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Augmented Reality and cultural heritage

the development of an Augmented Reality Experience in Museo del '900 in Milan

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Abstract - IT

Durante il nostro Progetto di tesi abbiamo esplorato le potenzialità della realtà aumentata applicata al settore del turismo e della divulgazione dei beni culturali. Iniziamo con una panoramica su come il digitale ha modificato la nostra esperienza come turisti con una particolare attenzione a come musei e gallerie d'arte hanno impiegato queste tecnologie per migliorare la loro offerta. In seguito, ci concentriamo sull'utilizzo della realtà aumentata e sul valore aggiunto che può fornire al turismo culturale, cercando di capire come catturare un riscontro positivo. Nell'ultima parte di ricerca analizziamo lo stato dell'arte portando una panoramica di oltre 100 applicazioni ed esperienze sviluppate dentro e fuori laboratori di ricerca. La ricerca effettuata ci ha fornito una conoscenza sufficiente delle potenzialità e dei rischi che potremmo incontrare introducendo la realtà aumentata in un museo o sito culturale, fornendoci una buona conoscenza come base necessaria allo sviluppo del nostro progetto.

Nella seconda parte della tesi raccontiamo la realizzazione di un'applicazione in realtà aumentata per il Museo del '900 di Milano utilizzando Unity 3D. Raccontiamo tutto il processo di design, dalla ricerca preliminare e all'analisi del contesto allo sviluppo di personas e user paths più dettagliati, con l'obiettivo di formulare un concept valido. Dopo questi studi di contesto e la definizione del concept abbiamo selezionato le opere d'arte specifiche su cui lavorare e quali contenuti e informazioni inserire nella nostra narrazione, cercando il modo migliore di implementarli. L'esperienza finale è strutturata su due opere: Manifestazione Interventista di Carlo Carrà e Natura Morta (Piccola Velocità) di Ardengo Soffici e consiste di una prima parte di spiegazione e un'esperienza interattiva con all'interno del dipinto. Una successiva fase di test ha mostrato il successo del nostro prototipo e ha riportato come il nostro utilizzo della realtà aumentata sia stato coerente e di come abbiamo trovato un modo di implementarla con successo, per migliorare l'attuale esperienza offerta da musei e siti culturali.

Abstract - EN

During our thesis project, we explored the potential of Augmented Reality applied to the tourism and cultural heritage sector. We start by giving a first overview of how digital technology has changed our experience as tourists, giving particular attention to how museums and art galleries apply those technologies to improve their experience.

Then, we focus more on Augmented Reality and the value it can add to cultural heritage tourism (art galleries, museums, and cultural heritage sites) trying to understand how to capture a proper technology acceptance.
In the last part of the research, we analyze the state of the art, giving an overview of over 100 applications and experiences that have been developed inside and outside research labs. The research we made gave us sufficient knowledge about both the potentialities and possible risks we might encounter when introducing AR in a museum or cultural heritage experience, giving us good background knowledge that was a necessary basis for the development of our project. In the second part of the thesis, we describe the development of an Augmented Reality app for Museo del 900 in Milan, using Unity 3D. We cover the whole design process from the preliminary research and context study to the development of detailed personas and user paths to formulate a valid concept. After this contextual study and concept definition, we selected the specific artwork to work on and decided which contents and information pieces were worth to be inserted in our augmented narration and found the better way to implement them.

The final experience was structured on two artworks: Manifestazione Interventista by Carlo Carrà and Natura Morta (Piccola Velocità) by Ardengo Soffici. It was structured with a first explanatory part and a successive interactive experience within the augmented paintings. Our subsequent testing phase showed the success of our prototype being highly engaging and very well reported, showing that we made coherent use of Augmented Reality and successfully found a way to implement it to improve the modern museum and cultural heritage experience.

Part 1
Context Research

Chapter 1
Museums and digital technologies

Introduction

Before going into detail about the applications of Augmented Reality within cultural heritage tourism, we are taking a broader look at how digital technologies have been integrated into the tourism sector to later focus on museums, art galleries, and cultural institutions and on the specific uses they are making of digital technologies. In this chapter, we are first taking a quick look at the different kinds of digital services available for tourists and the different ways they help them both before their journey (with suggestion platforms and online booking) and during their explorations with wayfinding apps and digital information. Even if not deeply related to our topic, these pieces of information give us a good and necessary overview of how digital technologies have affected the tourism experience and the general benefits digital technologies can deliver to travelers and tourists.

We are then going to the specific usage museums are making on digital technologies both inside and outside their spaces, both before, during and after the visits. We not only have digital experiences and activities planned during the visits (which will be the main focus of the next chapters), but we can also see how cultural institutions are using both their channels (such as websites) and social media platforms to promote themselves and to make their collections accessible everywhere. This also creates the chance to give access our visitors to all the knowledge and information available, giving the opportunity for a further divulgation of knowledge and culture beyond any previous possibility. We are also analyzing those applications planned to be used during a visit and inside the actual museums not using augmented reality. We space from touchscreens and multimedia installations to mobile apps and guides, covering a wide range of applications and possibilities, many of which will be re-proposed (using Augmented reality) when we analyze the case studies more deeply. For each of these two main categories, we will describe a few meaningful applications.

This chapter is not yet going deep in the topic of our thesis but is providing some corollary knowledge on the broader sector we are taking into consideration. Before

analyzing the relationship between AR and cultural heritage tourism, it's essential to have a general understanding of how digital technologies have affected the whole tourism sector and redesigned the experience we have as tourists, and we must understand the general usage museums and art galleries are making of digital technologies as well, to understand how AR can help to provide those benefits, and how it can actively contribute to the improvement of the actual cultural tourism experience.

and art galleries are making of digital technologies as well, to understand how AR can help to provide those benefits, and how it can actively contribute to the improvement of the actual cultural tourism experience.

1.1 Digital technologies and tourism

The tourism industry has undergone a significant transformation in recent years, largely driven by advancements in digital technologies. From the way travelers plan their trips to the on-site experiences they encounter and the post-trip sharing of memories, digital technologies have revolutionized every aspect of the tourism sector. This paragraph will explore how digital technologies have affected the tourism sector: we identified different kinds of digital services developed for tourists and change our travel experience in different ways. We are now spacing trhough the main service categories that we identified affecting tourist experiences; for each of them, we are providing a short description of the kind of service we are referring to, and a few data to show how relevant and impactful those services have been.

Online Booking Platforms:

The advent of online booking platforms like Expedia, Booking.com, and Airbnb has revolutionized the way tourists plan and book their trips; the main online platforms have generated a combined revenue of over 144 Millions $ in 2022. According to a survey by Statista, in 2020, approximately 83% of US adult travelers prefer online travel agencies (OTAs) to book their accommodations and flights. This represents a significant shift from traditional travel agencies. The most important reasons that lead to this strong preference are mainly the following: Online booking platforms make it easy for travelers to book their trips 24/7, from anywhere in the world, they offer a wide range of travel options, from budget-friendly flights and hotels to luxury accommodations and experiences. Online booking platforms often offer lower prices than travel agents. This is because online booking platforms can negotiate volume discounts with airlines,

hotels, and other travel suppliers. Lastly, Online booking platforms give travelers access to detailed information about travel options, such as prices, amenities, and reviews. This helps travelers to make informed decisions about their trips.

Mobile Applications:

mobile applications have become essential tools for travelers. With apps like TripAdvisor, Yelp, and Google Maps, travelers can access real-time information on local attractions, restaurants, and transportation options. These apps have made travel more accessible and convenient, helping travelers make the most of their holidays. Statista.com listed the most downloaded apps for tourists in 2022: Google Maps is the most downloaded with 113 millions new user only in the last year, followed by Uber with 107 millions downloads, follows the already mentioned Booking.com and AirBnB with 80 and 51 millions downloads respectively. It's interesting how we find in this list very different applications: we have route planning and wayfinding such as Google Maps, suggestion and reviews services like TripAdvisor, booking sites such as booking.com or Airbnb and transportation apps like Uber or Indrive. This variety of mobile services and the amount of success and popularity they have show the different ways mobile technology affects tourism experience, providing different benefits and advantages for the tourists.

Social Media :

Social media platforms play a crucial role in tourism marketing. Instagram, Facebook, and TikTok are filled with travel influencers who promote destinations and experiences. A report by Influencer Marketing Hub shows that the global influencer marketing industry is expected to be worth $13.8 billion in 2021. Tourists now share their travel experiences through user-generated content on social media platforms. This content serves as a form of word-of-mouth marketing, influencing others' travel decisions. Social media has a big influence on travel decisions. As Hudson et Al (2012) 44% of respondents strongly agreed that the reviews posted by other users helped them during the initial decision of vacation destinations. Živković et al. (2014) affirm that the most popular activity during and post vacation among tourists is sharing self-made videos or photos. After vacation, almost 25% are proactive travelers as they write reviews versus 20% of them who do it already during vacation.

Online Travel Communities:

Online travel communities and forums, such as TripAdvisor and Lonely Planet's Thorn Tree, have become invaluable resources for travelers. These platforms facilitate knowledge-sharing and community-building among tourists. As of 2020,

TripAdvisor had over 463 million reviews and opinions. Whiles some of these communities are member initiated (we can find numerous discussion groups on Facebook or Reddit and other social platforms) some others, like TripAdvisor are company sponsored and created with that precis outcome; thus makes the concept of Online Travel Community a bit blurred, not referring only to a specific service, but to a way to engage and communicate online. Zhou et Al. (2021) made an extensive review trying to better understand Online Travel Communities (OTCs); their main findings

Digital communicative artifacts:

Digital technologies have contributed to the reduction of paper printed artifacts in the tourism industry. It was common a few decades ago to find tourist guides and city maps in almost every hotel; nowadays those artifacts have been almost completely substituted by digital artifacts: E-tickets, e-brochures, and digital maps have become always more accessible and popular, significantly decreasing the need for printed materials. This gives both an advantage to the user, which is not bounded to many pieces of paper, but also has an environmental positive consequence, decreasing paper consumption. we should also consider the economic implications of this transformation: tourism businesses have saved considerable money on printing and distribution costs and have reached a broader audience through online marketing and distribution platforms. These digital tools have not only made travel more convenient but also more environmentally and economically sustainable.

IoT and Smart Tourism

The Internet of Things (IoT) has enabled smart tourism experiences, with connected devices providing real-time information and enhancing convenience. Smart hotels, for example, allow guests to control room settings through mobile apps. Tomislav et Al. (2019) mapped the possible IoT applications inside smart tourism, providing a list of many different services deliverable with smart sensors: we have personalized hotel rooms with customizable and controllable lights, temperatures and tv channels, Voice interaction affecting other devices (such as Amazon Alexa), Mobile integrations (at Starwood and Hilton hotel, key cards and switches are now available at the click of a button on a mobile device.) and many other applications like remote health monitoring while traveling, Valpas has developed an autonomous bed bug prevention system that allows guests to stay carefree from bed bugs. The possibility of IoT, when applied to the tourism and hospitality sector, are multiple, and it will continue to impact guest service and customer relationship management in tourism and hospitality.

1.2 Digital Museums

Museums and art galleries have traditionally been revered institutions that house our cultural heritage and artistic achievements. However, these institutions have undergone a remarkable transformation in recent decades, embracing digital technologies to enhance visitor experiences, expand access, and preserve invaluable artworks. In this section we are going to explore how museums and cultural heritage institutions can benefit from digital technologies. We are going to cover different benefits and advantages IT can bring to cultural heritage both inside and outside museums and art galleries. We are firstly going to cover the benefits digital technologies bring to museums and cultural institutions outside their actual experience and how they can rely on the Web to increase their attractiveness, then we are going to analyze more specifically those digital applications developed inside museums and how they are re-designing the visit experience.

Digitalization is offering institutions the chance to get an always stronger internet presence through websites and social media. Over than reaching a wider audience museums, and cultural institutions can rely on Online Collections and Digital Archives: Many museums and galleries have digitized their collections, making them accessible online. This not only broadens the audience but also preserves artworks for future generations. The availability of high-resolution images aids researchers, educators, and art enthusiasts in granting enhanced accessibility: digital platforms enable people worldwide to explore collections and exhibitions, breaking down geographical barriers. Moreover, museums can gain valuable insights into visitor behavior and preferences using online visors' data, allowing for tailored experiences.

Marty (2008) has narrowed down the role websites have in the relationship between the user and the museums. They ran a survey on over 1200 participants asking questions on a five-point Likert scale asking about their preferences towards museum websites and their habits towards both museum websites and real-world museums. They found out that:

> *"Online museum visitors see museums and museum websites as complementary, where one is not likely to replace the other as users search for and access information. They operate within a complicated relationship that governs their use of museum information resources in their daily live."*

The survey also pointed out how users have different needs towards museums' websites and actual museums but does not go deeper into the differences between those needs and expectations; from the data they report, we can see how artifacts, images and research material are the most desired information to found on a website, when compared to virtual tours or online workshops. The respondents still pointed out how the visit on the website can't substitute the actual visit, with over 70% of the respondents agreeing to the statement "When viewing artifacts or exhibits, it is possible for a visit to a museum's website to substitute for a visit to that museum."

The paper still remarks exhibitors and curators should take advantage of the online environment to create unique experiences that can't be duplicated in a museum, including personalization and customization techniques.

Nancy Proctor (2010) has instead taken curators as a champion investigating the relationship they have with digital and social media: she interviewed different curators and summed up different speeches during conferences, getting other insights from expert curators all over the globe: she firstly reports how:

> *"Although the museum may have a Flickr account, for example, the museum does not own or control the underlying Flickr site and its functionality. Moreover, people may publish their photos of the museum in their own online Flickr photo-albums, called "photostreams," without any editorial control by the museum itself... In other words, the museum's digital presence is no longer confined to its website. In consequence, it controls increasingly less of the digital media published about its collections."*

Curators and experts use these insights to use their internet presence as a collaborative tool to share and create relationships with their audience rather than as a fixed tool to present their artifacts. They also created exhibitions and activities that actively involved visitors and their user generated contents like the case of Click!: A Crowd-Curated Exhibition (2008) at the Brooklyn Museum or How We Are at the Tate Britain. This is an interesting approach that leads to strong community building, with online platforms promoting and giving space to communities of art enthusiasts, researchers, and educators who can share knowledge and insight. The author then points out, on the other hand, how this tendency to make "the citizen curators" can become risky as, with the information sources proliferating online, the role of curators and expert knowledge becomes necessary. We can see two contrasting tendencies: the need to democratize the control of and access to culture through programs involving "citizen curators" and "user-generated content," while preserving and valuing the subject expert and a traditional curatorial role.

Many institutions, on the other hand, rely on Interactive Exhibits and Touchscreens; those Interactive exhibits and touchscreen displays allow visitors to explore artworks in-depth, visually exploring what would otherwise only be told. They can zoom in on details, access related historical information, and further understand what they are visiting. These technologies promote active engagement and learning. Mobile Apps and Multimedia Guide are another way museums and cultural heritage institutions use digital technologies to improve their experiences. Mobile apps and multimedia guides have become commonplace in cultural institutions. They provide visitors with self-guided tours, audio commentary, and additional content, enriching their on-site experiences. These apps may also include features like wayfinding, making navigation within the museum more convenient.

Gabriella Giannicchi (2021) has studied the concept of a digital museum, not intended as a digital collection or digital archive, but taking into consideration multimedia installations that take place inside the museums. She considered Digital museums as:

> *" the space of digital art as well as the hybrid place produced in the experience of encountering collections through technology. I use an inclusive definition of the term digital, encompassing a wide range of technologies, including virtual, augmented, and mixed reality, as well as websites and web-based mobile apps, to show how the use of digital has radically modified the space within which visitors encounter collections inside the museum and beyond."*

The author describes the digital museum as a hybrid place where users are no longer just passive viewers, but they become "participant, spectator, consumer, prosumer, explorer, visitor and even a curator or conservator of the work." The author points out how these digital artworks often rely on an augmentation process triggered by the visitor, who becomes the performer and an active part in the functioning of the artwork rather than just a simple spectator. The author provides various examples of how museums have been experimenting with a wide range of technologies to generate new kinds of narrations, experiences, and interactions with artworks and cultural heritage. The author concludes that:

> *"the space of the digital museum acts both as a microscope and telescope. It augments, enlarges, brings closer, lets visitors penetrate the work of art or the item of heritage so that they can become part of it. The space produced by the digital museum is hybrid and continuously shifting. It is a space that constantly changes, relocating visitors interacting with artefacts and each other between the physical and digital world. Here, visitors do not only learn about art or heritage, but also adopt multiple roles through which they coproduce that art or that heritage."*

It's worth to notice how the examples provided by the author, sometimes exit the realm of cultural heritage, being more related to digital and new media art (terms that are constant around the paper). This overlapping between cultural heritage, the use of new media and digital artwork can create some misunderstanding: contemporary art galleries may already incorporate digital artworks in their exhibits as well as provide digital installations which are not related to the improvement of a pre-existing experience, but are stand-alone applications of digital art. Those installations are not related to any existing artwork but still make parts of a museum (or art gallery) experience, and contemporary art galleries are also contributing to the development and divulgation of culture; the border between new media art and cultural heritage applications becomes blurry and it's hard to find a proper categorization for all what happens in the "hybrid space" described by Giannicchi. It's still important to understand the different potentialities that the physical space of a museum offer for the development of digital applications.

The integration of digital technologies into museums and galleries is undoubtedly a powerful and transformative endeavor, but it is has its fair share of challenges and considerations. This section will explore these challenges and considerations in greater depth, emphasizing the nuanced complexities that institutions face as they navigate the always-evolving landscape of digitization in the cultural sector:

Digital Divide and Accessibility:

One of the most pressing challenges in adopting digital technologies by museums and galleries is the persisting digital divide. While digital platforms have the potential to make art and culture more accessible than ever before, not everyone has equal access to digital devices or the internet. This issue threatens to create disparities in access to online offerings, excluding certain demographics, particularly those in underserved or remote areas, from the benefits of digitization.

Data Privacy and Security:

The responsible collection and management of visitor data present museums and galleries with intricate challenges, primarily concerning data privacy and security. As these institutions strive to offer personalized and engaging digital experiences, they must do so while upholding the highest privacy protection standards. Ensuring data privacy involves robust policies and practices that safeguard visitor information from unauthorized access, breaches, or misuse. Museums and galleries should be transparent about data collection and usage, obtaining informed consent when necessary. Compliance with relevant data protection regulations, such as the General Data Protection Regulation (GDPR), is paramount.

Financial Costs and Sustainability:

The integration and maintenance of digital technologies in museums and galleries can be financially demanding. This challenge extends beyond the initial investment in hardware and software; ongoing updates are essential to keep digital experiences relevant and functional. The financial burden of technology adoption is challenging, especially for smaller institutions with limited budgets. To address this issue, museums and galleries should develop comprehensive digital strategies that align with their long-term financial goals; this includes exploring potential revenue streams from digital initiatives, such as online ticket sales, memberships, and e-commerce opportunities. Collaborations with corporate sponsors, philanthropic organizations, and government grants can also provide additional financial support and are a possible way for those institutions who want to invest in digital technologies. Moreover, institutions should prioritize the development of scalable and adaptable digital solutions that can evolve over time without increasing costs.

Visitor Experience Balance: The Digital and the Authentic:

Maintaining a delicate balance between the integration of digital tools and the preservation of the authentic, contemplative atmosphere within museums and galleries is a multi-faceted consideration. While digital technologies enhance

engagement and education, there is a risk of detracting from the traditional, unmediated experience of art and culture. Institutions should adopt a visitor-centric approach to digital integration to navigate this challenge. This involves a deep understanding of visitor preferences and behaviors, allowing museums and galleries to tailor digital experiences to complement, rather than overshadow, the physical presence of artworks. Interactive exhibits, touchscreen displays, and mobile apps should be designed to enhance rather than replacing the authentic encounter with art.

1.2.1 Meaningful applications

Now, we are going to examine in depth some valuable applications we encountered during our research. We are going to see the different uses various institutions have made of digital technologies and how they made real the considerations above about the advantages digital technologies can bring. We are covering both the digital collections made available on the web through digital catalogues and virtual tours, as well as the multimedia and interactive installations that have been developed inside the spaces of museums and that are part of the experience. By doing so we aim to get a more comprehensive knowledge of the way in which museums are using digital technologies and the benefits and advantages they are delivering to their final visitors. Watching real-life applications is going to help us to better understand the possibilities and the opportunities that can be taken and providing tangible examples of how digital technologies have been integrated into cultural heritage related experiences.

We are now analyzing those museums who made the most out of their internet presence, creating online catalogs and databases, making them accessible everywhere. These digital museums are innovative platforms that provide unique and immersive experiences for exploring art, history, science, and culture. These digital museums and platforms not only bring art and culture to a global audience but also enhance the accessibility and understanding of historical and artistic treasures. They represent the evolving landscape of museums in the digital age, making knowledge and culture available to a broader and more diverse audience:

The Louvre Virtual Tours:

The Louvre Museum in Paris, home to the iconic Mona Lisa and countless other masterpieces, offers an exceptional virtual experience. Users can explore the museum's vast collection through high-resolution images, 360-degree tours, and detailed descriptions of artworks. The museum's website provides an immersive journey through its galleries, enabling visitors to appreciate art from anywhere in the world. A screenshot from the virtual tour is shown in Figure 1. The platform was developed in 2021 as a response to the Covid closure and resembles a good application of virtual tours that allows everybody to access

the contents of the museum from everywhere with their smartphones or computers. The service also offers interactive maps of the museum to make the users navigate the artworks just as if they were visiting the real museums. A screenshot of the map is shown in Figure 1.

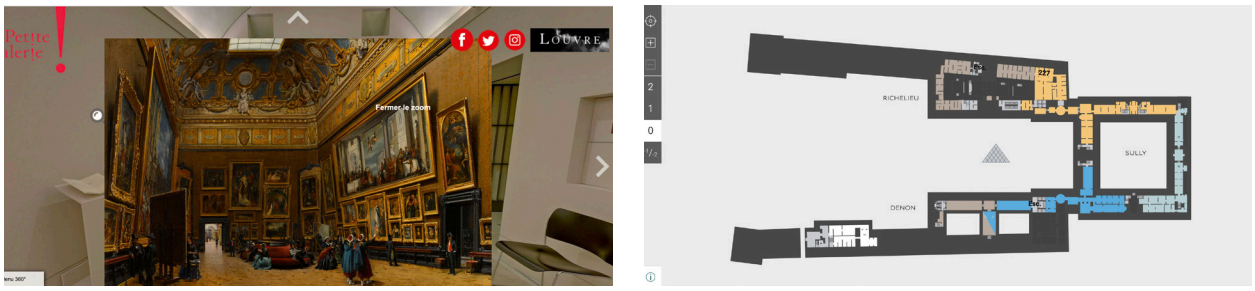

Figure 1: Screenshots of the Louvre Virtual Tour and interactive map of the museum.

Smithsonian Open Access:

The Smithsonian Institution provides an open-access digital platform, which includes a massive collection of images, 3D models, and data related to their extensive collections. This platform allows users to explore the Smithsonian's artifacts, artworks, and specimens, promoting learning and research across a wide range of subjects. The service offers free access to many different artifacts, from paleontology and natural science to modern history and even sci-fi. They made and strong and remarkable use of 3D scanning and reconstruction to provide 3d models of more than 2800 artifacts. A screenshot showing the visualization of the George Washington Statue is shown in figure 2. The service is not directly related to the way objects are exhibited (like the case of the Louvre) and allows the user to search for specific artifacts offering different filters and search options, creating an incredible database of artifacts which can offer a strong amount of knowledge to users from all over the world.

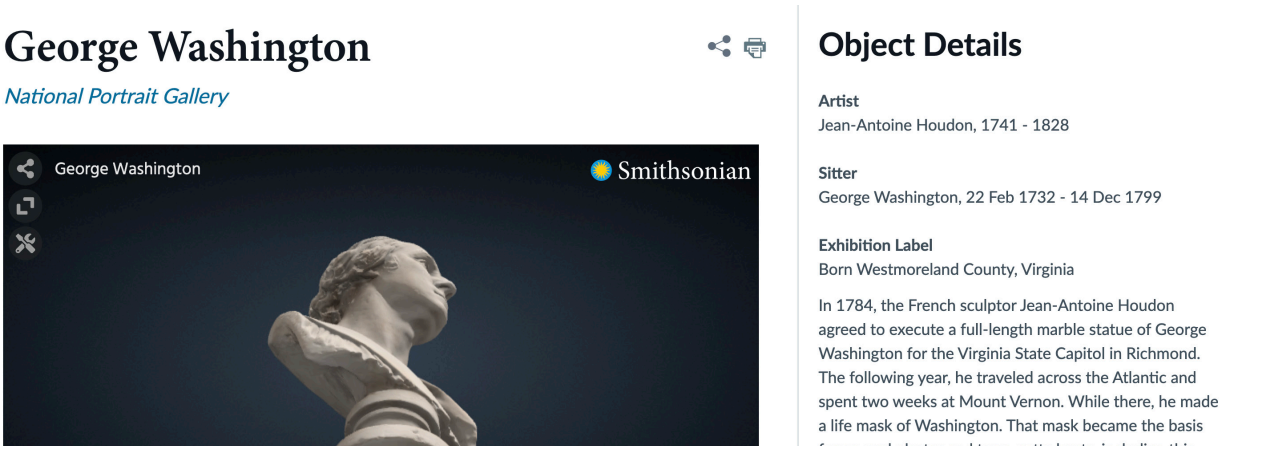

Figure 2: a screenshot visualization of the George Washington statue from Smithsonian Open access.

British Museum's Digital Collection:

The British Museum offers an extensive online collection with over four million objects, from ancient relics to contemporary art. Users can search, explore, and learn about various cultural artifacts and even create their own collections to share with others. A new online collection launched in early 2020 includes new records and allows for new ways to search. Cultural open data is uploaded in the form of high-resolution images of art. The database of the British museum is one of the world's earliest and most extensive online museum search platforms. There are currently 2,335,338 records available, which represent more than 4,000,000 objects. At least 1,018,471 records have one or more images. A screenshot of the research page (searching Napoleon with over 4000 artifacts matching) and an artifact visualization are shown in Figure 3. The British Museum's dedication to providing open access to its treasures is a notable aspect of its digital presence.

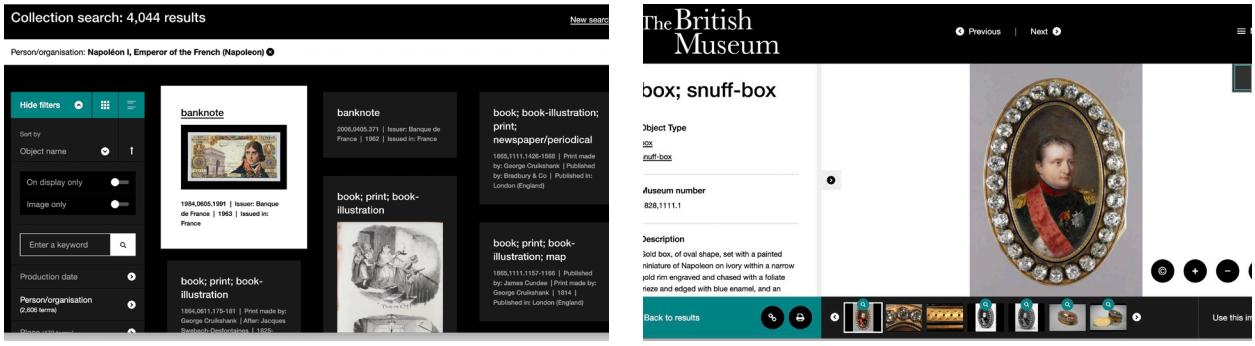

Figure 3: the research page of the British Museum digital collection and the content visualization of a specific artifact.

Museum of Modern Art (MoMA) Online Courses and Exhibitions:

MoMA in New York offers an array of online courses and exhibitions, providing an educational and immersive experience for art enthusiasts. Through these digital offerings, users can dive deep into the world of modern and contemporary art, including artist profiles, multimedia content, and interactive learning experiences. The user has a platform with different classes to choose from, many of which are free, and must then register to attend the lectures, held by experts from the museum. Users can enroll any time and take the courses at your own pace. In these courses, they will look closely at artworks in MoMA's collection and exhibitions and hear directly from artists, architects, designers, curators, and others through video and audio. Readings and resources provide enhanced context, and quizzes and discussion forums offer opportunities to check your knowledge and share ideas and creative projects with others. They also made their course available on other platforms such as coursera.com or Class Central to make them available to a further audience outside their official channels.

Many museums and art galleries have instead embraced multimedia experiences to engage and educate their visitors in innovative ways. These institutions make use of multimedia and digital technologies to enhance the visitor experience, making art and culture more accessible and engaging for a diverse audience. Through these experiences, they blur the boundaries between traditional art forms and the new world of digital technologies. Here we report a few examples of such institutions that offer multimedia experiences:

Padova Walls' Multimedia Museum:

The Padova multimedial museum, developed between 2016 and 2017, created and directed by Comitato Mura di Padova, the experience takes place inside the walls of the ancient city of Paduva, Italy and consist of a series of projections about the history of the walls and the ancient city. The journey doesn't have any physical findings to show but consists of only digital and audiovisual content. The aim was to have the walls of the city, tell about themselves, some first person narrations of the main character of the city's history were integrated for a better storytelling. Some projections presented during the experience are shown in Figure 4. The formula has met with excellent success and unanimous approval and the municipal administration has expressed its intention to make the structure permanent, extending it to other artefacts, as part of the broader project concerning the Park of the Walls and Waters of Padua.

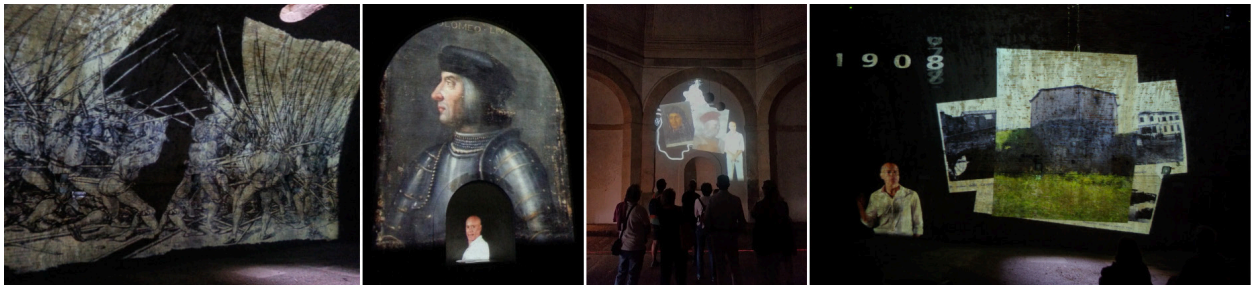

Figure 4: Padova Walls' Multimedia Museum

Mori Digital Art Museum - Tokyo:

Located on the island of Odaiba, in Tokyo, the Mori Digital Art Museum can be defined as a museum of contemporary art, but everything (or almost everything) is based on digital projection. The museum has great size and it extends itself over approximately 10,000 square meters and on several levels; inside there are several rooms, each with its own particularity and with a specific setting. The museum was designed and created by TeamLab, a working group made up of artists, programmers, animators, and engineers, with the support of the developer Mori Building, and was inaugurated in June 2018. The museum is currently being relocated and is scheduled to open again in January 2024. Figure 5 shows some of the rooms inside the museum and we can see how the use of

visuals is high-level and very evocative. Some rooms, such as the “Tea’s room”, also have references to some cultural aspects of Japan linking contemporary art to their national tradition and culture.

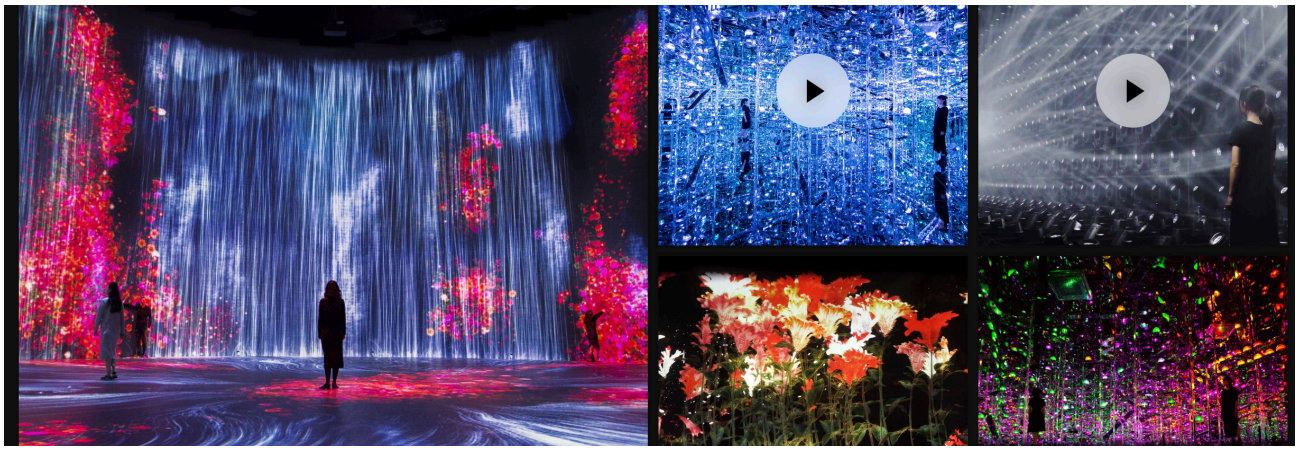

Figure 5: Mori Digital Art Museum

Van Gogh Experience, Next Musuem - Rome

Creating experiences in different cities (currently available in Turin, Milan, Rome and Bilbao) next museums offer different multimedial experiences about arts and culture. We are analyzing the Van Gogh experience available in Rome in the ex-cinema Avilia, close to Villa Borgehse. Figure 6 shows the projection of all over the walls of the room of the painting Starry Night (1889). Next Museum was designed to offer multi-sensory experiences on art, history, and society. The rooms are equipped with advanced technologies such as video mapping, 3D images, and virtual reality viewers.

Figure 6: Van Gogh Experience – Next Musuem

The exhibition begins with a timeline chronicling the artist's life, providing visitors with an overview of the key moments that influenced Van Gogh's art. Subsequently, the user can immerse themselves in the Dutch painter's paintings, reproduced in the videomapping room. This surface of over three hundred square meters comes to life at 360 degrees, transporting the public into the artist's world. The videos are shown in loop, visitors can watch it several times from different perspectives; the audience therefore becomes an integral part of the scenic framework, a true protagonist of the work. The soundtrack, composed of classical music pieces, further amplifies the emotion of the journey.

M9 Museum – Mestre, Italy

The exhibition consists of a multimedia experience about the history of Italy in the 20th century through a journey through digital materials, including approximately 6,000 photographs, 820 films edited in a total video projection of over ten hours, and 500 iconographic objects. The museum was opened in January 2018 and was defined as "the most important project to contribute to the revitalization and development of the Venetian mainland." Figure 7 shows the multimedia room about the landscape transformation in Italy during the twentieth century. M9 works like an encyclopedia. The user can switch from one content to another, according to inclinations and curiosity. Or follow the story section by section. There is no single obligatory path: each visitor can decide where to start, what to look at, and which topics to delve into. In this way, the journey actively involves the users who can follow their own interests and create a personalized and always different experience.

Figure 7: the M9 museum

1.3 Extended Reality and Tourism

In the last section of this chapter, we are analyzing more in detail the specific relation between Extended Reality technologies (AR and VR) and tourism and all the ways in which XR has had an impact on tourist experience. Extended reality technologies can accompany us through all the phases of a journey, from the booking part to the actual stay. Different services and applications have been developed according to the part of the touristic experience they are meant to promote; we are trying to put a categorization among the number of applications developed to understand in which kind of context AR, in particular, is more useful, when compared to other Extended reality applications.

R.Young and C. Khoo-Lattinmore (2017) are the first trying to make a systematic review of the research of AR and VR applied to the tourism sector. Starting from Hobson & Williams assumptions (1995) about the possibilities of applying AR and VR to tourism: the two authors consider the travel itself as a secondary reality in which the tourist escapes temporally. According to this, AR and VR push the tourism experience one step forward, where the user immerses himself into a simulated experience, assuming that this extension of sensory participation can expand and enrich the information and the experience.

The two authors took into consideration 46 studies about both AR and VR, dividing the technology into five different categories: Virtual Worlds (18) Virtual Environments (11) Augmented Reality (8) Virtual Realities (6) and Virtual communities (3) as shown in Table 1. Considering the different distribution of the studies, where the first two categories fill more than 50% of the total material taken into consideration, the authors noticed a lack of fixed nomenclature, considering Virtual Worlds and Virtual Environments as non-technical names often used inconsistently and without a precise definition.

Table 1. Different kinds of Extended reality applications In the tourism industry.

Category	**Frequency**	**Frequency**
Virtual Worlds	18	39.13
Virtual Environments	11	23.91
Augmented Reality	8	17.39
Virtual Realities	6	13.04
Virtual Communities	3	6.52
TOTAL	**46**	**100**

They also identified six sub-sectors of the tourism industry in which they sorted the before-mentioned studies; in particular: Marketing (13), Education (9), Conceptual Tourism (7), Experience Enhancement (7), Food & Beverage (2), Meetings, Incentives,

Conferences and Events (2), and Others (6). The results of this categorization are shown in Table 2.

Table 2. Extended Reality applications frequency in different sub-sectors of tourism.

Category	**Frequency**	**Frequency**
Marketing	13	28,6
Education	9	19.57
Conceptual Tourism	7	15.22
Experience Enhancement	7	15.22
Food & Beverage	2	4.35
Meetings	2	4.35
Others	6	13.04
Total	**46**	**100**

It Is worth mentioning how VR was mostly related to Destination marketing and advertising, creating Virtual environments to enable users to visit a site before moving to the actual location, facilitating their decision-making process toward a destination. VR was also widespread in tourism education, using virtual environments and experiences as a learning tool. All seven studies regarding the tourism experience enhancement were instead making use of AR, specifically making it the best option for on-site applications, probably due to the mobile nature of AR (when compared to VR usually requires the user to be steady in one position) making it useful for location with a large information-dissemination such as museums or art galleries. The use of AR in these contexts was usually perceived as novel and very interactive (Dueholm & Smed, 2014; tDieck & Jung, 2015). On the other hand, some site managers were reluctant to adopt this kind of technology because it would reduce the authenticity of the sites and objects presented.

When it comes to the methodology used by the different authors; 13 relied on conceptual papers only, while other 13 authors relied on surveys and interviews without previous experimentation of the intended technology, tending to explore future possibilities of these technologies rather than nowadays user behaviours and inclination. On the other hand, only 11 studies showed a clear theoretical framework sustaining their results. The authors then noted a lack of established theories about AR and VR, probably due to the novelty of the subject. The most used approaches were the Technology acceptance model and the Theory of Planned Behaviour.

In conclusion, the authors summed up three major issues in the whole AR/VR tourism research: first terminology issues, often used inconsistently or in a heterogenous way with an overall lack of definitions, secondly the lack of theory-based research and last (and more important for us) some gaps and challenges regarding the use of the technology itself such as: Lack of Awareness about AR and VR, usability, time commitment (intended as the time necessary to adopt the new technology) and the

unwillingness to adopt digital substitutes to the real experience; the main findings and challenges identified are shown in figure 8.

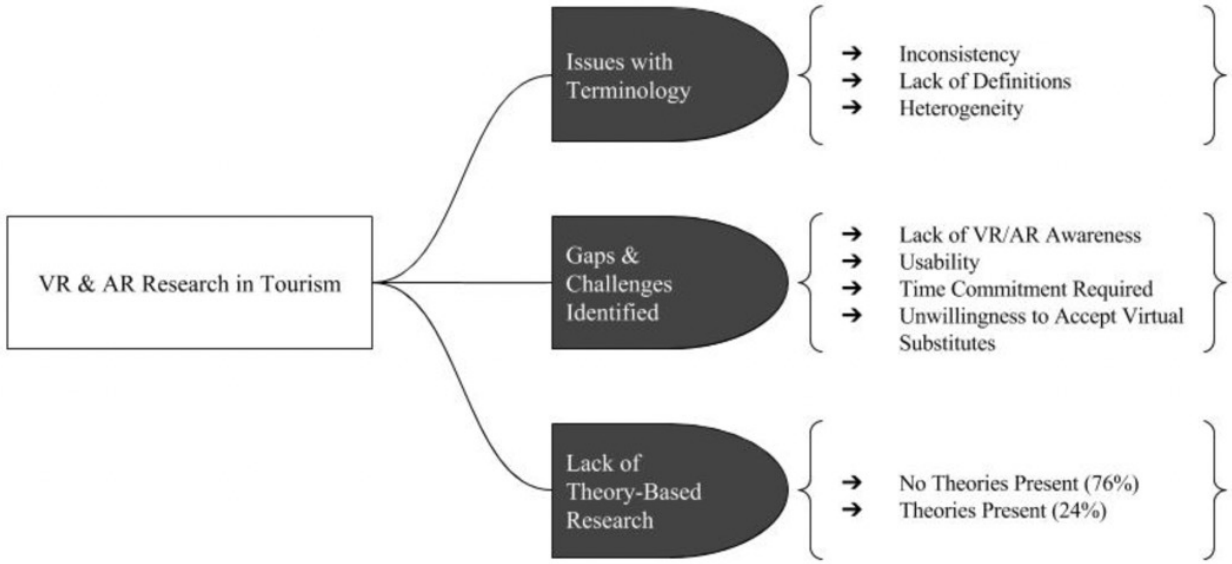

Figure 8: Main challenges associated with ER Acceptance

1.4 Conclusions

As we move forward in the digital age, the tourism industry will continue to evolve and adapt to the ever-changing landscape of technology, striving to create experiences that are not only accessible but also meaningful and enriching for all travelers while addressing the challenges and limitations that come with these innovations. In this chapter, we considered the profound impact of digital technologies on the tourism industry: we have seen online booking platforms that revolutionized trip planning and booking, mobile applications that provide real-time information and enhance convenience, and the role of social media in marketing and influencing travel decisions. These different services show us how digital technologies have left an indelible mark on tourism.

We took into consideration the case of digital museums and how they are using digital technologies. We have considered the possibilities and opportunities behind we've explored the meaningful applications that offer immersive and educational experiences, blurring the lines between traditional and digital art. Furthermore, Extended Reality technologies have expanded the possibilities for enhancing tourism experiences, providing opportunities for marketers, educators, and experience enhancement. In the following chapters, we will focus more deeply on the specific role and advantage Augmented Reality can bring to cultural heritage tourism as well as describing the most relevant application developed and the most common approaches followed by researchers and developers.

We also got a first glance on the different uses made of Extended Reality technologies and how they fit in the different kinds of services delivered by tourist organization. This has been valuable to understanding how Extended reality technologies are related and integrated into the digital services that are already offered by curators and will help us relate the knowledge we will gather about AR to the more general theories about digital services. The information provided so far gives us a good understanding and overview of the changes digital technologies have brought in tourism, with particular attention to the museum experience and the specific benefits the digital can offer to visitors and curators.

These considerations are valuable to understand how AR can concur, with other digital technologies, to the improvement of visitor's experiences and will help us address our research to understand the benefits and advantages of augmented reality, both following the values and benefits generally offered by digital services and both trying to understand the specific opportunities this fascinating technology can offer.

Chapter 2
AR and Cultural Heritage

Introduction

When visiting a cultural site, booklets and maps are still the most common ways used by tourism management organizations to deliver information to their users, but multimedia tour guides are becoming more popular since they allow users to understand better what they are visiting through video or audio content. AR was firstly used in the early 90's to help airline and air force pilots during their training (Caudell & Mizell, 1993). Over the years, AR has become, more and more accessible to implement and no longer requires expensive headsets of head-mounted displays, but can easily rely on smartphones and everyday devices that can support it. There is increasing interest in this kind of technology from different kinds of organizations. Tourism and cultural management organizations are no exceptions and are relying on AR to create multimedia platforms and tours to enhance visitors' experience.

Fritz et al. (2005) note that since the information-seeking process has become faster and more iterative during the last decades, also the expectations from the visitors have increased. They also note how museums or art galleries rely on digital technologies for the collection, preservation, exploration, and diffusion of arts and cultural heritage. However, they noticed that most electronic texts, audiovisual content and multimedia or geographical information remain unseen to the users, and it is only barely used from electronic guides. They explicitly state that:

> *"If tourist organizations want to reach wider audiences, they would have to build attractive multimedia content that attracts tourists. Therefore, new systems that support these innovative applications and provide added-value content are required."*

Going further, the authors try to enumerate some of the requirements an AR system must have to be successfully implemented in the field of cultural heritage, such as: being attractive and user-friendly, providing an informative and educational value, relying on existing knowledge, and being able to reuse some already available data

and being globally available. They even hypnotize a future where human guides will no longer be necessary, and people can access personalized content and explore the environment on their own.

In this chapter, we are going deeper into the assumptions above, trying to understand which added value AR is giving to tourists and tourism organizations: the interest from users and curators towards new narratives and media is sometimes given for granted, leading us to create applications that don't have a reason to be and are not providing a meaningful integration to the actual visit experience. That's why we have to discuss the possibilities associated with the new medium and the different intrinsic values of the touristic experience, trying to find links on how AR can address and enrich the values of touristic attractions.

We are also focusing on the challenges associated with AR acceptance, knowing that it is spreading slower than expected, and we will understand the personal factors involving the inclination towards AR and how design-related elements can lead to success or dissatisfaction in the user, going through different acceptance model that have been proposed by scholars, we are trying to list the different dimension that can affect the user experience, getting insights about all the facades of the project we are dealing with to create applications that are going to be well receipted by our users.

2.1 AR definition

Before going to examine which AR applications have been developed in the tourism sector, we must briefly clarify what AR exactly means for us and what we consider AR and what we don't. The first definition of AR comes from Azuma et. Al (2001) who consider AR as

> *"a technology which overlays virtual objects (augmented components) into the real world. These virtual objects then appear to coexist in the same space as objects in the real world"*

The authors precise that they don't restrict AR to a particular displaying technology such as Head Mounted Displays (HMD), which were the most popular available AR devices before the coming of smartphones, or limit it to visual information and content, but precise that AR can be as well auditory, tactile and olfactory.

A very crucial step in defining what AR had already been done by Milgram (1993), who supposed the mixed reality continuum (figure 1). The author relates Augmented Reality to its close neighbor Virtual Reality, using them as the two ends of a

spectrum. If AR is “emersive“ where digital content “emerge” into the real world, VR is immersive, asking the user to enter a digital environment. Milgram shows how these two concepts are linked to each other and finding a fixed boundary between the two is almost impossible, and how they are meant to be “mixed” together, creating application with both a certain degree of “emersiveness” and a certain level of “immersiveness” making AR (and VR) a “blurred” concept which has not a real definition (intended as the characteristics necessary and sufficient to acknowledge something as a part of a category) but will be more or less present in different kinds of application.

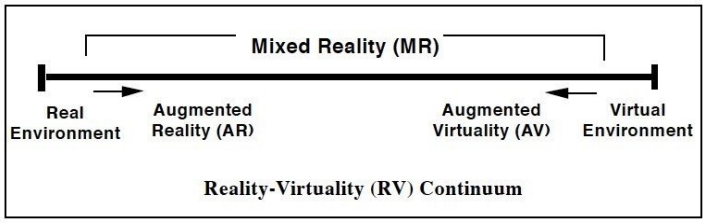

Figure 1: Milgram reality-virtuality continuum

The definition from Azuma can be too discursive and not cutting-edge enough. Applications like Google glasses can fit in these definitions even if the digital content they present is not linked to the real world. (when Azuma writes Google glasses were not yet even hypothesized). In his study he also presents applications that today would be no longer considered AR, such as broadcast live information while watching sports. Milgram instead, correctly defines AR as something blurry, but, for research purposes, we need a more precise definition AR, which allows us to firmly decide what we consider Augmented reality and what we don’t. Lester Madden (2011) helps give us a more analytic definition of augmented reality. The author defines five characteristics a project must include to be defined as AR, which are the following:

- It combines the real world with computer graphics
- It provides interaction with objects in real-time
- It tracks objects in real-time
- It provides recognition of images or objects
- It provides real-time context or data

This definition, even if listing the points AR needs to have to be accounted as it, might be a little bit blurry and may present some inconsistencies. The focus on real time interaction (three out of five points talk about real time interaction) is correct but might be misleading since most of digital application require real time data. Everybody while playing online video games has unpleasantly experienced lagging, giving us the perfect example of how not only AR needs to present real-time data. It also may not be clear what we mean with “real world” and “real time tracking”. Body

tracking, for example, used in VR arenas, tracks the user's movement, and creates and makes digital content react according to them. This process combines real-world actions and computer graphics as well as real-time tracking, but the results is not an AR experience. This is one example explaining why we still need a more specific definition.

Going further, V. Geroimenko (2012) argues that the definition offered by Madden does not including some features such as location-based AR, which is not properly "tracking" any real objects but is indeed becoming much more prevalent along the years and is instead including some technologies that may not be defined AR such as QR codes or Barcodes. The author then proposes five conceptual "building blocks" that allow us to define the different parts of an AR system. AR is, therefore defined as a system, which includes:

- The presence of the real world
- Real-time visualizations
- The presence of computer-generated sensory objects (sensory means related to, or using, human senses of sight, hearing, smell, taste, or touch)
- Close or seamless integration between the real environment and the computer-generated content;
- the use of an AR-enabled device.

This definition seems to be the most complete and exhaustive since it's not taking into consideration a specific kind of marker or tracking process but focusing more on the interaction with the real world which can be seen as the core of the full AR experience. This is the one definition we are using as a reference to orientate ourselves in the variety of digital experiences related to tourism, since it allows us to look at specific applications with a clear mindset which is neither too strict on a specific kind of tracking or marker, neither too broad to enclose what can barely considered AR. With Geroimenko, we have a good discerning framework that has resisted till nowadays, remaining valid with the various technological innovations and different kinds of mixed reality experiences produced in the last ten years.

2.2 AR added value

Augmented reality has a lot of applications in various contexts: it has been used as an educational tool, allowing textbooks to come alive and dynamically visualizing figures and diagrams having applications in different subjects such as Science and engineering, but also history or foreign languages (Boyels, 2021). It has enhanced the retail experience with virtual try-ons, AR walls, or furniture placing (Fingent, 2022; Overly, 2023). In the healthcare sector, it helps surgeons with live information and updates (Dessele et al., 2020). In this section, we are going to examine the added value generated by AR and the specific advantages AR can bring in tourism and cultural heritage enhancing, exploring why touristic institutions such as museums or art galleries can benefit from AR.

It might be hard to understand the value of AR in general since it is always linked to the specific field of application. We can find a lot of material about the advantages of AR in the medical or educational field. We will later discuss some specific studies about AR in tourism, museums, and cultural heritage. Still, we must first understand the potentialities of the tool itself before going deeper into the advantages it can offer to our specific field.

Davidavičienė et Al. (2021) used a very interesting approach applying different testing methodologies to two applications: Inkhunter and Arilye. In the Inkhunter app, users can explore various virtual tattoo designs through AR with marker-based functionality. Users can save, edit, and easily share these photos on their social networks.
The Arilyn app also follows a marker-based approach designed to promote the Kalnapilis brand and boost product sales. Users must direct their smartphone, toward a specially designed Kalnapilis product. The immersive solution incorporates 3D graphics, animations, and sound to narrate the story behind Kalnapilis products visually.
Those two applications were chosen because:

> *"they have a different goal and target audience, do not require long-term user commitment, operate both on Android and iOS mobile operating systems, it is easy not onlyto find out the purpose, content, and features of the application in a short time but also to evaluate these applications characteristics. Besides, these applications are trendy among customer"*

Davidavičienė et Al. (2021)

Even if different, those two apps follow the same technological approach making more interesting to compare them, applying the same analysis to two different contexts to understand some general advantages of AR even when used in different situations.
The authors considered a various number of testing methodologies, from the most commonly used to evaluate the end-user experience, and opted for the User Experience Questionnaire (https://www.ueq-online.org/) due to its complexity and precision, being one of the most detailed available. The questionnaire took into consideration 6

dimensions, respectively:

- Attractiveness: overall impression of the product
- Efficiency: how the product is easy to use
- Perspicuity: how the product is easy to learn
- Dependability: level of control felt by the user
- Stimulation: motivation to continue to use the product
- Novelty: how the product is felt innovative

The questionnaire was addressed to thirty participants (User Experience Questionnaire has been proved to obtain significant results with 20-30 respondents) mostly aged from 18 to 24 (73%) with the remaining 27% being between 25 and 35. The results of the test are shown in Figure 2, comparing the two apps for each dimension tested. Inkhunter app was dominant in all the sectors, performing the best in novelty (2.35 out of 2.5) and lowest in dependability and stimulation(1.73 and 1.80 out of 2.5). All the values were above the sufficiency level. Arilyn app was rated lower in all the scorings but shows a real discrepancy between novelty and attractiveness (2.20 and 2.07) compared to efficiency, dependability and stimulation (0.97, 1.10 and 1.14).

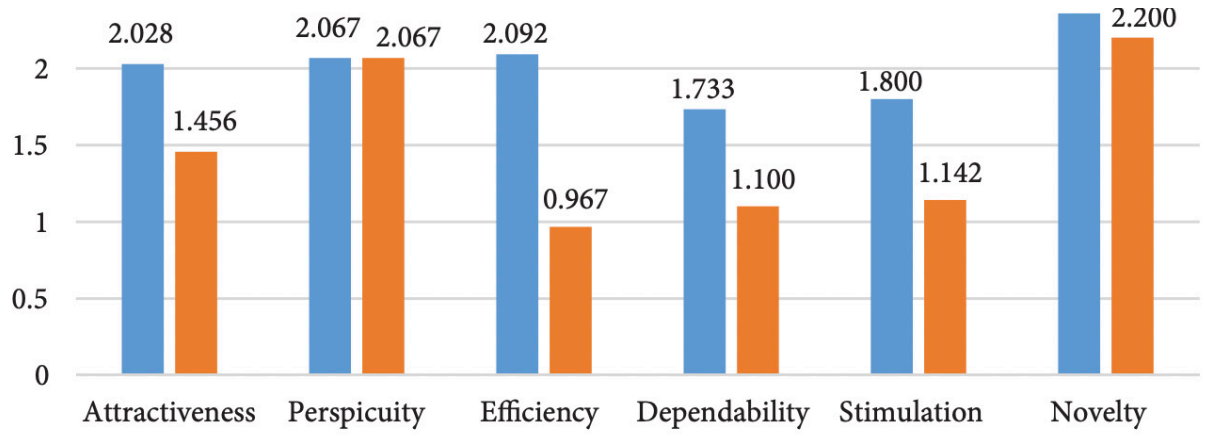

Figure 2: findings from Davidavičienė et Al. (2021) questionnaire

Besides the different scorings of the two apps (which are confirmed by their respective Google ratings), it is interesting to see how we can identify similar patterns. Both the applications scored their highest in novelty, followed by perspicuity and attractiveness. AR seems to be perceived as innovative and creative and is somehow natural and easy to use, but looking at dependability and stimulation factors, which are scored between the lowest, we can see how users may feel out of control of AR and how the motivation to have a further usage of the product is somehow missing. This may be confirmed by the fact that both apps had shown to have stronger hedonic qualities rather than pragmatic qualities, as shown in Figure

3. This information can be particularly threatening since both apps were selected for their commercial purpose showing still a lesser pragmatic quality when compared to hedonic qualities, showing how AR can be a fascinating and novel experience but if without a pragmatic value, there will not be a subsequent use without and the advantage offered by AR will soon be forgotten without an additional loyalty of the user.

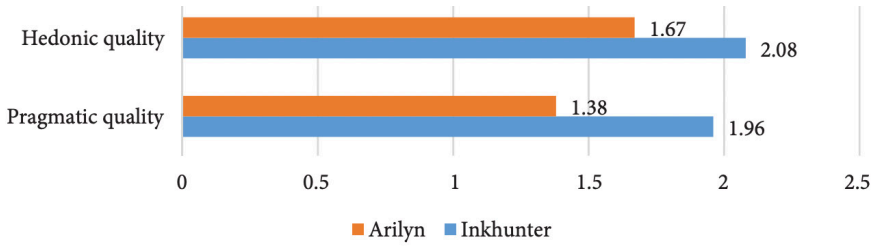

Figure 3: findings from Davidavičienė et Al. (2021) questionnaire

Thomas Olsson (2012) made a precious systemic work evaluating the use of AR in different scenarios, pointing out different values AR brings according to different contexts. His work is somehow unique since he is investigating multiple and different possible settings and applications, creating a holistic view of AR capabilities and potentials.

> *"The goal was to evaluate scenarios representing augmented reality already in an early phase of development, before enforcing any service implementation efforts ... A special focus was set to identifying potential use cases for future mobile AR services and understanding what is their overall value to the user."*

T. Olsson, 2012

The decision to present AR applications as possible scenarios, instead of testing a real experience, can be seen as a limit of Olsson's research, but he aimed to understand which field had the most potentialities rather than addressing specific usability and technological issues. It was also crucial for the author to link the experiences to real-life tasks to better assess and evaluate the overall experience and value of the service. The author took into consideration five different hypothetical scenarios, which are described as follows (the descriptions, except for scenario n.2, are taken directly from Olsson's article):

> **On the bus:**
> The scenario described MAR services offering everyday practical and location-dependent information and advertisements. Specifically, it is related to public transportation: assistance in planning the trip and offering both informative and entertaining content to pass time. The services included paying the bus fare with the mobile and receiving an automatic AR notification when to get off the bus.

Between the features offered on the bus, route planning, mobile payment and bus stop notification were mostly appreciated, while ads, mobile games and bus specific services were considered not necessary and somehow obtrusive, even if entertaining features were more appreciated on longer rides.

Jogging:
the scenario imagined a smartphone app connected to some Smart Glasses helping the user deciding which route to follow while jogging, according to other routes followed by other users. The glasses will guide the user with 3d indications and allows users to view comments left by other runners as well as a night vision equipment to help them run in darkness.

When jogging, the most appreciated features involved navigation and signals, mostly when running in unfamiliar places; also, night vision was commonly accepted, increasing the sense of safety. Social features such as comments or other runners' position was less popular and somehow unnecessary; many users also claimed that people run to "disconnect" themselves and have an offline moment, and they didn't want a digital aid while doing that.

Shopping furniture:
This scenario focused on additional product information and AR-based visualization of furniture models. The users have had their living room 3Dmodeled and now use the virtual model in finding new suitable furniture in the room. In a furniture store, the users can collect related information like the virtual model, price information, the stock situation and the colour options to their mobiles by touching the price tags of the furniture on display.

The Shopping furniture service was seen as very useful and valuable, both the real size simulation and the option to see information about the products, even if some concerns were raised about the projection not being perfectly aligned with reality and about the not visually related factors we consider when buying furniture (stability, texture, capacity, etc.)

Virtual Mirrors:
the fourth scenario described a virtual makeover service located in a clothing store. The service consisted of a virtual mirror and data glasses connected to it. By wearing the glasses, the users could see themselves in the mirror with different styles and appearances. They could try on different clothes, hairstyles, make-up, accessories, and piercings. The virtual look could be shared with others using the same mirror with glasses on.

Virtual mirrors were not considered particularly useful, but entertaining: users found them funny to virtually try out different styles and to share them with other for recommendations, even if they were concerned about how well the virtual model was similar to the real styling. It was also seen that the physical fitting of clothes is an important part of the shopping experience, with users still wanting to try the clothing pieces physically.

Street art:
This scenario described a service focusing on artistic and amusing content, i.e., user-generated virtual street art attached to real-world objects. The users can view the graffiti with their mobile, add comments, or create new art and share them with others. The creation in situ happens by painting in the air with the phone or compiling existing images and text previously saved to the mobile. The service could be set to notify about nearby pieces of AR art that represent selected topics or are created by selected friends.

This service was also perceived as entertaining and as a good way to express themselves increasing the tidiness of public spaces, the notification of nearby artworks were also regarded as useful, even if users were concerned about the quality of the content and a possible harmful or illegal use of the app.

An online survey was run to evaluate the different scenarios collecting both qualitative and quantitative data from 282 participants of English and Finnish nationality. Shopping furniture (scenario 3) was rated as the most appropriate for the situation, while Street art was rated lowest even if all the scenarios got ratings over 5 on a scale from 1 to 7. Some differences in demographics were taken into consideration, showing how sporadic differences were noticed in various aging groups, however those differences did not follow any trend, with some scenarios being more attractive to younger people, while others were preferred by an older audience, but without showing a real difference, since the middle values were mostly the same; according to this it seems that AR can be addressed to all the age groups and can provide different values to different generations. Gender was also taken into consideration showing how men seems to have a slight stronger attitude and were more positive and willing to try AR.

Lastly technological orientation e proficiency was taken into consideration grouping participants in different "technological levels" from "highly technological" to "slightly technological" showing how highly digitalized users have a more positive attitude towards AR; besides this consideration is worth to see which services were more positively accepted by slightly technological users: in shopping furniture, technology readiness showed no effect on the evaluation and was slightly influencing virtual mirror, while having a huge effect on the other two scenarios (Jogging and On the bus). The author refuses to speculate on why technology readiness has such a different influence according to the kind of service; he supposes that the utility and practical advantage of Shopping furniture was stronger and easily identified by less digitalized users, but this consideration can't be applied to Virtual mirror and Street art.

We suppose that the most "out of the ordinary" action is the most positively the use of AR is evaluated: everyday activities (such as jogging or taking the bus) are usually well established in someone's routine and are performed in a more consolidated way, making AR less advantageous as it is more difficult to make a technological intervention on an already established practice; to make the user change their habit, we must provide a much stronger value, while in an extraordinary situation (such as

Shopping furniture, action which is usually performed no more than a few times a year) the presence of AR and digital technologies is more easily accepted, since it is not asking to perform an already known action differently. This is an important insight for us since tourism and visiting a museum is a completely routine experience and is valuable only if it provides new stimuli, showing new places and attractions. The absence of preconcepts people have towards new and unfamiliar places help creating meaningful digital experience since we don't have to challenge an already established habit of the user.

2.2.1 AR added value in Arts and Culture

Geroimenko, investigating the relationship between AR and art, gives us some precious insight into which features are characteristics of AR when compared to older supports and media; the aim is to understand the potential of AR as a new artistic medium. Even if intended for artistic (rather than design) purposes, many considerations can be extended to our field since we consider the characteristics and advantages of a certain media, regardless of its final destination. The author identifies three major advantages and potentials that we can exploit through AR:

> One first advantage of AR, when compared to traditional media, is that AR is not spatially limited, but our content can be accessed and placed everywhere. This has allowed creators to "abusively" exhibit their artwork in famous galleries without asking for permission (it's famous the "Art Invasion" abusive exhibit in 2018 at MoMa from Veenhof and Skwarek). It also allows different contents to co-exist at the same time and in the same place free from spatial limits. If we imagine a touristic activity, it will probably take place on-site, enriching the actual visit and activity. Still, we can allow the users to recreate the experience a second time (as long as they can keep the marker), creating a form of satisfaction that lasts over time and is not concluded in the few hours of the visit period.
>
> In terms of costs, AR artifacts are free from materials and manufacturing costs, being mostly digital; they can be created in any number of copies and sizes without any effort. Since every user nowadays has an AR-enabled device, there are no costs for the institutions, which do not have to provide specific hardware or audio guides (which represent an implementation cost and could be broken). Moreover, AR artifacts can't be damaged, stolen, or vandalized and do not need maintenance. When applied in museums or art galleries, AR can allow us to interact with digital representations of delicate objects (such as archaeological findings or paintings), interacting with them freely without the risk of damaging them.
>
> The possibility of animating our digital content and making it interactive is the last (and maybe more important) aspect of AR we have to take into

consideration. We can allow our users to move or displace artifacts at their own will, interacting with them in many different ways, more engaging than sampling staring at it. This point may seem obvious, but sometimes developers tend to forget about it, creating AR experiences that realize themselves just with the view of the augmented content, leaving the user passively involved with the content without really interacting with it. AR can become an optimum tool to show the functioning or the use of different artifacts in a real-life scale environment, showing how they used to work and allowing the user to actively take part in the show, creating their own personal experience and educational process. This interactive exploration can improve the informative process enabling the user to discover many more details of an exhibit.

Puspasari et Al. (2017) have considered the added value of AR, specifically inside museums, in particular the Museum of Sultan Mahmud Badaruddin II, which was taken as a case study. They considered the different aspects a project must fulfill to propose an effective Technology Enhanced Learning (TEL) as illustrated by Howland et Al. (2012). According to the authors, a meaningful TEL experience must be active, constructive, authentic, intentional, and cooperative, where:

> *"Active means student engage in manipulation of the learning objects such as cultural artefacts and observe the resulting phenomenon. Constructive means students should be able to construct ideas about the subject matter taught through a process of inquiry and reflection. Intentional means students are the ones with the initiative and have the capability available to them to pursue learning goal, understand their own progress and adjust their approach. Authentic, The case presented to the learners are real world problems with meaningful context and realistic complexity Cooperative, Focus on interaction and working with peers to foster learning"*

Puspasari et Al.

The authors propose AR as a powerful tool for technology-enhanced learning since it can potentially cover all the points listed above, which are giving us precious insights into how to develop effective experiences. The role they put on the activity and activeness (most of the points they mention, such as constructiveness, intentionality and cooperation, imply and depend on the fact that the user is actively involved in the experience and is not only witnessing passively any content) is interesting since visiting a museum is generally a passive activity where the user is not allowed to interact (due to obvious reasons) with the artifacts they are enjoying. AR can easily overcome this limit, allowing it to interact with digital reproduction and representation of the artifacts exposed in the museum. Moreover, they took the insights from M. Ding (2017) who, after having studied different applications in the U.S. museums such as ArtLens 2.0, from the Cleveland Museum of Art (2016), Skin and Bones, in the Smithsonian Museum of Natural History (2015) and Layar app int Blanton Museum of Art (2016) has summed up the three main opportunities AR can offer to museum environment which we report as follows:

"1) Endless Layers of Information: AR offers to user the possibility to deploy their own mobile hardware as pocked sized screens through which surrounding spaces become a stage for endless extra layers of information. The AR feature on museum apps work with automated image recognition to realize the scanning of real world objects by tracking marker or marker less.

2) A Powerful Tool of Engagement: Virtual museum enable visitors to explore information about the displayed artworks by themselves, and enjoy the live camera view when inspecting the details of a work. Visitors do not only gain some basic knowledge of the displayed artworks or the exhibition itself by checking the texts on the Museum walls, but also absorb layers of information on top of the work. When visitors and museum engaged, conversations among visitors will be easily, and there is a strengthened connection between the museum and its visitors especially for cultural artefacts. It can awaken the sense of ownership and desire for protect the nation identity through cultural heritage preservation.

3) Creative Tool of Education: In addition AR allows visitors to obtain knowledge of the displayed cultural artefacts through an engaging and informative way. It also inspires the visitors to discover the details of the displayed by interacting with marker or applications features."

Puspasari et Al. paraphrasing M. Ding

We have already mentioned how AR is not spatially limited. Still, it offers the chance to insert potentially infinite content in a portable device, extending museum walls and displaying different kinds of content according to the user's will. Overcoming spatial and technical limits by merging digital and physical objects and information makes AR a powerful tool to enhance the learning possibilities for users. It also allows visitors to have a major degree of freedom, giving a sense of control of the visit and a sense of "ownership" of the artwork strengthening the connection between the visitor, the artwork, and the institution itself. The author also tells us to be creative with AR, creating interactive and engaging experiences with artifacts and objects that would have been otherwise enjoyed passively. The study of M. Ding gives us another precious contribution, enunciating both the factors museums that want to embrace AR must consider and the actions that museums that already use AR should consider implementing. For the first ones, the author suggests to consider:

"Museum's ability: A museum should first consider their financial situation when deciding whether to develop their own AR app or use an existing one. A museum should also consider if the app requires free WiFi access throughout the exhibition space

Museum visitors' needs: The museum should collect information of visitor behaviors and visitor preferences to pre-examine the most effective way to implement AR technology.

Special requirements for the exhibition: A museum should consider the necessity of using an AR app for its permanent collections or a temporary exhibition. Artwork that requires curatorial and interpretive information, other than the text panels and labels, might be best to feature in an AR app."

M. Ding, 2017

The author focused on three different aspects regarding the place and its suitability to Host AR experiences. We may provide wi-fi access to the user if he has to download the app or if it requires a huge amount of web resources, but we may also need to track the user inside the place using GPS or other technologies (GPS in indoor contexts may not work properly) such as Bluetooth or Beacons. We may also consider giving the user a specific device instead of letting them use their own devices; this will make the costs levitate but will prevent compatibility and responsiveness issues. Finding a balance between the actual museum's capabilities and supports, the investments they are willing to make to implement AR, and the outcome of the project itself is a crucial part of the service design of AR in museums.

Besides the museum capabilities, a proper user study is also necessary to understand the actual behaviors of the visitors, which artifacts they are mostly attracted to, and where their attention is mostly directed: we may decide to use AR on the most popular artworks of the museum, which generate the most attractiveness, bringing them one step forward, making them the "diamond tip" of the museum offerings (as Amir Baradaran did, working on Mona Lisa in 2011) or to use AR to grow interest among less famous artifacts or even decide to show with AR objects that are not usually exposed in the museum allowing to explore the museum warehouse and archives, but these decisions must start from the normal behavior of the visitor and considering how AR will modify that behavior, trying to add new activities or to follow and enhance what is already offered by the museum, according to the specific directions we want our project to take.

At last, we must consider the artifacts we are working on and the kind of exhibition we are developing for. A temporary exhibition may be already subject to a huge money investment, making AR implementation part of the realization costs; the effects and success of AR will be directly linked to the exhibition itself, making it seamlessly integrated with the special and temporary offer of the museum. This makes AR implementation less risky since it is related to the special event (which may be successful or not) and does not have to be a stand-alone project, with all its value inside itself, but is a part of the special exhibition and is contributing to co-create value instead of generating added value only on his own. It may be more difficult to work on a permanent collection since the AR is often perceived as an "extra feature," an addition to the normal museum offering, which has to be consistent on its own. Considering the kind of exhibition also means considering the specific artworks that are shown in the collection: it's different from designing something for a painting (or work of art in general) and an archeological finding such as a vase or a tool; different artifacts offer different insights and different relevant information to show. We are

taking the next chapter to go into more in detail about the different applications and how different developers worked on various kinds of artifacts and exhibitions. Still, Ding already gives us a precious asset in the mindset we must adopt to capture value. It's also worth mentioning how this analysis from Ding considers three different aspects that will be recurrent in user and technology acceptance studies, dividing the aspects and factors that lead to value generation into three main categories: the first is related to the context and the facilitations it can offer, the second relates to the user, his belief, attitudes, and expectations which must be followed and fulfilled, the last regards the presented stimuli and the object of the augmentation. These three main categories have to be addressed separately and will all concur to the creation of value and, therefore, the success of a new AR implementation.vThe author also provides advice for those museums who have already implemented AR, such as implementing:

> *" An effective evaluation process: A museum should collect data and feedback for their AR app use, and adjust or update various components accordingly. The feedback from visitors can also indicate areas for improvement.*
>
> *Create awareness among patrons: A museum should establish and maintain an effective operation and communication system that supports AR app use. In addition, promotion of the AR app both inside and outside the museum is important to attract new app users."*

M. Ding, 2017

The idea of an evaluation progress gives the idea of AR implementation as an iterative process, leaving room for constant improvement and updating. This iterative process ensures that the AR experience remains engaging and aligned with visitors' preferences. The acknowledgment that data and feedback should lead to adjustments or updates of various components underscores the dynamic nature of AR development. It also raises questions about which components are most critical for user satisfaction and how to prioritize updates based on feedback. Design a proper evaluation system is crucial as it may affect the feedbacks and their quality: there will probably be some features and specific aspects we want to particularly investigate, but we must also leave freedom for the user to leave comments and suggestion raising awareness on different topics.

The author also emphasizes the awareness and proper communication of the AR project. Puchiar and Kljun (2018) also put a strong emphasis on communication activity inside a museum, showing how visitors can be willing to share their experience providing additional visibility to the curators and the institution. The author raises questions about user demographics, outreach strategies, and the appeal of AR to different visitor segments. Creating a proper awareness and effectively communicating our project is not directly affecting the value of AR. However, it is still an important part of the project since it may lead to or prevent the project from being successful.

Cranmer et Al. (2018) went a step forward, analyzing and discussing how AR can generate revenue streams and economic advantage for the touristic institution itself. They investigated the business model and revenue model that can be applied to AR, identifying different ways it can generate money. The authors found that this lacked research since AR is commonly researched from a visitor's perspective rather than discussing its economic sustainability. The authors declared:

> *"The economic value of AR for tourism is undefined, and as a result, organisations remain unsure how to implement the technology to add value to the visitor experience while generating economic return. The potential to add value by implementing AR is widely researched, but, the majority of studies explore ARs value from a visitor perspective, rather than how it can be adopted to generate profit or create additional revenue."*

Cranmer et Al. (2018)

The authors interviewed all the different stakeholders from Geevor Tin Mine Museum, in Cornwall. Respondents were shown a short video about AR and some preliminary information to create a common background knowledge about the topic. AR was firstly indicated as a secondary revenue generation, as it increases the time people spend inside the museum, reflecting this in their consumption at cafés or museum restaurants. It was also suggested that the additional engagement generated by AR can lead to a stronger connection with the exhibit and to a stronger will to spend money in souvenir shops and museum merchandise. Stakeholders also recognized AR as a powerful marketing tool to create awareness and give visibility to the institution, attracting not only visitors, but also founders, which were identified as a crucial resource for Geevor. Two other doubts were given to the respondents; whether AR should be free or not, and whether it should rely on devices loaned by the museum or own by the visitor: on the first point the respondents were divided. The first half suggested that as people already pay extra for the audio guides, they would also be willing to pay extra for AR, even if a suitable cost was not identified. The other half said that they won't pay extra for AR, which should be offered as a part of the visit rather than an extra, but they would support increasing the normal entry ticket after the implementation of an AR experience. On the second point, it was supposed that if users borrowed the devices from the institution, they might have to pay an insurance or deposit fee, while if they were using their device they had to pay to download the AR app. The stakeholders favored the first option even if they were aware of the long-term commitment and investments this option would bring such as: deposit, pre-booking, device tracking, manutention etc.

Tom Diek and Jung (2017) also interviewed the stakeholders of a small museum (which less than 15 000 visitors per year), asking them to identify the possible values and reasons to implement AR. Museum's CEO had already declared that "the key strategy is to start engaging with more audiences, to make the museum more engaging and relevant to a much broader range of audiences using technologies" showing a strong interest and attitude towards new technologies and new forms of

engagement. The stakeholders identified different forms of values AR could deliver. The insights we get from this research differ from the previous ones and delineate more generic values that can be, for the most part, addressed to the visitors. The different values associated with AR are discussed as follows:

Economic value relates to the monetary costs involved and if the services or products we are developing are worth investing in. AR was seen as a potential way to justify an increase in the admission fee and as a way to attract new audiences (such as organized classroom visits that may enjoy virtual educational experiences). Another economic value was identified in the idea of fundraising and donations, which are often an important revenue stream for small museums.

Experiential value refers to customers' perceptions of products or services through direct use or indirect observation'. Museum experience can be very static, and all respondents suggested that AR could bring stories to life, resulting in more fulfilling and enjoyable interactions. Experiential value can be a multi-faced and somehow complex concept that can encompass all the other values identified, making it a crucial concept for our research. A more detailed paragraph about the experiential value and its sub-dimension will be discussed afterward.

Epistemic value is an important concept linked to consumers' curiosity about new products and their willingness to experience something new, which may be linked to the novelty factor of AR. Consequently, there was strong interest in the potential of AR for the enhancement of the experience.

Social value is connected to customers (and businesses) recognition that the product or service leads to personal fulfilment and impression making. Various stakeholders discussed the idea of gamification and how interactive games could enhance the social aspect of the museum visit. They proposed a scoring system inside the AR app, suggesting that users will engage more actively if they are being tested at the end of the experience. This idea of social fulfillment was essential for external stakeholders, which identified social aspects to be very important, also given the chance to ensure positive word-of-mouth recommendations among visitors.

Historical and cultural value: There has been a general recognition that AR would enhance cultural and historical value by providing additional information for all age groups. AR was seen as a tool to show artifacts and places as they once were, showing the role they had in the culture and historical context they came from. Another cultural value given by AR is the chance to digitally show those parts of the collection that are not normally shown in the exhibits.

Educational value: There has been a general recognition that AR would enhance the visitor learning/educational experience by providing information for all age groups. AR would allow visitors to gather information by themselves, at their

own pace, which was considered a big advantage for a personalized educational experience. It was also noted that multi-media guides give the possibility to repeat and listen to the proposed information, more precisely when compared to a human guide, making it easier to memorize and recall the experience.

The information reported so far can illustrate how AR's versatility, cost-effectiveness, interactivity, and alignment with educational goals make it a valuable asset for museums. The insights from the different authors provide a comprehensive framework for museums to understand the potential benefits and considerations when implementing AR. These considerations underscore that AR has the potential to enhance visitor engagement, provide dynamic learning experiences, and create long-lasting impressions in the cultural heritage and tourism sector.

2.2.2 The role of Novelty

During user studies, AR has often been associated with "novelty" and "fascination" as the user, which is not used to this technology and does not adopt AR in everyday life, is projected to a futuristic experience; "novelty" and "innovativeness" can therefore be seen as strong values are can provide, but rely on bare novelty as a reason to implement AR can't be sufficient. Looking with a long-term view, we can imagine and hope that AR will always be more popular and widely adopted until it becomes an everyday tool we use at work and in our daily routine; in this scenario AR will no longer be perceived as a new and innovative but as a normal technology well integrated into our life and we will no longer be able to use "novelty" as a value driver.

Distracted by the fascination of novelty, we can easily forget about the real utility and reason behind the adoption of a given technology; we can implement AR on any image or object but there's no reason to do that beyond a sort of "AR for AR sake" which can push us to create nice technological demonstrations, but those applications would end up being "self-referring", becoming useless and easily forgettable when put in the real world.

Novelty can also be a false success predictor. When testing, users will express positive feelings due to the WOW effect provided by a first glance at Augmented Reality. Following these positive feelings, users may express a huge satisfaction leading us to think our application is working and meaningful. We should consider that the "WOW" effect delivered by AR won't probably last long and will decrease over usage, leaving shortly the user without reason to repeat or continue the experience. We must be aware that the first use of most AR applications will be much more engaging than the subsequent uses. Taking the first use to get insights and feedback can be misleading and lead us to think that our product is more successful than it is. It's worth to consider that not all the AR application are meant to be used multiple times. It's quite common to see in-place experiences that are not meant to be reproduced at home; most of the applications designed by museums or site curators

are supposed to be run inside the museum or the site itself. These case studies have a lesser risk of making the user lose interest over time since there are not many chances for subsequent uses. AR becomes a unique and unrepeatable experience whose main purpose is engaging the user rather than providing a utilitarian value as it does in other contexts. Also, in these cases where utility is less important, we must still reason about the meaning of our AR implementation.

In order to create meaningful AR applications, we must ask ourselves what are the specific advantages and added values of AR adoption. AR can enrich a touristic experience, but its application would be pointless if we could deliver the same value and reach the same objectives with a less advanced but less costly technology. If we only need to deliver textual information, a booklet or a QR code leading to a webpage would probably still be the best option since they have inferior implementation costs and require less efforts from the users. There must be a reason to link a specific object to some digital content and to make them somehow interact. Otherwise, we could just present our multimedia content without attaching it to the real-world counterpart, delivering the same information and messages. The necessity and presence of the physical object or marker can even become a limit and a further constraint rather than a potentiality, making the experience less accessible and locally limited when we could have shared the same information globally, without a real advantage for the user.

2.2.3 Experiential Value

When it comes to tourism, the key concept that determines the success or failure of an experience is the "perceived experiential value" (He et. Al, 2018), which is based on the transaction or co-creation of experience between the service provider and the customer particularly on the interactions involving direct either usage or distant appreciation of goods or services which become the basics for the relativistic preferences of single users, rather than a trade-off between quality and price, in which we commonly intend "customer value".

Experiential value has different dimensions according to the different experiences that the user is attending, and it can be distinguished into "extrinsic" and "intrinsic" value, where the first relates to the utility of an exchange and task completion while the second focuses on the fun and playfulness of completing a process or task (Babin et. AL, 1994). Holbrook (1994) added to this dichotomy the one between "active" and "reactive" value, defining active value as the close collaboration of a customer with product or service providers and reactive value as the perception, appreciation, understanding, or reaction of a customer to a consumed item or experience.

Mathwick et. Al (2001), taking the insights from the previous researchers, defines four sub-aspects of experiential value considering the values of playfulness (intrinsic/active), aesthetics (intrinsic/reactive), service excellence (extrinsic/reactive), and

customer return of investments (CROI) (extrinsic/active). Furthermore, another level of sub-dimensions has been identified, dividing playfulness into "enjoyment" and "escapism": one referring to the potential emotional value put by the user, the other referring to the degree in which the experience allows to escape from daily-life demands. Moreover, aesthetics can be distinguished into "visual appeal" and "entertainment" where the first is perceived through senses and provides satisfaction while the second refers to the appreciation for the dramatic or spectacular aspects of a performance. Also, CROI has two sub-dimensions "efficiency" and "economic value", but extrinsic values are taken less into consideration from researchers focusing more on the intrinsic dimensions of experiential value identifying them as the major drivers for a good success of AR applications (Han et. Al, 2021). All the different factors and dimensions constituting the experiential value are summed up in the figure 4.

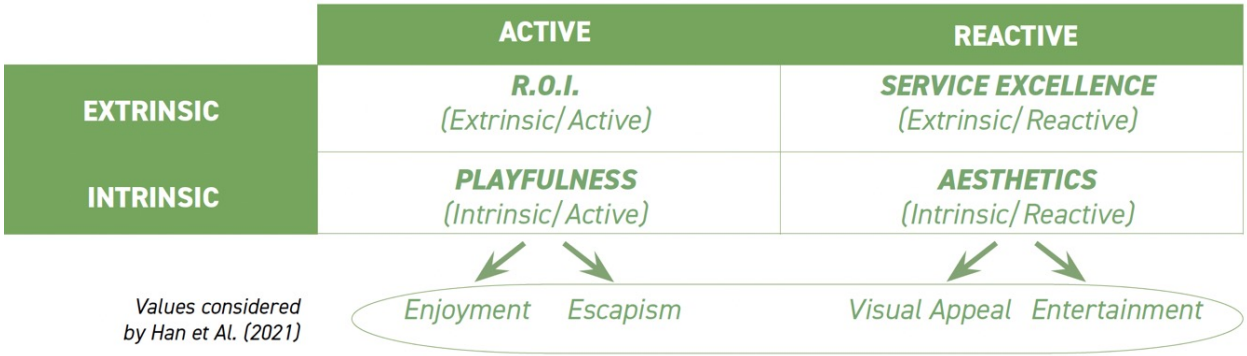

Figure 4: factors influencing experiential value.

According to Han et Al., one other major driver (strictly related to experiential value) is the "experiential authenticity". The concept of "authenticity" can be quite complex and multi-faced; "authentical", in this context, does not mean "realistic" but relates to the totality of the experience and how it is capable of activating different emotions in tourists as they're far from the ordinary; users subjectively evaluate their authentic experiences on the basis of the degree to which they are not subjected to the constraints of their daily routines and are engaged in activities other than their usual practices. The authors conducted a survey showing a strong correlation between the intrinsic experiential value of AR and the experiential authenticity of a destination, enhancing major AR satisfaction and a stronger willingness to support the institution.

2.3 AR acceptance and T.A.M.

Even if almost everybody nowadays has an AR-enabled device (sometimes even unaware) and despite the interest in AR rising between exhibitors and curators who perceive AR as an innovative medium, Augmented reality applications are taking place slower than expected. According to Gartner analyst Tuong Nguyen:

> *"There are just so many bad examples of it. Let's say I see an ad in a magazine and say, 'Hey, this is AR-enabled' and so I pull out my phone to point at the ad and something comes up, like an animation or a Web site. But I'll say, "OK, that's interesting, but I could have done it at home on my big screen and all you are offering me is the same thing on a smaller screen that costs me data use, so I'm not likely to do that again."*

(Computerworld, 2014)

It's then important to consider the specific acceptance issues that arise when we develop an AR application, and which are preventing people from adopting AR. A lot of studies have been conducted about the usability and usage of specific applications, showing us how good or bad AR is receipted, but the key metrics affecting the acceptability of AR remain uncertain. We need to take a more theoretical approach to systematize the different issues preventing people from using AR.

The Technology Acceptance Model, since its introduction in 1989, has been evaluated as a superior model in terms of conciseness and predictability in many fields; various studies have been extensively conducted by applying a TAM related to users' acceptance of IT. It relies on two mayor concepts: "Perceived usefulness" and "Ease of Use," where the first refers to "the degree to which a person believes that using a particular system would enhance his or her job performance," and the second can be defined as "the degree to which a person believes that using a particular system would be free of effort."
It's worth to notice how the T.A.M. is designed to give insight about a given system and the insights we can get from it tend to be particularly specific about the texted product or system. It's not taking into consideration individual differences about the users (Lin et. Al, 2007).

Scholars who apply the T.A.M. to different scenarios tend to use the two concepts of Perceived Usefulness and Perceived Ease of Use as the major dimensions influencing users' attitudes, but they also usually list and examine the different factors influencing Perceived Usefulness and Perceived Ease of Use; the Framework proposed by Young & Lattinmore is an example of how researchers are using the T.A.M. as a starting point to create further, more detailed and more specific models. Chung et Al. (2015) try to accomplish this task by identifying three different kinds of factors influencing people's attitude towards AR: personal (technology readiness), stimuli (visual appeal), and situational (facilitating conditions). We will now examine the different factors

taken into consideration. A graph showing visually the contents of the model is available in figure 5

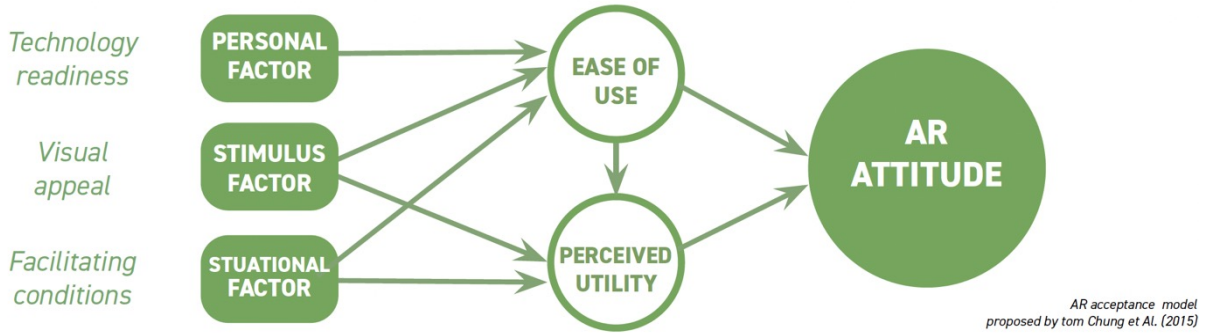

Figure 5: AR acceptance model proposed by Chung (2015)

Technology Readiness can be defined as "people's propensity to embrace and use new technologies for accomplishing goals in home life and at work" (Parasuraman, 2000) and consists of four dimensions: Optimism, Innovativeness, Discomfort, and Insecurity. Those users with a lot of optimism have an open mind and are more likely to accept a given technology. People who favor innovation show a tendency to be early adopters and to search for the latest technology actively. On the other hand, people who feel uncomfortable with new technologies tend to feel it too complicated. In addition, people with a high score on insecurity have an innate fear of technology and avoid using it. Different authors, Berger (2009) in particular, disagree on this structure, stating that Discomfort and Insecurity are not stable enough, leading other scholars to consider only the two enablers (Optimism and Innovativeness). Technology Readiness (TR) has been considered an important factor affecting visitors' beliefs, attitudes, usage intention using AR, and destination visit intention.

Visual appeal relates "to the exhibition of fonts and other visual elements such as graphics; it acts to enhance the overall presentation of information systems" (Liu, Li, & Hu, 2013). Visual attractiveness is a major determinant, considering how aesthetics plays an important role in the tourist experience. Previous research ascertained that AR systems reinforce the user's view of the real world and that a user's familiarity with AR applications affects perceived usefulness and perceived ease of use of AR applications (Chou & ChanLin, 2012; Damala, Cubaud, Bationo, Houlier, & Marchal, 2008; Yovcheva et al., 2013).

Facilitating conditions refer to "situational factors related to the use of AR at a heritage destination" and can be defined as "the degree to which a person believes that the use of AR is supported by an organizational and technical infrastructure". This definition encloses all the external help and guidance given as support to the users to help them use AR properly. They are positively related to ease of use rather than the perceived utility of the functions offered by the system, which is independent of external support. We can assume that, supported by guides or assistants, people will find AR adoption easier and safer.

The model described above gives us a more detailed situation of some factors influencing the attitude people have towards AR. It's really important to distinguish between personal, stimuli related, and situational factors. The first are individual beliefs and propensions about new technologies, as well as the benefits perceived from AR experience, unluckily we can't act "a priori" on what people find interesting or repelling, but we must keep in mind the different mindsets a user can have. We must also consider it a possible deterrent as stimuli-related factors we can consider over visual appeal, the functionalities offered by the AR system, and how they're presented. Their design can play a crucial role in the success or failure of an AR system, even more important in our context of study, considering how a touristic experience should be visually pleasant and relaxing. At last, we must keep in mind situational factors considering how the environment in which we design is not neutral but can support the efficient use of an AR application through informative labels or human support from guides, as well as all the complementary assets we need to access the new technology (charged phone, with internet access and a proper connections). Moreover, AR is deeply related to the real world on which she superimposes digital content, thus making the connection with the environment in which the user is supposed to act even more crucial.

Through this model, we can easily differentiate between the three categories, giving us good insights about how to address each of them differently. Still, we can notice how many issues that could influence users' attitudes are not taken into consideration: it's noted the propension a person has towards AR (TR) but not the effects the usage has on this propension (perceived benefits). It's taken into consideration the facilitating conditions, not the prerequisites or the costs necessary to access AR and develop the application. Lastly recalling all the stimuli-related factors to visual appeal might be misleading, not considering other factors such as the functionalities offered or the information quality, which are also related to the stimuli we design and can influence both the perceived utility and the ease of use coming from our system. Tom Diek & Jung (2015, 2018) manage to fill this gap by proposing an alternative T.A.M. for AR in tourism, using different insights coming from previous literature (taking sources from subjects other than Tourism itself, but also reviewing papers about e-commerce, web-design, service economy ecc...) they identified five dimensions (which will be later updated to seven) which are influencing the attitude towards AR from tourists. In this case, we don't have a differentiation between categories, but they are listed as separate factors, which are illustrated as follows:

> Enjoyment was the first dimension identified; in particular, Haugstvedt & Krogstie (2012) stressed out the importance of perceived enjoyment as a strong factor influencing the willingness to use AR apps as important as perceived usefulness (ease of use was considered instead less crucial) and suggest that institutions should focus as well on the fun and useful aspect of their applications such as games where the hedonic aspect is predominant.
>
> Perceived Benefits was identified as a second key factor. Olsson et Al. (2012) have particularly stressed the importance of pragmatic and practical advantages while using AR services. The authors proposed different scenarios in which AR

could be applied (on a bus, furniture shopping, street art, etc...) and showed with a survey how the most meaningful applications provided direct and practical benefits. They also say people seem to better justify the expenses for something practical than something hedonic.

Personal innovativeness was identified as the third factor. Intended as "The willingness of an individual to try out any new information technology" (Agarwal & Prasad, 1998). The positive correlation between personal innovativeness and ease of use was pointed out by Yussof et Al. (2011) (as well as the forehead mentioned the importance of enjoyment) and Olsson (2012), showing how the expectations towards the applications were higher in more technology-oriented users for which novelty was an important added value.

Information Quality also plays an important role in the Model. Strongly related to the perceived benefits dimension, information quality is here intended as the capability of the application to provide direct and immediate information, allowing users to save time and effort (Olsson et Al. 2012). It shown how users demand high quality and contextually relevant information; the functionalities and information offered were even perceived more important than how the information is accessed.

Costs of use were listed as the last antecedents for mobile use of AR. This item consists of different subfactors, both internal (like the difficulty of usage or privacy concerns) and external (implementation efforts), and are defined as "the sacrifices, both monetary and nonmonetary, made for the sake of using applications" (Parra-López et al., 2011)

Going through the sources of the study from Diek & Jung, the role of enjoyment is a bit controversial: it is considered a vital aspect for Yussof (2011) and Haugstvedt & Krogstie (2012) while its importance is relative and secondary to the practical value for Olsson (2012). For this purpose, it is worth saying that Olsson et Al. focused more generally on services instead of the specific tourism sector. Tourism is often seen as an aesthetic experience where the enjoyment and visual appeal play an important role, so if we can agree on the statements from Olsson about pragmatic utility, we must yet underline the important part of aesthetic and amusement when it comes to tourism and cultural heritage. Figure 6 contains a visual explanation of the five dimensions listed above.

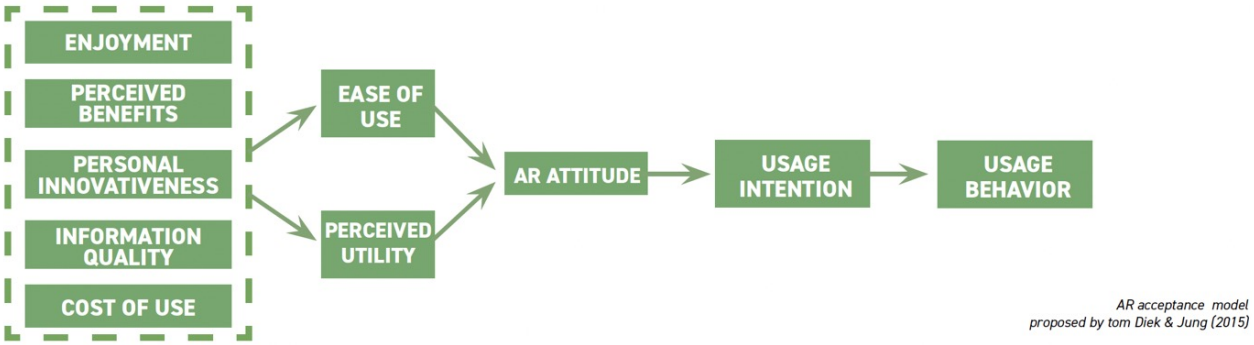

Figure 6: AR acceptance model proposed by Diek & Jung (2015)

The five dimensions listed above constitute another example acceptance model for AR in the tourism sector. However, one limitation of this study was the lack of direct information from users, while regarding only on literature. For this main reason the authors proposed an updated version of their T.A.M. for AR and tourism (Tom Diek & Jung, 2018). This time the authors used focus groups as a main data source; they took this decision because of the qualitative nature of focus group outputs, since they identified a lack of qualitative approach and data in the literature, focusing mostly on surveys and quantitative data. The study was conducted after participants (a group of female British students) had tried an app prototype for smart tourism in Dublin developed by the authors as a project promoted by Dublin's city council in the context of Dublin's Heritage Trail and was consisting of both marker-based AR and GPS based AR showing navigation functions as well as presenting audio and video contents. This time, the authors identified seven dimensions as antecedent factors of AR acceptance. The authors' main findings are listed in the following table, while the different dimensions are discussed singularly in the following paragraphs.

Themes	Sub-themes	Key findings
External dimensions	Information quality	Importance of gathering of information Timeliness of information Relevance of information Attractiveness of information
	System quality	Multi-language support, Language quality Accuracy of system Navigation quality Design quality Personalization according to interests
	Costs of Use	Cost of comfort Costs of internet Costs of missing out on information Cost of application Annoyance, tourists might just want to explore by themselves
	Recommendations	Word of mouth, star rating system from other users Preference, recommendations given based on previous behaviour
	Personal innovativeness	Excitement, WOW feeling Cleverness
	Risk	Privacy concerns Risk of having phone stolen
	Facilitating conditions	Availability of hardware Battery life, battery should not be drained

Perceptions	Perceive usefulness	Alternative to traditional visit Convenience of gathering information
	Perceived ease of use	Instructions needed to facilitate handling Costs of effort
Attitude	Attitude	Favourable Unfavourable
Behavioral intention	Intention to use	Use application Download application

Table 1 Findings from Tom Diek & Jung (2018)

Information Quality:
It was first noted that users need instant up-to-date information, enhancing the immediate awareness users have of their surroundings and the overall tourist experience. The attractiveness of the presented content was also raised as an important metrics to consider. In particular, it was appreciated that the modality of the presented contents was always different and presenting not only visual steady information, but also audio and video content, making the AR experience more variegated and entertaining.

System Quality:
some issues were raised about the quality of the system itself such as navigation quality, quality of design and functions or the capability to segmentation according to groups or interests. The lack of multi-language support was noticed by many participants raising the importance of multiple languages in order to enhance user experience. The accuracy of the app itself (especially when it comes to GPS) and tracking process were also identified as a problem, leading the app not to work correctly in some occasions, being laggy or not aligned to the real-world counterpart. The chance to save information and reaccess it was also seen as a possibility to create more meaningful added value.

Cost of Use:
in this category, the authors list both monetary and non-monetary prices for the users. Many participants stated that they would be willing to pay for this kind of application and assumed that it would add meaningful value to the experience. Between non-monetary costs, we can notice the comfort cost of constantly holding your phone and the risk of missing the real-life experience.

Recommendations:
many participants raised the lack of recommendations as an issue, decreasing the willingness to use the app, asking for ratings and suggestions from previous visitors. Ayeh et Al. (2013) raised the importance of World-of-Mouth (WOM) as an important determinant in tourism research when planning a journey, leading the authors to insert recommendations and WOM as an important dimension to predict user acceptance.

Innovativeness:
most users were using this kind of application for the first time and considered it very innovative. The novelty of the experience generated a good WOW effect in most of the study participants. AR is usually perceived as very innovative, and novelty can be one of the most direct added value AR can provide. It's important to notice that the participants of the various focus groups were college students that we can assume to be fully digitalized and ready to try new digital experiences. Novelty and innovativeness may not be a positive value for everybody and depend on the personal innovativeness of the user, which may be different if we consider different user groups.

Risk:
some users raised the chance to be robbed while using the app to scan objects and destinations (this risk is higher when compared to normal phone usage since the device is exposed for a longer period); moreover, due to the immersive nature of AR, users may forget about their surroundings, this causing physical danger, as well as more common privacy concern and issues.

Facilitating conditions:
regarding external factors that may preclude the use of the app, firstly, a mobile device must be available; other issues could be the size of the device and its display, the battery durability, and the storage room available to download the app. All these requirements may preclude access to any AR experience. It's important to notice how the authors use the term "facilitating conditions" in a different way from Chung referring more to the "prerequisites" necessary to access the technology rather than the external help that curators can offer.

When we compare the two models from the same authors, we can notice how the first (relying only on previous literature) is more generical in the consideration and the outputs it provides while the second one is raising more specific issues and design insights to improve the prototype. On the other hand, many issues coming from the focus groups were too specific towards the application the participants had just tried and may not be helpful to talk about the whole context of AR. It is worth noticing how "Enjoyment" and "Perceived Benefits," which were in the first list, disappear from the second one: the participants were very specific and analytical about the app functionalities rather than commenting on their general impressions; many of their comments regarded the app utility and the additional information provided by it. However, these comments were seen as regarding "information" or "system quality" rather than the "Perceived Benefits" from the users, which were removed as a category. Some issues taken from the focus groups, such as problems about the physical risk for the user or the facilitating conditions (or requirements) to access the application, can make us notice how the second model is more context-aware of the scenario in which the app is used while the first barely consider the influence of the usage context to the experience. It's also worth to notice how the second model consider the "personal innovativeness" of the user and the "innovativeness" of the offered service as two sides of the same medal, while the first is only considering the

personal factor. Both models show some criticalities and can be seen as two ends of the same rope: the first being too generical, the second too specific, but we can see them as complementary studies and, together, can give us a valuable idea of the metrics that can predict the user acceptance of AR as well as the key concepts that we must keep in mind when we Design AR applications.

2.4 Conclusions

In this chapter, we have discussed the concept of AR and its implications within the tourism and cultural heritage sector. We have discussed some of the different definitions of AR, trying to find the one that was neither too broad nor too specific, to exclude those applications that are no longer considered AR (such as QR codes), and to include those applications of AR who don't rely on visual information or visual tracking of a marker, such as geolocation-based AR or markerless AR, as well as auditory or olfactory AR implementations. This operation was necessary to delimitate the field of our research to have a more precise mindset in selecting the most relevant applications (which are discussed in the next chapter). Before going into detail about what has been developed so far, we found it useful to investigate and understand the factors that lead to a successful AR implementation: to do so; we asked ourselves which are, on one side, the added values created by augmented reality, on the other side the factors influencing a proper technology acceptance of AR.

The first point responds to the question "why implementing AR", which are the advantages it takes and how it can be profitable, which are the "good effects" of augmented reality and how it can be useful to enhance existing experience. We have discussed different possible values AR can deliver, focusing on the "experiential value," which we consider the core value associated with digital technology and cultural heritage as it encompasses other sub-values (entertainment, aesthetic, playfulness, etc.) and that, given the context, is considered more important than economic or utilitarian and pragmatic value. We also examined the role of novelty, another value always associated with AR, how it can be a false-friend and how we should not focus our offer on the novelty and fascination created by AR. The WOW effect generated by novelty will soon disappear without leaving the user a further motivation to interact with AR. It was also pointed out how AR seems to fit better with non-everyday activities, enhancing experiences that already are out of the ordinary, like visiting a museum or a cultural heritage site.

The second point explains "how to implement AR", which are the factors we have to keep in mind while designing and how their negligence can lead to failure. We

have followed the T.A.M. approach, which has been the most widely adopted by researchers, who have investigated which factors can negatively influence "the ease of use" and the "perceived utility" (the two critical dimensions of the T.A.M. proposed by Davis). We have seen how different authors have considered different factors, and summing them up, we have an idea of all the design challenges we are facing in the development stage: some are related to usability and efficiency (system quality and cost of use) and the internal organization and design of the AR experience, while other regard the content itself (information quality, visual appeal, etc.). We also got aware that a proper acceptance of AR technology also depends on personal attitudes and beliefs of the user which are out of our direct control. Besides the personal factors influencing the attitude towards AR we must be aware of the real context we are operating, which may present facilities or obstacles we have to detect and face, and which can address our design.

With all this knowledge we have the mindset to effectively analyse the large field of applications developed in the tourism and cultural heritage sector and to redact a proper state of the art, understanding which AR application are taking the best of the potentials behind AR and manage to use it as an effective tool to enhance visitors' experience. We can understand which projects creates the most engaging and coherent experiences, which ones are making the best use of the available technology, using the right AR method for the purpose they declared, which mediums and contents have more reason to be augmented and why, which feature and actions are better supported by AR and which ones can be delivered effectively also with older supports. We believe and hope that the pieces of information acquired in this chapter are sufficient and exhaustive to orientate ourselves in the variety of projects created in the previous years and that they can effectively lead our design choices in the development of our own project.

Chapter 3
State of the Art

Introduction

In this chapter, we are investigating which applications have been developed so far and in which ways authors and researchers have tried to exploit Augmented Reality in relation to tourism and cultural heritage divulgation. We talk about tourism and cultural heritage together because we realize how "tourism" encloses a much wider range of activities, which do not regard museums or artworks but can be related, for example, to leisure and relax. AR could also be useful and helpful in those tourist activities that don't cover arts and culture. AR has been efficiently augmented in retail and can effectively enhance the shopping experience, but it's not our research topic. We are focusing only on those projects that regard the discovery and narration of the cultural heritage of a place intended as follows:

"Cultural heritage includes artefacts, monuments, a group of buildings and sites, museums that have a diversity of values including symbolic, historic, artistic, aesthetic, ethnological or anthropological, scientific and social significance. It includes tangible heritage (movable, immobile and underwater), intangible cultural heritage (ICH) embedded into cultural, and natural heritage artefacts, sites or monuments. The definition excludes ICH related to other cultural domains such as festivals, celebration etc. It covers industrial heritage and cave paintings."

UNESCO glossary term

During our research, we have encountered many different applications developed in the most different contexts; we tried to list them up trying to be as rigorous as possible, enclosing all the studies and projects developed into a fixed number of categories. We are aware that it is not possible to fit all the projects into some precise clusters: the same category is going to comprehend very different projects (for both content and technologies), and someone may argue that one particular project may better fit into another cluster, also based on what subjectively values the most. Our aim is to identify some common approaches and identify the main operational

possibilities behind the use of AR in cultural heritage. We are then going to examine more in detail each category, analyzing the best examples developed and in which more clever and creative ways each path has been followed. In the last paragraphs of this section, we are going to discuss in deep detail a selected number of case studies we found particularly interesting and unique; we also selected them because of the clever use of Augmented Reality, which is really in line with the context of application and with the goals.

In addition to examining Augmented Reality projects developed within academic settings, we are also taking a closer look at those created outside the traditional academic environment. These projects have been deployed and commercialized by companies, design collectives, and startups. By examining these projects, we hope to gain a better understanding of how augmented reality is being adopted by museums and cultural institutions in the real world. It is particularly interesting to note the differences and similarities between these commercial projects and those developed within academic contexts. While academic projects often have an informational or educational focus, commercial projects are more market-oriented and need to capture a strong economic value. This is because they are developed to be sold or used to generate revenue.

With all these operations, we are getting an all-comprehensive knowledge of how AR has been adopted in tourism and cultural heritage, getting both a quantitative overview of the main statistics of the application and a qualitative knowledge through the examination of the most common approaches used. We are in the end getting a deep understanding of some precise case studies thus allowing us to have a both deep and wide knowledge of the state of the art of our topic.

3.1 Literature review

We are now spacing through the applications proposed by different authors, integrating some other meaningful applications that were not listed. Still, we encountered while researching to find some common approaches and features. We have listed 126 projects from 2002 to 2021, which were developed in the tourism and cultural heritage sector. The projects come mostly from academic sources: Puchiar and Kljun (2018) and Hamood and Hussein (2022) gave us precious help listing many of the projects developed so far. From their lists, we excluded those projects whose source was missing and the ones that were merely technical, developing visualization systems but without proposing a real context application. We also excluded those

spatial installations consisting merely of LED walls and screens without an accurate tracking or augmentation behind, which sometimes came up in the sources. We are not analysing all the applications in deep detail, but we are using this data to get quantitative insights about the methods used by other authors: which are the trends, how they changed over time, and we will try to speculate on the reasons behind those common patterns. Our aim is also to divide all the applications into a fixed number of categories so that we can identify similar and recurring features between the different projects to summarize the possibilities inherent in AR.

The main information about each application is shown in Table 1. For each project, we listed: the name of the project (when present) and authors behind it, the year of development and the country in which the project was run. These data are essential for a quantitative purpose, allowing us to investigate "when" and "where" the case studies have been developed. The most relevant information about AR usage is noted in the right columns and presents information regarding the context typology, the AR approach used, whether they are set outdoors or indoors, the kind of device used, and the typology of the application we are considering (falling into some categories we made up to encompass most of the case studies). These data cover the "how" and "what" have been developed and are particularly relevant to understand which usage of AR has been done.

These Data are worth to be examined in detail, providing the most valuable insights about the different kinds of projects we can develop. In the next paragraph, we are getting a methodological overview explaining more in detail how we intend the different categories and explaining the possible outcomes we identified for each category to clarify the further readings of the data better and to briefly explain the different modalities adopted in the studies.

Context Typology (CT) refers to the kind of place in which the project is developed. We listed three main context typologies being respectively:

Cultural heritage sites (CS) are all those places that hold significant historical, cultural, or artistic value to a particular society or civilization: cultural heritage sites are churches, temples, industries, architectural monuments, parks, cemeteries, and so on.

Museums (M) institution or building dedicated to collecting, preserving, and exhibiting objects, artifacts, or findings. Under this category, we have mostly historian museums, spacing from paleoethology museums (natural science museums) to motors passing through all the phases of history.

Art Galleries (AG): under this typology, we have those institutions who are debited to only show works of arts. We differentiate it from normal museums since they only show objects or findings with historical or cultural value but are debited to art. We operated this differentiation because of the different typology objects shown, which leads to different augmented content.

Displaced (D): here, we list all those projects that are not bent or meant for a specific place. Some applications are designed as "gadgets" the user can take home and are meant to be used everywhere (still delivering an artistic value and enhancing the experience) or projects whose content is placed all over a city, focusing on more than one place or cultural site.

Augmented Reality Methodology (AR) refers to the kind of application developed and which kind of AR technology is used. The main possibilities we identified all fall under these casuistries:

Marker (MB): Marker-based AR relies on specific visual markers, often printed images or patterns, to trigger augmented content when viewed through a device's camera. These markers serve as reference points for overlaying digital elements onto the real world, enabling precise tracking and interactions. Marker-based AR is well-suited for applications requiring accurate alignment of digital objects with physical markers.

Geolocation (G): Geolocation-based AR uses the device's GPS, compass, and other sensors to determine the user's location and orientation. This information is then used to superimpose location-specific AR content into the real world. It's ideal for outdoor applications like navigation, location-based gaming, and providing context-aware information based on the user's surroundings.

Object Recognition (OR): Object recognition AR goes beyond markers and identifies real-world objects or items through computer vision technology. It recognizes and tracks objects, allowing AR content to interact with and appear attached to them. This approach is versatile, as it doesn't rely on predefined markers, making it suitable for recognizing a wide range of objects, including products, artworks, or everyday items.

Surface Recognition (SR) Surface recognition AR, also known as surface tracking, focuses on identifying and tracking flat surfaces in the environment. It allows digital content to be placed and anchored onto tabletops, floors, walls, or other surfaces. Surface recognition is beneficial for creating interactive experiences on various surfaces without specific markers or objects.

Indoor or Outdoor (I/O): it's important to differentiate between the projects meant to work indoors (Musem, school, university, lab, room etc.) or outside (parks, streets, outside historical buildings, etc.) since the different environments give us different assets. Indoor AR experiences typically occur in controlled, stable environments with reliable lighting and limited space. In contrast, outdoor AR operates in dynamic, unpredictable conditions with changing lighting, expansive areas, and potential obstacles. The distinction is vital because indoor AR often involves precise object recognition and surface tracking, suitable for museum exhibits or retail applications. Meanwhile, outdoor

Table 1: AR projects 2002-2021

Project	year	country	CT	AR	I/O	DT	CAT
Archeoguide (Vlahakis et Al.)	2002	Greece	CS	SL	OD	W	HR
Interactive Theathre based experinece (Cheok et Al.)	2002	Singapore	CS	SL	ID	W	AW
ARCO PROJECT (Wojciechowski et Al.)	2004	UK	M	M	ID	H	HR
(Bimber et al.)	2005	Germany	CS	M	ID	H	IG
The voices of Oakland (Dow et. Al)	2005	U.S.A.	CS	G	OD	H	AW
ViewPompeei	2005	Italy	CS	G	OD	W	HR
PoneGuide (Bruns et Al.)	2007	Germany	M	OR	ID	H	IG
Virtuoso (Wagner et Al.)	2007	UK	AG	M	ID	H	ED
(Damala et Al.)	2008	France	AG	M	ID	H	IG
TimeWrap (Herbst et Al.)	2008	Germany	CS	G	OD	H	AW
TARX (Lochrie et Al.)	2008	UK	CS	G-M	OD	H	AW
Louvre NDP Museum Lab (Miyashita et Al.)	2008	France	M	M	ID	H	IG
MobySpray (Scheible & Onana)	2009	Finland	D	SL	OD	H	ED
E-Tree (Gilroy et Al.)	2009	UK	D	OR	ID	S	ED
Caarls et. Al.	2009	Netherlands	D	M	ID	W	SO
MARCH (Choudary et Al.)	2009	France	CS	M	OD	H	EA
ANR GAMME (Tillon et. Al)	2010	France	AG	M	ID	H	IG
Streetmuseum for Iphone (Museum of London 2010)	2010	UK	CS	G-M	OD	H	AW
Set et Al.	2010	Korea	CS	SL	_	H	HR/IG
Angelopoulou et Al.	2011	UK	CS	SL	OD	H	HR
Olbrich's house (kei et Al.)	2011	Germany	CS	SL	OD	H	HR
be the path (Yoon & Wang)	2012	U.S.A.	M	OR	ID	S	ED
The ulitimate TimeWrap (Blum et Al.)	2012	Germany	CS	G	OD	H	AW
Thelamon (Tanasi et Al.)	2012	Italy	M	OR	ID	H	HR
City Vew AR (Lee et Al.)	2012	Ner Zeland	CS	SL	OD	H	AW
ARtSENSE (Damala et Al.)	2012	Spain	M	SL	ID	W	IG
Memories of the Wall (Madesn et Al.)	2012	Denmark	CS	M	OD	H	ED
Bottari (Balduini et Al.)	2012	Korea	CS	G	OD	H	AW
Van Eck & Kolstee	2012	Netherlands	AG	M	ID	S	EA
Cultural Heritage Sites Visualization (Han et al.)	2013	Korea	CS	SL	OD	H	HR
6 Animated paintings (Weiquan Lu et Al.)	2013	Singapore	AG	M	ID	H	EA
Koldinghus Chapel (Madesn et Al.)	2013	Denmark	CS	SL	ID	W	HR
Trees as time capsules (Van Eck & Kallergi)	2013	Netherlands	CS	OR	OD	H	AW
Taking the Artwork Home' (Coulton et Al.)	2014	UK	D	SL	ID	H	SO
Chess (Keil et Al.)	2014	Greece	M	OR	ID	H	EA

AR relies more on geolocation and context-aware information, which is ideal for navigation, location-based gaming, or tourist guides.

Device Type (DT): Distinguishing between the types of AR devices is essential since it directly influences the nature of the augmented reality experience. The choice among these devices should align with specific use cases, user engagement goals, and the desired level of immersion to ensure the optimal AR experience for the intended audience.

> **Handled (H):** Handheld devices like smartphones and tablets (both rented by the institution or owned by the user) are widely accessible for AR experiences. They offer portability and versatility, allowing users to engage with AR content easily in various locations. These devices rely on their built-in cameras and sensors to deliver marker-based or object recognition AR, making them suitable for everyday tasks, gaming, and educational applications. However, their limited field of view and reliance on touchscreen interactions can sometimes hinder immersive experiences.
>
> **Wearable (W):** Wearable AR devices, such as smart glasses or Augmented Reality headsets, provide a more immersive and hands-free AR experience. They offer a larger field of view and can overlay digital content directly into the user's field of vision. This enables seamless integration of AR into work environments, training scenarios, and complex tasks like maintenance and repair. However, the adoption of wearable AR is still evolving, and these devices often come with higher costs and potential privacy concerns.
>
> **Spatial (S):** delivered through large screens and LED walls, it creates shared augmented experiences for groups of people. It's commonly used in entertainment, live events, and advertising. These setups can offer high-quality visuals and immersive storytelling but are usually limited to specific locations. Unlike handheld or wearable AR, spatial AR provides a collective experience where multiple users can interact with the same digital content simultaneously, making it suitable for public events and exhibitions.

Category (CAT): Taking into consideration the aim of the projects and their outcomes, we identified five categories respectively in which we can insert almost all the applications we have seen. The four categories are:

> **AR informative guides:** Applications that utilize the identification of artworks or objects to provide users with supplementary information about the object being studied are closely tied to the museum experience. This is often done to enhance the information which the institution already offers.
>
> **Augmented walks:** This category encompasses all AR applications that utilize GPS to generate outdoor experiences that are displaced from reality. By harnessing GPS technology, we can establish instant interactions and triggers that result in cohesive experiences, engaging users for extended

BeThereNow (Giannis et Al.)	2014	Greece	CS	OR	OD	S	ED
VirtualZakynthos (Chalvatzaras et Al.)	2014	Greece	CS	G	OD	H	AW
Pure Land (Kenderine et Al.)	2014	China	CS	M	OD	H	HR
AR Kinect (Botanci et Al.)	2015	Turkey	D	OR	ID	H	HR
CorfuAR (Kourouthanassis et Al.)	2015	Greece	CS	G	OD	H	AW
The Loupe (Van der Vaart et Al.)	2015	Netherlands	M	OR	ID	H	IG
LecceAR (Scopigno et Al.)	2015	Italy	M	M	ID	H	HR
Città Ideale (Pierdicca et Al.)	2015	Italy	CS	M	ID	H	IG
Pucihar et Al.	2016	UK	AG	M	ID	H	ED
KnossosAR (Kasapakis et Al)	2016	Greece	CS	G	OD	H	IG
Střelák et Al.	2016	Czech Republic	CS	SL	OD	H	HR
(Hu & Tsai)	2016	Taiwan	D	G-M	OD	H	AW
WestWood Experience (Wither at Al.)	2017	U.S.A.	CS	G-M	OD	H	AW
iARtour (Herumurti et Al.)	2017	Indonesia	CS	M	OD	H	ID
(Barberán et Al.)	2017	Ecuador	CS	M	OD	H	ID
(Nóbrega et Al.)	2017	Portugal	D	G	OD	H	AW
Exploresia (Safitiri et Al.)	2017	Indonesia	D	M	ID	H	IG
(Kadi et Al.)	2017	Indonesia	D	M	OD	H	ID
(Sato et Al.)	2017	Japan	CS	M	OD	H	IG
Flaneur (Ioannidi et Al.)	2017	Greece	D	M	OD	H	IG
(Gimeno et Al.)	2017	Spain	CS	SL	ID	H	AW
(Younes et Al.)	2017	Lebanon	CS	SL	OD	W	HR
(Arias-Espinoza et Al.)	2017	Ecuador	M	M	ID	H	IG
(Morandi & Tremari,)	2017	Italy	CS	M	OD	H	HR
Rediscovering Dareungwon (Shin et Al.)	2017	Korea	CS	M	OD	H	AW
Zaffiri et Al.	2018	Morocco	CS	M	OD	H	IG
GokovAR (Ömer Faruk Demir; Enis Karaarslan)	2018	Turkey	D	G	OD	H	ID
GoFind! (Sauter et Al.)	2018	Switzerland	CS	G-M	OD	H	AW
(Dangkham)	2018	Thailand	CS	G	OD	H	AW
Watermills (Tzima et Al.)	2018	Greece	M	OR	ID	H	IG
Map marker AR (De et Al.)	2018	Indonesia	D	G-M	OD	H	ID
(Meriem et Al.)	2018	Tunisia	CS	M	ID	H	IG
(De la Cruz et Al.)	2018	Philippines	CS	M	OD	H	HR
AG Turismo (Llerena et Al.)	2018	Ecuador	CS	M	OD	H	ID
CAPSULE (Gao et Al.)	2018	U.S.A.	CS	M	OD	H	AW
(Kolivand et Al.)	2018	Malesia	CS	M	OD	H	HR
World-as-support (Schaper et Al)	2018	Spain	M	SL	ID	H	AW
When History Comes Alive (Siang et Al.)	2019	Malesia	M	SL	ID	H	HR
(Nusawat et Al.)	2019	Thailand	D	M	ID	H	IG

durations. The prevalence of GPS-based AR applications is rapidly expanding, leading to many diverse applications.

Historical reconstructions: AR provides us with the means to recreate scenarios that are missing, damaged, or absent. By overlaying augmented content, we can fill in the gaps and bring these scenarios to life. Additionally, AR allows us to reconstruct past scenarios, enabling users to experience the sensation of immersing themselves in ancient times.

Enhanced artworks: In this category, we encompass applications that utilize digital augmentation to elevate an artwork's artistic and aesthetic worth. These applications, frequently employed on renowned masterpieces, can be applied to any reproduction of the paintings, extending their presence beyond the confines of the exhibition space and enabling widespread and repeated access.

Each of these categories represents a different approach used by researchers and developers providing very different kinds of applications. Each category will be discussed in the next paragraphs, showing for each one the evolution of the applications developed, how they changed over time following technological advancement, and the major availability of AR technologies; we will also take into consideration the best and most interesting examples developed.

From the year column we can see how many applications have been developed per year; the condensed data are shown in figure 1. The most prolific years for AR were 2017, with 18 case studies. We can see a general augmentation of the number of projects per year as the years grow. This is signaling not only an always increased interest by scholars towards AR, but also that developing AR experience is becoming always easier and quicker, giving researchers the chance to explore more AR potentialities. In the last two years, this growing trend of a number of projects seems to be inverted. This might be due to the Covid pandemic, which might have slowed down the research.

AR is often context-bounded and it is difficult to try that out without people meeting in presence (we must also consider that museums and art galleries were closed and cultural sites were also inaccessible due to the restrictions; even if it could be possible for researchers to work, it was meaningless for institutions to develop interactive projects, since they wouldn't have visitors to use it) but may also be the sign of a sort of disinterest towards AR as we get more conscious about the limits and challenges (sometimes unsurpassable) associated with AR. It is also true that we haven't, in the last years, invented any new interaction modality for AR (the last one is the SLAM algorithm which allows for a better surface location) and most of the possibilities available so far have already been explored and testes therefore the academic interest towards AR has somehow decreased. Some further experiments have been done trying to integrate natural feature processing (Yoon & Wang 2012)

ARM (Venigalla & Chimalakonda)	2019	UK	M	OR	ID	H	IG
(Polyakova et Al.)	2019	Korea	CS	M	ID	H	IG
(Sulaiman et Al.)	2019	Malesia	M	M	ID	H	IG
SCAN-ME (Adnan et Al.)	2019	Malesia	D	M	ID	H	ID
(Kyriakou & Hermon)	2019	Cyprus	AG	M	ID	H	EA
(Blanco-Pons et Al.)	2019	Spain	CS	M	ID	H	EA
iMars (Basori et Al.)	2019	Saudi Arabia	D	G	OD	H	ID
ArkaeVision project (Bozzelli et Al.)	2019	Italy	CS	M	ID	H	EA
(Rahaman et Al.)	2019	Australia	D	SL	ID	W	HR
iMARECulture (Bruno et Al.)	2019	Italy	CS	M	OD	H	HR
(Yu et Al)	2019	China	D	SL	ID	W	HR
(Wang et Al)	2019	China	M	M	ID	H	HR
TourGuru ((Thennakoon et Al.)	2019	India	D	G	OD	H	SO
ARTeller (Perra et Al.)	2019	Italy	D	M	ID	H	IG
(Puspasari et Al. 2019)	2019	Indonesia	M	M	ID	H	IG
(Peng)	2019	China	D	OR	ID	S	SO
V museum (Kadri et Al.)	2020	Morocco	M	SL	ID	H	AW
Kazan sightseeing system (Loptev & Bikmullina)	2020	Russia	CS	G	OD	H	IG
(Saragih)	2020	Indonesia	D	M	ID	H	ID
(Shin & Chen)	2020	Taiwan	D	M	OD	H	HR
(Kaghat et Al.)	2020	France	M	G	ID	H	IG
(Izani et Al)	2020	Malesia	D	SL	ID	H	HR
(Godewithana et Al. 2020)	2020	India	CS	M	OD	H	IG
(Lo & Gong, 2020)	2020	Taiwan	CS	SL	OD	H	IG
InvercARgill (Cheah & Baker)	2020	New Zeland	D	M	OD	H	ID
(Xin et Al.)	2020	China	D	M	ID	H	IG
VITICA (Hincapié et Al.)	2021	Colombia	D	G	OD	H	AW
DinofelisAR (Marto et Al.)	2021	Portugal	M	OR	ID	H	IG

Legend:
1st row:
CT = Context Typology,
AR = Augmented Reality Method,
I/O = Indoor vs outdoor,
DT = device typology
CAT = Category

2nd row and subsequent:
CS = Cultural site, M = Museum, AG = Art Gallery, D = Displaced
MB = Marker Based, OR = Object Recognition, SR = Surface Recognition,
G = Geolocation ID = Indoor, OD = Outdoor, H= Handled, W = Wearable, S = Screens,
IG = Informative Guide, EA = Enhanced Artworks, ID = Indication, HR = Historical Reconstruction, AW = Augmented walk

and emotional computing into AR (Damala et Al. 2012), as well as multisensory AR trying to integrate smells and other multi-sensory elements (Marto et Al. 2021) but these working areas remain somehow unexplored and present some technical and logistical difficulties.

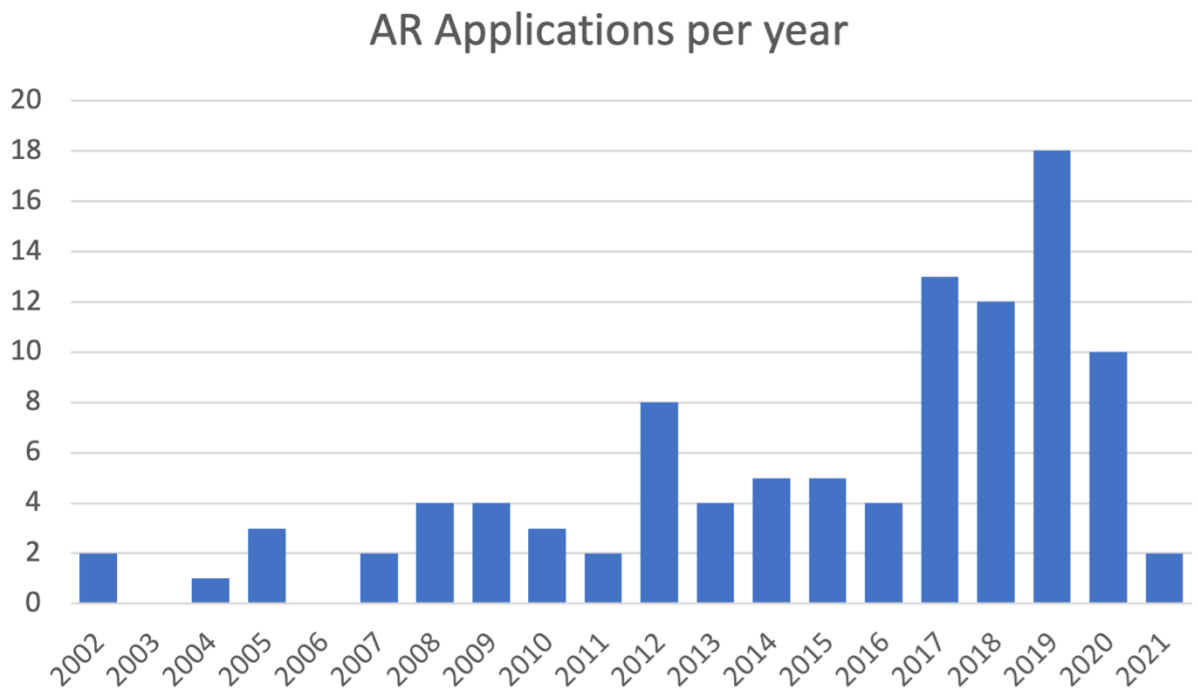

Figure 1: AR applications per year

If we consider the nations the studies come from, we can see how AR is a global phenomenon, with people worldwide experimenting with its potentialities and possibilities. Above the studies mentioned we can see that Europe is the most prolific continent with more than half of the contributions (53) followed by Asia (35). A detailed description of the distribution by continent is shown in figure 2.

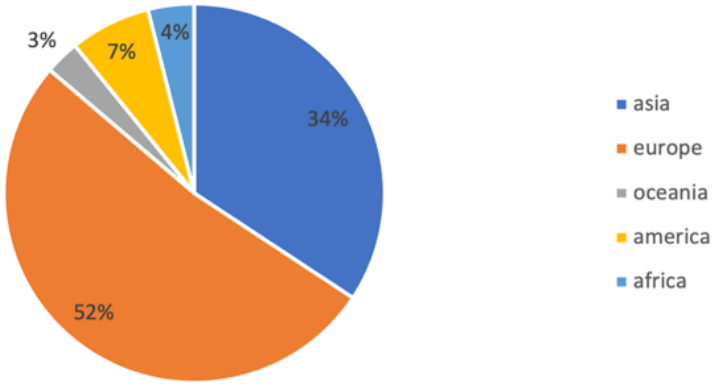

Figure 2: AR applications per continent

It's worth to notice how European countries were the first ones investigating the potentialities of with the first experiments in 2002 with Archeoguide (Vlahakis et Al.). Europe also has the most variety of countries contributing to AR research with fourteen different countries developing AR applications in academic environment; with United Kingdom with nine case studies, followed by Italy and Greece both with eight. A more detailed distribution of the AR researches among Europe is shown in figure 3. it's interesting to see how Italy and Greece together make around 30% of the total. This can show a correlation between what is associated to classical culture and AR, which is giving not only the possibility to recreate and interact with ancient scenarios but also to restore ancient buildings digitally; it's not surprising that this possibility has been mainly exploited buy those countries who were rich of antiquities and ruins (the ways Italy, Greece, and other countries developed this possibilities will be discussed later on this chapter).

The Asian panorama is also quite variegated to be seen more in detail, with 35 studies divided into twelve countries as shown in figure 4. Also, in Asia, we can see some local trust with southeastern countries such as Indonesia & Malesia developing around one out of three of the studies, with Indonesia being the most prolific with 6 studies out of thirty-five, China, Malesia, and Korea follow closely with 5 reported studies. In Africa, we can mention the work developed in Medina Fez by Zaffiri at Al. (2018) and Kadri et Al. (2020), with Morocco contributing to half of the studies from Africa.

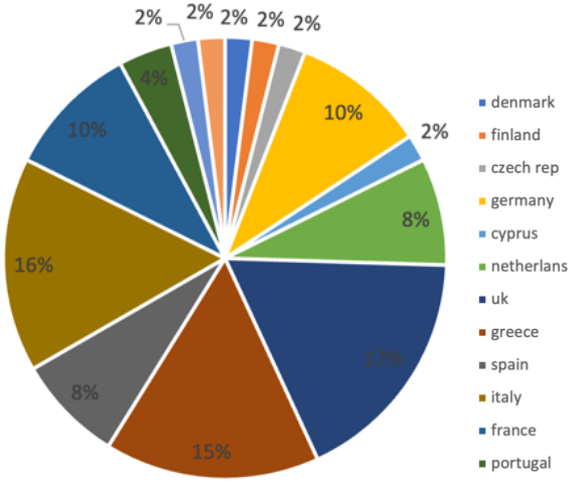

Figure 3: AR applications in Europe

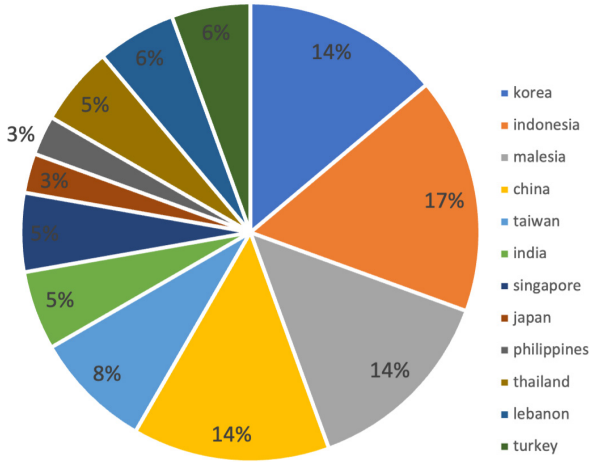

Figure 4: AR applications in Asia

We identified three different types of contexts in which AR has been adopted, which were cultural heritage sites, Museums, and Art galleries. To we added one extra category to sum up those applications that were meant to be used in more than one location and we named that "displaced". We can see how Cultural heritage sites are the preferred context of application, covering almost half of the case studies. If we compare these data spacing from 2002 to 2021 and we compare them with the ones obtained by Puchiar and Kljun in 2018, we can see how Cultural heritage sites were and still are preponderant between all the chosen places. The primate of this category

is also stronger considering that Puchiar and Kljun don't consider the "displaced" category, and those projects would fit in the Cultural Heritage site section rather than museums or art galleries. It's also true that Cultural heritage sites are the most variegated category, spacing from ancient temples to cathedrals to modern buildings, offering many more possibilities for AR development. It's also worth to notice how the displaced category gained a lot of importance; this might be witnessing the interest towards portable devices and geolocation allowing for seam-less real time integration and due to the ubiquitous nature of Augmented reality allowing various experiences to be available in multiple spaces.

Art galleries are much less present if compared to the data from 2018. This is partly due to the exclusion of a considerable number of cases (which Puchiar and Kljun still considered in their count) since they were mostly projective installations without a real tracking. These projects were mostly deployed in Art galleries; this partly explains the discrepancy. Another possible cause could be the more possibilities offered in other contexts which are more aligned with technological advancements: in art galleries we always seeing marker-based AR (all the projects developed in art galleries were using markers). Marker was the first AR method fully developed and experimented while research in last years is exploring newer solutions like Object recognition or Geolocation, which are better suitable to museums exposing artworks in the first case and need outdoor environments in the second one. Art galleries are still not a forgettable environment as we will see later on with commercialized applications where these tendencies are somehow completely reversed.

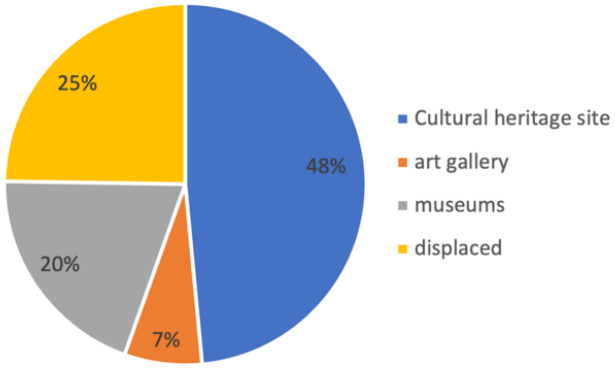

Figure 5: Different contexts in which AR was implemented

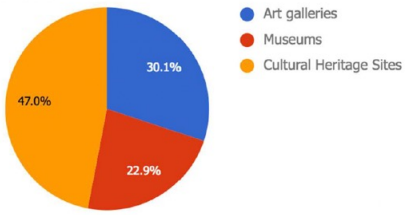

Figure 6: the same data gathered by Puchiar and Kljun in 2018

Marker AR is largely the most used in all the case studies, covering almost half (45%) of the totality of the projects, object recognition, surface location and geolocation have similar numbers attesting between 13% and 20% as shown in figure 7. Marker-based AR is the first one developed being the most reliable and stable, requiring less computational power and being easier to implement. Surface location and object recognition later required more advanced computer vision algorithms. Geolocation AR may not require much computational energy but requires portability. Since it

is only suitable for outdoor environments, portable devices such as smartphones or tablets powerful enough to load and support AR environments and scenes are needed. Marker-based AR has also become easier to implement with mostly any SDK support, making it the most popular also considering the limits of markers, which are necessary for reference and stability but may somehow be a distraction from the real object and often lead to less natural and organic interactions if compared to object recognition, that enables to interact with the object in real-time, and surface location and geolocation that automatically place the augmented contents around the user. In those last technologies lies a strong potential but often still lack stability for being employed at a good level.

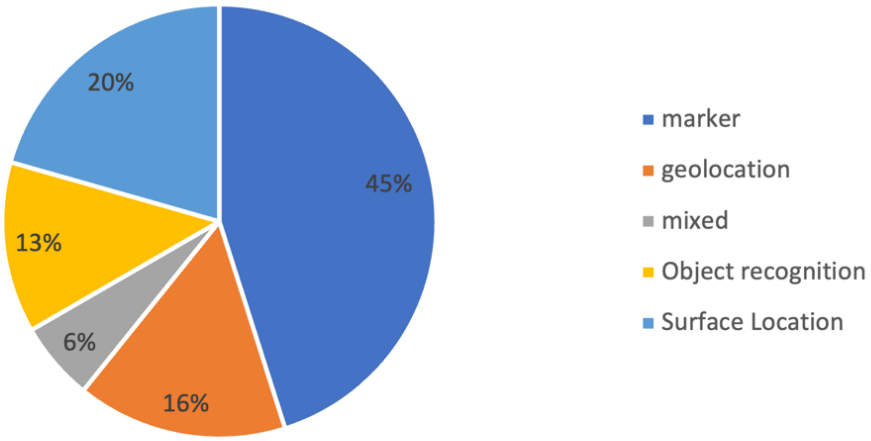

Figure 7: AR methods distribution of the case studies

We can see an incredible balance between outdoor and indoor AR, showing how both kinds of contexts furnish great possibilities for project development. Outdoor AR enhances navigation and exploration, relying on long and displaced interactions. It's worth to notice how almost all the studies the used geolocation were set outdoor and that only few outdoor applications were using markers. When used, Indoor AR tends to be more of an informative tool, enabling one to examine further and go more in detail about what is generally exposed in museums or art galleries; here, the use of marker is largely dominant, and it is the only context in which it is possible to use object recognition. Surface location is instead equally dispersed, being suitable for both indoor and outdoor applications.

About the device used we can see a strong dominance of handled devices (over 80%) as shown in figure 9; being largely the most used due to their versatility an easy implementation. They are the devices users are most used to and they are they represent the fewer economic effort for implementation. With handled and portable devices, users can download AR applications directly on their smartphones without an economic investment for the institution, which would otherwise have to buy its own devices to rent to the users. Nevertheless, the possibility to largely eliminate the costs is still a common habit for the institution to loan apposite devices for AR

experiences to ensure compatibility and minimize setup time.

Wearable devices on the other side are a great opportunity, permitting much more immersive experiences but are often cumbersome and expensive with the necessity of a huge economic effort to buy only a few setups allowing only a small number of users to try the experience simultaneously. It's also worth to say that users are not that used to wearable devices which need a stronger effort to be used and the interaction would probably feel more complex.

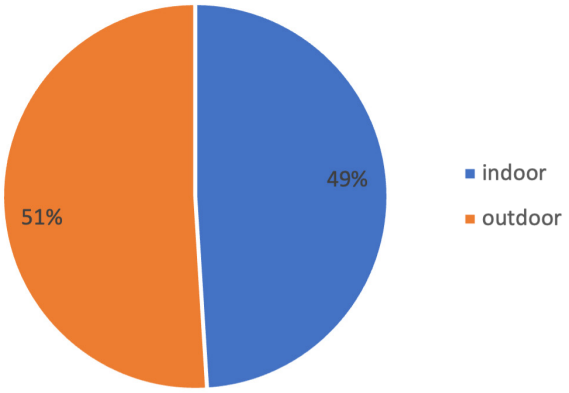

Figure 8 Indoor and Outdoor distribution of the case studies

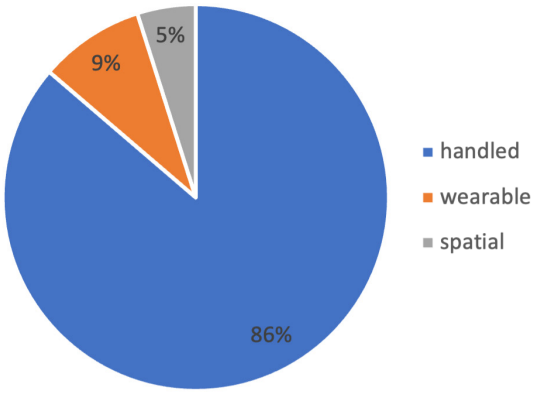

Figure 9 Different device typologies used in the case studies

We had identified four qualitative categories in which we can encompass almost all the case studies we identified. Informative Guides (IG) were the most popular with 39 case studies falling in this category, this might be due to the strong correlation between the informative value of Augmented Reality and the educational and informative function inherent cultural heritage, which must pass through information and divulgation. Augmented walks come second with 25 projects counted showing a strong interest towards displaced GPS application which have grown a strong popularity. Historical reconstructions follow closely with 22 case studies witnessing the potential AR has to revive ancient buildings and objects with the possibility to interact with the reconstructed object when the original is not available or can't be touched for preservation reason. Enhanced artworks are the less present, with only 9 applications identified, we still counted them for the importance they receive outside the academic environment and for the different and more artistic mindset they have.

Our categorization was not able to encompass all the tourism-related AR experiences, but there are some applications left that are difficult to fit into a precise category without having similar projects to create a category of their own. Some of these stand-alone projects are still worth mentioning since they often use AR in unique and original ways: Mobi Spray (Scheible et Al. 2009), a virtual spray can that allows users to virtually draw over buildings through surface recognition, while the Prosthetic reality AR catalog (Eyejack, 2012) providing a collection of AR original artworks for

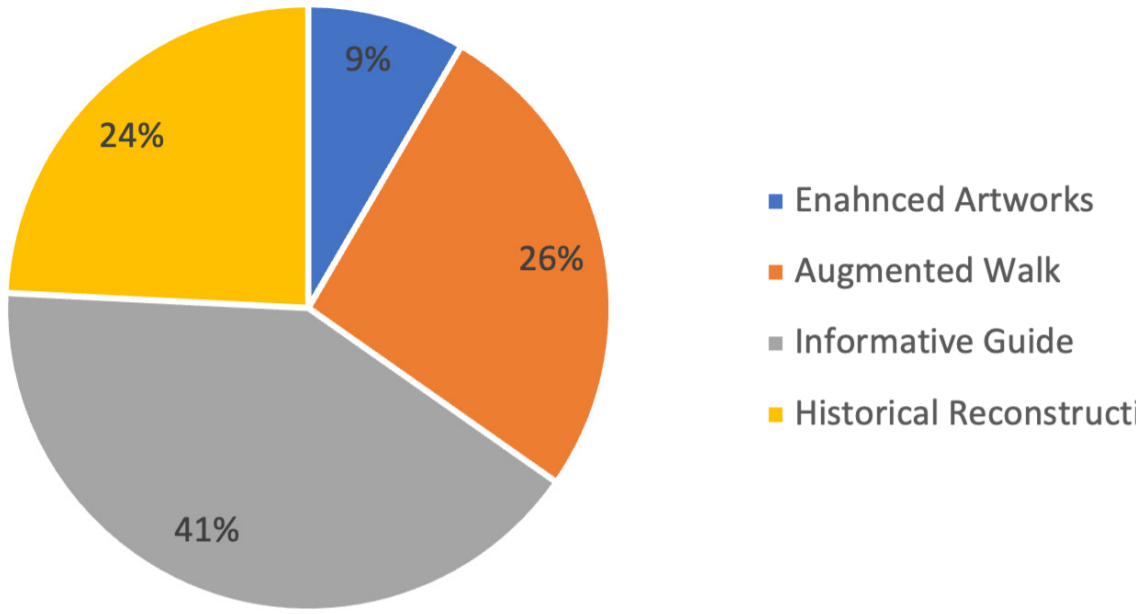

Figure 10 different categories identified in the case studies.

the user to take home as a sort of "augmented gadget" (the book is also sold online). At last, we present E-tree (Gilroy et Al. 2008), an AR artistic installation that reacts to user behavior affecting the growth of a virtual tree. We also left out those applications where AR was a standing-alone experience (educational activities or workshops) and did not rely on pre-existing exhibitions or items, even if the activity proposed was taking place in a museum or art gallery.

These categories are not meant to be completely isolated from each other. Still, they can overlap each other in different ways: an augmented tour can integrate the informative elements of an audio guide, or different historical reconstructions can be displaced among sites or cities, making the distinction between the above categories blurred and not always fixed, but it allows different projects to be asserted into more categories at the same time. Even if not cutting-edge, the proposed framework can still give us good guidance between the different approaches adopted by developers, knowing that we are not fixed to a single one but we can mix and integrate them to create a huge variety of different experiences, making AR play different roles and delivering different messages, spacing from merely informative to aesthetic and playful experiences.

In the next section, we will discuss each category separately, going deeper into the specific experiential value each of them provides, as well as the different technological approaches they have led to. For each category, we are providing examples of the different projects developed, and we are describing some of the most interesting ones. While describing the category, we have decided to quote the most

exemplifying projects of the category, even if not the most exciting and interesting ones. In contrast, the projects we describe more in detail were chosen for their importance in the development of that precise kind of project or for the interesting and innovative approach they were using.

3.1.1 AR Informative Guides:

Being the first developed AR informative guides rely on recognizing artworks or objects to deliver additional information to the user about the object under examination. These applications are the most related to the museum experience since they tend to augment the information that is already provided by the institution. One of the first and more interesting case studies is the AR guide developed by Damala et Al. (2008) in the Museum of Fine Arts of Rennes where the users can trigger an audio description and video presentations about four selected artworks after framing them. It's worth to say that without the video elements, this case study would have been really similar to a normal audio guide already used by museums. Informative guides are also the most popular choice in the literature due to their high informational and educational value making them really suitable for those institution who want to widespread culture.

In 2012 Damala et Al. tried to go a step forward tracking biometrics and behavioural data from the user to create personalized experiences that fit the emotional state of the visitor; the possibility to track emotional behaviour can create strong design assets to enrich and personalize the experience but its use could still be too expensive and intrusive, but it remains a strong possibility for the future. Tillon et Al. (2010) instead tried to make a step forward from the audio guide format by trying to give some tasks to the users (colour matching or detail searching) to create a treasure hunt experience making more conscious use of AR and trying to increase the user engagement, proving that these informational guides can be not only a passive explanation but can involve more actively the user.

During the last years, a new trend has emerged, especially in southern west Asian countries, (Saragih 2019, Adnan et Al. 2019, De et Al. 2018), taking these applications outdoor when they are firstly placed in museums or art galleries, and scaling the information process to a much wider area, often a whole city or districts, even if often relying on GPS these application are mostly informative therefore we fit them in this category rather than in the next one, even if many times they offer route suggestions and indications there are no objects tracked along the route that's why we consider them more informational guides rather than augmented walks (the category we are examining next).

We have chosen a selection of a few numbers of applications that deserve a closer look, highlighting the possibilities this approach holds. Our selected projects

encompass a wide range of diversity, illustrating how digital augmentation can offer information on a multitude of subjects:

Virtuoso: designed by Wagner et Al. in 2007, the virtuoso project is a pioneering and trend setting case study was relying on really simple marker to show 3D reconstructions of famous buildings or objects from various places and cultures, whit a 3D character describing them. The users were asked to chronological order the art pieces represented by the markers, which tell by themselves if they needed to be placed right or left in the timeline. All this turns the informative process into an educational activity. The project is limited by the time in which it was developed (markers are not much more elaborated than a QR code, and the visualizations are small and low graphics) but already presents a deep understanding of market possibilities as well as good multi-marker interaction.

The Loupe: designed by Van der Vaart et Al. in 2015 at the Allard Pierson Museum (APM), the archaeology museum of the University of Amsterdam, the Netherlands, the authors designed a magnifying glass-like device (which was holding a screen) that showed the silhouette of the objects to be scanned. Once scanned, the screen in the magnifying glass shows information about the scanned object. To pass from one object to another, the user has to shake the device. This application was chose since it shows a very interesting and playful interaction and product design as well as an interesting way to meet object recognition but still using marker AR and an interesting way to "overcome" the limits of the marker asking the user in a non-intrusive way to properly interact with the environment.

ArTeller: developed in 2019 at the University of Cagliari by Perra et Al., this application focuses on Marker identifications of a series of different and famous paintings. Once interested in a painting the user can press a button to start a scanning process, if the tracking process finds one of the available paintings, an informational card is displayed. The application relied on an external library of artworks, which the user had to install separately, making the application really wide and potentially expandable by the user who could upload more artworks or artworks library to the app. The app was not meant to be used in a specific place but in all the most famous museums of the world containing famous artworks from all over the globe, showing a remarkable approach that is not bound to a specific context like normal in these cases.

SARIM: Kaghat et Al. 2020 developed at Musée des Arts et Métiers in Paris 2020 an AR System which was not rely on visual objects, as the authors and some curators find them distracting. The authors designed an Audio Augmented Reality (AAR) system, which tracked the position of the user to create 3D stereo spatialized, content-aware audio content. Through this system, they aimed to create a much more immersive visit experience relying on the immersive power of sounds. The system was also powered through user gestures and their recognition to understand their preferences and behaviors, creating

personalized visits according to user preferences. This approach uses natural actions such as gestures and movements inside the room to create a natural and automatic interaction, making the system almost “invisible” as it’s naturally integrated into users’ behavior.

Explore Asia: designed by Safitiri et Al. in 2017 using the VUFORIA engine, this application enables to scan of a map of Indonesia, showing different points on the map representing different sites and places in the country. Users can tap on each POI and trigger a description a 360 virtual tour and a 3D visualization of the site. The project relies on a single marker to deliver multiple information. This approach is interesting since it doesn’t need a lot of materials but makes the tracking process only a trigger rather than integrating it into the whole experience. It’s also interesting how this project does not need to be in presence of the actual site but can (and has to be) accessed elsewhere resulting in an informative process, which is done prior the actual visit of the country making this both a touristic guide and an advertising tool.

Figure 11: the Location Screen
from Explorasia (2017)

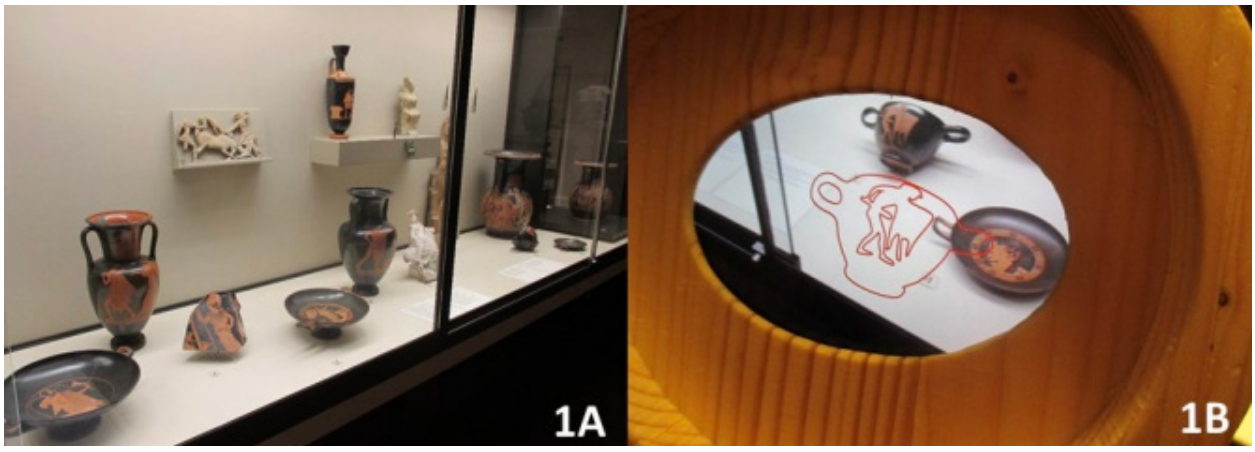

Figure 12: through the loupe, photos
taken during testing

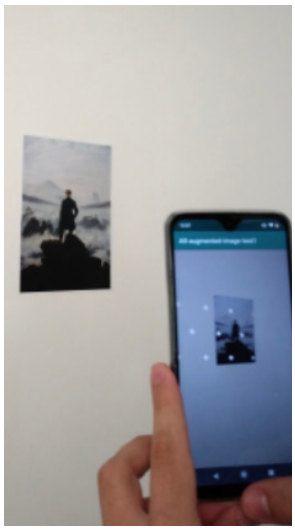

Fig 13: ArTeller, photos taken during testing

Fig. 1: Using the AR PDA version

Fig. 2: Virtual arrows providing game hints

Fig 14: Virtuoso, photos taken during testing

3.1.2 Augmented walks:

Under this category, we collect all the AR applications that rely on GPS to create displaced outdoor experiences. Almost all the application of this kind were set outdoors and were relying less often on markers using GPS and surface location. Using GPS, we can create immediate interactions and triggers to create consistent experiences that can involve users for a longer period of time. Here, we list those projects that involve the user for a whole visit, accompanying them consistently and guiding them along a series of POIs or showing information along the road. the fact that the app is "taking company" of the user for a prolonged period is a cutting-edge criterion for this category; if those POIs are too far away or if the experiences proposed in the different places are too unrelated, we tend to identify them more as informative guides.

GPS based AR application are spreading widely generating variety of different uses. GPS accuracy should ensure precise alignment of virtual content with real-world locations, offering users a deeper understanding of their surroundings. We can find playful applications like TimeWrap by Blum et Al. (2012) an AR location-aware game where two users have to collaborate to complete a sci-fi adventure in the city of Cologne. We also have more informational applications like the Westworld Experience (Wither et Al. 2107), a pre-fixed 75 minutes tour set in Westworld (Los Angeles) where the users are led by the major of the city telling his own story as well as giving information about the city, the users will also have to perform some tasks making the

experience more entertaining.

Additionally, AR-based tours provide a self-paced and customizable experience, allowing tourists to delve into specific aspects of a destination's history, culture, or ecology, catering to diverse interests. One of the best example of AR walks that combines marker AR and GPS is StreetMuseum developed by the Museum of London (2010), which allow users to view simultaneously old pictures of London overlapped with their nowadays counterpart while exploring the city. This application has no task to complete or a precise order to follow. Still, it can be integrated into a normal touristic activity without occupying the user but leaving him free to explore the city.

We have handpicked a limited number of applications that warrant further examination, showcasing the potential of this approach. The projects we have selected span a diverse spectrum, demonstrating how digitally augmented content can enhance a variety of experiences:

The voices of Oakland: this project, designed for portable computers in 2005, was set in the historic cemetery of Oakland and was between the first to use GPS for a location-based AR application with a unique setting and narrative. The narrative was realized through voice actors who play the parts of cemetery residents and tell stories about the time periods in which they lived. The user setup relied on a backpack with a laptop, headphones, and a controller. The experience took place in the wide area of the cemetery and consisted of five possible interactions with five different characters from the past who were telling their stories. This project is really valuable if we considered it was deployed in 2005 and relies on a relatively simple and not cumbersome setup for the user, as well as having developed strong and fascinating storytelling.

V-Museum: developed in Medina-Fez, Morocco, in 2020 by Kadri et Al. this application created a virtual museum accessible through a real-world placed portal. Once passed through the portal, the user access a virtual room where his movements are real-time tracked, and I can visit the augmented room in a responsive 360 experience. The application was developed using AR Core, and the scene was modelled in Unity. The augmented room contains the 3d model of an ancient fountain and different photos from the history of the city of Medina fez. The navigation inside the virtual room is interesting, as well as the real-world placement of the portal. The only critical issue may rely on the real-world scenario in which we place the virtual room, which may prevent us from explore it fully, but if placed in an open place like a field or a square, the approach followed by the authors may create strong and valuable experiences.

World as support: Schaper et Al. in 2018 realized a virtual heritage experience for a bomb shelter built during the Spanish Civil War that currently belongs to the Barcelona History Museum. The interactive experience consisted of multiple location-based events of projective AR, which was relying on surface and object recognition without altering the original environment, using surface location

in order to supplement missing GPS data. The application was designed for children, and the design process involved elementary school students who were firstly guided through the site and, after recording their feedback, they helped in the design process of the application, which was designed according to their preferences. This project is interesting for the design process, which actively involved the users as well as creating a location based experience in an indoor environment overcoming many technical difficulties.

Rediscovering Dareungwon: developed by Shin et Al. in 2017, Rediscovering Daereungwon is a location-based Augmented Reality(AR) mobile game application that aims to enrich the experience of navigating Daereungwon, a Korean cultural heritage site consisting of various royal tombs from the Silla dynasty. The authors created three POIs, which contained augmented content related to three characters and their unique burial moments. Markers installed at the POIs and other locations in the routes that link them had additional augmented content. Another key concept was the presence of smaller tasks, relaxing moments, and rewards in between the main challenges so that tourists can effectively maintain their level of interest and immersion to the very end without feeling fatigued. This project is a good example of the huge interactive potential this approach has, taking a step further from simply placing different interactions, but connecting them together to keep the user engaged.

Capsule: developed in 2018 by Indiana University, this project takes place in the campus itself, where it was designed and was meant to teach new students about the cultural heritage of the place where they live and study. The application used a mixture of marker and location-based techniques to allow students to meet historical figures of the university and view about different moments of the history of the campus. The students had the chance to take pictures with those historical figures and share them with other students with the precise aim to help them making connections among the campus. The project cleverly gives smart insights by choosing the place where developers can work more easily and provides a particular and sectorial informative value with a strong emotional component.

Figure 15: a screen interaction during World AS support

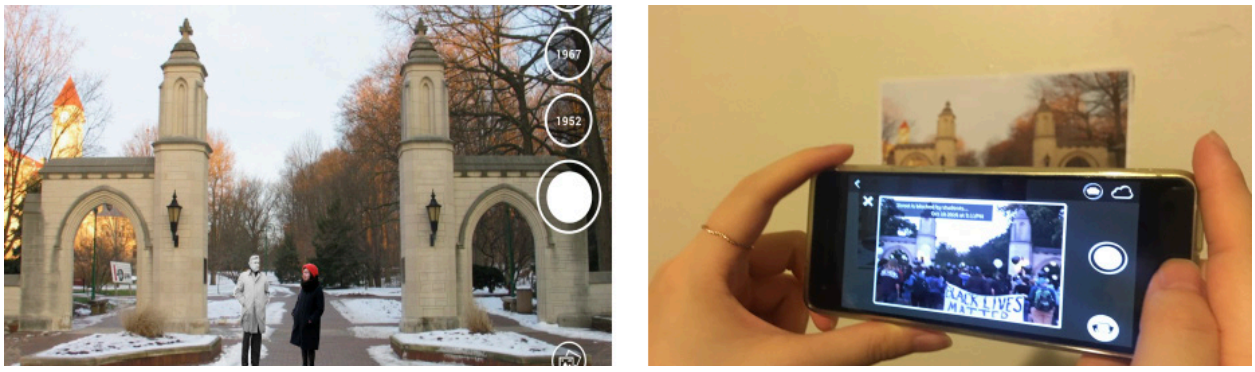

Figure 16: A Screen from Capsule and a user interacting with a prototype

Figure 17: A user interacting with The Voices of Oakland

Figure 18: V-museum: the portal and the augmented room

3.1.3 Historical Reconstructions:

Historical reconstructions were the second-last category for popularity among the identified literature. Even if they show some of the greatest potentials, allowing for never seen before visualizations, they require a high amount of study and reconstruction effort to be developed. Moreover they need great immersivity to be successfully implemented, thus making them powerful, but expensive in time and effort and monetary relying the most often on wearable setups, which are much more expensive than wearable devices.
AR allows us to recreate missing, damaged, or absent scenarios, super-imposing the missing parts as augmented content, as well as the possibility to recreate past scenarios to give the user the impression of immerging in ancient times. A good example of this kind of application can be found in View-Pompeii (Kennedy et Al. 2005), where visitors, using AR glasses, can immerse themselves in ancient Rome and visit the city as it was 2000 years ago, while Tanasi et Al. (2012) created a laser-scan replica of the Telamon statue (which was constantly degrading) to superimpose over the real artwork to "save it" from decaying. Those applications represent two major advantages and possibilities behind this kind of project: the chance to recreate an ancient scenario (giving the users the possibility to live no more accessible contexts and lifestyles) and the chance to see the undamaged object as the original users were experiencing them.

This emerging field showcases the potential to resurrect ancient contexts and present artifacts as originally experienced. However, successful historical reconstructions depend on a thorough understanding of the historical context, ensuring accuracy and authenticity in bringing the past to life; these applications must be deeply interconnected with the history of the related content and from that history, developers can find material to show and superimpose like Bimber et. Al (2005) did when they reconstructed the original version of different paintings through AR, which were later retouched. To create this kind of application, it is necessary to know perfectly the history behind a given artwork and the assets it can offer; in this case, we must be aware of the retouches made on the painting and have access to a non-retouched version recorded otherwise the implementation of the project wouldn't have been possible or would have been misleading. This kind of reconstruction can not only be applied to the presented artworks or items but can also be used to create reconstructions "from sketch" of artworks that are no longer really there (maybe they were destroyed or stolen). It's the case of "Virtual Zakyntos" an app developed by Chalvatzaras et Al. (2014) to enable user to see those buildings that were destroyed by the earthquake of 1894 in the places where they were once.

We selected 4 applications worth mentioning more in detail, showing the potentialities this approach can have. We selected some projects that were as variegated as possible, trying to show how, through digital reconstructions, we can create very different experiences:

MARCH: This app was developed by Choudaray et al. in 2009 and is working on ancient paintings in caves. Using marker-based AR, MARCH highlights the engravings that have been ruined by time, making it easier to understand the story behind them. MARCH has been widely praised for making the entire visit more enjoyable and educational. Visitors can use the app to explore the caves at their own pace, stopping to examine the paintings in greater detail. This application mixing a historical reconstruction and artwork augmentation provides strong informative content, making the whole visit more easy an pleasant. This combination of technology and art is an excellent way of preserving history while making it accessible to a broader audience.

Archeoguide: Developed in 2002 by Vlahakis et al., Archeoguide at the Olympia archaeological site is one of the first AR projects that addressed towards cultural heritage and archeology. It used a large and cumbersome wearable setup (portable devices were not yet affordable) to project the Greek temple of Hera as it was in ancient times, as well as other monuments like the famous ivory Zeus Statue, which is no longer available. The tracking process was realized using different photos of the place to be compared to the camera view, and accordingly, the 3D models were adjusted accordingly. This Surface location is still an embryonal Algorithm and can be used only on that site and in precise places. Even if still limited, Archeoguide lies on a really strong concept explaining perfectly how AR can be useful in reconstructing ancient buildings and recreating missing and damaged scenarios.

Morandi et al., in 2017 reconstructed digitally the Basilica of S. Michele situated in Cavaion Veronese, Verona, Italy. The authors took a lot of effort recreating the aspect of the church, of which only a few rest remain, showing only the planimetry of the place. They studied different ruins in the same area (north east Italy) and at the same time (11th -13th century) to recreate a digital reconstruction of the church to be placed. They used a photogrammetric approach to recreate and detect the shape of the terrain and the ruins, turning them into really detailed 3d models. The models were linked to two markers to allow the AR visualization of the reconstructed site. This project is a good example of the visual quality available nowadays and of an incredibly reliable reconstruction.

Izani et Al. in 2020 worked on the Famosa fortress in Melaka, Malesia, a huge former construction consisting of a fortified city of different squared Kilometres. The area of the former fortress is now part of the Melaka city, and it is enclosed in the urban tissue of the place. The authors edited a model of the fortress on Sketchfab and created a markerless AR application to place it scaled on any surface around the user. The project also contains audio description music texts, and the view is bird eye animated along the fortress. This application shows the historical reconstruction of a large-scale place and no longer existing environment, demonstrating the power of AR in telling about ancient places also when the site where they were placed has been completely transformed.

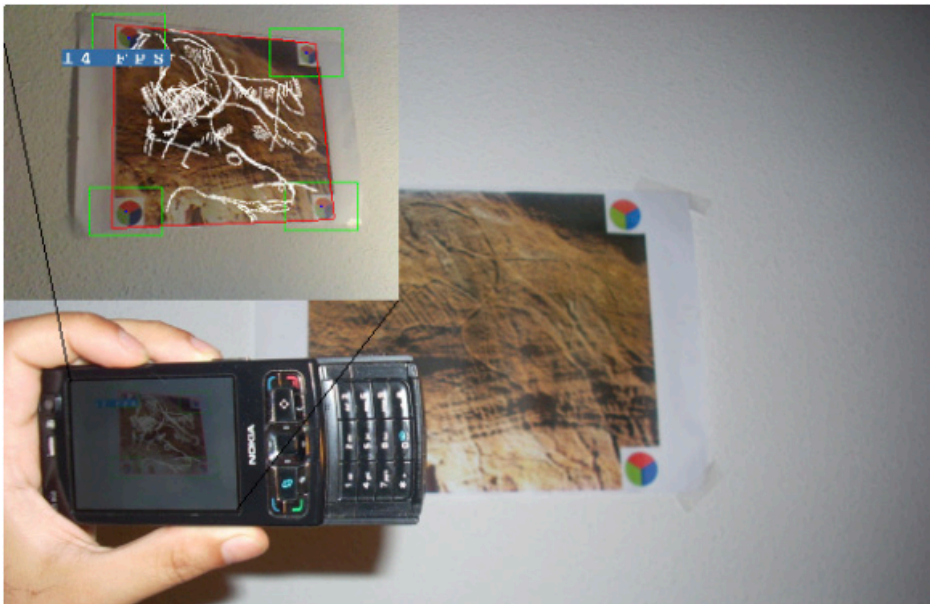

Figure 19: a user interacting with MARCH

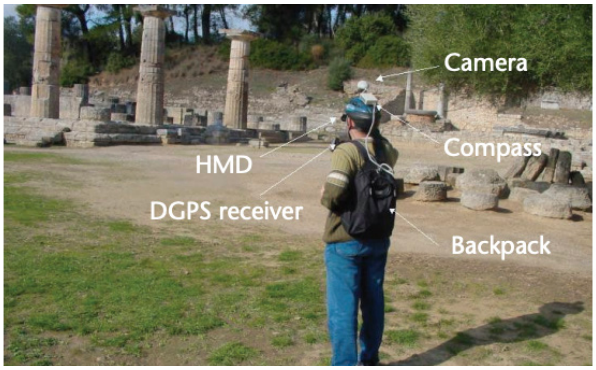

Figure 20: the user setup of Archeoguide and the 3D view of the experience

Figure 21: the reconstruction of the St. Michele's church by Morandi et al.

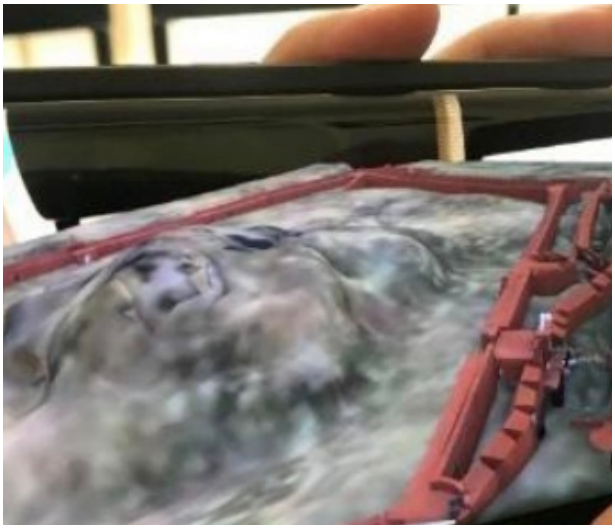

Figure 22: the 3d AR visualization of Famosa Fortress

3.1.4 Enhanced Artworks:

With the advent of augmented reality (AR) technology, the world of art has been revolutionized. One of the most interesting applications of AR in the art world is the ability to create animated versions of static items, such as paintings and sculptures, by superimposing these animated versions onto the original artwork. This allows us to bring them to life, creating a truly unique and immersive experience for the viewer. From enhancing the details of an artwork to creating an entirely new layer of animation, the possibilities are many. Using digital augmentation, we can generate a bigger aesthetic and artistic value, transforming a static piece of art into a dynamic and interactive experience. One example of this approach is Ararat: an iPhone application designed by Kei et Al. (2012) where we can real-time view animated versions of different paintings, both classical from van Gogh or Da Vinci, and both created ad hoc with contemporary artists.

Despite this potential of AR in art, the number of applications in this category is relatively low, being the smallest category identified. This may be due to the fact that these applications often focus on artistic possibilities rather than practical design applications. While they offer incredible aesthetic value, they may have limited functionalities and exploration possibilities within the project. Despite these limitations, applications that use AR to enhance famous artworks offer a precious asset. By working on well-known pieces, these applications can be used on every painting reproduction, rather than being limited to the exhibition space. This allows the artwork to be ubiquitous and repeatable, creating a lasting impact on the viewer. One example is Amir Baradaran (2011), who used AR to attach to the Mona Lisa a 52-second animation, where the woman is wearing a robe representing the French flag, adding a completely new message (in this case, political and patriotic) to the original artwork.

We selected three applications worth mentioning more in detail, showing the potential this approach can have. We selected some projects that were as variegated as possible, trying to show how AR can enhance different kinds of artworks.

6 Animated paintings: Weiquan et Al. (2014) commissioned six original paintings to be animated. This was then taken a step further with the development of an iPad application called AR Muse. This application allows users to view the animated versions of the paintings by simply framing the original artwork with their iPads. The result of this creative collaboration was an exhibition in Singapore that provided viewers with a completely new way of interacting with art. Not only did the use of animation and augmented reality (AR) technology capture visitors' attention, but it also resulted in a higher amount of time spent looking at the artwork. Furthermore, the use of AR technology also led to a better long-term identification of the artwork, as viewers could recall the specific details more accurately.

ArkaeVision (2019) is a user-centric integrated system that seeks to offer

different modalities of exploitation of Cultural Heritage. Through this system, individuals can explore the Hera II Temple of Paestum and the slab of the Swimmer Tomb in a more immersive and engaging manner with a strong emphasis on the emotional component of cultural heritage experiences. Moreover, ArkaeVision also recognizes the importance of user engagement through gamification; the app is designed to encourage active participation by users. The system has undergone preliminary evaluations, which have shown that the communicative approach employed is auspicious for education and engagement in cultural heritage experiences.

Pure Land: Developed in 2012 and showed at the Shanghai Biennale, September 2012 to March 2013. The projects integrate high-resolution digital archaeological datasets (photography and 3D architectural models) with immersive, interactive display systems. The installation recreated the grottoes temples at Dunhuang, Gansu Province, in north-western China. The application allowed users to interact and choose between different visualizations and interacting with the augmented wall paintings with wearable glasses. The installation manages to provide cultural value about the artifacts and the scenes portrayed in the paintings as well as animating them, creating a powerful, fascinating effect that is giving the reconstructed wall paintings a robust aesthetic value as well as a strong knowledge about the original place and the referring culture, making This project represent an excellent mixture of aesthetic and artistic content.

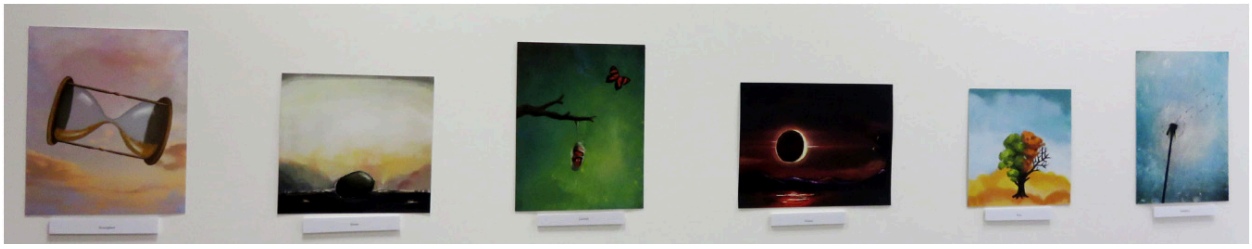

Figure 23: the six painting realized for 6 animated paintings

Figure 24: a user using the Pure Land application

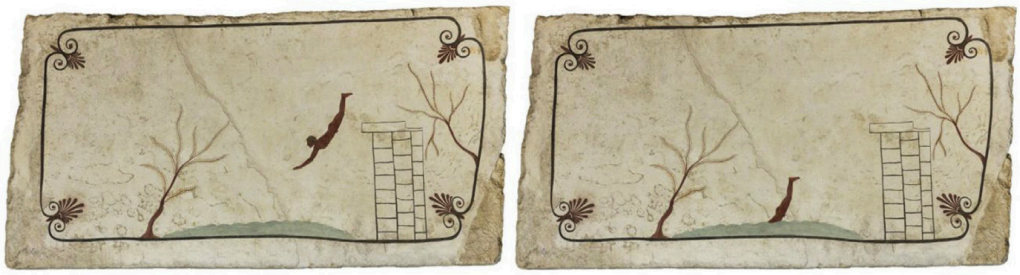

Figure 25: Arkaevsion: the top slab of the tomb and a frame of the animation

3.2 Commercialized AR applications

We are now going to investigate those applications that went out of the research environment and came out to the public and the different use companies and institutions are making of AR outside the context of laboratory studies. To do so we searched for the web outside academic databases, looking for the most documented AR applications in the field of cultural heritage and analyzing them in the same way we did for academic case studies, looking for similarities and differences between what has been done by academic researchers.

AR is becoming much more of an interest in startups and businesses investing more money as AR technology becomes more and more affordable. It's important to investigate the differences between the approach followed by research studies and the one followed by startups developing applications with a stronger focus on economic feasibility and economic value for the user. If university researchers tend to explore the most recent and advanced possibilities, companies are looking for a consoled system to develop experiences that are more stable and always accessible. The differences between the aims of a research study and the needs of a company (which has to make AR profitable) will lead to different developments, as we will discuss in the following paragraphs.

We listed 26 case studies we found searching the Web for documented applications of AR in cultural heritage. We had to navigate ourselves in the many tech blogs available on the internet, searching for the most documented case studies. Each case study reported below was found in at least three sources, with at least one including video documentation from YouTube or Vimeo to be sure that we only chose those project we could be sure were more than demos (it was common to find startups

that were showing only trailers or incredible applications whose level is nowadays far from reachable). It was hard to follow a precise methodology when searching the web outside of academic databases, which are more structured and organized. Still, we had to deal with sources that had very different formats and styles with a more differentiated target and scope. The 26 case studies listed in table 2 (which analyze the projects with the same criteria we followed for academic case studies) may still give a good understanding of what installation and experiences have been developed and set out on stage for the big public.

Table 2: Commercialized AR applications (2007-2021)

project	year	country	CT	AR	I/O	DT	CAT
ARART (Kei et Al.)	2007	Japan	AG	M	ID	H	EA
Holoman (Ars Elettronica Futurelab)	2009	Germany	M	OR	ID	S	IG
Frenchising Mona Lisa (Baradaran)	2012	France	M	M	ID	H	EA
Prosthetic reality (Eyejack)	2012	Australia	D	M	ID	H	SO
N Building (Qosmo Teradesign)	2014	Japan	D	M	OD	H	IG
Navi Penguin	2014	Japan	CS	G	ID	H	AW
Skin & Bones	2015	U.S.A.	M	OR	ID	H	HR
LNMA app	2016	Lituania	AG	M	ID	H	EA
Riga Motor Museum	2016	Lituania	M	OR	ID	H	EA
The Speaking Celt	2016	Austria	M	M	ID	H	IG
ArtLens 2.0	2016	U.S.A.	AG	SL	ID	S	SO
(Cleveland Museum of Art)							
Ultimate Dinosaurs: Giants of Gondwana , Royal Ontario Museum	2017	Canada	M	SL	ID	H	HR
Invasive Spaces (Grodin)	2017	U.S.A.	AG	SL	ID	H	EA
ReBlink (Mayhew)	2017	Canada	AG	M	ID	H	EA
Story of the forest	2017	Singapore	M	SL	ID	S	SO
Pop-Up (AR)t	2018	U.S.A.	D	M	ID	H	EA
Archaeological Park Carnuntum,	2018	Austria	CS	SL	OD	W	HR
Artour	2020	Italy	CS	SL	OD	W	HR
SDMA App	2020	U.S.A.	AG	M	ID	H	EA
La Fée Eléctricité,	2021	France	AG	M	ID	H	IG
REVIVRE	2021	France	M	G	ID	W	HR
Continuity at the Asian Art Museum	2021	U.S.A.	AG	SL	ID	S	EA
MRT Visual	2021	Italy	M	OR	ID	H	EA
Augmented Reality Art Gallery	2021	UK	AG	M	ID	H	EA

The year column shows a strong delay between AR studies and real-world commercialized applications, with the second category starting seven years later. This delay is easily explainable since must pass a good amount of time between when a technology is developed in a laboratory and when it's mature enough for its release to the public. After the first case study in 2009, we had to wait until 2012 to see the first AR applications developed for commercial use. This might be due to the smartphone boom, which made portable devices an everyday item in our lives. Before smartphones, it was almost impossible to deliver AR experiences without asking the user to wear or carry cumbersome setups and gear. With the smartphones available to the mass public after 2010, the pioneers have tried to develop AR and take the first studies about augmented reality into the consumer world. We have to wait until 2016 and the release of Pokémon-Go to see the first large-scale application using AR and see some other players trying to follow the wave of augmented reality. That's also true in cultural heritage, with 2016 and 2017 having the highest number of AR applications developed so far. We can also notice how the post-pandemic world has given newer insights for augmented reality with people more used to facing digital content in small everyday tasks, as well as a renewed interest in travel and tourism, which has made the demand (and consequently the offer) of touristic digital experiences, including AR applications.

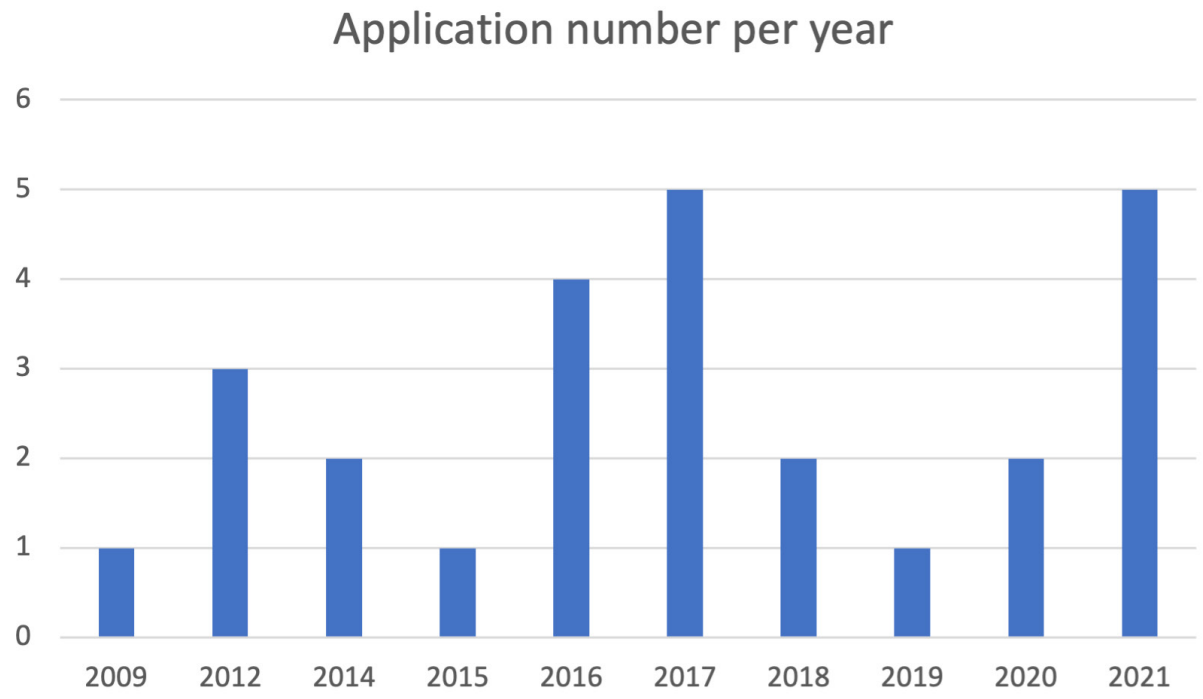

Figure 26: commercialized applications per year

One first noticeable difference lies in the context of whether the application is indoors or outdoors. If we had, in academic literature, a strong balance between indoor and outdoor applications, in real-life commercialized applications, we can see a strong majority of indoor applications, as shown in figure 27. If the exploration of open space

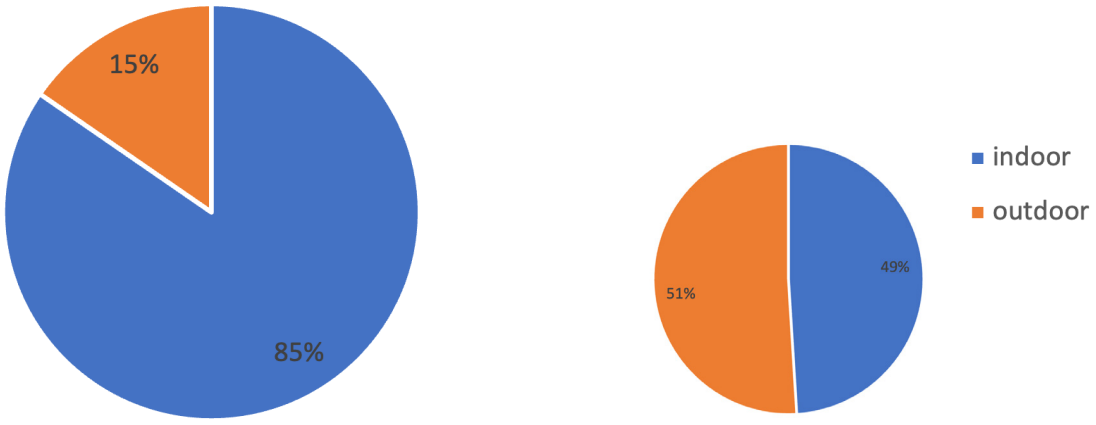

Figure 27: Indoor and Outdoor comparison between academic studies and realized applications.

realities was more interesting in academic environment, which were investigating the potentialities of positioning technology and the chance to work in an open, accessible space, these applications are drastically bounded to the context and institution they are deployed with, and to the spaces (generally closed) they offer. It's also more logistically complicated to run an AR experience in open places where more distractions and unexpected variables may occur, considering that we are no longer in a laboratory and testing phase. Still, these applications are supposed to go "on stage" normally, designers and developers opt for a more stable environment.

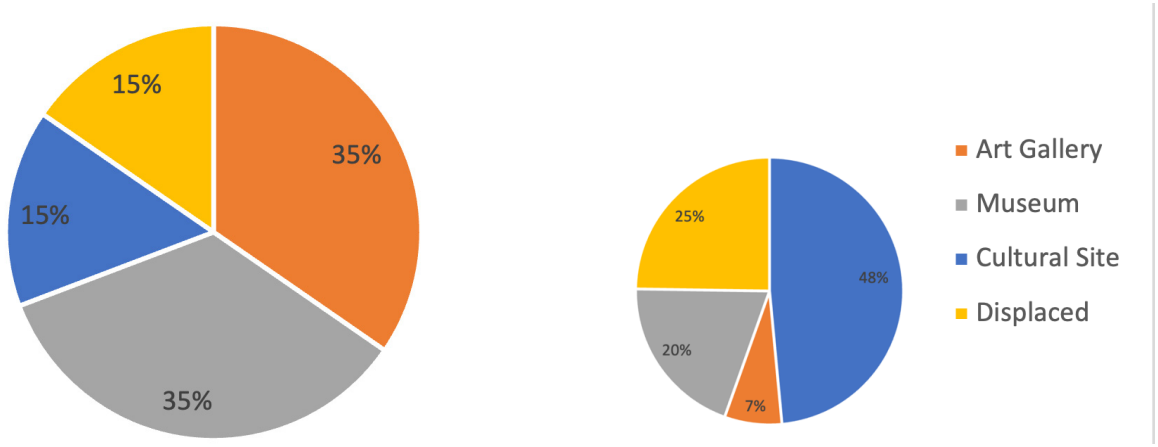

Figure 28: Context comparison between academic studies and realized applications.

The large majority of indoor applications are strongly reflected in the context in which those applications are developed. If cultural heritage sites were making 48% of the population in the academic environment, they are much less present in the commercial context, getting only 15%. Also, the displaced category was RI

dimensioned from 25% to 15%. Considering those contexts together (most displaced applications were relying on multiple cultural sites) we can see how 75% of those categories fall down to 30% as they were both strongly dependent on outdoor contexts. On the other hand, art galleries and museums went from being relegated to the last quarter (27% together) to 35% each, with a total of 70%. These contexts mostly relate to indoor realities and offer quiet, less distracting environments.

This tendency to work more in indoor realities such as art galleries and museums, rather than outdoor cultural heritage sites is remarkable and it's worth investigating. The development feasibility and the less distracting environments can play a role in these choices but are not explanatory enough. One possible reason could be the strongest will curators of museums and art galleries have to intercept the most advanced technologies: between art galleries, in particular, we also have contemporary art galleries, which are presumably more open and interested in digital technologies, including AR. Museum curators, especially archeological or historical museums, may instead rely on AR potential to reconstruct their exhibits as well as the informative and educational possibilities (which are still less relevant if compared to academic applications). On the other hand, many outdoor applications work "in the open air" without a precise institution or curator behind it, making it more difficult to find a precise interlocutor to set up a project.

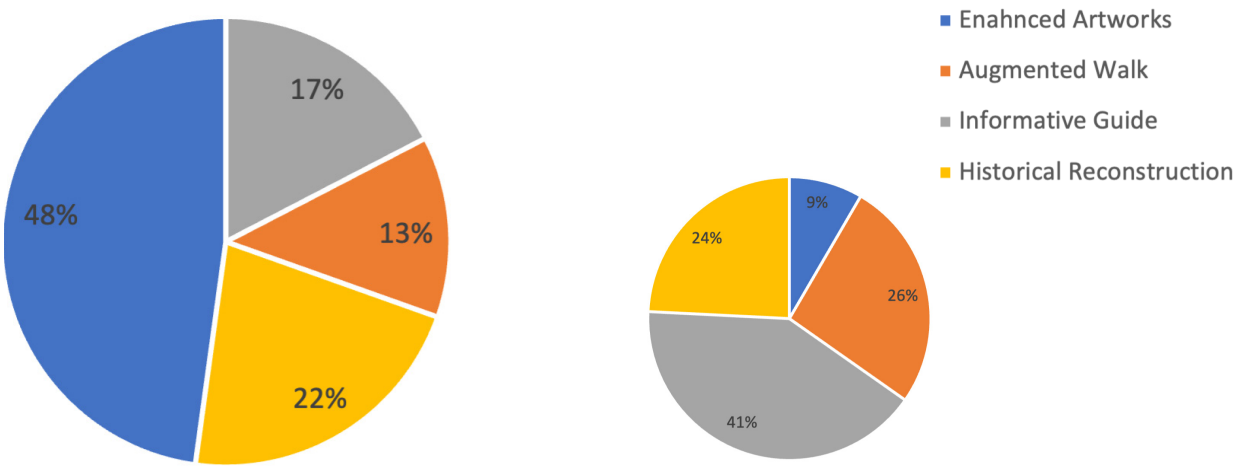

Figure 29: Category comparison between academic studies and realized applications.

Another main difference lies in the category of applications that have been developed. If most academic studies focused on the informative and educational value of Augmented Reality with informative guides (making over 40% of the total amount of case studies), in the commercial context, that kind of application is re-dimensioned to 17%. This may result in a lack of willingness by design companies to work on informative and educational artifacts as they may be less attractive and sensational for the public when compared to more aesthetic solutions. Enhanced artworks, on the other side, rise from 9% to 48%, becoming largely the most common category when we move out of the research environment.

It would be interesting to speculate about such a remarkable difference of approach: one reason could lie in the aesthetic and attractiveness, which are two of the strongest drivers of this category of applications. The second could be the attractiveness, which is already inside the piece of art the designers are working on; if we work on a famous and relevant piece of art, which is already visited on its own, the eventual AR experience is enhancing, but also intercepting the value and attractiveness on the artwork it works on. Another reason could be the willingness creatives have to use AR as their own medium to run personal storytelling rather than working on an informative process. In this thesis, we are not considering Augmented Reality art, but there are some remarkable case studies where artists worked and collaborated with museums or galleries to run AR experiences on what was already exposed. It's the case of ReBlink! (2017), where Alex Mayhew re-imagined artworks of the Art Gallery of Ontario, adding his storytelling, but without moving too far from the original subjects.

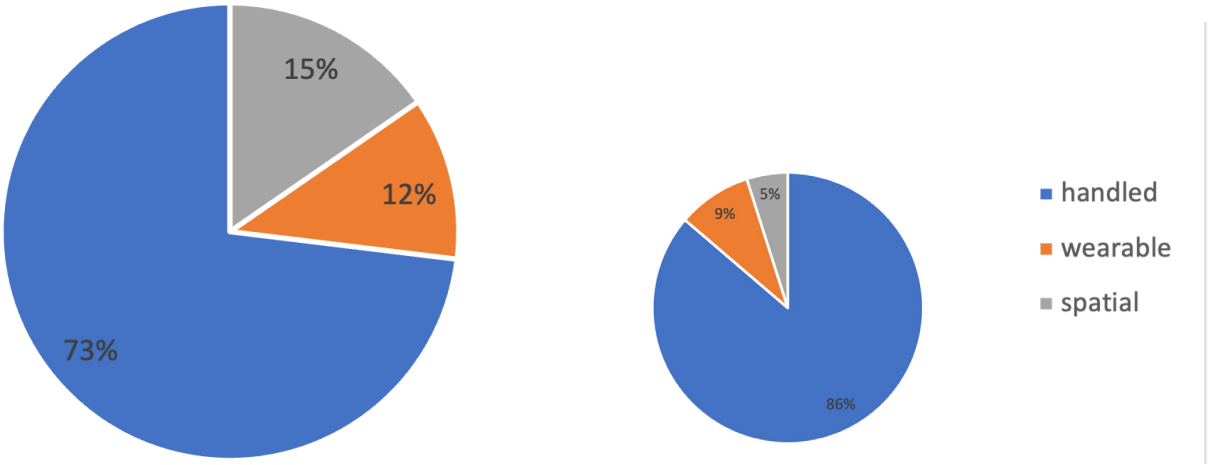

Figure 30: Device typology comparison between academic studies and realized applications

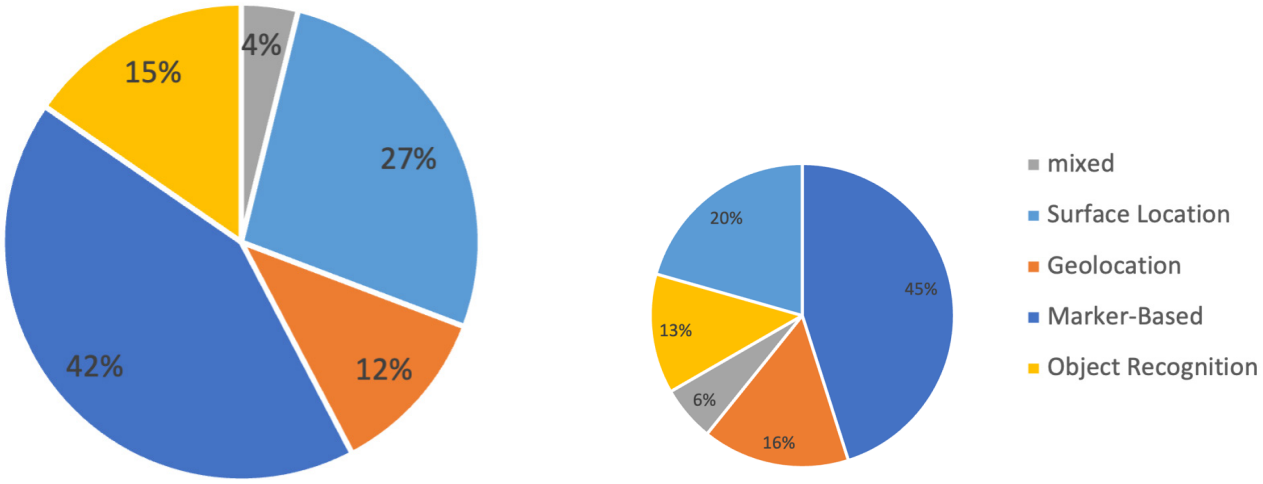

Figure 31: AR methodology comparison between academic studies and realized applications.

In the end, with what regards to the AR methodology and the device typology used, we can see a very similar situation as shown in figure 30 and figure 31. Handled devices are still largely the most chosen device typology even if screens and wearable devices occupy a slightly larger part of the chart. One of the few noticeable differences is the relatively strong growth of surface location; this can be explained for the feasibility it has when many people are interacting with the same experience simultaneously. With marker and object recognition AR we need all the users to have access at the marker, or object, at the same time, which can be a constrain. This problem doesn't persist with the Surface location, where all the users can access AR experiences simultaneously, as long as they can fit the room in which the application is set.

If the data analyzed before were referring to the context of the application and the content that was developed, this last information regards more on the kind of technology used. We have seen how, in a commercial context, it changes the context of the application and the kind of experience that is developed. Still, the AR method and device stay the same, showing how (even if the concepts are different) the AR technological trend is confirmed and stable. It's not surprising that the technology and interaction modality most used in research labs is also the one that most easily gets out on the market. Still, it's important to notice how the developing trends are staying stable on the use of handled devices and that marker-based is still the strong lead of the industry.

Summing up, we can see how commercial application tends to take outside of research labs the most consoled technologies and methods but tend to develop different contents in different contexts. From a substantial percentage of outdoor cultural sites, designers and developers tend to collaborate more often with art galleries and museums, tending to develop more aesthetic and sensationalistic applications when compared to researchers, who developed a lot of informative and educative content. Commercial applications also lean more towards the realm of digital art. This might be due to the stronger attractiveness aesthetic artistic content have on the public and to the will designers and artists have to show their storytelling. This will also seems corresponded by curators willing to explore AR as a new creative medium. This still doesn't preclude the informational and educative potential that lies in augmented reality, which been widely explored in literature, but rather lays out some new perspectives and new approaches that are also profitable.

3.3 Conclusions

In this chapter, we have extensively covered state-of-the-art AR applications in cultural heritage. We have listed around one hundred applications developed between 2002 and 2021 all over the globe, and we have analyzed the main characteristics analyzing geographical and chronological information, the context of the application (being outdoor or indoor and in which kind of site the project was developed) the AR methodology and the device used. This operation gave us sufficient data to run a quantitative analysis to understand which approaches were more common and to understand where AR seemed to have more possible applications. We have seen AR interest growing over the years, with some strong peaks in 2012 and 2017 with a descending trend over the last few years. We saw how AR has equal outdoor and indoor potential, with an almost equal distribution. Indoor people tend to use Markers (which are the most consoled AR technology) or rarely object recognition, while Outdoor Geolocation AR plays a huge role. We also identified a predominant presence of archeological or cultural sites when compared to museums and art galleries, showing a strong versatility AR has, being appliable to the most different contexts.

We also ran a qualitative analysis, observing the contents developed and to what those contents were applied; we identified four common approaches: Enhanced Artworks, Informative Guides, AR walks, and Historical Reconstructions. The first directly applies AR content to the artwork using digital technologies to increase the aesthetic value or the storytelling inside the art piece. The second relies on the recognition of markers or objects to provide real-time information, the third guides consistently and for a prolonged period the user around one or more places, and the fourth reconstructs a damaged object or building, showing it as it was in ancient times. These categories may not list all of the applications developed (some applications remained that were not listable in any category), and some applications may fit more than one category. We met sometimes multi-faced experiences, delivering multiple values, which may be listed in more than one category. Still, this categorization was sufficient to create a discerning direction between all the different contents developed using augmented reality. Through the analysis of each category (from the first approaches to the most recent and innovating), we got a clear understanding of the different approaches followed by previous researchers and a good number of qualitative insights about the directions our project can follow.

At last, we found different applications developed outside the academic context and the literature published in reviews. We analyzed them using the same criteria we used to schedule academic papers and encountered some substantial differences: a much stronger presence of indoor applications (with museums and art galleries being a strong majority) and a tendency to develop more aesthetic and artistic content rather than informative. We speculated about these remarkable differences, but further investigations (maybe running interviews with developers and designers from both sides) might be necessary. It's still essential to notice another approach, which is more followed outside the academic context, which might be profitable.

After all this research and analysis, we have a strong number of references and a clear understanding of the state of the art. We are strongly aware of AR's potential when applied to cultural heritage. During our investigations, we have identified numerous applications that highlight how AR can be used to enhance and enrich our experiences with cultural artifacts and historical sites. From interactive exhibits that allow visitors to explore ancient ruins or historic buildings in virtual reality to mobile apps that provide real-time information about artworks and artifacts. we have clearly understood the technical requirements and techno-logical assets we can use to develop our AR experience. We are trying to put all the information and knowledge into developing a new AR application to be used in a cultural heritage site in Milan. In the next part, we are describing all the decisions and integrations implemented, from context study and concept generation to the realization of a functioning prototype.

Part 2
Project Development

Chapter 1
Context study and concept development

Introduction

In this chapter, we will examine all the preliminary steps we took before starting to prototype. We start selecting the context in which we are deploying our application and proceed to a keen and in-depth analysis of the context itself and the users visiting it. We are listing the main challenges and opportunities associated with the chosen place before analysing our users' behavior in more detail. We will create a general user journey representing the overall experience and some more specific user paths to understand individual differences and the main fruition modalities we could identify. To finish our work on the target audience, we are going to create some personas to see more in detail the feelings, goals, and struggles our users could meet.

After proceeding with these various operations, we will be able to gain a comprehensive understanding of our project's requirements and expectations. By conducting our research and analysis, we will be able to identify all the key factors that could impact the success of our project. This will enable us to formulate a detailed brief that accurately reflects the goals and objectives of our project. Our brief will serve as a foundation for the development of a strong and innovative concept that will guide us throughout the prototyping phase.
Our concept will need to be carefully crafted and refined to ensure that it meets all the necessary criteria for success. Once we have developed a strong and viable concept, we can move on to the prototyping phase, where we will bring our ideas to life and create a tangible product that can be tested and refined further.

1.1 Context Selection:

The first step we took in our project was to decide the context and specific place in which we were going to design our application. During our studies, we identified three kinds of contexts in which AR experiences have been developed being, respectively: Cultural Heritage Sites, Museums, and Art Galleries. We identified three possible places, one fitting in each category. For Cultural Heritage Sites, we choose Giardini Pubblici Indro Montanelli in Porta Venezia (fig 1), which is a wide open space, accessible and frequented both by the local population and tourists. For Museums, we have chosen Museo della Scienza e della Tecnica, near S. Ambrogio (fig 2) Church, which is one of the most important scientific museums of Europe with a collection spacing from heavy industry to astronautics. Lastly, for Art Galleries, we choose Museo del '900 (fig 3), the very central art gallery hosting modern and contemporary artworks from early Avant-guards to the eighties.

Public outdoor spaces offer many possibilities: they are fully accessible without any ticket, and we can rely on GPS to create meaningful experiences and provide a strong cultural value by being actively part of the urban context. However, they also present some difficulties: it's more difficult to find an institution to talk to (being often managed by the town hall), and users may be there for many different reasons that may not be related to cultural and discovery activities. Lastly, it's hard to offer the user adequate support during the experience, being displaced over the whole garden and with the lack of guides and personnel helping the users. For all these reasons, it was the first to be discarded

Science museums offer many insights for Augmented Reality (exhibiting objects and machineries we can create meaningful interaction using object recognition) and AR can show the functioning of the machineries. Still, this kind of places are mostly addressed to local audience rather than tourists and the exhibits is somehow unrelated to the cultural heritage of the city. For this reason, they might not fit for the cultural exploration and discovery experience we are developing.

Art galleries, on the other hand, have a strong artistic and cultural relevance: Art galleries are dedicated to the appreciation of art and culture, making them an ideal environment for AR experiences. AR can enhance the visitor's understanding of the artworks, provide historical context, and engage them in a meaningful way within the context of the art on display. Moreover, art galleries already are a reference point for both tourist and provide a strong attractiveness by themselves, making them an excellent place to experiment with new technologies.

After these considerations, we selected Museo del '900 as the context for developing our project; One of the city's most famous and rich art galleries and close to the dome. The implementation of AR in the Museo of '900 in Milan offers a good range of benefits that enhance the visitor experience. It can foster engagement with art, educate visitors, preserve delicate artworks, enhance accessibility, and promote

Figure 1: Giardini Indro Montanelli

Figure 2: Museo della scienza e della tecnologia

Figure 3: Museo del ‘900

technological literacy.

Implementing AR can significantly improve the visitor experience by providing an immersive, educational, and interactive platform for engaging with artworks. Visitors can use AR applications on their smartphones or dedicated devices to access additional information, audio commentary, or interactive elements related to the artwork they view. This will enrich their understanding and appreciation of the art.

1.2 Context Study: Gallerie del ‘900

The Museo del Novecento in Milan is a permanent exhibition of 20th-century works of art housed in the Palazzo dell’Arengario and the adjacent Palazzo Reale in Milan (fig. 4). The museum was inaugurated in 2009 and absorbed the collections of the previous Civic Museum of Contemporary Art (CIMAC), which closed in 1998. The Gallery of ‘900 is a venerable art institution that focuses on the art and history of the 20th century. It houses an extensive collection of artworks, including paintings, sculptures, and multimedia installations from some of the most influential artists of the 20th century.

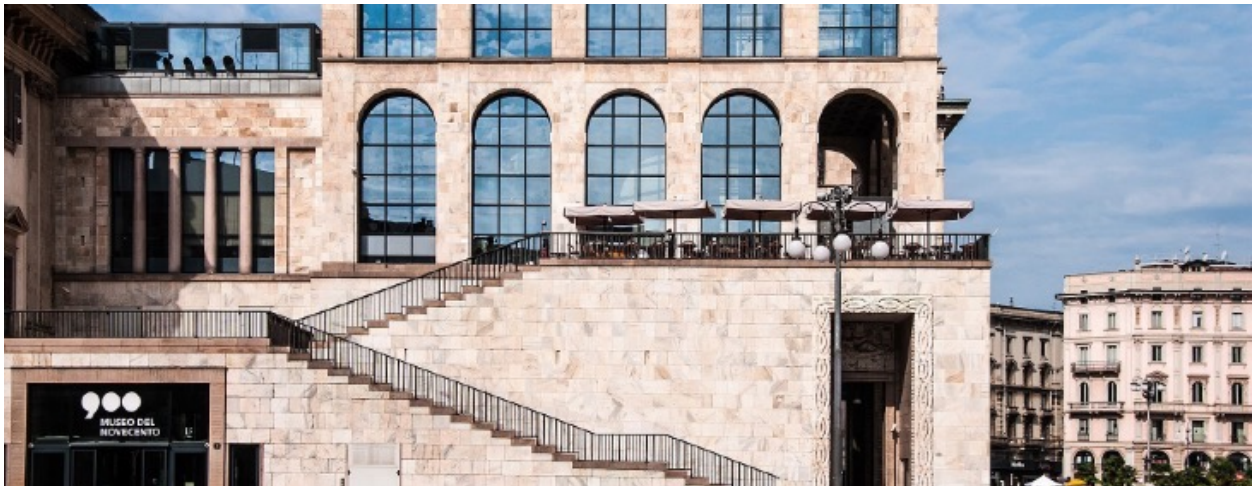

Figure 4: the palace hosting the gallery

The Collection begins with a nucleus of works unique in the world exhibited in the Galleria of Futurism, with Umberto Boccioni, Giacomo Balla, Fortunato Depero, Gino Severini, Carlo Carrà and Ardengo Soffici. There are also some insights into particularly significant transversal themes in the art of the century, like Metaphysics. On the fourth floor, we cross the period that from the fascist period leads to abstractionism. After the space dedicated to Marino Marini, which aims to provide a glimpse of the artist’s rich and varied production, there is the characteristic Sala Fontana, overlooking Piazza Duomo and designed as an immersive environmental work to accommodate the large 1956 ceiling (fig 5.).

The path continues with the Second World War, where personal and contextual rooms alternate. The “new ways of abstraction” room presents large-format works through which the bold abstract experiments of the 1950s and 1960s are addressed. Through the suspended walkway connecting the museum to Palazzo Reale, you enter the final section, which deals with the period between the early 1960s and the early 1980s. From Kinetic and Programmed Art, we reach Pop experiences and analytical paintings, while conceptual art is represented in its Italian and international declinations. The itinerary continues with the room dedicated to Luciano Fabro and then unfolds in a reflection on the birth of the installation through the works of artists

such as Jannis Kounellis, Eliseo Mattiacci and Amalia Del Ponte; finally ends on the threshold of the Eighties with Mimmo Paladino, Nunzio Di Stefano, Paolo Icaro, Giuseppe Spagnulo and Alighiero Boetti.

Figure 5. the inside of the museum with the view over the Dome

1.2.1 Context observation

The first step we took to analyze the context was an exploratory study using self-observation and shadowing. We went to the museums twice (once on a weekday and once during the weekend) to analyze the experience in the museum and to observe the behavior of the visitors to identify common patterns and struggles. Our visit to the museum gave us the chance to identify different recurrent struggles and some opportunities provided by the context we can rely on. We also listed the main challenges to achieve to improve the overall museum experience, as listed below.

Struggles:

Wayfinding inconsistencies and difficulties: even if the planned route was quite linear, it becomes difficult, once moved from the suggested route, to come back and to understand what way we are following. The presence of temporary exhibitions also asks the user to deviate from the optimal route, breaking the path.

Fragmentary and not cohesive information: the information provided by the institutions presents some inconsistencies (the number of rooms is visible only from the third floor, signs are different between floors, and there are strong differences between the wayfinding and the information about the artworks.

General lack of Multimedia support: the only multimedia artifacts was a QR code leading to a static landing page, there was no multimedia support (we didn't notice anyone using or asking for audio guides) and all the communication was relying on traditional printed media

Lack of Multi-language support (only English): the information printed on signs was available only in Italian and English, without any other way to translate the information in our preferred idiom.

Acoustic noise and other distractions: Even if the whole place was quite silent, we encountered some distractions, mainly presented by organized groups, which occupied most of a single room. It's also possible to be distracted by passers-by and the guides explaining.

Challenges:

Keep the user's attention constant during the visit: the attention span of the users may not be enough to follow the whole exposition, so it's important to constantly renew user attention, mainly in the last rooms where the user is already tired of walking and has already seen a lot of artwork and information.

Increase the amount of time spent looking at the artwork: when the user looks at an artwork they often don't know which details to notice and only give a summary look about the painting. We must guide the analysis of a painting, taking the user to spend more time with it.

Isolate the user from distractions: create a personal and intimate experience can help keep the user concentrated on the artwork. Using headphones can easily manage to prevent acoustic distractions, and concentrating on visual screen elements can help focus on the painting.

Create further curiosity and willingness to inform: the explanation given by the institution (and our experience) is not to exhaustively explain everything about an artwork (which will take too long) but rather to create further curiosity in the user, maybe taking them to buy catalogues and art history books in the souvenir shop as well as promoting a stronger willingness to discover.

Explain the relationship between various artworks and artists: The XX century was a great movement, rather than the work of some stand-alone artists. It's important to make the user understand how different artworks are related, showing the evolution of a single artist and their influences on each other, showing how the artworks create a continuous dialogue between themselves and are not unrelated.

Opportunities:

The shape of the rooms is always different: the width and shape of the rooms are always changing; this offers many opportunities for surface location, and we can rely on the conformation of the museum to create our experience. It's also mentionable that many rooms are "thematic," allowing to create content that may fit an entire space.

Medium audience quite young and used to digital technologies: most of the users were Gen Y and Z, already digitalized, and very familiar with screens. This leads us to think that our users will have a good technology readiness, and we can ask them to use a new technology (such as AR) with few preoccupations.

Rely on already provided information: art historians and museum guides are really well prepared, and we can rely on them for information gathering. The huge amount of information available is a precious asset that gives strong insights on which content to augment.

Possibility to give specific tasks to the user: the overall museum experience is relatively static and redundant. We have the chance to make it more variegated by asking for specific actions and tasks. These operations are breaking the monotony of the visit and will make our application more acceptable to the users.

These valuable insights arise from the context itself and how it is currently presented. We listed them using ourselves and our judgment as metrics, trying to analyze the context in the most meticulous way, identifying struggles and opportunities the place is giving us. These insights don't take into consideration users' behavior and differences, which will be discussed in the following paragraphs, realizing both a general user journey (which is supposed to represent the most general experience) and more specific and different user paths to show the differences between the different typology of users.

1.2.2 User Journey

We created a user journey describing the most common experience (without taking into consideration the individual differences among the users), and we mapped the main phases of the experience. We identified the most important steps of the actual experience, and for each stage, we associated the perceived user feelings and all the possible pain points. We also divided the steps into three main phases and created a line chart, which gives a chronological perception of the evolution of the user's feelings during the whole experience.

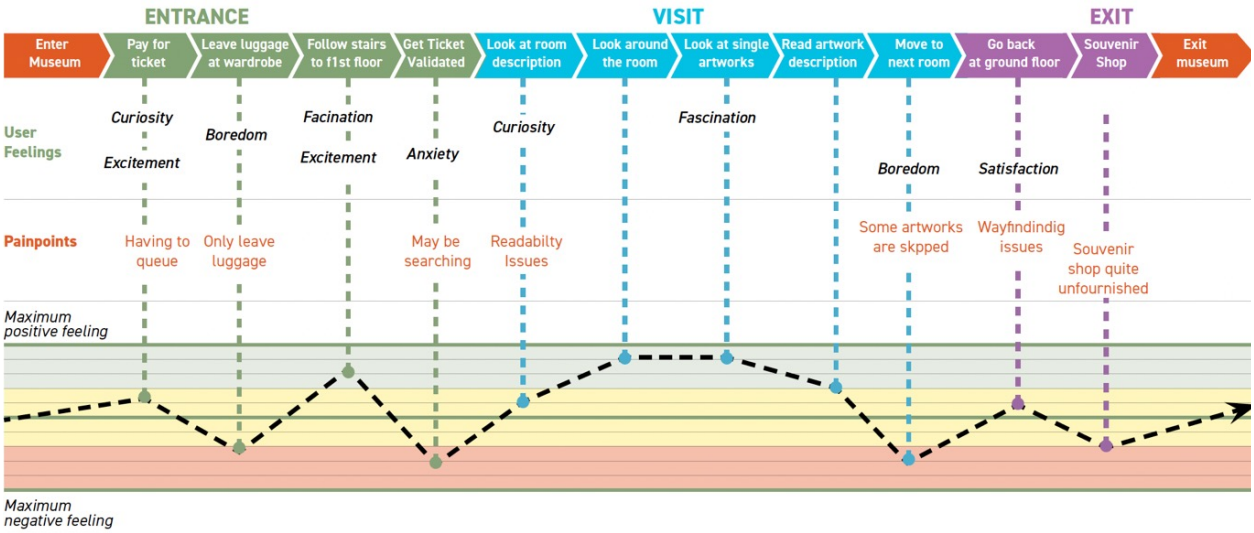

Figure 6: user Journey

We identified three main moments: the entrance, which is characterized by many different moments and a mixture of feelings going up and down from excitement and curiosity to boredom when queueing to anxiety when being controlled at the entrance. The actual visit is the longest phase (even if it doesn't contain that many different moments). The steps the user is taking here are often similar and redundant (in the user journey, we described the exploration of a single room, but the process is repeated many times). The feelings associated with this part are quite linear, with a strong curiosity in the first rooms, which decreases to boredom the more we walk around the gallery. At last, the exit part consists of only two steps, and even if there are some pain points in this part, the main feeling associated with this phase is relief and satisfaction as the experience is concluded. The user feels they have done something important for their culture and education.

The positive feelings we encounter more often are excitement and curiosity for what's coming and fascination for what we are currently viewing. The user has the most positive feelings during the first parts of the exhibitions when they have just entered the actual exhibition, after the ups and downs they experienced during the entrance, and when they are still curious and excited about what they are about to see. The most negative feeling we experienced was boredom, which arose the more time we spent in the museum and became more dangerous in the last parts of the visit. This user journey gives us a precious overview of the whole experience and a good understanding of user behavior and responses when exposed to the typical museum experience. Even if it does not consider individual differences, it gives a strong understanding of the general experience, which will be crucial for the development of our project.

1.2.3 User Paths

We are now going to consider different kinds of users and behaviors. Observing individual differences among users, we aim to identify some common approaches and modalities of interaction. User paths are the most suitable method for identifying single differences in users' behavior, allowing us to highlight the most different modalities to enjoy the visit.

We aim to list the more interesting and common interaction modalities and paths. To do so we didn't focus on the whole visit but took as reference the exploration of a single room (we suppose that the same path is going to repeat for all the rooms) as the main timeframe to analyze users' behavior. When observing how people explore a room in the art gallery, we identified Three different main interaction modalities leading to different user paths, which are shown in figure 7 and are illustrated as follows:

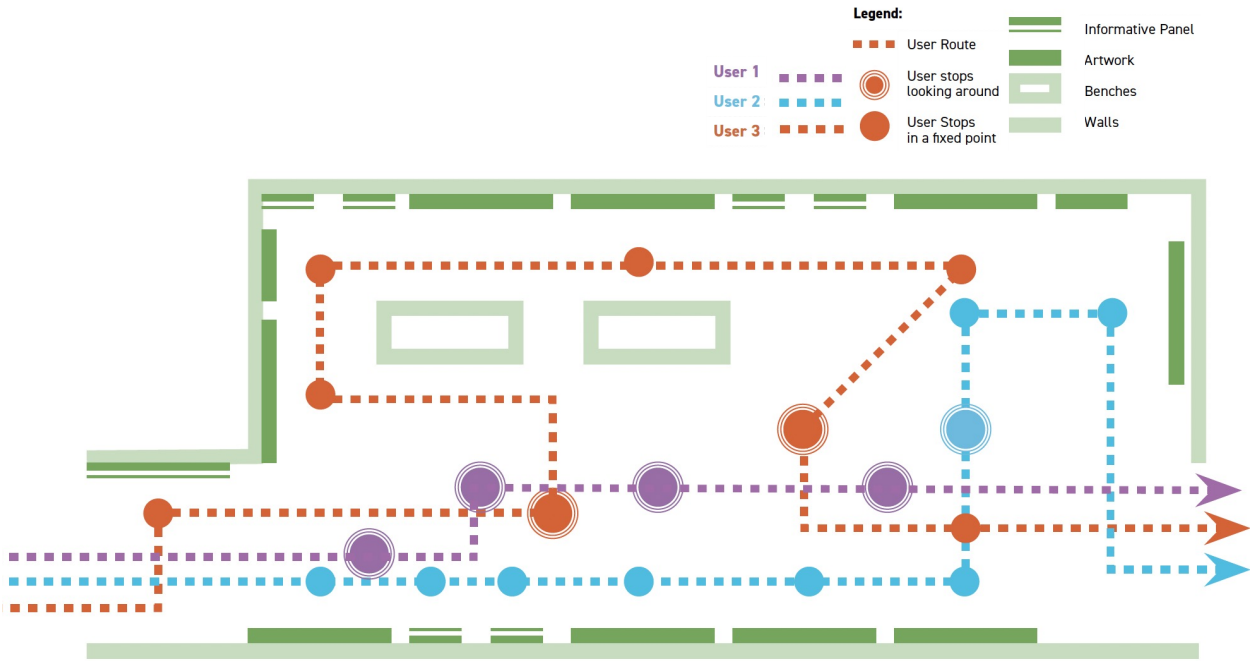

Figure 7:User Paths

User 1 will never really stop walking and will move directly to the exit, but his look will move left and right, staring at all the paintings. This user will not get information about the single artwork but will get a strong impression of the whole room and will be sensible to the artworks exhibited together. As they walk, they might find themselves attracted to certain colors or styles, or perhaps they will be struck by a particular painting that catches their eye. He may not know the name of the artist or the story behind the painting, but he will appreciate the emotions it evokes and the way it fits into the larger context of the exhibition. This kind of viewer is not necessarily interested in detailed information or analysis of each artwork but prefers

to take in the grander picture and how each piece contributes to the overall theme and mood of the exhibition. They might leave the gallery with a sense of wonder and inspiration without being able to pinpoint exactly why or how each painting affected them.

User 2 will look closely at each artwork, sequentially reading the descriptions. They don't get a general impression but stay focused on single artworks. He will probably not follow the entire room, skipping some artwork in the end when they decide it's time to move. They step closer, examining the subjects and colors before moving on to the description. They read every word carefully, taking note of the artist's name, the title of the piece, and any interesting details about its creation. They do not rush through the gallery but rather take their time with each artwork, savoring the details and nuances that make it unique. Their approach to visiting an art gallery is based on mindful observation and appreciation. They do not simply glance at the artworks and move on but rather take the time to truly engage with each piece and learn about its context and meaning.

User 3 takes a moment to survey their surroundings. They want to get a general impression of the space before examining anything in detail. This initial glance allows them to take note of any aesthetic features or design elements that catch their eye. It also gives them a sense of the room's layout and how they might navigate it. Once they've taken in the big picture, they will look at the specific details that caught their interest. They're not the type to stop and scrutinize every little thing, but rather, they're selective in their observations. They want to focus on what they find most intriguing and relevant to their aesthetic sense. By actively and consciously choosing what to pay attention to, they have the most aware and intentional experience. They're not just passively absorbing information, but rather, they're consciously engaging with their surroundings.

1.2.4 Personas

To achieve a more profound comprehension of our users, we have taken a further step by creating three personas, summarizing the principal categories of museum visitors we've encountered during our site visits. The utilization of personas in our design process has strong importance, being a useful tool for shaping an application that aligns closely with the needs and expectations of our diverse user base.

Personas will serve as our compass, guiding us through the dynamic and varied number of museum visitors. By understanding the unique needs, motivations, and expectations of our potential users, we can create an application that not only meets their needs but enhances their overall museum experience. This process ensures that our design is user-centered and audience-appropriate, resulting in an AR experience that is engaging, informative, and accessible to everybody. The personas we created are described below:

PERSONAS 1/3

Name: Marco de Ruggeri
Age: 16 (genZ)
Occupation: High-school student
Education: Middle school
Martial Status: Single

Technology readiness:

●●●●●●○

Visit modality:

○ Single ○ Coupled
○ Small Group ● Organized Group

Content Preferences

Aesthetic — informative

Willingness to share

●●●●●○○

Biography:

Marco is a young teenager, who attends an high school in Milan and spends most of his free time with his friends. Even if he is interested in Art he finds boring to study it at school, and finds himself closer to pop culture rather than to the "great art" of the galleries.

Interests: Pop Culture (movies and videogames), Music (Rap & Trap), Social life/ Spending time with friends, Sports (Football & Basketball)

Motivations:

- Spend time outside school
- Find alternative ways to study

Goals:

- Spend time with classmates
- Get prepared for Tests and Interrogations
- Not to get bored

Struggles:

- The guide is boring
- Want to explore on his own
- Artwork he is interested may be skipped
- Not get reproached by the teacher

PERSONAS 2/3

Name: Francesco Paolini
Age: 56 (gen X)
Occupation: Office Worker
Education: Bachelor degree
Martial Status: Married

Technology readiness:

Visit modality:

- Single
- Coupled
- Small Group
- Organized Group

Content Preferences

Aesthetic — informative

Willingness to share

Biography:
Francesco is an office workers, who enjoys to break the routine as soon as he can. he often travels or go to exhibit and museums. He feels culture as a strong value and want to get more and more accultured even if art and galleries are outside his normal life. He likes to have his wife joining his adventures, but he would still make those experiences alone.

Interests: Litterature (Novels & Essays) ,Politics (Left-wing / Progressive), Nature, Hiking & Trekking

Motivations:

- Breack Monotony
- Feel informed/ Accultured
- “Feed the spirit”

Goals:

- Watch as many artworks as possible
- Get informed and educated
- Have meaningful experience to tell

Struggles:

- Noises, people talking
- Want to know more about specific topics
- Feelings of ignorance

PERSONAS 3/3

Name: Chen Zhou
Age: 27 (gen Y)
Occupation: Waitress
Education: Bachelor degree
Martial Status: Single

Technology readiness:

Visit modality:

- Single
- Coupled
- Small Group
- Organized Group

Content Preferences

Aesthetic — informative

Willingness to share

Biography:
Chen is a former student from China, which is spending a couple weeks in Milan with a friend. She is fascinated by the different culture and want to explore as much as she can. Even if she is not passionate abouts art and cultural heritge, she still enjoys going to the exhibit while travelling.

Interests: Travel & discovering new places, Films & TV series , Animals and Pets, Food & Drinkings & Social life

Motivations:

- Explore the city and what she offers
- Get in touch with foreign cultures
- Occupy some spare time on Holiday
- Make as many experiences as possible

Goals:

- Report her travel (pictures & souvenirs)
- Be amuzed and fascinated

Struggles:

- Linguistic issues (also orientation)
- Don't want to loose her friends
- Not understanding much about artoworks

The personas we've developed effectively capture the primary categories of museum visitors we've encountered in the course of our extensive field research. Their creation is instrumental in our mission to delve more profoundly into the intricacies of user behavior, preferences, and expectations. By distilling the collective experiences of the individuals we've engaged with during our on-site investigations, we can acquire a richer understanding of how users interact within the museum setting, their preferences, and the expectations they hold.

1.3 Concept development

In this last part, we are going to use all the knowledge and insights we got from literature studies and form our contextual observation to create a strong concept, which we will later implement. Developing a concept allows us to define the direction and purpose of the project clearly; it will outline the most important ideas, goals, and objectives, providing a solid towards which we can work. The concept phase also enables us to identify potential challenges and obstacles in the early phases of our design process; this allows for thoughtful problem-solving and consideration of various design solutions. Developing a concept also helps allocate resources effectively. It enables us to outline the scope of the project, which in turn helps in resource allocation, time management, and project management. Lastly, concepts are grounded in an understanding of user needs, preferences, and behaviors. We will integrate these insights into the concept, ensuring that the final product is user-centered and aligns with the target audience's expectations.

1.3.1 Brief Definition

We tried to condense all the insights from our context research into a procedural brief, which will be our guideline and milestone in defining the concept of our project. The brief should not be a possible solution but define the scope of the project and the requirements it must meet. The design brief typically highlights the problems or challenges that the design needs to address. This problem statement guides the design process, ensuring the final product provides effective solutions. A good design brief may include information about the target audience or users. Knowing who the design is intended for allows designers to create a user-centric solution

that resonates with the end-users. A well-structured design brief is a foundational document that provides designers with the necessary information and context to embark on the design process with confidence. It ensures that the resulting prototype and final design are aligned with the client's objectives and meets the target audience's needs while staying within the project's constraints. This clarity is essential for creating a design solution that aligns with the client's goals and expectations. The first brief we proposed sounded like this:

> *"An Augmented reality Treasure-hunt-like game to encourage the exploration of a single room in the gallery asking the user to take specific actions to discover additional details."*

This brief is explanatory enough of what we want to design. Still, the word "game" was later seen as misleading since it guides the attention to something that can be "playful" or "competitive" and may not be in line with the high culture context in which we are developing. That's why we opted for a more general term like "experience," with our final brief being:

> *"An Augmented reality Treasure-hunt-like experience to encourage the exploration of a single room in the gallery asking the user to take specific actions to discover additional details."*

The description provided here is effective and exhaustive. It encompasses all the necessary details and requirements that are essential for the successful completion of our task, and it is a comprehensive guide that can be used as a strong reference point in the development of a concept. This brief effectively describes our mission and requirements and can be a strong guideline into the definition of an operative concept. It is a clear and concise sentence that outlines the project's objectives, goals, and requirements. This information is essential in developing a proposal that is well-structured, coherent, and meets all the expectations.

1.3.2 Concept definition

We explored different possibilities for our project concept and ways to solve our proposed brief. We considered different artworks and the possibilities behind each of them: what could be augmented and which information was more meaningful to share. We proposed four different concepts and possible applications:

> **Proposal 1** was meant to be deployed on three cardboard-on-paper artworks by Carlo Carrà. While standing in front of three big artworks (Carbon on paper), the user is asked a series of questions about the artwork. After completing the quiz, the artwork will get animated. This concept is easy to implement and animate, but the user remains quite static and passive toward the content.

Proposal 2 was designed for the portrait sculptures by Francesco Romini: while looking among the statues, the user will be asked to find the sculpture portraying a specific person. After a match, the 3d reconstruction of the face and the audio description of the person will be triggered. This concept is making advanced use of AR features relying on photogrammetry and object recognition, but the 3d reconstruction of the artworks is a very challenging point.

Proposal 3 focused on futurist painting and their interest in typography. We will ask the user to look at the painting to find some letters; after completing the task on different paintings, dynamic texts will appear from the walls on which the paintings are placed. This concept aims to explore a specific theme and encourages a closer look, but the information is not that related to the actual artwork.

Proposal 4 was also focused on futurist painting. The app will allow the user to enlighten the figures distorted in the futuristic paintings, showing what the different parts represent, the app will guide the user towards different artworks on the same floor. This proposal is answering realistic questions but doesn't ask particular actions to the users which remain passive.

These concepts represented four possible applications and were useful mental exercises to understand what to develop, but they remain pretty simple and don't offer many insights to go further. We noticed how it becomes difficult to understand what to augment without a proper study of the actual artworks and that directly deciding on which artwork to work, before having a clear mind on what we want to design, seems precipitous and hurried. Deciding a priori which artwork we are using and how may lead us to create unrelated interactions on the different artworks without a "common line".

We need to take a step back and decide on a common approach that can be applied to multiple artworks, deciding first which kind of approach we want to follow, then determine what artwork is more suitable with the given approach rather than given an artwork that interests us, find a way to narrate it using augmented reality without some criteria. Since many proposals did not engage the user who was only passively enjoying the content, we decided to split the single artwork experience into two parts: one informational and one interactive, where the user is asked to take action on the painting. We opted for a first passive and explanatory, which is supposed to last less than a minute, giving the user the information and the context to better enjoy the interactive experience. The final concept sounds like this:

> *" the project is supposed to work on a pre-fixed number of paintings. The user will be asked to frame the painting using a mobile app, triggering AR and visual information about the artwork. After that, the user will have the chance to interact with the artwork, exploring some details through specific tasks related to the subjects of the painting. "*

This final concept may seem a bit vague, which is perfectly fine since we have not

chosen the artwork we are going to work on, which will be decided later. Still, it is sufficient to identify a specific application and approach we will follow in the prototype implementation. Through this concept, we can ensure that our prototype implementation is both effective and engaging. We look forward to applying these concepts as we move forward with our project and select the artwork we will be working on.

Chapter 2
Prototype Realization

2.1 Content selection

We will now cover one of the most critical and determining phases of the project: the decision on which artwork to work on. This step will crucially affect whatever we are doing later on; before we proceed, we must take the time to examine and evaluate our options thoroughly. We must consider the relevance and significance of the artwork, as well as its potential to inspire and engage our target audience. Furthermore, we must also take into account the technical and logistical aspects of working with the chosen artwork. The decision of which artwork to work on is a critical and determining factor in the success of our project. It is essential that we approach this phase with care and deliberation and that we make a decision that is both informed and strategic. To operate this crucial decision, we are following these criteria:

The artwork parts must be easy to isolate:
We are probably going to show some visual details that are relevant inside the paintings. Therefore, it's important that those parts can be easily isolated and cut using Photoshop or another image editing software. For this reason, our artworks cannot have blurry parts or unclear edges. Once isolated and moved, these parts may create visual aberrations and unexpected behaviors. That's why we need images with clear and not blurry edges.

The artwork must be neither too simple nor too complex:
Both a too-complex and abstruse artwork and a too-synthetic and minimalist one may be more difficult to track using marker technology. That's why we need to find a balance between complexity and minimalism to find the artworks that are more suitable to be used as markers.

The artwork must present some valuable insights for AR:
All the paintings offer a little room for AR augmentation. They can all be at least animated, but many of them don't offer any other real asset on how to use augmented reality and how to make the user interact with it. The artwork

we choose must have a strong possible AR interaction. This requirement was probably the most difficult to meet as it requires much effort to find meaningful, always different interactions.

The artwork must be exhibited on the first floor:
We have decided to place our experience only on the first floor, both because they're the first artworks shown and the user attention is probably stronger and because we can't ask the user to go around the whole palace to complete our experience, that's why we decided to limit the experience on the first floor locally. Moreover, the first floor shows surrealist and futurist artworks that, compared to abstract art, offer more connections with real-world objects, and they are easier to understand and visually explained since they rely less on conceptual and abstract ideas when compared to more recent pieces.

The artworks cannot share the same author:
Since the number of artworks we are developing is limited, none of them can share the same author, and if we have the same author twice, we may as well consider realizing a monographic application working only on one artist. This is a viable approach, but our is not coherent with our aim, which is to work on the museum exposition and not on a particular artist.

The chosen artworks must be very different from each other:
Since we are working on a limited number of artworks, we must use very different ones. We do this both to show the potentialities of AR applied to different styles and narrations, both to create a more variegated and engaging experience, asking to interact with artworks with very different styles and techniques.

Ultimately, we opted for the two artworks that better fit the criteria listed above. In Manifestazione Interventista by Carlo Carrà and in Natura Morta (Piccola velocità) by Ardengo Soffici, we identified the two futuristic paintings that gave the most insights when pondering the augmentation possibility. They are not too complex, and the objects are clearly delineated. In the following paragraphs, we are giving a brief description of the two operas, and we are writing down all the content that the user is supposed to see during the single AR interactions. We are also giving particular attention to the script that will be told alongside visual content and the coherence between the information told by the audio description and the one that is deployed visually.

2.1.1 Manifestazione Interventista

"Manifestazione interventista (festa patriotica)" is an artwork (we can't properly define it as a painting) realized by Carlo Carrà in 1915. The art piece consists of a huge collage with many words taken from newspapers (mostly numbers of Lacerba,

a magazine that was fundamental for futurism). The artwork aimed to represent (metaphorically) the noise, excitement, and confusion of a crowd exulting during a public manifestation the artist had attended. The instant that particularly struck the artist was a flight of propagandistic flyers from an airplane during the manifestation. The choice of the words is not random but follows the main themes of futurism, such as: speed, modernity, and movement, as well as presenting a lot of Italian flags, patriotic elements, and references to the monarchy and military world (the manifestation that inspired the artwork was supporting Italian descent into ww1 against Austria).

We have chosen this artwork for its complexity, its abundance of details, and the "Chaos" that was composing the artwork, from which we can use AR to identify better some meanings (a spiral can be seen starting from the center, as well as some radial lines and a stylized airplane propeller). The artwork is rich in details that are still not very complex (most of the words have only one color and well-defined borders) and quite easy to manipulate with image editing software. Moreover, we have many terms and details that we can highlight to provide the user with new insights about the painting. Even if chaotic and abstract, this painting fits very well with the use of augmented reality, offering many assets and insights that can be told but would pass unnoticed without a proper narration showing them.

Script - Animated Part:

"The painting is supposed to represent a flight of propagandistic flyers during a manifestation the artist attended."

some flyers are enlighted and "fly" towards the user (1)

"On the top left, you can see the words "ZANG TUMB TUMB", a futuristic poem from Filippo Tommaso Marinetti, witnessing the proximity to the moment and their literal technique."

ZANG TUMB TUMB is underlined, a picture of the poem appears (2)

"At the center of the painting, we can see a circle from which some radial elements are present."

Radius Enlighted (3)

"From the centre we can also see starting a spiral."

Spiral Enlighted (4)

"All The structure resembles then an airplane propeller throwing out some fliers."

Helix Enlighted (5)

"The artwork's writings and the onomatopoeic words are meant to represent a crowd manifesting."

Some words are enlighted, the noise of crowds in the background (6)

Storyboard – Animated Part:

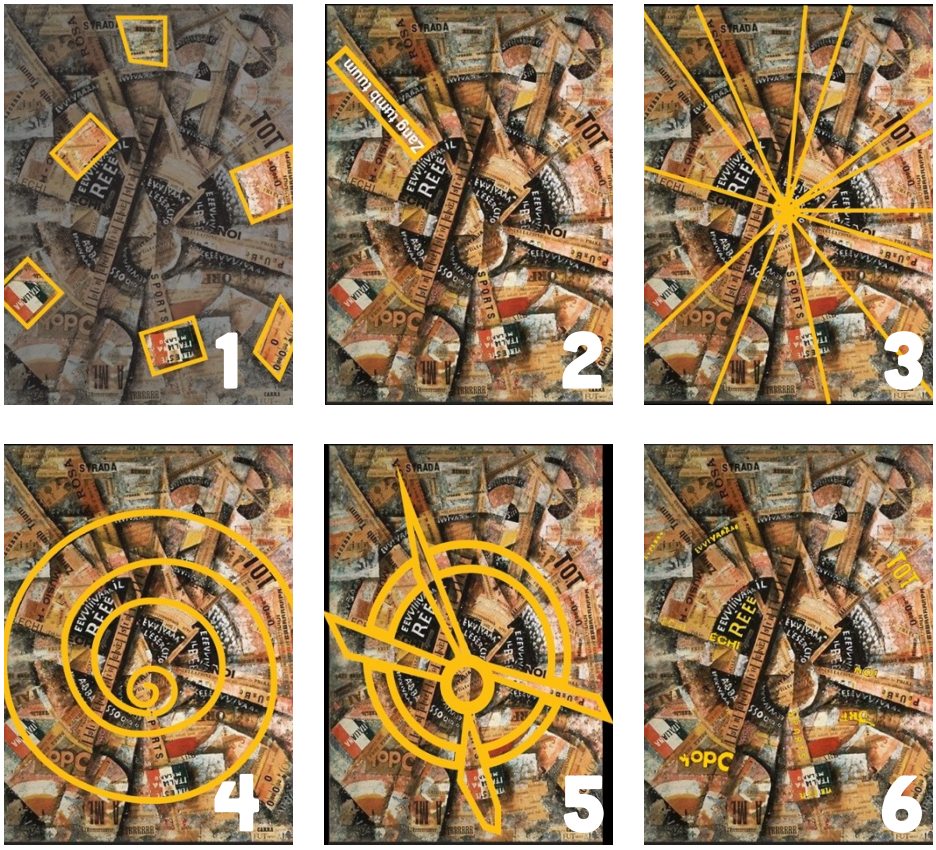

Figure 1:
first artwork
storyboard

Script – Interactive Part:

The user must look carefully at the painting and tap on specified elements, each tap will trigger a new little piece of information

"Find the word "LACERBA and tap on it".

After successful tap

"Lacerba" was a magazine published in Florence from 1913 to 1915, it was fundamental for futurism and for the first avant-gardes of the 20th century. Most of the words in the artwork are taken from articles and advertisements extrapolated from Lacerba, which in this way the artist pays homage to as a tool of great importance for his work."

user taps on NEXT
“Look for the word “EVVIVA” “ITALIA” and “GUERRA”

Each tap will trigger a crowd yelling, After the user has successfully tapped the three words, the following information will be displayed

“The propagandistic aim of the artwork was to support Italian descent into WW1 against Austria for irredentist purposes; it was first released in “Lacerba” magazine on 1st Aug 1914, the day in which Germany declared war on Russia.”

user taps on NEXT

“Look for the “OooOo,” the “Trrrr” and “trank tatatrank” sound written in the artwork”

Each tap will trigger the corresponding sound, , After the user has successfully tapped the three words, the following information will be displayed

“Many terms refer to musical sounds, onomatopoeias, and noises inspired by Luigi Russolo's intonarumori. The onomatopoeias transcribed with the futurist parolibera technique are a declaration according to which even environmental noises possess musical dignity.”

2.1.2 Natura Morta (Piccola velocità)

"Natura Morta (Piccola Velocità)" by Ardengo Soffici is a remarkable piece of art that exemplifies the essence of Futurism. It reimagines the traditional still-life genre by infusing it with the energy and dynamism of the early 20th century.

Soffici's innovative approach to form, composition, and motion creates a thought-provoking visual experience that challenges our perception of stillness and speed in the modern world. This artwork's composition is arranged with a dynamic and rhythmic quality that captures the sensation of rapid movement. The objects depicted are fragmented and geometric, representing everyday items like bottles, glasses, and other typical subjects of still-life paintings. However, in "Natura Morta (Piccola Velocità)," these objects are distorted and reimagined through a Futurist lens. The painting is part of a series of works in which Soffici explored the concepts of Futurism, which celebrated modernity, speed, and the dynamic energy of the industrial age.

We have chosen this particular artwork for its simplicity in the drawing style, which allows us to act on the painting, separating its parts and subjects easily. This artwork is a good example of the Futurist collage being composed on different layers upon each other, but in a number that makes them easily distinguishable, even if not very famous and lacking hidden meanings to be shown (like the previous artwork). This

artwork offers a precise demonstration of all the concepts behind futurism while still being linear and easily understandable (unlike many futurist paintings that are blurred and distorted), giving us a chance to isolate and work separately on the different parts of the painting without the risk of generating distortions or unexpected behaviors.

Script - Animated Part:

"The main subject of the painting are two bottles and a glass over some newspaper pieces."

a realistic reproduction of the scene is imposed on the artwork (1)

"The painting utilizes the futurist technique of the collage attaching newspaper pieces to cardboard."

Pasted planes pop-ups identifying the different layers (2)

"The painting is also heavily influenced by French cubism from Picasso and Braque in the representation of the objects."

The two bottles and the glass are enlighted (3)

"However, Italian cubism is less analytical and aimed at the disinterested exploration of the shapes."

Two other cubist artworks appear for comparison (4)

"The idea of "pure painting" as aimless and detached from reality was fundamental for Soffici, who wrote: "By pure painting, we mean the interpretation of forms for a disinterested purpose, considered not as elements competing in the composition of an expressing pictorial organism or evoking something above or beyond them; but as realities having in themselves, and only in themselves, their reason and their harmony"

The quote appears along the narration (5)

Interactive Part:

"The user is enabled to move the different objects in the canvas playing with the composition and the balances of the figures; when satisfied, the user can screenshot the artwork he has obtained"

In this case, the interactive part is a task without a particular and prefixed ending but offers multiple solutions. There will not be subsequent tasks but only one longer interaction that leads the user to a major degree of freedom. For these reasons, it was unnecessary to write down a real script, as we did for

the first artwork, as there would be no parts following each other but only one explanatory message.

Storyboard – Animated Part:

Figure 2: second artwork storyboard

2.2 Artwork Implementation

Now that we have precisely defined the contents we are going to develop in augmented reality, we will follow the implementation of all the contents and interactions.

2.2.1 Unity Setup

For the development of our application, we have chosen MARS as the AR SDK we are using to develop. MARS is a Unity extension and a set of companion apps that can address real-world objects and events such as GameObjects. It comes with a new UI and controls for this dynamic content. MARS includes an entirely new Simulation mode, which lets you test your content in different real-world mockups with an

incredibly tight iteration time. It helps you author content in the context of a real-world environment.

Figure 3: Mars Landing Page

Compared to other SDKs, such as Vuforia or Wikitude, we can see how the content created with MARS is much more stable and tends to have lesser lagging. Moreover, MARS offers better and more constant Unity support. The most useful MARS feature, which any other tested SDK does not support, is the simulation environment, which allows us to test our project in a realistic 3D scene instead of only relying on our webcam or having to constantly deploy the app on our smartphone which is making us save a lot of efforts and time. Moreover, MARS allows us to create proxies and simulated objects that can interact with our digital objects. It supports body and face tracking and many other features that, even if they're not going to be used in our project, are really useful and interesting and are making MARS the best available choice to develop AR mobile experiences.

After downloading and installing the MARS SDK, we are ready to launch Unity. We will see the new game object options related to MARS in the main navbar (fig 4), and we will have access to the MARS panel (fig 5), which encompasses all the main options available in MARS and the simulation view (fig 6) a simulated environment in which we can place our markers and test our application like in a real environment.

To set up the AR scene with MARS, we must first create and add a MARS Session object to our Hierarchy. Inside the MARS Session, we can create our marker library that will be used in the AR experience. We can set the single images and their real-world dimensions as shown in figure 7. After creating the marker library (to which we can add another marker later), we need to set the Main camera (or any other camera object) as a child of the MARS Session. This will add a MARS Camera script component to the object and will turn the normal camera into an AR camera that, once deployed on a device, will ask for permission to access the real camera, which will substitute the unity default one and will be ready to read all the AR contents we created in the scene.

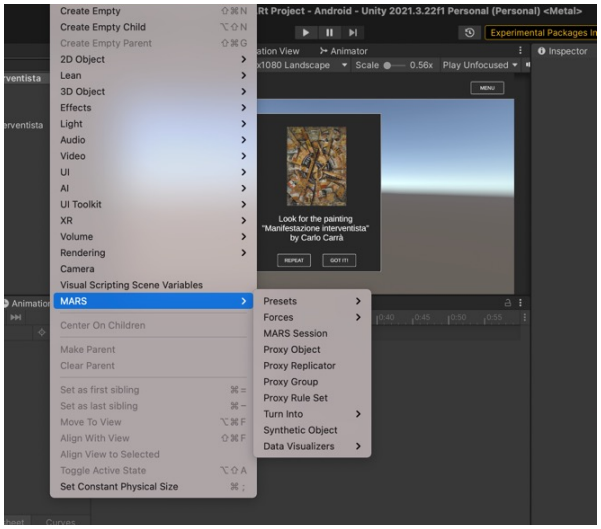

Figure 4: Mars Menu options

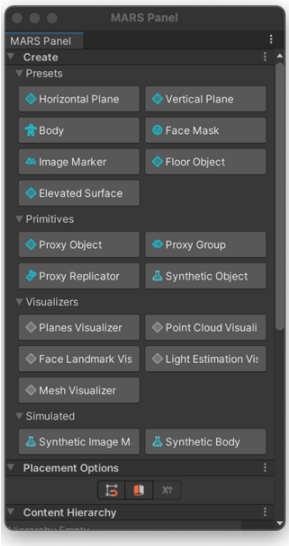

Figure 5: MARS Panel

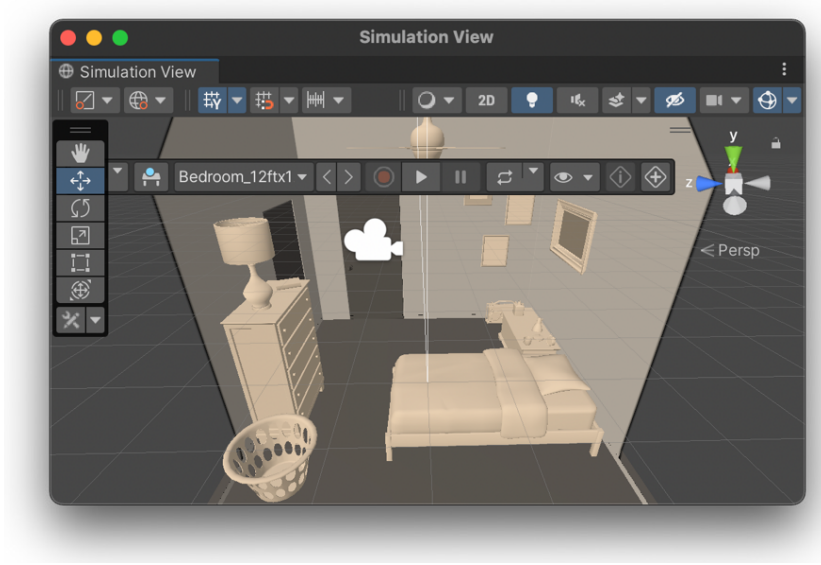

Figure 6: Mars simulation view

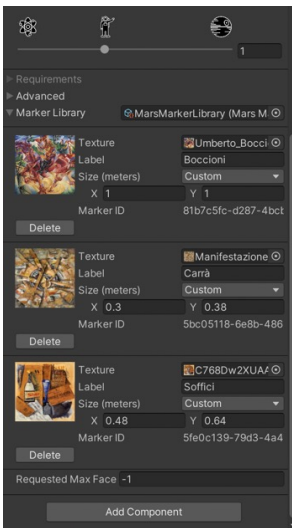

Figure 7: Mars Marker Library created inside Unity

At last, we had to set up our marker from the marker library. To do so, we must create an empty Proxy Object: A Proxy is a GameObject in your Scene that represents a real-world object that your app can detect and use as an anchor, such as a table, a face, or a cat. MARS uses Proxies as placeholders where you can anchor content that displays in the real world when conditions are met. Specifically, to create a marker interaction, we must add a Marker condition between the MARS available component and decide to which marker in our library the proxy must obey, as shown in figure 8. Inside our Marker Proxy, we are creating a manager empty object that will contain all the contents that will be displayed once the marker is triggered. The hierarchy of our final scene will look like in figure 9. Once we create this framework we can duplicate it

in other scenes since they will all hold a similar setup.

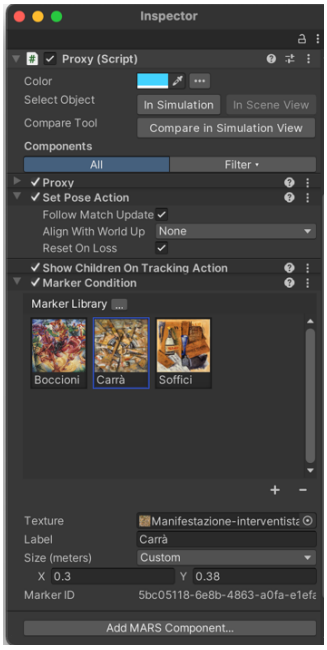

Figure 8: Proxy Component with an applied marker condition

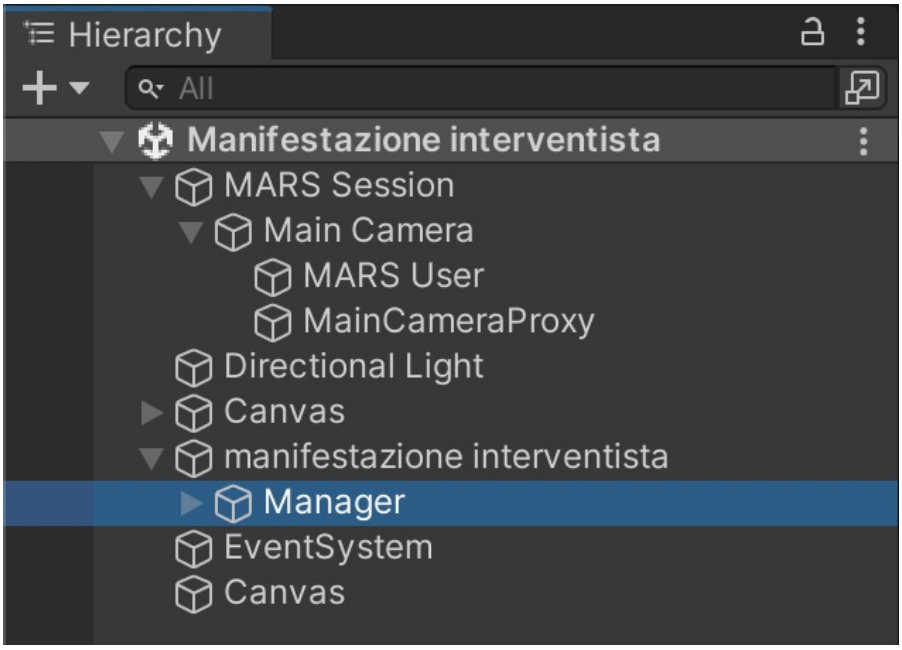

Figure 9: Unity AR scene basic setup

2.2.2 First Artwork

To realize the first, informative part is structured as a long animation setup applying an animator to the manager component (which is the parent of all the augmented contents). The informational part was divided, for commodity purposes, into four main sections. The sections were all setup in the hierarchy and set to inactive, animating the SetActive component (which is a Boolean property). We subsequentially turn on all the single pieces to create the total animation. The four main sequences are:

Flyers come out of the painting as if they were thrown from an airplane. The voiceover tells the user about the real-life event that inspired the painting.

The Zang-tumm-tumb word on the top left is highlighted and enlarges itself coming towards the user. The voiceover describes the relationship between futurism in poetry and paintings.

Three short videos appears to enlighten additional details about the paintings: the radial lines starting from the center, the spiral, and the helix hidden in the painting. The voiceover follows the animations.

Some of the words are enlightened and all together fly towards the users. The voiceover describes the ultimate meaning of the artwork.

For the audio parts, we used a free online text to mp3 converter https://ttsmp3.com/, which allows us to choose between a good amount of voices from different countries, including a good variety of English speakers. All the audio segments are created using ttsmp3 and were firstly attached to the 3d contents they were referring to, toggling the Play on Awake propriety, we can run our audio source only once the main object is activated, and we can set it not to loop so that they are working properly without being directly animated using the animator component. figure 10 shows the main interface of ttsmp3.com, while in fig 11, we have the setup for one of the audio components we attached to the augmented 3D objects.

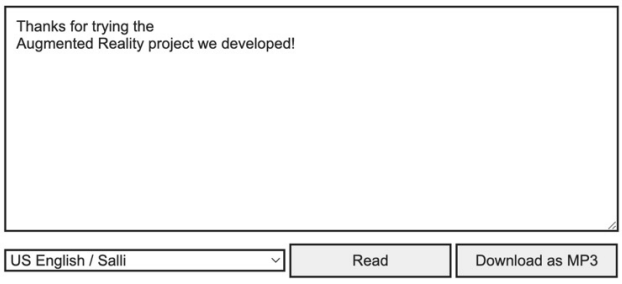

Figure 11: shows the setup of one of the Audio Components

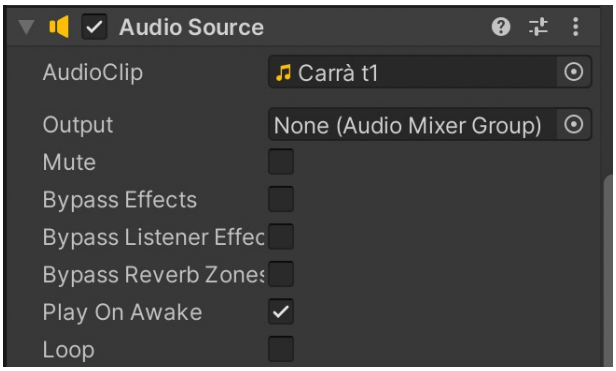

Figure 10: ttsmp3.com interface

The first sequence was created using different planes placed in the center of the painting. A parent component containing all the planes was created. The design of the single flyer was done using the Italian flag drawn in the painting to keep a similar aesthetic and graphic coherence and reaffirm the patriotic message behind the painting. A sample of the flyer is shown in figure 12. To animate the flyers, we used the Constant Force component, applying a torque movement with different parameters to all the planes to create the vortex effect we desired. We had to manually refine the torque amount of the single planes to make them not run all the same; we know that applying all the different forces manually is not the best way to reach this goal, but it allowed us to quickly get the desired effect. A sample of the force component applied to the planes is shown in figure 13.

The second sequence was realized by cutting out the word we were interested in, ZANG TUMB TUMB, from the picture image and applying it to a plan we manually made to coincide with the real word in the painting. To prevent from rendering the edges of the plain, even if set to transparent, were still visible, we adopted the Text Shader component instead of the standard unity material, allowing for a better graphical effect. We are again using the Text Shader component and all the enlightened words we see in the next parts of the narration, as we found it a precious

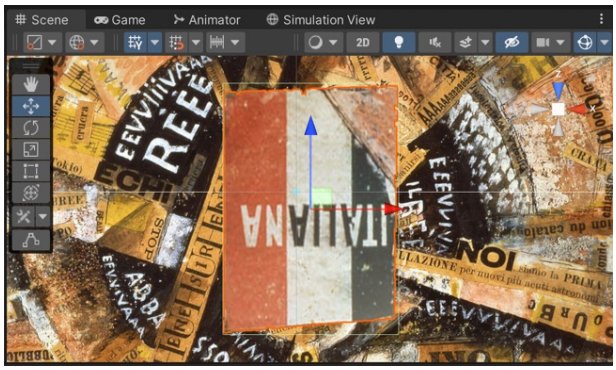

Figure 12: one sample of the single flyer without the force applied

Figure 13: one sample of the force component used with the relative torque parameter

asset for a good rendering view. One example of the text shader parameter we used is shown in figure 14. For the animation of the word, we created a pulsing effect animating its transparency that last for most of the intended voiceover, to end up with the word disappearing while coming towards the users. This animation was done directly in Unity and applied to the word plane, which was set as a children object of another empty object controlling only the selected Active property.

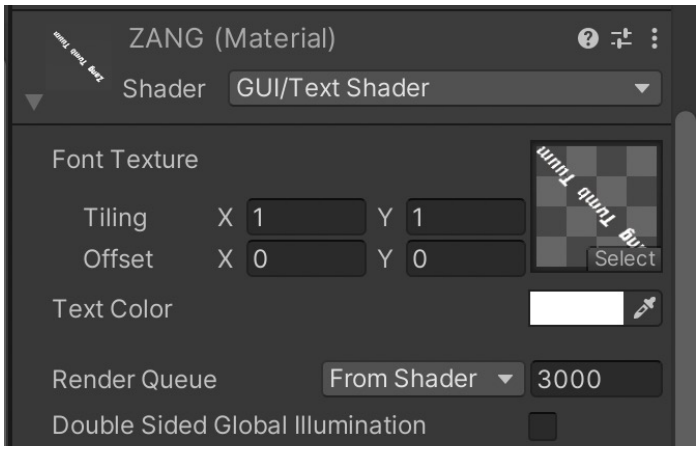

Figure 14: the text shader component we used

The third sequence was made up of some video elements. We created the simple animations in After Effects (we present a screenshot of the elaboration of the videos in figure 15), and we placed them in unity using the video player element applied to a plane. The most challenging part of this step was a compatibility issue: we had to find a video Codec that kept memory of the alpha channel (our videos are supposed to be transparent), and that was compatible with Unity and which does not produce too large outputs. After a few trials, we identified a good compromise in the Apple ProRes 442 a good compromise which, after being compressed using Handbrake, we generated some files of acceptable size that allowed Unity to read alpha channels. The

sequence of videos was later added to the manager animation sequence so as not to trigger them all at the same time.

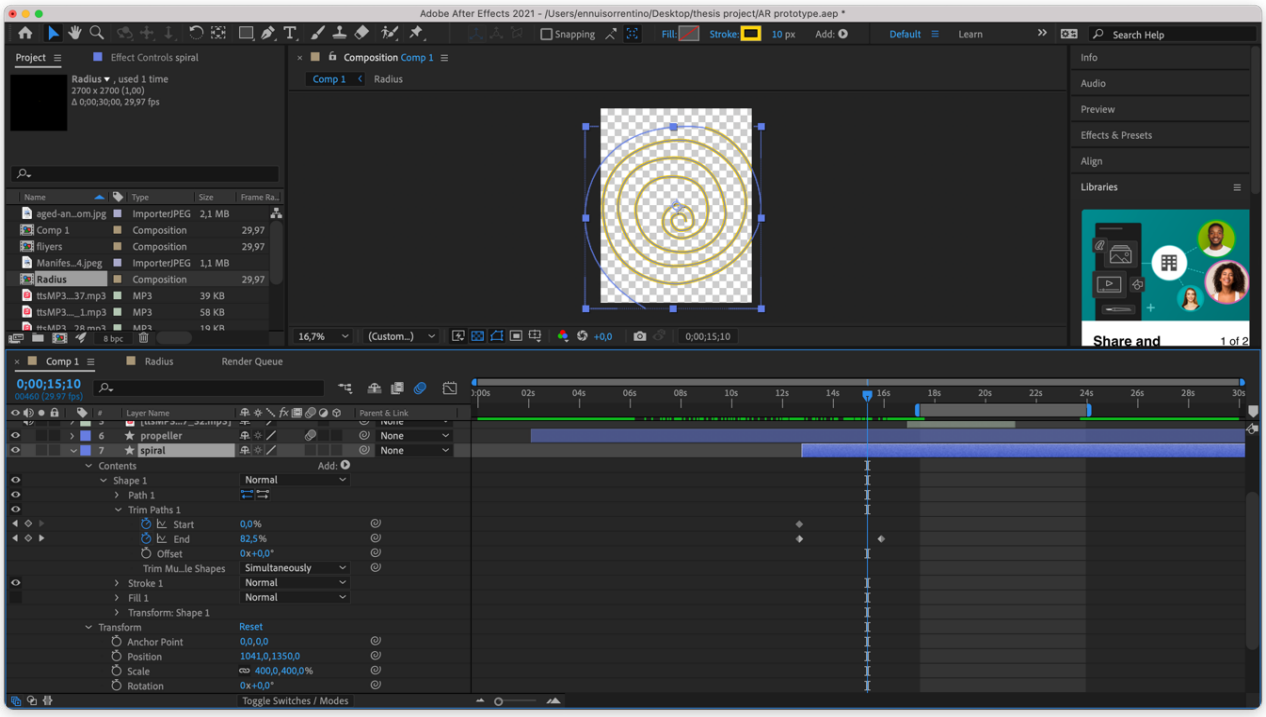

Figure 15: a screenshot during the after-effect elaboration of one of the videos

For the last segment of the explanatory part, we had to cut the image multiple times, creating many PNG files to be placed to match the corresponding words on the canvas. Some of the images we created are shown in figure 16. We turned all the words into white using the Unity text shader for readability issues. This time, instead of operating forces, we animated all the objects singularly, applying each of them a simple animation, making them come directly towards the user while getting bigger to simulate the effect of a yelling crowd visually. Animating all the planes singularly was long but allowed us to have full control of the timings to create the best visual effect.

Figure 16: some of the words extrapolated from the painting.

At the end of the animation, two buttons appear. The “Next Artwork” button brings the user to another scene with another artwork where they can explore the second artwork. The “Discover more” button triggers an interactive experience where the user has to play with the artwork. The button component is used to trigger the Set Active property of the instruction for the first task and the 3D element related to its completion, setting them to Active (turning them on) while turning off the last part of the informative animations (all the previous ones already had been set to inactive during the animation itself). All the subsequent interactions are managed by toggling or un-toggling the Set Active property of the different objects using different instances of the Button component.

Figure 17: The button interaction of the interactive part of the first action

The interactive part of the first artwork is structured into three tasks; each time, the user is asked to find some word between all the ones painted in the artwork. The first time, the user is asked to find only the “LACERBA” name in the top left of the canvas. To realize it, we created a transparent parallelepipedon to which we applied a collider and a button component to make it interactable. Once the user taps on it, an explanation is triggered, and through another button, another button appears at the end. Upon tapping on it, the user can continue to the second step. Figure X represents one step of these interactions from the unity Scene panel.

During the second step, the user is asked to find three words, respectively “Esercito”, “Guerra,” and “Noi”. Once the user has tapped on all three of them, in any order, another explanation is triggered. At the end, the user can enter the third step of the interactive experience. Here, we can’t rely only on the button component, but we have to implement a script to trigger the activation of the next part only when the third word is tapped. To do so, we associated a variable with each of the three-game objects (set to 0); only when all three variables are set to 1 is the next part activated. Every element has both visual and auditory feedback when it's tapped (a crowd echoes, and the word is enlightened). To apply the new material using the script, we had to access the <Render> component of each object. Part of the script we used is reported in the following page.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Wordgame : MonoBehaviour

  // Update is called once per frame
  void Update()
  { if (Input.GetMouseButtonDown (0)) {
       var ray = Camera.main.ScreenPointToRay(Input.mousePosition);
       RaycastHit hit;

       if (Physics.Raycast(ray, out hit, 100)) {
         // whatever tag you are looking for on your game object

         if(hit.collider.tag == "word1") {
           word1 = 1;
           child1.GetComponent<MeshRenderer> ().material = mymaterial1;
         }

         if(hit.collider.tag == "word2") {
           word2 = 1;
           child2.GetComponent<MeshRenderer> ().material = mymaterial2;
         }

         if(hit.collider.tag == "word3") {
           word3 = 1;
           child3.GetComponent<MeshRenderer> ().material = mymaterial3;
         }
       }
       Debug.Log("word 1 ="+ word1);
         Debug.Log("word 3 ="+ word3);
           Debug.Log("word 2 ="+ word2);
  }

 if (word1==1 && word2 ==1 && word3==1 ){
   myPreviousObject.SetActive(false);
   myPreviousObject1.SetActive(false);
    myNextObject.SetActive(true);
    myNextObject1.SetActive(true);
   }
}
```

The third step has the same functioning as the second step, and it's using the same script. This time, the contents regard the use of onomatopoeias made by futurist painters and poets. The user is asked to find the onomatopoeic sounds “Tank tatatrank”, “brrr”, and “trrrr”, we are keeping the auditory feedbacks, but this time they will be three times different, resembling the specific sounds of the onomatopoeias described. To download the single sounds, we used Pixabay.com, which offers a huge amount of free, no-copyright sound effects. At the end of the experience, one last button appears, leading the user to the second artwork, implemented in another scene.

2.2.3 Second Artwork

For the implementation of the second artwork, we followed an approach similar to the first one, with the same unity setup, we only had to develop the different contents for the canvas from Soffici. We were starting with the informative, animated part. At first, we planned to start the narration with a photorealistic version of the painting. We found that it was almost impossible to recreate the scene in the painting with real objects; a 3D scenario wouldn't have had the same appeal, and the effort was not worth the final effect. That's why we decided to eliminate that passage and start the narration, highlighting the main figurative elements of the painting. In the end, the narration was divided into three sequences:

> At first, the borders of the main figurative elements of the painting are highlighted, and then they get filled to represent the different planes of paper attached to the main canvas. The planes come forward, letting the user see the different layers composing the painting.
>
> While the voiceover talks about the relationship between Italian and French cubism, explaining how the artwork is influenced by Picasso and Braque, next to the painting, two other cubist artworks appear to show how they are close to each other and, at the same time, different. When the voiceover talks more generally about Italian cubism, two Italian artworks appear alongside the other ones.
>
> At the end, a quote from the author is presented, explaining the will behind the realization of the artwork. The quote in the voiceover is followed by the text appearing in front of the canvas.

For the implementation of this artwork, we took a more systemic approach when using the animator: we applied to the main container (manager) an animation that was only triggering, at the proper time, the three main parts of the informative narration (which are the same described above) each one was an empty game object containing the 3d elements of the single sequence, to each of these containers we applied another animation regarding the single parts for the corresponding sequence. This setup enabled us to have good control of the animation, keeping the animations more organized without having too many clips or animations and without having all the 3d elements animated in the same clip, which we found more challenging to manage.

To realize the first sequence, we used Illustrator to realize some vector outlines for the main subjects we wanted to highlight, respectively, the two bottles, the glass, and seven newspaper pieces, representing all the different paper pieces applied on the original canvas. Figure 18 proposes a sample from the Unity project panel with all the vector outlines and planes we used to generate the animation clip. In figure 19, we show a sample of the shader component we used through both the parts.

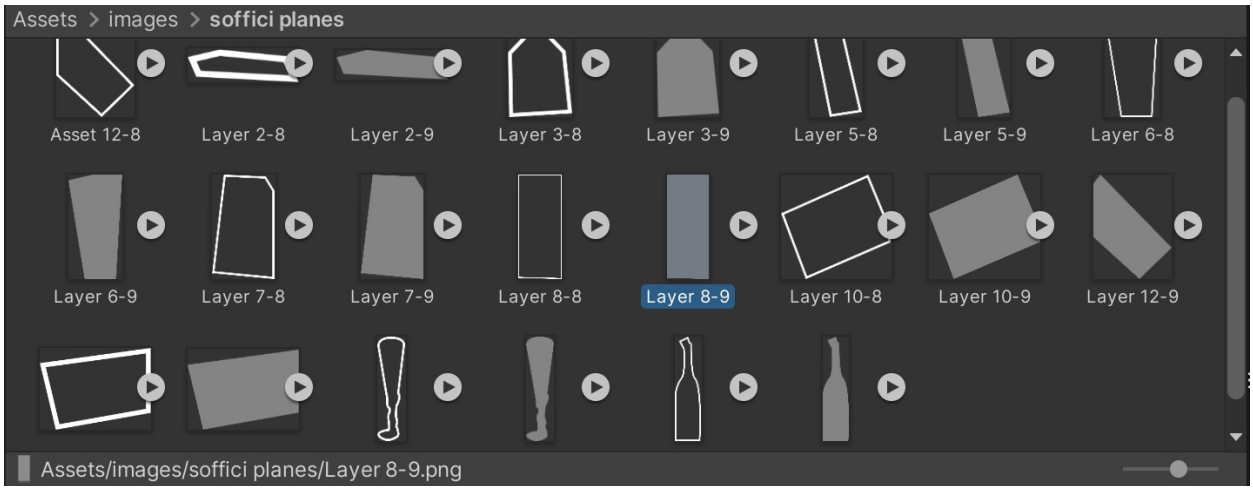

Figure 18: the vector parts of the artwork we animated in unity

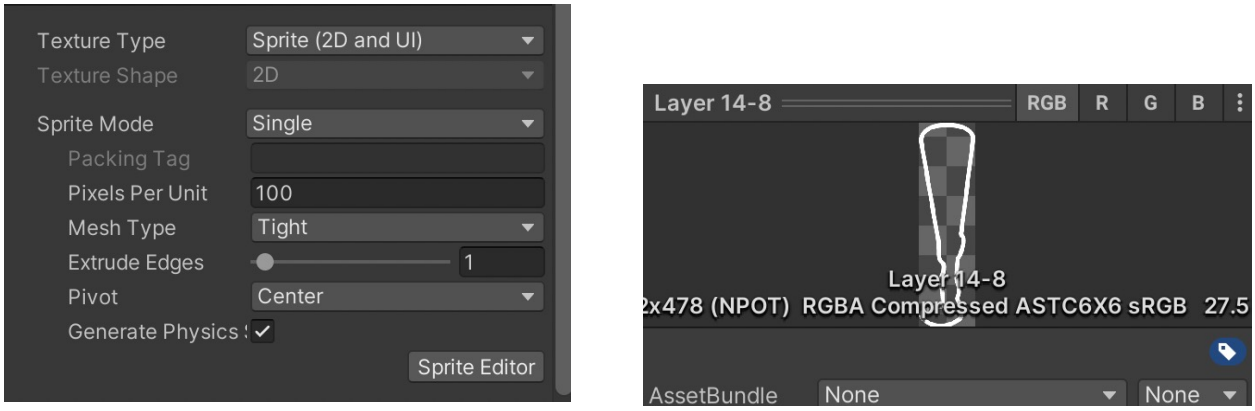

Figure 19: the shader setup of one of the animated elements

These illustrations not only cover the main figurative elements of the paintings but can also be used to reconstruct the layer structure of the painting and the main planes that compose it. We had to animate the single planes separately to make them appear alongside the narration, with the main figurative elements coming first and then all the newspaper pieces in rapid sequence. To make them pop up to show the exposed version of the paintings, we placed them slightly differentiated on the Y axis, placing them slightly above the painting (instead of keeping them directly stuck on the painting) and coming towards the user. This allowed us to show the different layers coming in front of the user, only animating the scale property of the main container. Then, we also applied a rotation to better show the planes imposed one on the other.

For the second sequence, we had to place the images of the reference paintings next to the painting and make them appear along the narration. Figure 20 shows the reference paintings from other artists placed next to the painting for comparison. It was then problematic to scale the paintings so that they were scaled responsively. To do that, it was necessary to apply a world canvas element to the main container and insert the paintings as panels instead of using standard 3d planes. The world canvas

was placed a few centimetres to make it more visible and less contrasting with the original painting.

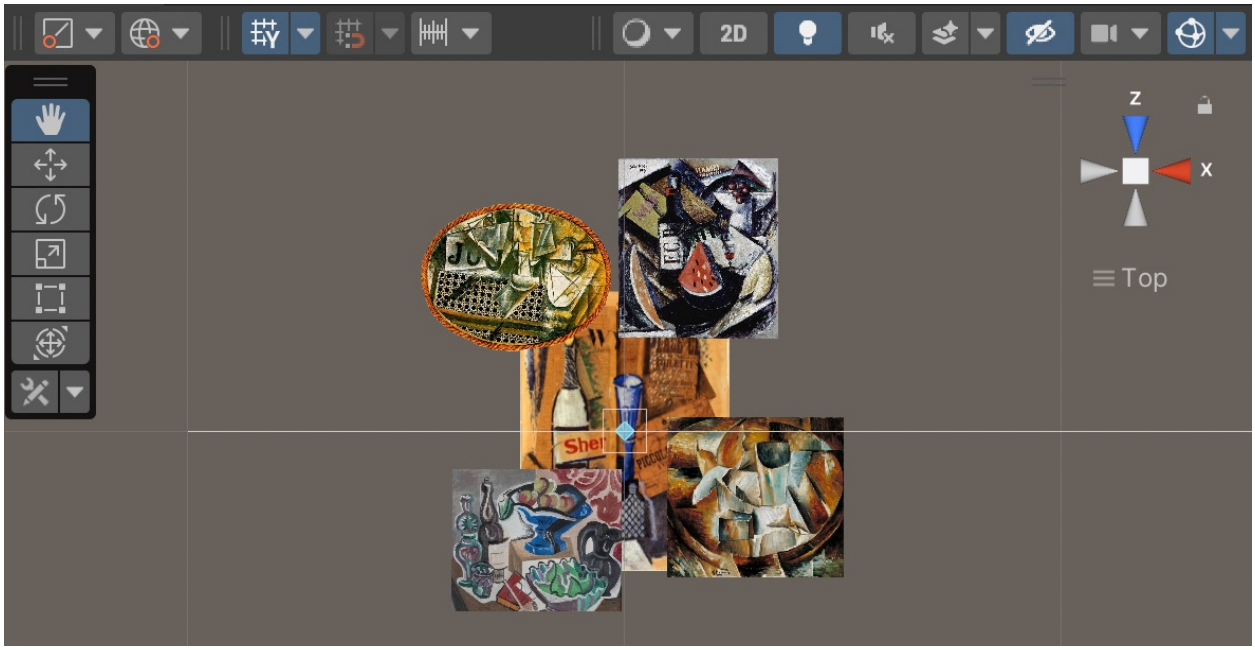

Figure 20: the reference paintings in the unity scene

For the third sequence, we created the animated text in After Effects, which allowed us to create a typewriting effect, making the letters appear one after another (this animation was hard to develop directly in unity). We also could regulate the speed of the letters appearing to make them follow the different velocities of the audio. We tried implementing a shadow blur as background to the text for better contrast and visibility, but this made it harder to find the right video codec to render the video since the text-shadow was hardly supported, and the only ones supporting them in unity were generating very heavy outputs, which were increasing heavily the size of the application and giving loading issues when deployed on the smartphones. We also tried implementing the animation as an image sequence, but the total output size was still huge, and creating a proper sprite sheet for a ten-second animation was difficult. In the end, it was not possible to implement efficiently the text shadows, and we had to renounce them.

At the end of the narration, the user can explore the artwork further or end the experience. In the interactive part, the user can move five objects along the paining (the two bottles, the glass, and two newspaper pieces) and freely replace them. This enables the user to experiment with the compositive elements of the painting and to create their composition. Once satisfied, the user can take a screenshot and save it on their device gallery. To create the interactive elements, we used Photoshop to cut out and export the single elements, and we had then to “fill” the gaps in the background. Figure 21 represents the background layer of the painting after we removed the main elements, while figure 22 represents the interactable objects extrapolated from the painting.

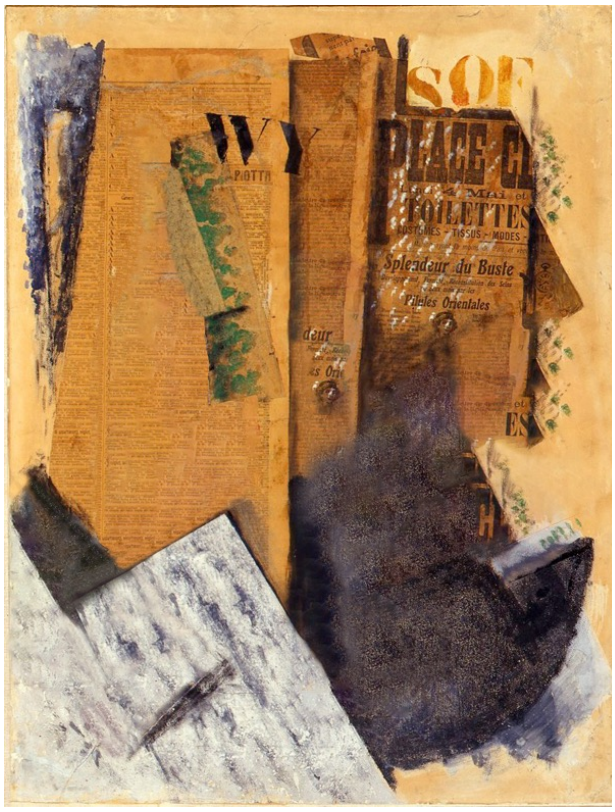

Figure 21: is the “background” of the painting without the moveable objects.

Figure 22: the interactable objects taken away from the canvas.

The user can move the five elements, dragging them among the canvas. To implement the possibility of making the object movable, we had to access the mouse position of the finger of the user. We also had to implement a collider on the 3D elements to make them interactable. We then had to apply a script to each of the graphic elements. Each time the user taps on the object, the collider automatically triggers the script that enables the movement of the object, following the updates of the mouse position. The script we used to implement the dragging function is reported below:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Drag : MonoBehaviour
{ Vector3 mousePosition;
 private Vector3 GetMousePos(){
   return Camera.main.WorldToScreenPoint(transform.position);  }

 private void OnMouseDown(){
   Debug.Log(Input.mousePosition - GetMousePos());
   mousePosition = Input.mousePosition - GetMousePos();}

 private void OnMouseDrag(){
 Debug.Log(transform.position);
   transform.position = Camera.main.ScreenToWorldPoint(Input.mousePosition - mousePosi-
tion);}}
```

The most difficult part of the interactive part was enabling the user to take a screenshot. We can tell the user to use their own device and the normal commands to get a screenshot, but those screenshots will also incorporate the UI elements, such as the instructions. Moreover, we found it a bit tricky to rely on commands placed outside our app; for those two reasons, we decided to implement a screenshot function with a script. At first, we used the ScreenCapture C# method, which was working properly on desktop (we don't need permissions, and we can choose which folder to save our screenshot) but was giving errors when deploying on a mobile device raising both permission and path issues (mobile devices have specific folders and paths to save files). To properly get access to the gallery on a mobile device was the most challenging part of the entire project. To do so, we found a Plugin called Native Gallery, which allowed us to access the device's internal storage. A screen of the Native Gallery page from the Unity asset store is reported in Figure 23.

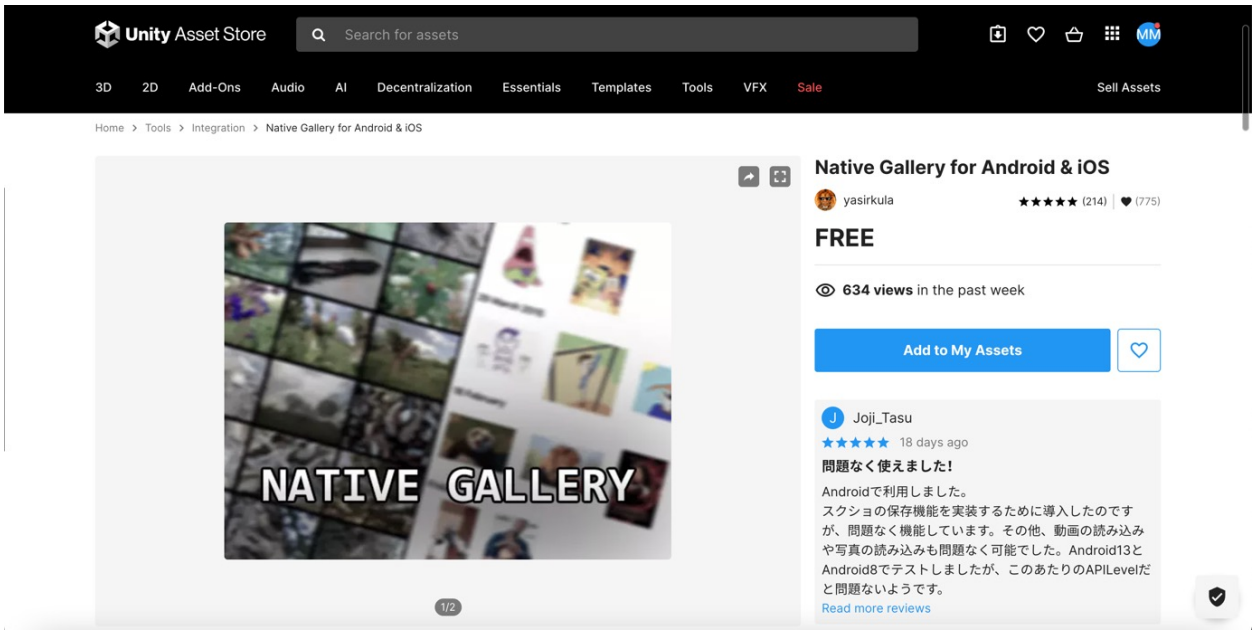

Figure 23: Native Gallery page on the Unity asset store

After creating an image out of the unity scene and saving it to the gallery, we also had to make all the UI elements momentarily disappear. To do so, we set them all to unactive before creating the screenshot, then we used the Invoke method to make them appear again after one second (the invoke method only accepts integer values, but is way more efficient than implementing a Timeout using C# and unity time data) The final script we implemented to run the screenshot is reported in the following page.

The user can continue to play with our interactive painting, taking multiple screenshots (this step is not meant to have a sequence, and the user can interact with it freely). Once satisfied with the images produced, the user can end the experience by clicking on the specific button, allowing for a quick and efficient way to close the

application instead of using the closing buttons provided by the phone.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.IO;

public class ScreenshotManager : MonoBehaviour
{

        public GameObject MyGameObject;

  void Start()
  {
        Debug.Log(Application.persistentDataPath);
       GameObject[] enemies = GameObject.FindGameObjectsWithTag("outline");
}

  public void TakeScreenshot()
  {
        GameObject[] enemies = GameObject.FindGameObjectsWithTag("outline");
        for(int i=0;i<enemies.Length;i++){
        enemies[i].SetActive(false);
}

    MyGameObject.SetActive(false);
    Invoke("MyFunction", 1)
}

  private async void RequestPermissionAsynchronously
( NativeGallery.PermissionType permissionType, NativeGallery.MediaType mediaTypes )
{ NativeGallery.Permission permission = await NativeGallery.RequestPermissionAsync
( permissionType, mediaTypes );
   Debug.Log( "Permission result: " + permission );  }

  private IEnumerator TakeScreenshotAndSave()
  {

   yield return new WaitForEndOfFrame();
   Texture2D ss = new Texture2D
( Screen.width, Screen.height, TextureFormat.RGB24, false );
   ss.ReadPixels( new Rect( 0, 0, Screen.width, Screen.height ), 0, 0 );
   ss.Apply();
        NativeG\allery.Permission permission = NativeGallery.SaveImageToGallery( ss,
"GalleryTest", "Image.png", ( success, path ) => Debug.Log
( "Media save result: " + success + " " + path ) );
 Debug.Log( "Permission result: " + permission );
   // To avoid memory leaks
   Destroy( ss );   }

  public void MyFunction()
  {
    GameObject[] enemies = GameObject.FindGameObjectsWithTag("outline");
    for(int i=0;i<enemies.Length;i++){
    enemies[i].SetActive(true);}   }}
```

2.3 UI Design

After realizing the 3d elements meant to appear on the paintings (in the real-world context), we moved to realize a series of User Interface elements that support the interactions. We decided to implement two main UI elements: an introductory scene explaining to the user what to do (we are aware that they may not be used to augmented reality) and some subtitles for the narration text (the audio-only content could have been misleading and not that clear, since there's no way to retrieve information if I miss the audio sentence) for better clarity of the information, we also have to take into consideration the possibility that the user has no access to some headphones and won't be able to listen to the audio (they are supposed to be silent in a museum).

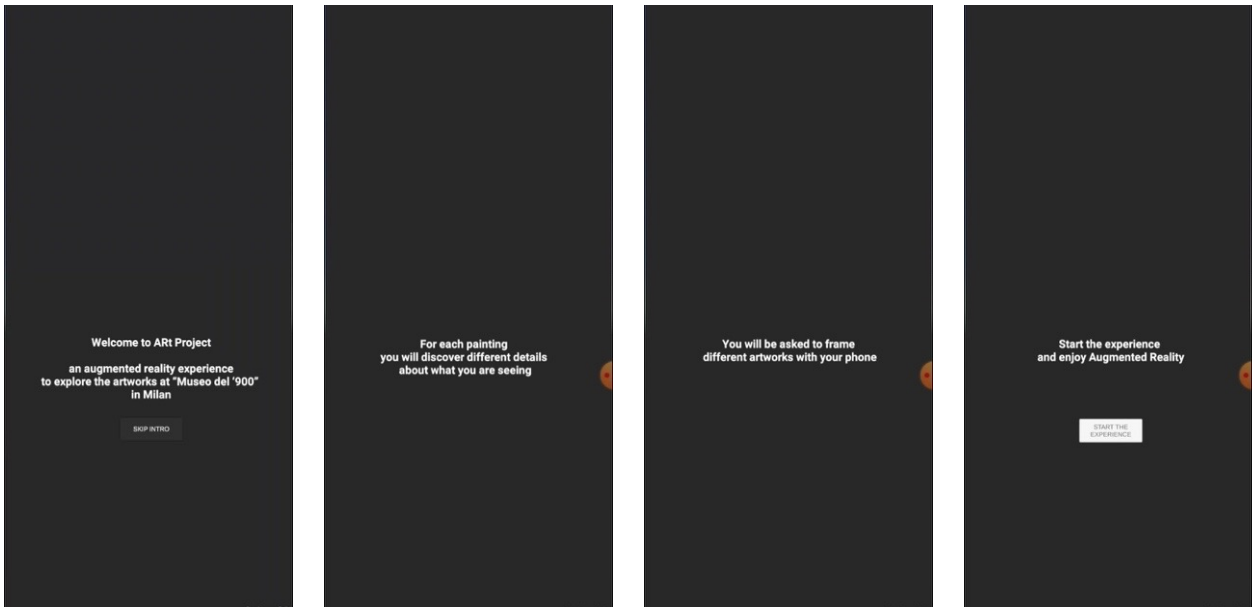

Figure 24: the four text segments of the introduction

To implement the introductory scene, we divided an explanatory text into four segments. We then implemented a scrollable rectangle to let the user pass from one segment to another. With the first text element, there was a button to skip the intro if the user felt confident enough, and a button (with the same functioning) accompanying the last piece of information to make the user close the opening and lend on the first scene, with the first artwork. Figure 24 represents the four steps of the introduction, starting with the first image the user sees after opening the app. We wanted to keep the scenes as empty as possible and have as few UI elements as possible to help the user better focus on the AR scene where the most important interactions and visualizations occur.

For the subtitle texts, we created a canvas element as a child of the marker object (we want it to be triggered only when the painting is recognized) and placed all the texts

inside that canvas. We decided to split the audio segments to avoid having text walls but a maximum of three lines of text. We applied an animation to pass from one text segment to another. We then decided to link the audio elements to the text elements in the subtitles rather than the 3d elements inside the scene. We opted for this option to have a better and more immediate synchronization between the audio and the texts (the audio sources are reproduced automatically once the text element is shown). We also added an instruction at the beginning telling the user which artwork they must look for; once the artwork is framed, the instruction disappears automatically, and the narration starts. We opted for a white text to which we applied a shadow background (using a sprite) for better readability; we considered the option to use a background panel (like a footer), but we desisted since it was occupying a too large portion of the screen. In figure 25, we show the subtitles in four different moments to resemble the main outputs we have throughout the project.

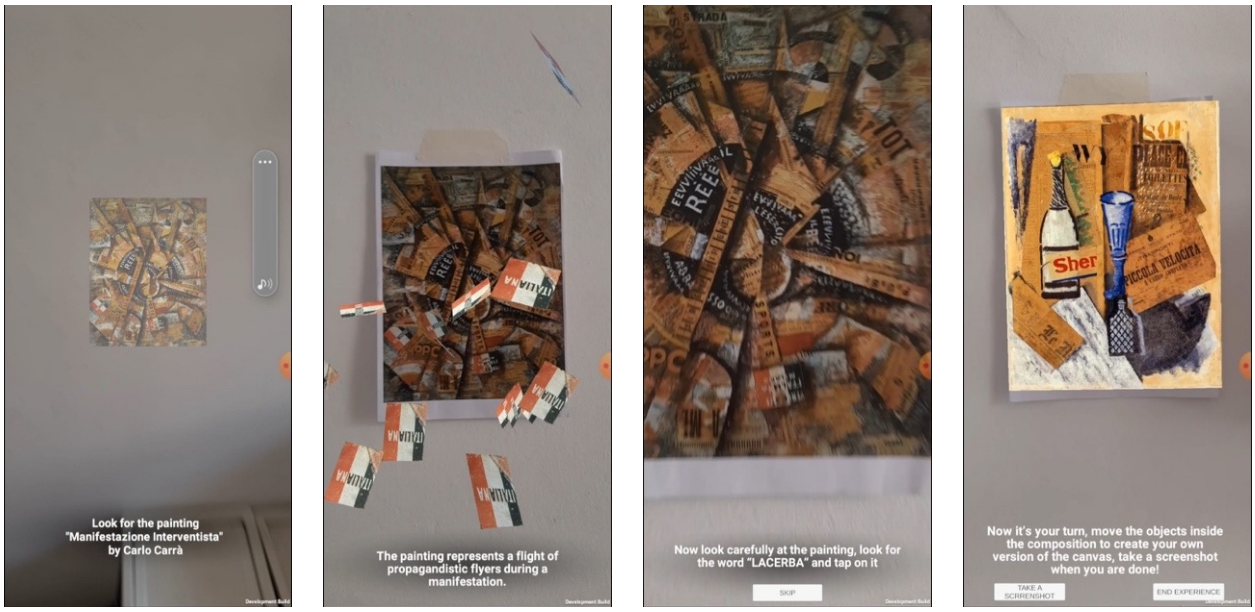

Figure 25: four moments of the AR experience with the UI texts and buttons

2.4 First test

After the first preliminary implementation of the two artworks and after trying to deploy the application prototype on an actual device, we decided to run a few tests with fresh users. We decided to do that to understand the user acceptance of the prototype and to see whether they found our use of AR interesting and useful. We run

this text in an unstructured way on purpose to observe the users interacting with it with the most empty-minded and free from preconceptions mindset, and to get the most various feedback possible. At the moment of the testing, not all the functions were completely implemented (the screenshot was not functioning yet), but still, we were able to get a good impression of the users interacting with the prototype. Since we could not bring the users to the museum, we used at first some digital versions of the paintings (displayed on the user's smartphone) and some printed versions later to reproduce an experience more verisimilar to the one they would have if they really tried the application inside the art gallery. In figure 26, we show some of the first users trying the prototype.

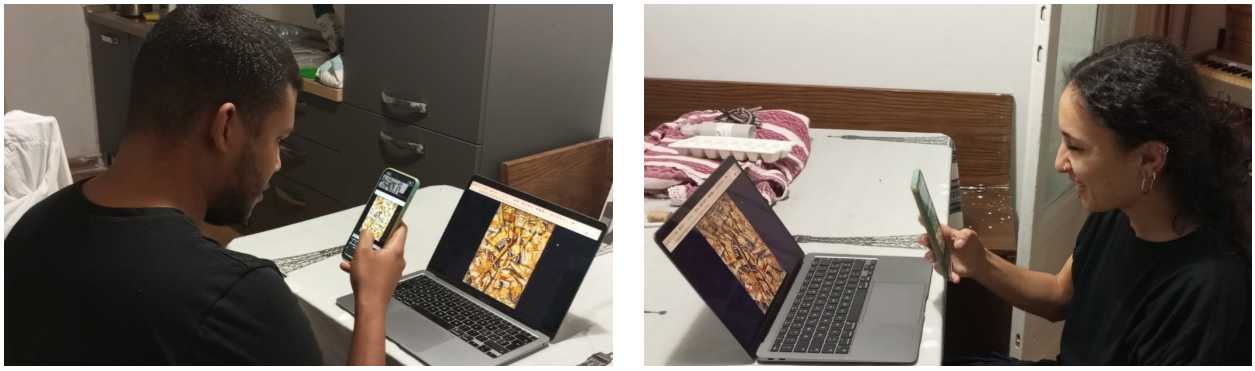

Figure 26: users trying our preliminary prototype

The acceptance of the prototype was generally very positive; all the users pointed out the usefulness of the prototype, and they said that, if they had really visited the museum, they would perfectly remember our artworks and the information we proposed. Even the less technologized users, who said they would not use the app for themselves, were happy that a potential user would adequately understand what they were viewing. We report some of our users' quotes after using the prototype that show the positive feelings associated with the experience.

> *"I want to hear that again" Anna, 61*
>
> *"if I go back there, now I remember everything " Giacomo, 20*
>
> *"finally people are understanding what they see " Mimmo, 60*
>
> *"it's good to have visuals along the explanation; it helps you follow what they say, and you are sure to focus on the right detail" Lucia, 27*

Nonetheless, our user still found some difficulties and had some adjustments and improvements to suggest. Moreover, we found them struggling in some situations and not feeling that confident. We report below the main observations that were made to us by our users, as well as the problems we identified while monitoring the use of the prototype:

One user asked for the possibility of hearing the explanation again. We must consider that the user might miss some information, and we must find a way to retrieve it.

Many users skipped the interactive parts of the experience, probably due to wrong positioning; many clicked on the first button they saw.

One user asked to be able to change the artwork during the experience, and it is a good thing to implement functions that give the user more control of the experience.

None of the users scrolled during the introduction (there were no affordances telling the user to do so).

The overall experience was too long and full of content, the attention was fading away, and it was quite difficult to follow all the information (especially on the first artwork, which had a longer explanation).

Even if none of the users complained about it, none of them managed to find the words during the game related to the first artwork, which we needed to make easier (without making it too obvious)

2.4.1 Adjustments

We decided to implement a few different functions to help the user navigate and control the experience: a restart button that reset the scene from the beginning and a menu button that opens a scroll view that allows the user to select the artwork they want to make the experience of. The restart button allows the user to hear the information they missed again, and the menu allows the user to skip an artwork (if the user can't find it or isn't interested). Those integrations allowed us to have better control of the experience without intervening directly on the scene elements and their functioning but only relying on the scene manager. We also implemented a background bar not to have the buttons floating in the air but to give them a structured position in the screen layout. Figure 27 shows a close-up of the navbar implemented during the experience.

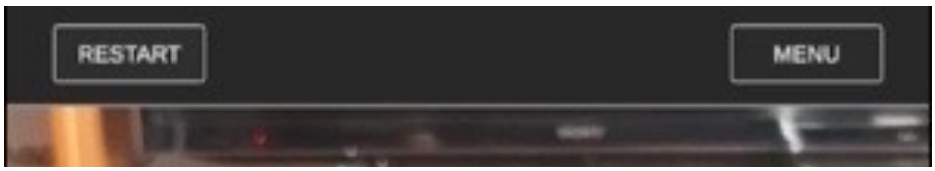

Figure 27: the top nav bar with the menu and restart buttons

To improve the introduction, we implemented some dot like elements under the text segments to better signal that there are other contents to view. Moreover, we found the scroll interaction not that smooth but was presenting some visualization issues like, shown in figure 28: the scrolling behavior not only makes us see the text being cut out of the scrollable rectangle but also doesn't let the user position the upcoming text in the center of the screen. We tried implementing the same interaction using the swipe interaction, but it was much more difficult and required too many coding skills and effort for minimal adjustments. So, we decided to implement some buttons to make the user pass from one text to another; it may not be the most natural interaction, but it resulted in an excellent compromise between visual appeal and implementation ease. Figure 29 presents the updated version of the first screen of the introduction, compared to the first one we realized.

Figure 28: the problematic scrolling behavior of the first introduction

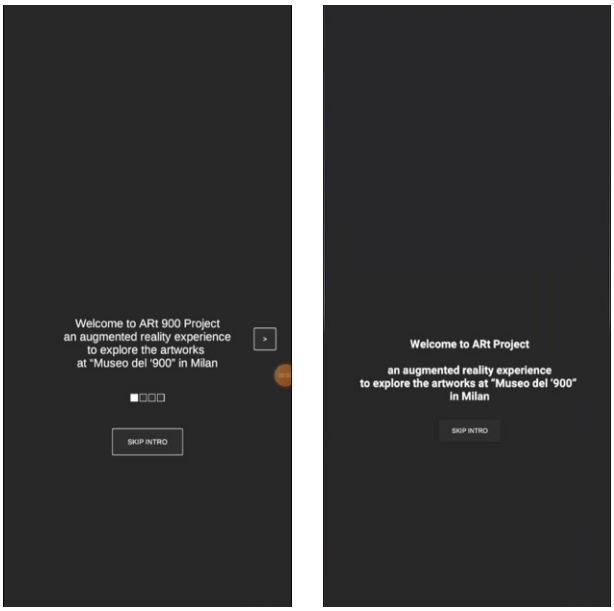

Figure 29: the comparison between the final screen of the introduction (on the left) and the first one implemented (on the right)

We decided to cut some parts of the explanation. To do that, we have rewritten the scripts to make the information more synthetic. This process allowed us to leave some silent space between an audio and the next to better let the user follow the whole narration. The first artwork explanation was still too long, so we decided to cut the second sequence (the one related to the Zang tumb tumb words written in the artwork). We opted for this decision since we found it a bit boring to stay focused for so long on a minor detail and because it was strongly interrupting the rhythm of the narration as well as being the less interesting part from a visual point of view.

We found it necessary to re-design the interactive game of the first artwork, considering that nobody was able to complete the task. We decided to eliminate

the three-word interactions, which were making the whole experience too long and always less engaging, but we decided to ask to find only one word at a time. Once tapped, each of the words provided information related to all three of them. We also gave the user the opportunity to skip some steps of the game if they felt stuck using a specific button (whose visibility was reduced to make it less appealing). The new interface of the instruction for the game is shown in figure 30. We also decided to add a help button, which gives a visual clue presenting the section of the painting in which the words are portrayed. Moreover, the new instruction text also mentions the part of the painting where the user must look. The screen presenting the clue to help during the game is shown in figure 31.

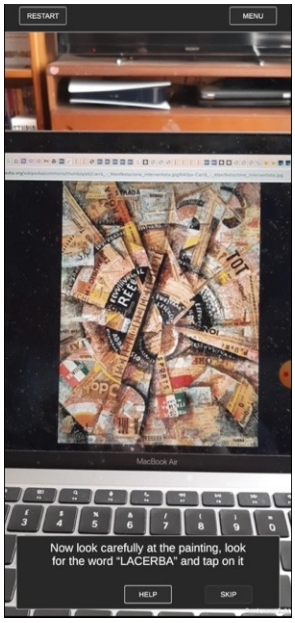

Figure 30: the game's new interface with the skip button

Figure 31: the visual clue the user can access to make the game easier

In the end, we made some UI improvements to make all the elements fit the same graphic style. We made sure that all the texts had the same formatting and spacing. We applied the same style to all the UI elements, granting a major graphical coherence. We opted for a less thick font (we used Liberation Sans, which was already available in Unity), and applied a dark grey background to all the elements, the same tone we used for all the buttons and the background of the intro. We decided to remove the shadow behind the subtitles, which no longer matched our style, to implement a background panel more in line with the interface elements. In figure 32, we propose different screens showing all the parts of our final UI.

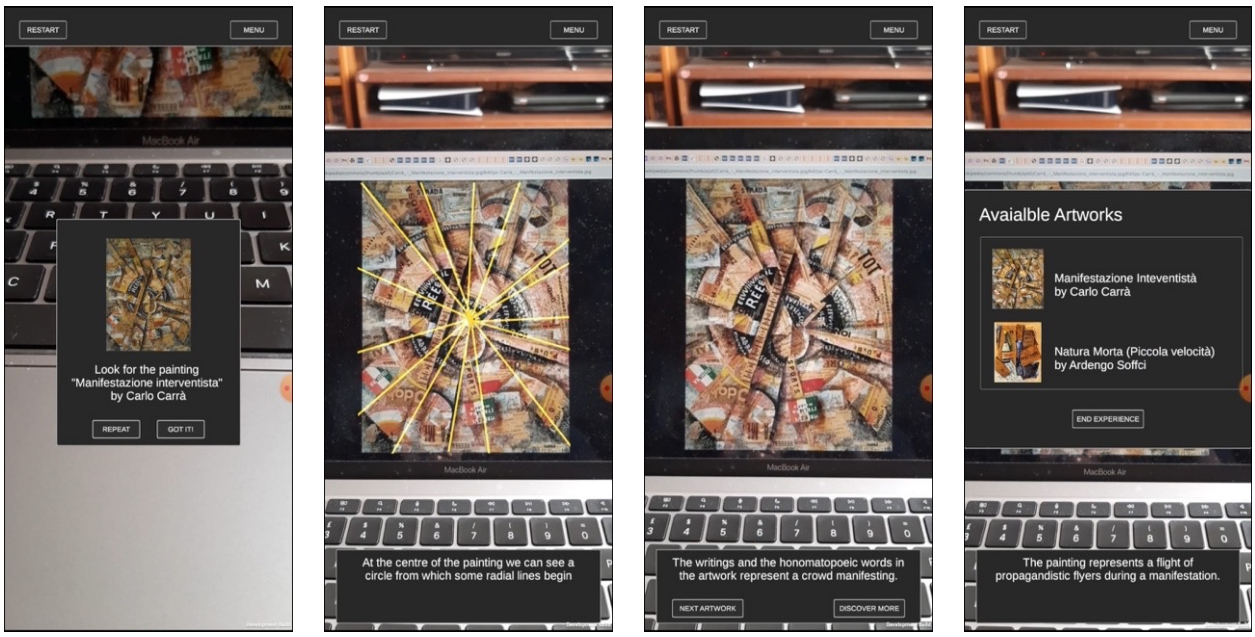

Figure 32 shows some screenshot of the experience showing the UI elements: the instruction page, the subtitles text, the button interface, and the navigation menu.

2.5 Final Testing

Now that we have the fully functioning prototype, we have to run a more proper and structured testing phase with our users. We asked our co-workers in a small IT company to try the prototype during their breaks. We are aware that our testers are more expert users when compared to normal museum visitors and are, at the same time, somehow technologized and familiar with augmented reality. Even if atypical users were very happy to try the prototype and provided valuable feedback and suggestions, we can evaluate to implement it in the remaining time we have. Those suggestions we are not able to implement can still be considered further improvements. Moreover, their suggestions are really useful if we have to make a real application. They gave us precious insights from which we have a lot to learn, and we are very grateful to them.

The users were asked to fill out a survey to collect some feedback in a more structured way. Our questionnaire consisted of twenty questions: each question presented a statement, and the user had to tell if they agreed or disagreed based on a five-point Likert scale (with one being 1 strongly disagree, and five being 5 strongly agree). The first ten questions follow the System Usability Scale (SUS), one

of the most popular standardized questionnaires. SUS is widely appreciated for its quickness (it only consists of ten questions) and for being applicable to almost any digital system. It has a specific counting to be done to read the results and has a numeric output that indicates the overall performing of our system, and it's very easy to make comparisons with other similar systems. The second ten questions were still asked on 5-point scale but were more referring to our specific case, making questions about the experience they just had and about the use of Augmented Reality. We mainly want to understand if our use of AR is perceived as meaningful and if the experience was felt as positive. Here, we report the twenty questions of our questionnaire.

01) I think that I would like to use this system frequently:

02) I found the system unnecessarily complex:

03) I thought the system was easy to use:

04) I think that I would need the support of a technical person to be able to use the system:

05) I found the various functions in the system were well integrated:

06) I thought there was too much inconsistency in the system:

07) I would imagine that most people would learn to use this system very quickly:

08) I found the system very cumbersome to use:

09) I felt very confident using the system:

10) I needed to learn a lot of things before I could get going with the system:

11) I think that the experience was too long:

12) I would have preferred the same information presented with other media:

13) I found that augmented content was distracting me from the real artwork:

14) I think that the explanation was difficult to follow:

15) I wanted to have more control during the experience:

16) I will remember better the information that were presented to me using augmented reality:

17) I found the augmented content coherent with the artwork and with the information proposed:

18) I wish I had the chance to explore more artworks in this way:

19) I think the use of augmented reality fits this kind applications:

20) I found that the overall experience was engaging:

2.5.1 Test results

In the end, we got 12 people trying our prototype and responding to our survey. They were very kind, giving us time during their breaks and spare time. We are aware that our testing population is not neutral, but (being mostly different kinds of IT workers) some expert users are very used to digital innovation and digital technologies. Suppose this enabled our respondents to give precise and clear feedback about what they wanted and what could be improved. In that case, it's also true that working in the digital sector, they are fully digitalized and have a strong technology readiness, which makes them more willing to accept and use digital applications when compared to the medium museum user. The results we got from the questionnaire are particularly positive, showing how they enjoyed the application and the project itself. They also provided many constructive feedbacks that we could later discuss as further developments.

Starting with the analysis of the first ten questions, we applied the standard formula to calculate our score in the SUS. At first, we calculated the average rating for each question; then, for the odd-numbered questions, we subtracted 1 from the average score, and for the even-numbered ones, we removed the average score from 5. This has transformed all the values (both the positive and the negative ones) into values between 0 and 4. Summing up all the values and multiplying by 2.5, we have a score between 0 and 100, representing our application's overall performance in the SUS. The average score for SUS is 68, meaning that any value beyond this digit can be considered reasonable. Our score in the SUS was 88.9, showing an excellent usability and function integration result.

We go further in the second group of questions, which are not part of the SUS or any standard questionnaire but were written for the specific purpose of this test. The questions from 11 to 15 were negative statements, while the 16-20 were positive. The negative statements regarded specific potential criticalities we might have encountered. In contrast, the positive ones were more general and aimed to validate our concept and prove that we made consistent use of AR technology. Figure 33 shows the detailed results of this part of the survey; for better clarity, the first negative statements were scored backward and the results are not presented

numerically from 1 to 5, but textually (awful, low, neutral, good, excellent).
The survey results are particularly good, with no item being voted with the lowest score. 5 questions out of 10 were voted the highest score nine or more times, especially the positive statements (4 out of 5) to which the users widely agreed. That shows the validity of our concept and the coherent use we made of augmented reality. The experience was considered particularly engaging, and users wanted to explore more artworks in this way (according to questions 18 and 20); on questions 16 and 19, which were more specific, the users were more divided between the two highest options, showing, maybe, more pounded reasoning which always led to a positive answer. Looking at the negative statements, we can see that the votes are a bit lower (even if still very positive). Those questions target very specific issues and potential criticalities we must be sure to avoid; that's why they deserve to be analyzed in further detail.

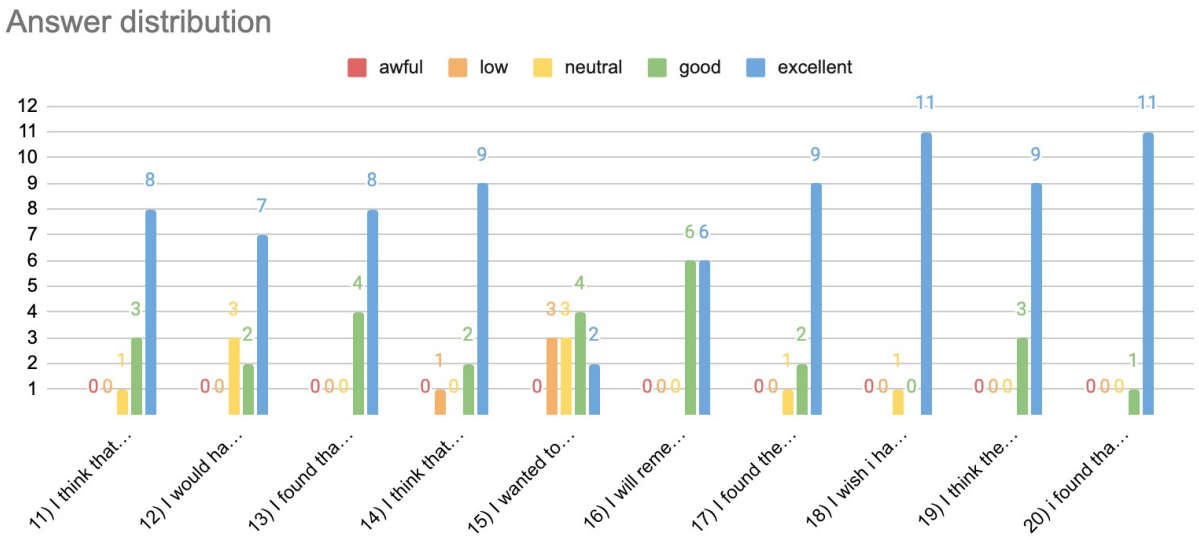

Figure 33: results of the second part of the survey

Question 11 asked whether the experience was too long; if not everybody disagreed, it's also true that nobody has explicitly considered the length of the experience inappropriate, meaning we managed to fit the timings of our narration, asking our users for the proper attention span. The only moment that took more time than desired was the interactive part of the first artwork, where more users were prone to keep the third step (even if they still finding the idea of the interaction engaging).

Question 12 asked whether they preferred the same content on other media. This is very important to understand if we implemented AR meaningfully. Its introduction was never seen as a disadvantage (there were no other preferred media). In the worst case, some users needed to be more neutral about the implementation of AR, stating that they would have neither preferred another media nor found the use of AR particularly relevant. Instead, a few users

mentioned how useful it is to have shown the artworks where to look at, mentioning how sometimes it was difficult for them to follow the explanations just because they needed help figuring out where to look.

Question 13 addressed the possibility of perceiving the augmented content as a distraction, which was never seen as a problem, even if the augmented content was "covering" the real artwork, especially during the second experience. It was possible that the digital content didn't allow the user to appreciate the painting, but that was never the case. Instead, the narration helped the user visualize and understand more details, leading to a major appreciation of the art piece.

Question 14 asked if the explanation was difficult to follow, which was rated partially true only once. Regarding the instructions we gave our users, the SUS already shows that they were clear and that the users learned how to use our application quickly. Also, the narration was relatively easy to follow, even considered the number of stimuli and information we provided. The users also had no difficulties following the audio explanation and the visual contents simultaneously.

Question 15 shows the most critical issues, with the lowest average of all questionnaires, with an average rating of 2.41 on a scale from 0 to 4 (all the other answers are rated over 3). We asked the users if they wanted more control during the experience, and 25% of the users agreed, and only two were satisfied with the control they had. Some issues were raised about the possibility of playing and pausing the narration, which was not implemented, and some other users didn't find the option to hear the narration again. It was a common feeling that once information was told, it was hard (if not impossible) to find it again, which was raised as a strong criticality, also considering that this issue would become more apparent when the user is interested in the content, making unsatisfying not being able to fulfill that interest.

Over the feedback related to the issues we addressed, our users gave us other suggestions worth reporting. Their interest in providing additional feedback and suggestions shows the overall interest our project evoked as they wanted to give and share their contribution to it. We have suggested an alternative portal (more realistic and accurate but still accessible) from which we could take our voiceover called elevenlab.com. We were suggested to insert the common scan icon somewhere during the explanation for better clarity and to make the buttons more visible. Generally, some improvements in the UI were also suggested: we opted for a minimal style to keep the user focused on the augmented scene, but it was told us that instead, it was not valorizing the entire project and could be improved to give a better impression of the work that was done. The last criticality that was addressed regarded the interactive part of the first artwork; it could have been clearer the difference between the explanatory part and the interactive game making it look like an information that was unnecessarily hidden. The whole interaction was sometimes perceived as too difficult and could be made easier by showing the hint directly on the artwork: even if it may be more considered, like giving a solution rather than a

hint, it's still an implementation we can consider. We may not be able to implement all those suggestions. Still, this feedback can give us valuable insights on the directions to improve our prototype further to grant our users an always more satisfying and engaging experience.

2.6 Final Visualizations

For the final visualization of our experience, we went back to the museum for one last time to try the prototype in its real intended context. Moreover, we can see the real-size paintings and the real-scale visualization of our project. In Fig 34 (1 - 8), we show some pictures we took while testing the app in the museum. The pictures are meant to represent the main happenings during the usage and are not focused on the app realization but are aimed to extensively tell and describe the AR experience in our project.

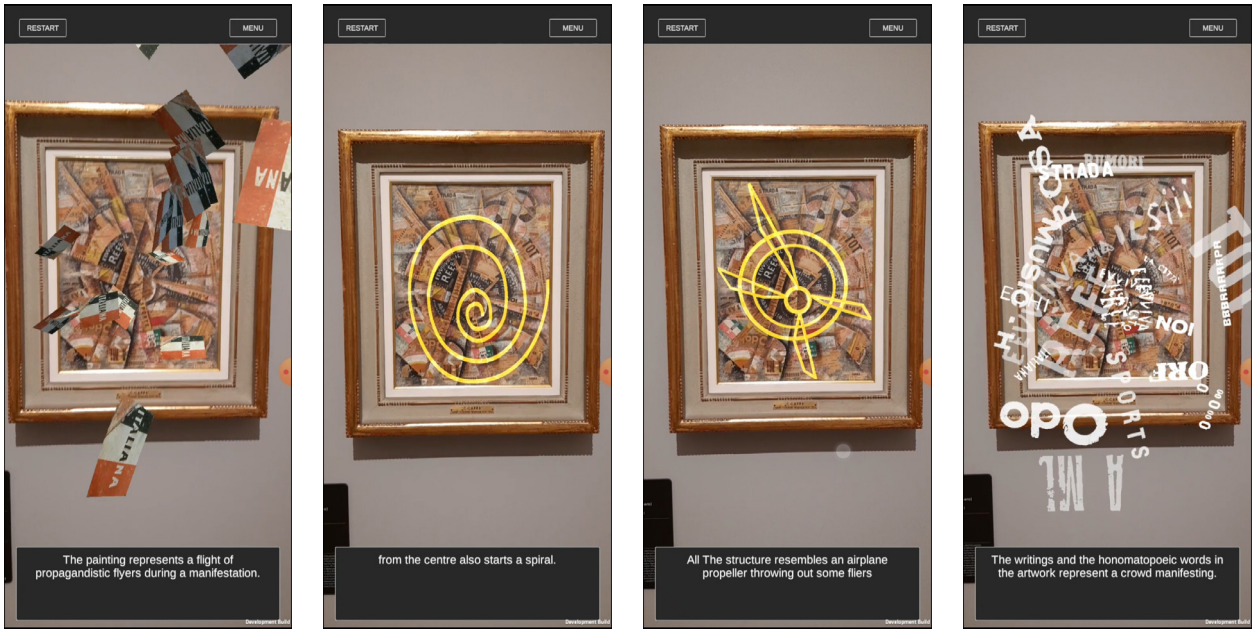

Figure 34 (1-4): Final visualizations of the first artwork

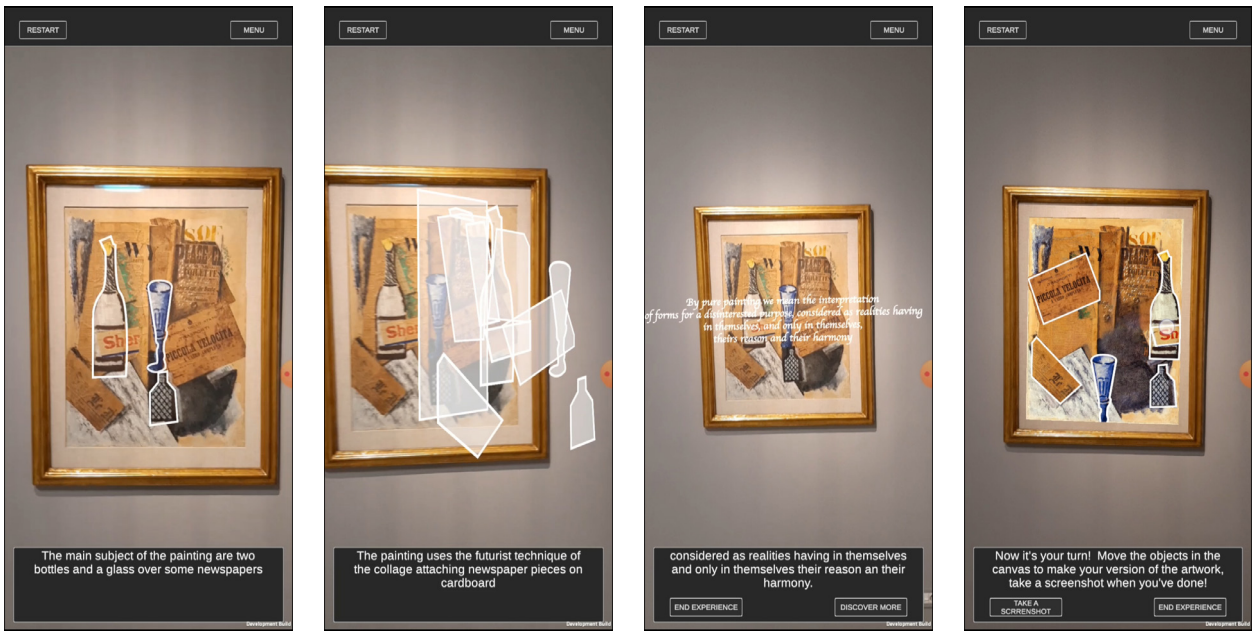

Figure 34 (5-8): Final visualizations of the second artwork

Conclusions

We have reached the end of our project; during this journey, we analyzed the potentialities of Augmented Reality applied to the world of Cultural Heritage Tourism, and we successfully implemented one potential AR experience for an art gallery. We have started our research analyzing the changes occurring in the whole tourism sector due to digital technologies and how cultural institutions are trying to intersect these changes. Then, we discuss the added value Augmented Reality can bring to this kind of context, we identified the different factors and dimensions determining the "experiential value" of an AR experience and a proper "Technology Acceptance". We provided a detailed description of the State of the Art, taking under consideration over 100 applications from 2002 to 2021, thus enabling us to understand the development of the discipline and the various common approaches followed by scholars; we identified four categories that enabled us to make a more qualitative analysis of the proposed content. We also compared them with those applications developed for commercial use outside research labs to understand how the different contexts affect the experience design. This research phase gave us a strong knowledge about the topic: what has been done, what can be done, and all the risks and potential criticalities we might encounter. We got a deep understanding of the specific potentialities of Augmented Reality as a medium, where it's more meaningful to implement it, and which are the possible technological assets we can rely on.

During the context study, we applied the different UX design tools we learned how to use during our study. We run a detailed context analysis to understand the users' needs and context-related opportunities. This enabled us to develop a strong concept and basis for our project. The project development part was also challenging. We have learned how to use the MARS Unity SDK (which is added to our luggage of software skills). During the development of the project, our skills in Unity significantly improved, and we were asked to implement a lot of different typologies of 3D (and 2D) objects in different ways. We are now much more confident with the Unity environment and C# scripts. We also successfully managed to access the device Gallery to take a screenshot, which was the greatest coding challenge.

The final testing phase showed that our prototype received good acceptance and very positive feedback. The approach we had was consistent and coherent with the

topic, we managed to find a successful and meaningful way to implement AR which fits really well with the context and requirements of a museum or art gallery. We are aware that our experience can be expanded and improved. We can improve the UI and the quality of the Voiceover, as well as design many more different interactions for other artworks, with potentially infinite possibilities.

During this project, we experienced and understood all the considerations, reasonings, and decisions behind a conscious use of Augmented Reality. We are more aware than ever of the effort required to implement a new technology and how we must provide a consistent added value to justify that effort. Most of the considerations we made about Augmented Reality can be applied (with all the necessary considerations) to other technologies and other contexts and can help us deal with and drive the technological innovations that are coming in the next years. This knowledge and keen eye for the reason behind technological innovation, the identification and focus on the technology's added value, and the cost and benefits calculation are the biggest takeaway from this valuable experience. Even if we are not, in future, developing this precise kind of applications, the mindset, the approach and the methods we have developed during this project will always be useful in any job regarding digital innovation and the implementation of digital experiences.

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CHAPTER 3

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