Cultural Heritage Preservation and Conservation play a crucial role . The technology advancements in these fields not only facilitate the preservation of art and culture but also enable the creation of digital twins — virtual replicas that can be shared with the public, allowing global access to our rich heritage. This idea was a fundamental motivational factor outlined in this thesis, as detailed in Section 1.1, which set the road map for this project along with the research questions defined in Section 1.3.

The developed system is presented in Chapter 3, following a deep requirements analysis. The methodology applied, as discussed in Section 3.3, followed an Iterative Design approach, allowing the development of multiple iterations of the website. Section 3.4 provides an exhaustive rationale for each design and implementation decision made throughout the process, that resulted in a collaborative effort of the research team and the partners at the *Academia das Ciências de Lisboa*, fundamental in identifying improvements and refinements of this project. The challenges imposed during the development phase, the collaborative effort between the teams and the multitude ideas for this project led to a formulation of a set of guidelines for creating similar platforms, presented in Section 3.5. Chapter 4 delved into the development phase, where the used tools and technologies were presented, followed by the development process behind the major functionalities and their technical implementation. Finally, Chapter 5 presented the testing protocol, detailing the tasks and questionnaires completed by participants during testing sessions. This chapter culminated in the presentation and analyze of the testing results, followed by a broader discussions that provided deeper insights into the data collected.

Although a considerable amount of data was collected through various types of questionnaires, each focusing on different aspects and dimensions, taking definitive conclusions is challenging given that only 30 user tests were conducted. Despite this limitation, there was still sufficient data to derive general insights, which are discussed in Section 5.6. This information provides valuable perspectives on user experiences and preferences, as well as answering the research questions posed for this project. As

mentioned in Section 5.6, data supports positive answer to question *Q1 -Is it possible to create a digital platform, focused on cultural heritage presentation, that is engaging and informative?*, indicating the possibility of creating such a platform. Question *Q2 - Can this platform ensure that all types of chosen media and media presentations run efficiently and smoothly in the browser?* also had data supporting a positive answer indicating the possibility of creating an efficient platform with a smooth user experience over a web browser. Lastly, there was no data gathered that could answer question *Q3 - Can this project be generalized for implementation in other museums?*, but it was concluded that in certain circumstances and for museums with similar content type, this project can indeed be generalized for implementation in other museums.

As this chapter is reaching it's end, it's also worth to leave a note on the biggest challenges of this project. Although I had previous experience working with some project's clients, this thesis gave me the chance to work directly with them, being responsible for most of the decisions made through the project, together with the coordinators and the Academy collaborators. This opportunity presented me a few challenges that arise only when dealing directly with clients, such as are understanding how the client works, establishing a workflow and schedules that accommodate both parties and being prepared to discuss the project and the decisions made at any given point. Overall, this thesis has offered me a unique chance to enhance my programming skills, improve my collaboration abilities, develop my communication and presentation capabilities, and deepen my enthusiasm for the path I want to pursue after completing this phase.

6.1 Future Works

While the current system has demonstrated its potential in presenting cultural heritage through a digital platform, there are numerous improvements and expansions that could be explored in the future. A good number of them were provided by the test subjects in Section 5.5.6, which are related to missing features, such as a search functionality to quickly locate rooms and objects. Others were provided in Section 3.5.4, where a number of possible features were described.

Although the website's design was considered visually appealing by most of the users, some of them mentioned that the color scheme could be different and the presentation of content could be more dynamic, such as presenting the instructions on the main page in a video or using animated images. Modern websites also use dynamic content reveal, which displays the page's content as the user scrolls down the page, which give a more engaging and interactive experience.

Regarding the virtual tour experience itself, the incorporation of portals within the 3D environment would be a significant improvement. Instead of having to press a button outside of the 3D viewer to transition between rooms, this feature would increase the immersive sensation and enhance the sense of exploration. Another interesting development would be the integration of 3D objects directly in the Matterport viewer.

This would create a more dynamic exploration of the objects that are present in the rooms, allowing users to interact them in different ways. Instead of the current system, which have labels on the objects that, when clicked, open a side window, this feature could be worked to create a more cohesive experience all inside the 3D viewer by creating a dynamic interaction with these objects.

Lastly, changing the way the rooms are presented initially could be a big improvement of this system. Currently, the Matterport's Guided Tour functionality jumps between locations in the room and rotates the camera when it's in a new position. By improving this feature to allow for aerial flights that smoothly move the camera continuously through the space, slowing down at certain relevant areas, we could create a much more dynamic and immersive presentation.

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A

Web Development Technologies and Libraries

A.1 Front-end Technologies

ReactJS[1] is an open-source library developed by Facebook that allows developers to make immense web-applications web apps using a component-based architecture. Developers can create reusable UI components, which can be personalized depending on the momentary needs and state of the system. Those components have internal state that, when changed, ReactJS renders it again without reloading the page. This is possible by ReactJS's virtual DOM (Document Object model) and reactive updates, that enables efficient rendering only on components that have actually been updated. When managing global state in larger applications, ReactJS's Context API provides a way to share state between components without having to pass props through every level of the component tree. Moreover, ReactJS uses JSX (Javascript XML), a syntax extension for JavaScript that allows developers to write UI elements in a mark-up style syntax, making the more readable and expressive.
A rich ecosystem of libraries and tools that complement its functionality, like Redux and MobX, together with a large and active supporting community, make ReactJS one of the most chosen front-end framework by modern developers. Websites like Facebook, Airbnb, Netflix, Dropbox and many others[2] were built with ReacJS, demonstrating it's versatility and efficacy by the variety of businesses that use is.

Angular[3] is a open-source framework developed by Google. Angulars architecture differ from React's by allowing changes with a model-view controller pattern[23]. When the model changes, the view updates the components that have changed, and vice-versa, simplifying the process of managing and updating application state. However, Angular

[1] React's website, https://react.dev, Last access: 2/2024
[2] Cmarix, 13 Most Popular Websites Built With React in 2023, https://www.cmarix.com/blog/most-popular-websites-built-with-react/, Last access: 2/2024
[3] Angular's website, https://angular.io, Last access: 2/2024

applications are organized into modules, each containing components, services and other building blocks, unlike React which has the UI composed by independent components. Moreover, Angular uses a real DOM and updates it directly, with change detection mechanisms in place to identify changes in the application. Unlike ReactJS, which is primarily a JavaScript library and can be built on JavaScript or TypeScript (a superset of JavaScript that adds static typing, interfaces and other features), Angular strongly encourages the use of TypeScript for development. State management in Angular is done by built-in tools, including services, RxJS for handling asynchronous operations and a centralized state management system for managing global state.

Lastly,**Vue.js**[4] is a progressive JavaScript framework developed by Evan You, described as a flexible and approachable framework that allows developers to incrementally adopt its features[20].
Vue differs from the previous frameworks by being praised for its simplicity and gentle learning curve, since its syntax closely resembles HTML and JavaScript. It also has a component-based architecture which allows easy encapsulation of HTML, JavaScript and CSS in a single file, which usually differs from the previous frameworks that have separate CSS files. State management it's made with its built-in tool Vuex for global state and components can also have their internal state which allow transferal of information between them using *props*. While not as large as the previous frameworks, Vue has a growing and active community having a supportive ecosystem with numerous plugins, extensions and third-party libraries.

Given a brief overview of the most known and used front-end frameworks nowadays, a comparison between them would be the next interesting step to take. In 2019, E. Saks wrote a paper with the goal of comparing those three frameworks in the following categories:

- **Popularity** - The information about frameworks popularity was collected from cloud services providers such as GitHub, NPM and Stack Overflow. On GitHub, information was gathered about what users have "liked" the most, what frameworks have most developers working on and what framework had the most issues opened about. Regarding NPM, information about how many packages were downloaded for each framework was acquired. Finally, from Stack Overflow, the interesting data was relative to how many questions were asked about each framework. It's important to notice that all of these data doesn't not directly imply the frameworks popularity as it can be ambiguous, but gives an overall overview.
- **Performance** - A single page application was built in each framework and applications' loading speeds were tested. The tests, applied equally to all frameworks, consisted on creating a table and removing or adding different number of rows a few number of times.

[4]Vue's website, https://vuejs.org/, Last access: 2/2024

Regarding popularity, E. Saks concluded that React was the most popular framework in 2019. When it comes to performance, Vue was the fastest performing framework in all tests. The author also compared the learning curve of the three frameworks but since it's a subjective evaluation, as it can not be measured quantitatively, his results are based on his opinion and should be taken with a dose of criticism. However, he pointed that Vue was the easiest one to learn for the newcomer, followed by React with a little more complex syntax and worse documentation.

As of 2023, Stack Overflow Insights Trends[5], which shows the popularity about frameworks(i.e, the number of questions placed on their website regarding a set of frameworks) declares that ReactJS is the framework with the most questions asked, followed by Angular and then by Vue.js, as seen on Figure Figure A.1. The analysis of this graph can either imply that Reach is in fact the most popular and used framework, but can also mean that it is hard enough to be the framework that make developers ask most of the questions regarding it.

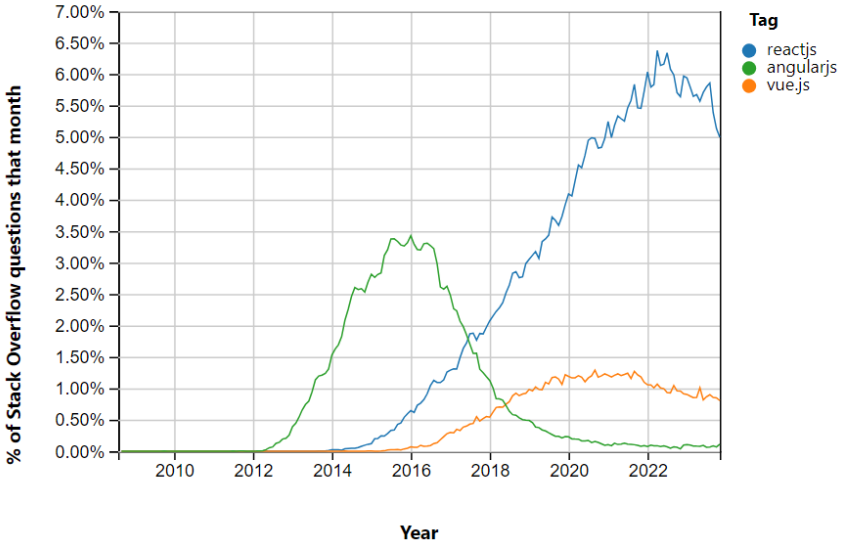


Figure A.1: Stack Overflow Insights Trends comparison of ReactJS, Angular and Vue.js, 2023.

A.2 Back-end Technologies

Node.js[6] is an open-source, cross-platform JavaScript runtime environment designed for server-side and network applications. It allows the developer to use JavaScript to write command-line tools and server-side scripts for building scalable applications. Internally, the runtime uses Chrome V8 engine - developed by Google, compiles JavaScript code directly to native machine code for better performance. Being built on an event-driven

[5]Stack Overflow Insights Trends, https://insights.stackoverflow.com/trends, Last access: 2/2024
[6]Node.js's website, https://nodejs.org/en, Last access: 2/2024

model, Node.js's execution code is driven by events and can handle a large number of concurrent connections efficiently with asynchronous programming, without blocking the execution of the entire program. This is achieved with the use of Promises, callbacks and async/await functions. Node.js can be used for a variety of goals, such as real-time applications, APIs, microservices and Web Servers [56]. With the use of Express.js, a web application framework build on top of Node.js, developers have a set of features and tools for building web applications, being one of the most popular choices for Node.js development[7].

PHP - Hypertext Preprocessor[8], originally created by Rasmus Lerdorf in 1994, is a widely-used server-side scripting language designed for web development. PHP is considered an easy language to learn, having its syntax similar to C and by giving the possibility of embedding PHP directly within HTML code. Other key features make PHP one of the most desired backend languages to develop with, such as built-in session management tools, cookie handling, easy process of form handling and file operations. One of the most used back-end frameworks is Laravel, a PHP framework known for its efficient syntax and robust features. [9].

Comparing both technologies, Lei et al. [35] concluded, after running different systematic tests and realistic behavior tests that, that Node.js performs much better than PHP in high concurrency situation. PHP handled small requests well, but struggled with large requests, and Node.js prefers to be used in IO-intensive situations, not compute-intensive sites.

A.3 3D Engines and Libraries

Three.js[10], JavaScript library that simplifies the creation of 3D content for web applications. Three.js was created by Ricardo Cabello around 2010. The library was initially developed as an experimental project to explore the capabilities of WebGL, and was soon released as an open-source project, allowing developers worldwide to access, use, and contribute to the library. This open approach has played a significant role in its widespread adoption and continuous development. It is built on top of WebGL, a web standard for rendering 3D graphics in browsers. It abstracts the complexities of WebGL which makes it more accessible to developers. Its adaptability and versatility ensure that 3D content produced using Three.js can be accessed across a range of web browsers and platforms, thereby extending the reach of such content to a diverse and broad audience. One of the distinctive features of Three.js is its high degree of customizability as it offers a comprehensive set of options for tailoring 3D scenes, models, and materials to specific requirements, allowing

[7] Epam, Top 6 Node JS Frameworks: Which One to Choose in 2023, https://anywhere.epam.com/business/best-node-js-frameworks, Last access: 2/2024

[8] Stack PHP's Website, https://www.php.net/, Last access: 2/2024

[9] Turing, Top 10 Backend Frameworks in 2024, https://www.turing.com/resources/backend-frameworks, Last access: 2/2024

[10] ThreeJS's Website, https://threejs.org/, Last access: 2/2024

for precise control over the visual aspects of the created content. Furthermore, Three.js provides robust capabilities for the management of 3D scenes, which encompasses the manipulation of lighting, cameras, and objects, smoothing the process of creating complex 3D environments.

Unity[11] is a cross-platform game engine and development environment. This game engine can be used to create 2D and 3D games and supports a wide range of platforms, including Windows, macOS, Linux, Android, iOS, PlayStation, Xbox, Nintendo Switch and WebGL [60]. Using Unity's "Build Settings", the developer can target multiple platforms from a single project. Unity offers high-quality graphics and rendering capabilities, including real-time lighting, shaders, and post-processing effects. The scripting language is C#, making it accessible for many developers and providing a powerful scripting environment, and developers can access pre-build assets, tools and plugins using the Asset Store, therefore enhancing their projects. Its built-in physics engine it's a powerful tool for simulating realist physical interactions withing games and simulations. As such, and amongst other reasons, this game engine is said to be very beginner friendly and is a popular game engine choice for the development of many indie games [16]. Another factor for its popularity it's its price - free if the revenue or funding is less than $100K in the last 12 months. A detailed and easy to understand documentation, a vast library of free (and many others paid) assets, models and plugins and a large supporting online community are a few other reasons to make this engine a great choice for beginners or students.

Unreal Engine[12] was one of the first game engines to ever be produced. It's origins can be traced back to the release of the first Unreal game in 1998. The engine itself, known as Unreal Engine 1, was developed by Epic Games. Since then, it has gone through several upgrades, with Unreal Engine 4 and Unreal Engine 5 being the most recent versions. When it comes to graphics quality, Unreal Engine is renowned for its advanced graphics and rendering capabilities. It offers features like physically-based rendering, global illumination, dynamic lighting, and a high degree of realism, being a better choice for those more concerned with graphics quality and realism. Users can code their games in C++, but this engine offers a very appealing way of building games, using Blueprint Visual Scripting which allows developers to create game logic and interactions without the need for coding directly. This allows users with no coding experience to build their own games. However, this engine provides an abundance of additional features and extensive customization capabilities, enabling the creation of exceptionally complex projects [57]. Many famous games in the industry were creating using this game engine, like Fortnite and PUBG (PlayerUnknown's Battlegrounds), amongst others. Unreal Engine has made a significant impact on the film industry, particularly in the realm of virtual production, where it's used to create virtual sets, environments, and real-time rendering. The Mandalorian and The Lion King (2019) are some examples where Unreal Engine was used, to create the

[11] Unity's Website, https://unity.com/pt, Last access: 2/2024
[12] Unreal Engine's Website, https://www.unrealengine.com/, Last access: 2/2024

breathtaking and realistic CGI environments.

PlayCanvas[13] is a web-based game development platform. It is entirely web-based, meaning that it's possible to create, edit, and publish games and interactive content directly in your web browser. This approach eliminates the need for complex installation and setup processes, making it easy to get started. The support of creating 3D graphics and realistic physics simulations are a few of the key features of this engine. Just like Unreal Engine, it also allows for visual scripting, allowing creators with no coding knowledge to develop their projects in the platform. As this is not as well known as other engines, there aren't any famous titles created with this engine, but it has found success in web-based games, interactive applications, and experiences with some small games having been created in this engine. A distinctive feature of this engine is its complete browser-based operation. It also offers a real-time collaborative editor, enabling multiple developers to concurrently contribute to a project without the necessity of integrating version management platforms.

The last game engine worth mentioning is **Babylon.js**[14]. Created by David Catuhe, a software engineer at Microsoft, the project began as an internal tool for rapidly prototyping and testing 3D web experiences and was developed within the Microsoft Corporation. In November 2013, Babylon.js was open-sourced and made available to the public. This step marked the beginning of the framework's growth and expansion into the open-source community. The core focus of Babylon.js is real-time 3D graphics which, as expected in a game engine, provides tools for creating and rendering 3D scenes, complete with objects, lights, cameras, and materials. It is compatible with a wide range of web browsers, ensuring that 3D content can be accessed by users on various devices and platforms. Babylon.js also offers a comprehensive set of features for game development and interactive content, including physics simulations, animations, particle systems, and sound support. A key feature of this engine is that is it's Physically Based Rendering (PBR) system that enables developers to achieve realistic lighting, shading, and material effects in their 3D scenes.

[13] PlayCanvas's Website, https://playcanvas.com/, Last access: 2/2024
[14] Babylon.js's Website, https://www.babylonjs.com/, Last access: 2/2024

B

Box Plot Reading Guide

This section summarizes the information contained in a box plot. A box plot, also known as whisker-box plot, is a graphical representation that summarizes the distribution of a dataset. It display's the data's minimum, first quartile (Q1), median, third quartile (Q3), and maximum. The "box" represents the interquartile range (IQE) between Q1 and Q3, while the "whiskers" extend to the minimum and maximum values within 1.5 times the IQR. Any points outside this range are considered outliers and are plotted individually. An example of this graph can be seen in Figure B.1.

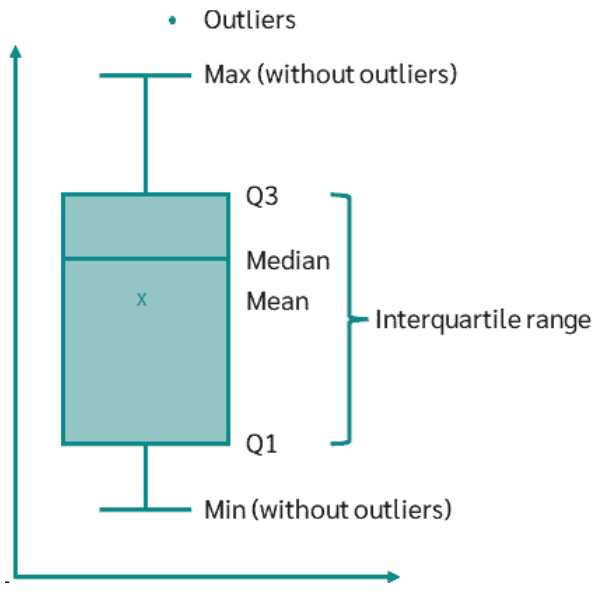


Figure B.1: Example of a box plot.

I

Consent Form for Testing Session

Consent Form

To participate in this study, you must be aware of the conditions of the experience, which data will be collected, and how they will be processed. You may only participate in this session if, after reading this information, you agree to participate in the study under the conditions stated below.

1. **Considerations about the nature of the experience**

This study is part of the master's thesis plan of student Nelson Faria. The aim of this study is to examine user experience, navigability, and usability of the website developed for the thesis project.

2. **Considerations about the data collected**

In order to evaluate the points under analysis, in addition to the responses to this form, the following data will also be collected throughout the session:

- Audio capture via microphone;
- Screen recording;

All data collected will be anonymized before processing and will only be used within the scope of the project in question, and will not be shared with third parties.

The information collected will be present in the questionnaire you will complete at the end of the session, along with values collected by the system and visual and verbal observations gathered by the author(s) of the study during the session.

By selecting "I Accept," you declare that you agree to participate voluntarily in this study, under the aforementioned conditions. Please note that even after agreeing to participate in the study, you can always request to pause or terminate the session at any time if you consider it necessary.

We thank you for considering being a part of this study.

II

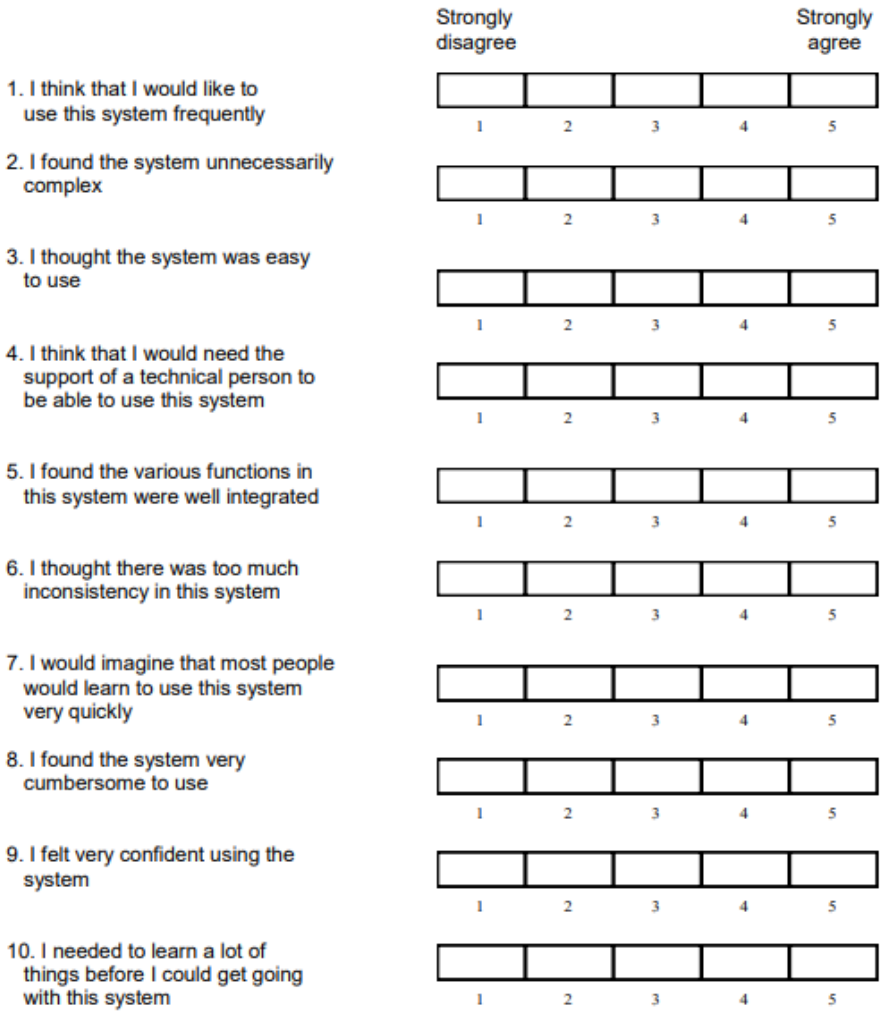
User Experience Questionnaire (UEQ)

Please assess the product now by ticking one circle per line.

	1	2	3	4	5	6	7		
annoying	○	○	○	○	○	○	○	enjoyable	1
not understandable	○	○	○	○	○	○	○	understandable	2
creative	○	○	○	○	○	○	○	dull	3
easy to learn	○	○	○	○	○	○	○	difficult to learn	4
valuable	○	○	○	○	○	○	○	inferior	5
boring	○	○	○	○	○	○	○	exciting	6
not interesting	○	○	○	○	○	○	○	interesting	7
unpredictable	○	○	○	○	○	○	○	predictable	8
fast	○	○	○	○	○	○	○	slow	9
inventive	○	○	○	○	○	○	○	conventional	10
obstructive	○	○	○	○	○	○	○	supportive	11
good	○	○	○	○	○	○	○	bad	12
complicated	○	○	○	○	○	○	○	easy	13
unlikable	○	○	○	○	○	○	○	pleasing	14
usual	○	○	○	○	○	○	○	leading edge	15
unpleasant	○	○	○	○	○	○	○	pleasant	16
secure	○	○	○	○	○	○	○	not secure	17
motivating	○	○	○	○	○	○	○	demotivating	18
meets expectations	○	○	○	○	○	○	○	does not meet expectations	19
inefficient	○	○	○	○	○	○	○	efficient	20
clear	○	○	○	○	○	○	○	confusing	21
impractical	○	○	○	○	○	○	○	practical	22
organized	○	○	○	○	○	○	○	cluttered	23
attractive	○	○	○	○	○	○	○	unattractive	24
friendly	○	○	○	○	○	○	○	unfriendly	25
conservative	○	○	○	○	○	○	○	innovative	26

III

System Usability Scale (SUS) Questionnaire



IV

General Feedback Questionnaire

GFD1 - Rank the following features in order of preference *

	1°	2°	3°	4°	5°	6°	7°	8°	9°
Room presentation with audio-guide	○	○	○	○	○	○	○	○	○
Audio-guide transcriptions	○	○	○	○	○	○	○	○	○
Labels with object's information	○	○	○	○	○	○	○	○	○
Free navigation in the 3D viewer	○	○	○	○	○	○	○	○	○
Visualization of 3D objects	○	○	○	○	○	○	○	○	○
Heritage page	○	○	○	○	○	○	○	○	○
High-quality image viewer	○	○	○	○	○	○	○	○	○
Change the website's language	○	○	○	○	○	○	○	○	○
Face the object with the "See in the space" button	○	○	○	○	○	○	○	○	○
Pause menu during room's presentation	○	○	○	○	○	○	○	○	○

GFD2 - What did you enjoyed the most in this website?

A sua resposta

GFD3 - What did you enjoyed the least in this website?

A sua resposta

GFD4 - Do you have any suggestions to improve the user's experience when navigating the website?

A sua resposta

GFD5 - Do you have any suggestions to improve the virtual tour?

A sua resposta

GFD6 - Comments

A sua resposta

V

Design Opinion Questionnaire

IMAGE A

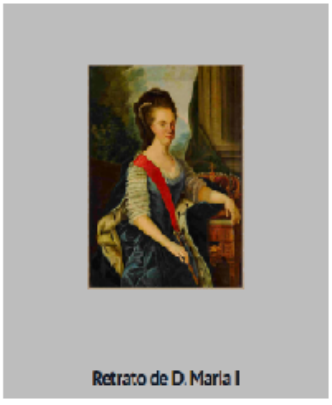


IMAGE B

IMAGE C

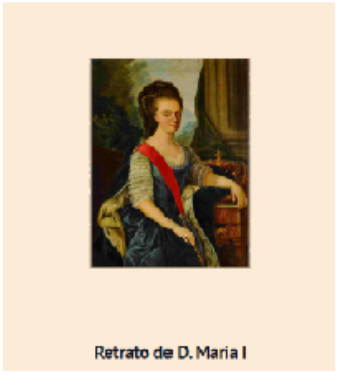
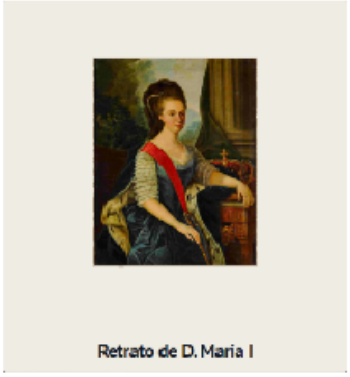


IMAGE D



DES1 - Which of the previous design options is your favorite? *

	1º	2º	3º	4º
Image A	◯	◯	◯	◯
Image B	◯	◯	◯	◯
Image C	◯	◯	◯	◯
Image D	◯	◯	◯	◯

Image E

Image F

DES2 - Which of the previous designs related with the type of font of the navigationam bar is your favorite? *

- ◯ Image E
- ◯ Image F

Imagem G

Imagem H

DES3 - Which of the previous designs related with the toolbar is your favorite? *

- ◯ Image G
- ◯ Image H

DES4 - With version of the interruption of the room's presentation is your favorite?

- ◯ With pause menu
- ◯ Without pause menu

VI

Characterization Questionnaire

IU1 - Age *

A sua resposta

IU2 - Education Level *

- ◯ Less than high school
- ◯ High school or equivalent
- ◯ Bachelor degree
- ◯ Master degree
- ◯ Doctorate

IU3 - Gender *

- ◯ Male
- ◯ Female
- ◯ Other

IU4 - How regularly do you visit websites in a computer? *

- ◯ Never
- ◯ Annually
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

IU5 - How regularly do you visit websites in a computer (phone,tablet)? *

- ◯ Never
- ◯ Annually
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

IU6 - How regularly do you play video games? *

- ◯ Never
- ◯ Annually
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

IU7 - How regularly do you watch videos on a computer or mobile devices? *

- ◯ Never
- ◯ Annually
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

IU8 - How regularly do you visit museums? *

- ◯ Never
- ◯ Annually
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

IU9 - How regularly do you visit websites of museums? *

- ◯ Never
- ◯ Annually
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

IU10 - Have you ever engaged in a virtual tour of a museum? *

- ◯ Yes
- ◯ Não

IU11 - What would be important for you to engage on a virtual tour?

S1- Get knowledge about the art *

	1	2	3	4	5	
Not important	○	○	○	○	○	Very important

S2- Get to know the physical space of the museum *

	1	2	3	4	5	
Not important	○	○	○	○	○	Very important

S3- See if a virtual tour compares to a physical visit to a museum *

	1	2	3	4	5	
Not important	○	○	○	○	○	Very important

S4- To see if after a virtual tour, I would be interest in doing a physical visit *

	1	2	3	4	5	
Not important	○	○	○	○	○	Very important