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Interactive Experience Design: Integrated and Tangible Storytelling with Maritime Museum Artefacts

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ABSTRACT

Museums play the role of intermediary between cultural heritage and visitors, and are often described as places and environments for education and enjoyment. The European Union also encourages innovative uses of museums to support education through the cultural heritage resources.

However, the importance of visitors' active role in museums as places for education and entertainment, on the one hand, and the growing and indispensable presence of technology in the cultural heritage domain, on the other hand, provided the initial ideas to develop the research.

This thesis, presents the study and design for an interactive storytelling installation for a maritime museum. The installation is designed to integrate different museum artefacts into the storytelling system to enrich the visitors experience through tangible storytelling. The project was conducted in collaboration with another PhD student, Luca Ciotoli. His contribution was mainly focused on the narrative and storytelling features of the research, while my contribution was focused on the interaction- and technology-related features, including the design and implementation of the prototype[1].

The research is deployed using a four-phase iterative approach. The first phase of the research, Study, deals with literature review and different studies to identify the requirements. The second phase, Design, determines the broad outlines of the project i.e., an interactive storytelling installation.

The design phase includes interaction and museum experience design. We investigated different design approaches, e.g., interaction and museum experience design, to develop a conceptual design. The third phase, prototype, allows us to determine how to fulfill the tasks and meet the requirements that are established for the research. Prototyping involves content creation, storyboarding, integrating augmented artefacts into the storytelling system.

[1] The project was conducted in collaboration with another PhD student, Luca Ciotoli. My colleague contributed the project through the research on creating content and narration for the storytelling system. His thesis is entitled "SAIL WITH COLUMBUS: UN PROGETTO DI TANGIBLE NARRATIVE APPLICATO AL PATRIMONIO NAUTICO LIGURE".

Th final phase, test, refers to the evaluations that are conducted during the aforementioned phases e.g., formative and the final usability testing with users.

The outcome of the research confirms previous results in the literature about how digital narratives can be enriched with the tangible dimension, moreover it shows how this dimension can enable to communicate stories and knowledge of the past that are complex, such as the art of navigating in the past, by integrating tangible objects that play different roles in the storytelling process.

Dedication

This research is lovingly dedicated to my real heroes; **the women**

And to:

Aba, my beloved grandmother;

Forough, my love;

Laya and **Zahra**, my precious sisters.

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Table of Contents

Table of Figures

List of Tables

1. INTRODUCTION

1.1 PHD PROGRAM AND RESEARCH CONTEXT

Cultural heritage is a source of creativity and inspiration. The transmission of cultural heritage knowledge and values can foster identity, the feeling of belonging and shapes our thinking [1].

Cultural heritage may be defined as important assets that depict the character and memory of a community, which provides an understanding of the past and helps face the present and shape the future [2].

Vecco in [3] discusses the semantic evolution of the notion of "heritage" and explains how the concept of heritage evolved from being defined based on its material to being attributed to certain immaterial values, thus meaning the adoption of an integral approach towards heritage. In this approach, a monument is no longer considered an object independent from traditional, chronological and geographical concepts of heritage. Vecco believes that the developments in this extension process pave the way to recognize intangible cultural heritage, which was ignored for a long time, as heritage to be protected and safeguarded.

Cultural heritage can be categorized as tangible and intangible. The tangible cultural heritage includes the physical and material elements of heritage (e.g., sculptures, paintings, monuments, buildings, archaeological sites, tools). The intangible cultural heritage refers to "Practices, representations, expressions, knowledge, skills—as well as instruments, objects, artifacts and cultural spaces associated therewith—that communities, groups and, in some cases, individuals recognize as part of their cultural heritage" (UNESCO, 2003: 2)[2] [4].

All Member States of the European Union are principally responsible to protect and preserve cultural heritage. However, the European Union has the obligation towards its citizens to ensure that Europe's heritage is safeguarded and enhanced.

[2] *https://ich.unesco.org/en/convention*

In this regard, the European research and innovation framework program Horizon 2020 enable the European Union to support a number of initiatives for preserving, reconstructing and promoting cultural heritage [5].

The program encourages the researchers to develop new and innovative methods and technologies for heritage preservation and protection.

Museums play the role of intermediary between cultural heritage and visitors, and are often described as places and environments for education and enjoyment [6] [7]. The European Union also encourages innovative uses of museums to support education through the cultural heritage resources [8].

The region of Liguria, in northwestern Italy, boasts a rich cultural heritage and together with its attractive landscapes offers huge potentials in the tourism sector. In 2018, Liguria welcomed 12% of foreign tourists, 9.3 million, in Northern Italy [9].

Liguria is the seat of magnificent artistic and architectural treasures that are recognized as a UNESCO World Heritage Site. In order to protect and preserve its cultural resources, the region contains numerous museums ranging from art to maritime science and navigation.

This cultural hub of the country represents an important resource for creating and maintaining identity, belonging and citizenship values and offers great potentials for research in the cultural heritage domain.

However, the importance of visitors' active role in museums as places for education and entertainment, on the one hand, and the growing and indispensable presence of technology in the cultural heritage domain, on the other hand, provided the initial ideas to develop the research.

This PhD Thesis is framed in this research context. It is EU funded for Ligurian Maritime Heritage enhancement.

In this thesis, I present the study and design for an interactive storytelling installation for a maritime museum. The installation is designed to integrate different museum artefacts into the storytelling system to enrich the visitors experience through tangible storytelling.

> *The high-level goal of this research is to investigate the potential of using integrated and tangible storytelling to engage visitors and promote cultural heritage, with a specific focus* on *the communication of maritime practices in the past*.

To this aim, we designed a case study project and deployed a four-phase iterative approach to the research. The first phase of the research, *Study*, deals with literature review and different studies to identify the requirements. In the second phase, *Design*, in order to determine the broad outlines of the project (i.e., an interactive storytelling installation).

The design phase includes interaction and museum experience design. We investigated different design approaches (e.g., interaction and museum experience design) to develop a conceptual design. The third phase, prototype, allows to determine how to fulfill the tasks and meet the requirements that are established for the research. Prototyping involves content creation, storyboarding, integrating augmented artefacts into the storytelling system.

The final phase, test, refers to the evaluations that are conducted during the aforementioned phases (e.g., formative) and the final usability testing with users.

Given the high-level goal of communicating maritime practices in the past introduced above, we identified the following objectives that are intended to address it:

- *Enhancing the visitors' active role in their museum visit*
- *Creating an enjoyable museum experience through interaction with the artefacts*

The immediate expected results would be an increased engagement of participants and higher understanding of the maritime instruments in an amusing experience, which are intended to have, as an effect, an impact on the promotion of cultural heritage relating to maritime practice.

Section 4.2 will specify the specific Requirements identified in this Research to address the objectives.

In the following section, we introduce the related research projects that supported and contributed to the definition of the above-mentioned objectives of this research.

1.2 MUSEUMS: MISSIONS AND OBJECTIVES

Museums have historically been oriented primarily toward collections and research. The first museums were private collections that were accessible to private visitors with certain intellectual interests toward collection [14]. However, as Wittlin argued [15], the spirit of enlightenment in the eighteenth-century created the public museum concept.

Over time, museums are recognized as public assets and become accessible to more visitors. This change in museums function gave them a more active role in society. Furthermore, the museum collections embody and exhibit social values [16] and have a responsibility to contribute towards society [17].

Bennet [18] believes that museums can enhance social behavior and foster a sense of community through spending time with others during the museum experience. The authors in [19] [20] believe that museums contribute to a good quality of life and serve public benefit. They argue that encountering museum artefacts provides us to gain a better understanding of our capacity for creative transformation [21] and enables us to reorganize our experience and remake our words [19].

Museums play an important role in serving public education as well as contributing to culture preservation and conservation (and related research) [22]. Despite the fact that education has always been associated with museums, private collections, per se, were not necessarily educational. However, when the former private collections were carried on in the public museums they were incorporated within a broadly educational project [23]. Museums became places for knowledge production that provide stimulation to learn and contribute to public education and enlightenment [5] [16] [20].

Over the past decades, museums made an effort to make their collections accessible to a wider public. Efforts to address more visitors and reach broader audiences highlighted the education role that frequently remained a minor activity compared to collection, preservation, research, and exhibition [24].

According to Awoniyi [25] using artefacts for education is one of the major functions of the museum. He believes that museums are recreational settings that provide their visitors with pleasurable experience [25]. Museums have undergone considerable changes in recent decades and have evolved not only into active learning environments for visitors, but establishments for public enjoyment [26].

Moreover, the expansion in the variety of museums required new approaches in definition and identification of an institution as a museum. There are different types (or genres) of museums (art museum, science museum, natural history museum). Different types of museums house different

types of exhibition items and have a different base of visitors, which constitute divergent genres in terms of rules and expectations of how to behave [22].

The authors in [27] discuss that describing some obvious characteristics concerned with technical and functional aspects (collection, conservation, research, etc.) results in a strict definition. Even though such a definition is thought to be wide enough, it freezes the essence of many museums and limits their evolution. They develop an alternative approach through which the definition is related to the various missions pursued by an institution identifying itself as a museum [27]. However, considering the broad and diverse definition of a museum, it seems difficult to determine the common goals of museums.

Since the intention of this research is not to propose a new definition of a museum, we avoid the on-going debate of what defines a museum. However, the reference in this thesis is the revised definition provided by the International Museums Association (ICOM) in 2007:

> *"A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of* ***education****,* ***study*** *and* ***enjoyment****." [ICOM Statutes 2007]*

This revision brought education to the forefront of the study for the first time and, including intangible heritage, recognizes the role of museums in the preservation and protection of both the tangible and intangible heritage.

In the following Chapter, looking into literature, we will describe how digital technologies open up new ways for museums to address broader audiences. We will highlight the role of digital technologies in providing *engagement*, *education* and *entertainment* experience in museums.

1.3 CULTURAL HERITAGE IN ITALY AND IN THE LIGURIAN REGION

The Italian cultural heritage is one of the richest in the world and attracts a massive flow of visitors from all continents for its cultural charm and variety. The nearly 5,000 museums, archaeological areas and monuments, public and private, in the Italian territory, welcomed over 128 million visitors

in 2018, about 94 million of which were foreign tourists who have chosen Italy as their destination [9].

UNESCO universally recognizes the value and uniqueness of the Italian cultural heritage. At present, Italy holds, alongside China, the largest number of sites included in the list of World Heritage Sites such as 5 natural places, 8 cultural landscapes, 42 monumental sites, architectural works and archaeological areas [28].

The Italian cultural heritage presents diverse widespread assets, works and structures of historical-artistic importance. One of the main characteristics of the Italian cultural heritage is its distribution throughout the territory and almost one out of three municipalities host at least one museum or similar institution [28].

Alongside the large centers with a high concentration of cultural interest, also the smallest municipalities enjoy this heritage. For example, large cities like Rome, Florence, Turin, Milan, Trieste, Bologna, Genoa, Naples, Venice and Siena each enjoys, on average, 52 structures, even in the smallest municipalities, with less than 2 thousand inhabitants, there is no lack of museum offer (i.e. 17.1% of this heritage that means between two and five museums and similar institutions) [28].

In general, in the national territory the most numerous museums are those of archeology (12.3% of the registered institutes) that are mainly in the southern regions. Then, come museums of an ethnographic and anthropological nature (11.7%), which preserve and exhibit testimonies and memories linked to the relationship with the territory and local culture and are concentrated in Basilicata, Valle d'Aosta, Piedmont and Trentino Alto-Adige. Finally, the specialized museums, with single-issue and / or industrial collections (11.1%), mainly located in the North (Liguria, Trentino Alto-Adige, Piedmont and Emilia-Romagna) and art galleries (10.1% since the Middle Ages 800 and 7.7% for modern and contemporary art) [28].

The overall visitors to cultural sites in 2018 are divided as 49.3% in museums, 10.7% in archaeological areas and 39.7% in monuments [28].

According to the ranking of the institutions, the Colosseum and Roman Forum complex in the first place with more than 7 million visitors. In the ranking of the institutions that recorded the highest number of visitors in 2018, we see the Colosseum and Roman Forum complex in first place with about 7.7 million visitors, where the overall visit to the Eiffel Tower in Paris in the same year was

around 6.9 million. The same ranking shows the Pompeii excavations in second place with about 3.7 million visitors [9].

Liguria: The region of Mountain, Culture and Sea

The region of Liguria, in northwestern Italy facing the Ligurian Sea is one of the richest Italian regions, together with its unique landscape possesses huge resources of historical and cultural heritage to offer. Two linked mountain chains constitute its mountainous and hilly territory, the foothills of the Ligurian Apennines in the east, and of the Maritime Alps in the west.

The stretched territory from east to west comprises the Ligurian arc facing the Ligurian Sea, which shapes the Ligurian coast as Riviera di Ponente from Genoa towards the west and Riviera di Levante from Genoa to the east.

The eastern part, the Riviera di Levante, is formed by a succession of rocky inlets, full of cliffs over the sea, with uniquely attractive landscapes in Portofino and the Cinque Terre. The western side, the Riviera di Ponente, is all bays and beaches.

Callegari in [29] discusses the importance of landscape and cultural heritage of the region and emphasizes the role of the duo "cultural heritage—landscape" in designing new sustainability-aware and development patterns in order to contribute to the protection of cultures.

The region's cultural heritage together with attractive landscapes offer huge potentials in the tourism sector. In 2018, Liguria welcomed 12% of foreign tourists, 9.3 million, in Northern Italy, being ranked fifth in this classification following Lombardy, Lazio, Veneto, Friuli [9].

Genoa: Cultural heritage and Museums

Genoa in the region of Liguria is the largest Italian port and one of the main in the Mediterranean. The historic center of Genoa contains magnificent artistic and architectural treasure that was recognized as a UNESCO World Heritage Site in 2006.

The Site includes the Strade Nuove ("New Roads"), where stand a series of residences of noble families in Renaissance and Baroque styles, constructed between the 16th and 18th Centuries[3].

In 1576 the Republic of Genoa established an official list (later called Rolli, hence the Palazzi dei Rolli) of prestigious palaces, obliging their owners to host State visits in turn. Depending on the rank

[3] *http://www.unesco.it/it/PatrimonioMondiale/Detail/145*

of the visiting guest, a palace was chosen to house them: the higher the degree of nobility of the guest, the more sumptuous the palace that hosted them must be. Later on, the Rolli became a housing model for the nobility of all Europe[4].

The Rolli system of Genoa consists of over 100 noble residences, 42 of which are included in the UNESCO World Heritage list. Each year Genoa celebrates these residences with the *Rolli Days* event: weekends during which the buildings open their doors and show their treasures to the public[5].

Genoa, a city with rich resources of heritage, protects and preserves these resources in numerous museums ranging from art to science. In order to show the variety of the museums in Genova we mention some as the following:

- The art museums (e.g., The Museums of the Strada Nuova preserve paintings, sculptures and applied arts from the 16th to the 19th century),
- The museums of world cultures (e.g., The Castello D'Albertis Museum includes ethnographic and archaeological findings collected by the Captain Enrico Alberto D'Albertis during his trips across five continents),
- The museums of nature, science and navigation (e.g., The Museum of Natural History "Giacomo Doria", is the oldest museum of Genoa and has an enormously rich scientific collection made up of 4.5 million artefacts and specimens from all over the world: animals, fossils, plants and minerals and 6,000 items are on display),
- The History Museums and Archives (e.g., The Historical Archive of the Municipality of Genoa, preserves the documents relating to the administration of the city between the 15th and mid-20th centuries and holds a collection of manuscripts dating to the 14th 19th centuries), and
- The Music and Entertainment (e.g., The Theatre Museum and Library, is one the few Italian museums about Theatre and Performing arts).

Moreover, The Galata Museo del Mare, the Commenda di Prè, the Naval Museum of Pegli and the Monumental Complex of the Lanterna are the four museums united in a single strategic structure of the Municipality of Genoa, the Mu.MA - Institution of the Sea and Migration Museums. The

[4] https://www.lamialiguria.it/it/
[5] https://www.lamialiguria.it/it/

Mu.Ma was funded in 2005 and aims to create a cultural center linked to the themes of the sea, travel and dialogue between peoples, knowledge and religions[6].

1.4 PROJECTS SUPPORTING THE OBJECTIVES OF THIS RESEARCH

The European Union, within its research framework programs, has supported cultural heritage research since 1986. Different innovative projects have been funded to promote the aspects of tangible, intangible and digital heritage. The projects have contributed to protection, preservation, management, enhancement and immersive experience through multiple innovations developed by European and non-European partners [10].

In this section, we present some of recent EU-funded projects that support the context of this research. All these projects aim to enhance the visitor's experience through providing them with an engaging experience. Although they use different tools to achieve their aims, the employment of digital technologies is a shared approach in all these projects.

Some projects use physical objects to offer tangible interactive experience (e.g., meSch), and some use interactive storytelling systems (e.g., EMOTIVE, i-MareCulture). Others offer playful tools and enable audiences to share their cultural knowledge and experiences (e.g., Gift, PLUGGY). There are also projects that promote intangible cultural heritage (i.e., Mingei) or focus on providing facilities for cross-disciplinary research and education (e.g., INCEPTION).

In the following, we take a brief look at these EU-funded projects as they have been a starting point for this research:

meSch (2013-2017), the project has the goal of designing, developing and deploying tools for the creation of tangible interactive experiences that connect the physical dimension of museums and exhibitions with relevant digital cross-media information in novel ways.

The project provides a platform, which uses smart objects and intelligent spaces to bridge the gap between the material and the digital and deliver curated and personalized digital content as part of the physical visiting experience.

[6] *https://www.museidigenova.it/*

The platform enables the user to upload content and define the visitors' interactions using a browser-based editor and a set of smart blocks (sensors, actuators, and small computing units) to compose the smart setting, with which, the visitor interacts.

The meSch project targets cultural heritage professionals - curators and exhibition designers for the benefit of their visitors. It allows professionals to quickly prototype and deploy interactive installations that engage both the senses and the imagination [10].

EMOTIVE (2016-2019), the principal objective of the EMOTIVE project was to research, design, develop and evaluate methods and tools that can support the cultural and creative industries in creating digital cultural heritage experiences, on-site and virtual, which draw on the power of "emotive storytelling". The output of this process is a number of prototype tools and applications for heritage professionals and visitors that produce interactive, personalized, emotionally resonant digital experiences for museums and cultural sites [6].

i-MareCulture (2016-2019) aims to improve the public awareness about the underwater cultural heritage by developing new tools and techniques that take advantage of the virtual reality technologies to allow the general public to explore the archaeological remains outside of the submerged environment.

The researchers developed and tested virtual and augmented reality applications to provide advanced, immersive and personalized experiences to be used at home, in-situ or at a museum. The projects, combining the recent advances in VR technology with the newest 3D reconstruction techniques, provides visitors an interactive and enhanced experience of diving into an unreachable underwater site, while offering additional information through storytelling about the artefacts displayed [11].

GIFT[7] (2017-2019) develops new approaches to creating hybrid physical digital visitor experiences in museums. Through design exploration of two concepts focusing on gifting and playful appropriation, the project charts how museums can create a deeper and more meaningful experience by giving visitors the tools to tell their own stories.

[7] The Gift Project*:* *https://pro.europeana.eu/project/the-gift-project*

Visitors are invited to select some artefacts in the museum and digitally “wrap” them as gifts to be sent to a loved one or a friend, who in turn may “unwrap” the gift and receive a highly personalized experience [12].

The project developed a set of free, open-source tools that provides resources to help museums and other cultural heritage institutions design, plan and implement enhanced visitor experiences.

INCEPTION (2015-2019) aimed to realize innovation in 3D modeling of cultural heritage through an inclusive approach for time-dynamic 3D reconstruction of artefacts, buildings, sites and social environments. The project develops a common framework for integrating different expertise, an advanced methodology for integrated data capturing, semantic modeling and a platform to collect, archive and share semantically enriched models and applications for models’ deployment. The project offers an open-standard Semantic Web platform for accessing, processing and sharing interoperable digital models resulting from 3D data capturing and holistic documentation [13].

Mingei[8] (2018-2021) explores the possibilities of representing and making accessible both tangible and intangible aspects of craft as cultural heritage (CH). Heritage Crafts (HCs) involve craft artefacts, materials, and tools and encompass craftsmanship as a form of Intangible Cultural Heritage. Intangible HC dimensions include dexterity, know-how, and skilled use of tools, as well as, tradition, and identity of the communities in which they are, or were, practiced.

Mingei will provide means to establish HC representations based on digital assets, semantics, existing literature and repositories, as well as mature digitization and representation technologies. These representations will capture and preserve tangible and intangible dimensions of HCs.

PLUGGY (2016-2019) aimed to develop an innovative social platform and a suite of smartphone tools that enable individuals, community groups, industry, museums and countries to document and share their heritage online. The PLUGGY software platform facilitates a continuing process for creating, modifying and safeguarding heritage, helping to build new virtual heritage communities. Content is either uploaded by end-users or derived from digital collections such as museums, archives and cultural institutions, allowing users to create links between seemingly unrelated facts, events, people and digitized collections, leading to new approaches of presenting cultural resources, and new ways of experiencing them.

[8] Mingei-project: *https://www.mingei-project.eu*

Moreover, four PLUGGY derived applications (augmented reality, geolocation, 3D sonic narratives and collaborative games) are developed and released to show the potential of the PLUGGY software platform [10].

The diversity of the projects indicate that the cultural heritage domain has high potential for research, whereas the variety of the projects shows the necessity for innovative and interdisciplinary research to achieve the objectives set out in the EU research framework program.

Some of the projects research and develop tools to address a broader audience and make cultural heritage accessible to all removing social, cultural and physical barriers. Some others develop frameworks to target cultural heritage professionals, curators and exhibition designers in order to enable them to design and create interactive experiences for their visitors. Other projects apply digital technologies to reconstruct and represent cultural heritage aiming to enhance visitors' experiences.

Despite divergent approaches used by each project to address the objectives, some common keywords like *engagement, interactivity, digital technologies, storytelling, and collaboration* can be identified. These keywords together with the latter studies contribute to outline the objectives of this research project.

1.5 THESIS STRUCTURE

The thesis is composed of six chapters, including this introduction. In Chapter 1, I provided a brief presentation about my PhD program and outline of the thesis through describing the context and the objectives of the research.

In Chapter 2, I conduct a literature review on the evolution of the museum concept, the role and function of museums in recent decades. I discuss the role and contribution of digital technologies in the museum's new identity.

In Chapter 3, I present the methodology of this research, which involves four iterative phases (Study, Design, Prototype and Test). In this chapter, I detail the methods and approaches applied in each phase.

In Chapter 4, I present the case study and mention the reasons and motivations of choosing the Galata Museum as the case study. Moreover, I discuss all the steps taken in the iterative approach of developing the research phases like field study, interviews with the museum curator, identifying requirements and evaluations.

In Chapter 5, I discuss the results we obtained in different evaluations conducted in the previous chapter and examine to what extent the research question was answered.

Finally, in Chapter 6, I conclude discussing the results, and reflecting upon the overall contribution made to the cultural heritage domain and conclude the chapter with a glance at the future work.

2. STATE OF THE ART

By evolving the concept of museum, from primary private collections to public assets, accessing heritage resources in museums is no longer a solitary and passive experience. Museums have become socio-cultural institutions, whose social role and mission is reflected in the way they offer their collections to visitors and engage them [30].

Museums shifted from being collection-centered to being visitor-centered [31]. Examining current trends in museum studies, a widely shared visitor-oriented and visitor-centered approach emerges [32] [33] [34].

Over the past two decades, museums are often described as places and environments for entertainment, as well as for learning (Skyrda, 2012 [7]; Garcia-Cardona et al., 2017 [6]). Museums shifted from being collection-centered to being visitor-centered [31]. Examining current trends in museum studies, a widely shared visitor-oriented and visitor-centered approach emerges [32] [33] [34].

In this regard, the European Union has set policies and strategies for audience development to promote access, produce and use cultural content via digital technologies [35].

Following a visitor-centered perspective, museums have to adapt to a diversity of visitors and satisfy a diversity of educational and entertainment needs, creating exhibitions that focus on a generalized understanding of diverse audiences [36].

However, understanding the visitors' expectations and interests is a complicated issue that could depend on multiple factors. Falk and Dierking [14] presented an interactive experience model and argued that visitors tend to learn more and repeat their visit when they are motivated and engaged. They identified three factors that affect informal learning in museums and categorized them under the personal, social, and physical context of visit.

The personal context includes visitors' personal agendas and expectations for their visit. The social context is related to the visitors' social surroundings- even if the visit is solitary- that can influence their behavior and experience in the museum. In the physical context, the authors argued that the physical setting of the museum and artefacts strongly influence the way visitors behave, observe and remember.

Hooper-Greenhill believes that museums are at a critical moment in their history. Museums need to demonstrate their social relevance and use in order to ensure their survival. This demands museums to develop public service functions through getting deeper insight into the needs of their visitors in order to provide them with enjoyable and worthwhile experiences [37].

The visitor-centered approach highlighted the application of technologies in museums to engage the visitors and mediate novel types of experiences [22]. Recently, museums have been using advanced technologies that innovate beyond traditional forms of engagement to improve the visit experience and to attract a wider audience. Furthermore, recent studies [15][38][39] highlight how technologies positively affect the overall experience.

A popular approach used within the premises of a museum is combining education and entertainment, called edutainment, to enhance one's learning experiences. For example, gamifying elements supported by technology can increase visitor engagement [40].

Over the past decades, changes in society and technology have reshaped museums' function, design and the way they deliver content and experiences to the visitors. In artefact exhibitions, technology-enabled samples can provide visitors a better understanding of objects and ideas, through offering complementary information, increase accessibility and enable opportunities for disable people [41].

The application of technology is seen as an essential instrument that facilitates the reproduction of stories, intangible content (i.e., sound, video, etc.), and other non-physical heritage. Furthermore, it can be used as a solution to expand information about heritage that cannot be exposed (i.e., artefacts and places that are no longer existing), enabling the reconstruction and providing access to replicas [42].

> "The worth and importance of the Institution are not to be estimated by what it accumulates within the walls of its building, but by what it sends forth to the world." [Joseph Henry] [43, page 21]

Virtual museum is a database made available over the Internet, mainly focused on content, communication and collaboration that can also be fully connected with the museum's own museographic tools [44].

Online museum, hyper-museum, digital museum, electronic museum, cyber museum, web museum, among others, are the many possible names for the virtual museum.

In a virtual museum experience, visitors can consult the information supported by the museum's website. Besides, visitors can have an active role in content creation during their experience through creating and sharing content (i.e., posting photos and videos, wikis and discussions, blogs, microblogs, collective subtitles, social bookmarking, tagging, integration and sharing of information via social media platforms, like Facebook, Twitter, Instagram, Pinterest, among others) [44] [45].

The virtual museum therefore offers an online experience that is based on viewing multimedia content, narration and interaction with a new type of visitor; the remote visitor. The user, therefore, actively participates in the construction of museum knowledge, structuring a new paradigm for the museum-visitor relationship [42].

Virtual museums create space that can host collections that come from an unlimited resource of institutions and museums all over the world. Furthermore, the dynamic and evolving characteristics of virtual museums is a valuable asset for the cultural heritage institutions that gives the museum curators flexibility and the freedom to apply the creative approaches in the exhibition design process, through innovative exhibition solutions and the embodiment of digital technologies.

There can be found different definitions for virtual museums. However, as Manzone et al. discuss some basic characteristics such as multimedia, interactivity, multisensory, connectivity, dynamism, being multidisciplinary, being narrative and deterritorialization can be identified [46].

Over the last two decades, the boom of web sites and social media associated with museums raised the question of whether those virtual spaces will, one day, take the place of the physical museum.

It is believed that no matter how well designed a virtual museum is and how many activities it can offer to users, a virtual museum will never be able to replace a real museum. In real museums, visitors have the opportunity to engage and interact concretely both with the works and with the people around them. However, virtual museums may work as a bridge toward reality or its amplification [42].

> "The transformation won't mean that museums lose what they have to offer as physical sites conveying knowledge through the medium of material objects. It means that the museum will get another dimension, a digital one." (MacDonald and Alsford 1997: 267) [47].

The Louvre Museum is an example of that kind of bridge. The museum's website provides tools, through which, the visitors can download the maps of the museum, take an interactive virtual tour in different parts of the museum, visit the museum's rooms with 360° images and 3D exploration, have access to dedicated web pages of specific works of art, and schedule visits to researcher-only areas such as technical reserves and fragile collections[9].

The Google Art Project (GAP) is a recent platform for hosting such representations and is already featuring a large number of well-known museum collections. The interface of GAP allows the detailed observation, even more than in a real-life visit, of the painting's surface, creating the possibility of technical and esthetical studies that would not be possible only with the direct observation of the work in the museum. The project aims to replicate the experience of a physical visit to the museum and make the user feel immersed in the digital space [42] [48].

The use of social media is inevitable for creating a collective experience. Social media are precious allies for museums and cultural institutions to extend their presence to the digital sphere. The award-winning site VanGo[10] Yourself is a different and surprisingly deep way for visitors to engage with heritage, based on emotion, playfulness and curiosity. In the website, users are asked to recreate paintings of author whose work is in the database with different levels of difficulties and then publish and share their work. The idea inspired many other museums to create challenges based on their collection during the COVID-19 confinement [49].

The Art Detective is a free-to-use online forum that aims to improve knowledge of the UK's public art collection. Participants can post or answer questions related to various aspects of the work under analysis. The participants discuss different subjects related to the discussion such as artist, theme, date of execution, technique, support, description, among others[11].

[9] *http://www.louvre.fr*
[10] *https://vangoyourself.com/*
[11] *https://artuk.org/artdetective/*

2.1 MUSEUM INSTALLATIONS: FROM STANDALONE KIOSKS TO MULTI-TOUCH SURFACES

Standalone kiosks were widespread in the early days of museum technologies. Kiosks, as fixed terminals, were providing information on hours of operation, staff, the building's architecture, floor maps, and collections [50].

Standalone kiosks can be used only by one person at a time [51] and the content to be delivered is configured according to the purpose that it intends to serve in the institution and the users navigate through the content (e.g., text, images, video and some games) by using keyboards, trackballs or touching screens (see Figure 1).

Figure 1. Different types of screen-based standalone installations. The small screens (left: Technical Museum Vienna, 2003) support individuals or at most pairs to interact, whereas the large multitouch table (center: Museum of Natural History in Berlin, 2007) provides space for a crowd and onlookers. The Riverside Museum in Glasgow (right) uses a consistent design for information screens related to adjacent objects[12].

According to the study conducted by Hall (2013) [52], these terminals were not designed in a way to allow visitors to have an interesting interaction and were not suitable for group use and limited the social activity during the museum visit. Kidd et al. (2011) discussed the use of interactive kiosks criticizing this limitation of the social experience during the visit [51].

Recently, there is an increased reliance on multi-touch screens. These interfaces facilitate the access to information to a larger number of users and offer great possibilities for social sharing. Multi-touch screens are designed to identify two or more simultaneous touches providing opportunities to several users to interact with an application at the same time [42].

[12] [22, page. 20]

In some cases, these interactive screens are integrated into the space narrative of the exhibition and visitors can receive an invitation to interact with the interface [51].

The ArtLens Wall, at the Cleveland Museum of Art's, is a 40-foot interactive, multi-touch, and MicroTile wall displays in real time all works of art from the permanent collection currently on view in the galleries—between 4,200 and 4,500 artworks at any given time (see Figure 2).

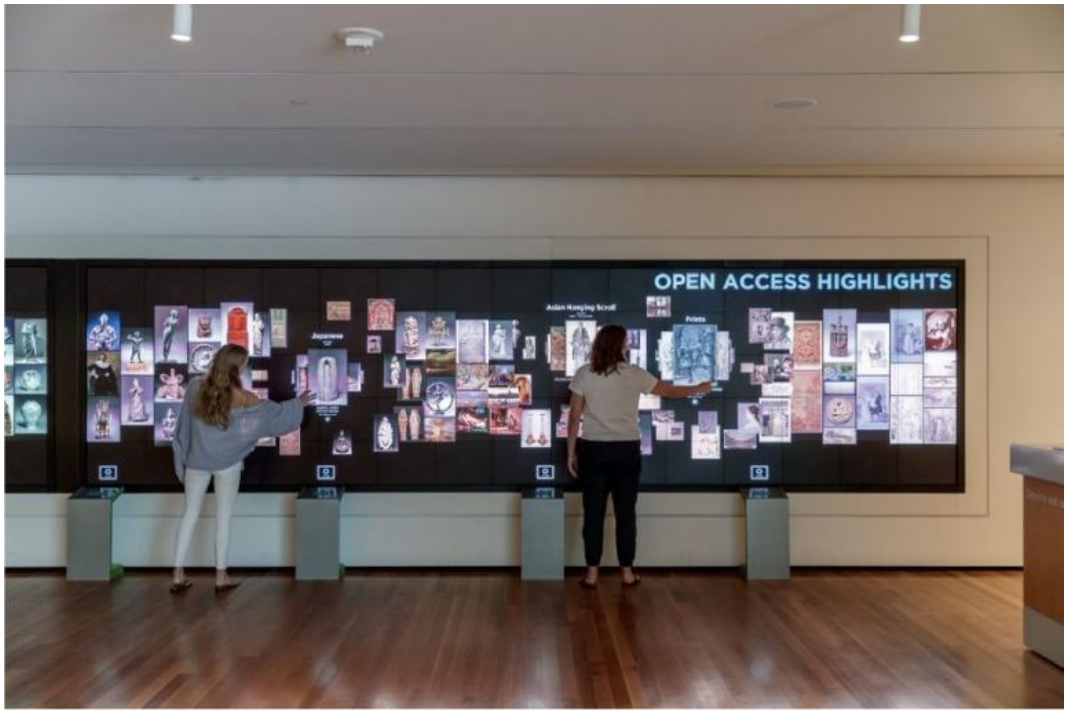


Figure 2. The ArtLens 40-foot interactive wall, at the Cleveland Museum of Art's[13].

The ArtLens Wall facilitates discovery and dialogue with other visitors and can serve as an orientation experience, allowing visitors to download existing visitor-created tours or create their own on their iOS or Android device. The wall enables visitors to connect with objects in the collection in a playful and original way, making their visit a more powerful personal experience.

In addition, the ArtLens Wall displays thematic groupings that may include highlighted artworks currently on loan as well as select light-sensitive artworks that are in storage[14].

The interactive Pen, at the Cooper Hewitt, Smithsonian Design Museum, allows visitors to digitally "collect" and "save" objects from around the galleries. By pressing the Pen on the museum label, the object is collected and saved. The collected object can be transferred to the interactive tables

[13] Retrieved from https://www.clevelandart.org/artlens-gallery/artlens-wall
[14] https://www.clevelandart.org/artlens-gallery/first-iteration

to explore them in more detail or add more objects. Moreover, after the museum visit the collected objects are accessible, at home or on mobile devices, and can be shared with others[15].

At the Los Angeles Museum of the Holocaust, visitors can interact with *The Memory Pool* [16], a multi-touch interface where information emerge on the surface of a table, as objects floating in a pool full of water, showing photographs of people in their daily lives before the Holocaust, like socializing with friends, playing sports, going to school, celebrating weddings, etc. When an image is touched, the information relating to these moments is loaded and visitors could get to know more about that moment. On the other hand, if there is no interaction with some of the pictures, the images fade away, representing the loss of these memories (Potion, 2010).

2.2 MOBILE INTERACTION

Mobile interactive experiences have been one of the earliest forms of interactivity in museums. Analog audio guides have existed since the 1950s, and since the 1980s, mobile digital devices have been adopted to deliver guidance to visitors or accompany them as they follow the narrative path of exhibitions in self-guided tours [22].

Audio guides allow visitors to enrich their knowledge of the collections simply by inserting the artefact's code in the device in order to play the narrative.

Being an economic equipment, the use of audio guides is widespread in museum institutions. Moreover, this equipment is often provided in multilingual mode to guarantee the service also to tourists.

Handheld devices provided by museums have evolved from basic digital audio players with headsets that deliver content through push-button interaction, to more complex and powerful computerized devices.

Due to the widespread popularity of smartphones and tablets, mobile interactions are still extremely popular as digital intervention in museums. These devices are able to deliver multimedia content or other digital services in correspondence to the user's location.

[15] https://www.cooperhewitt.org/new-experience/
[16] https://www.potiondesign.com/project/la-museum-holocaust

Since mobile interaction is linked to location detection, this can be enabled by various means such as proximity sensors (e.g., iBeacons), positioning systems (e.g., GPS), or by asking visitors to locate themselves by entering a location code or scanning an identifier such as a Quick Response (QR) code, to checking-in at particular points (via Near-Field Communication (NFC)) [22].

Many museums adopt a "Bring Your Own Device" approach and provide different applications that visitors can use on their personal devices (i.e., smartphones, tablets and smartwatches) during their museum visit.

Wei and Jianping [53] believe that since informal learning in museums is free choice and learner-centered, the mobile applications play a supportive role in museum learning. They mention that mobile applications allow visitors to choose what they want to know at any time. The authors discuss the supportive role of mobile applications in museum informal learning from five aspects: mobile learning, inquiry learning, cooperative learning, adaptive learning, and ubiquitous learning.

Mobile learning allows visitors to move around and learn freely, inquire learning, and enables the visitors to take an inquiry process (e.g., by scanning exhibits' pictures or other marks). The collaborative learning characteristic allows the realization of museum learning at the same time and different space (e.g., comparing the information of an exhibition displayed at two different museums). The adaptive learning aspect of mobile applications refers to the programs and offers suggested to visitors by analyzing the data in mobile application, and finally, ubiquitous learning supports tour path and exhibit information, integrating special learning activity, position guide and information guide, for example, mobile applications can recognize the scanned picture of the artefact and deliver corresponding information.

"ArtLens" is a mobile application of Cleveland Museum of Art. The gallery interactives paired seamlessly with ArtLens App for iPad, iPhone, and Android. Before, during, or after a visit, visitors could enjoy over nine hours of additional multimedia content, including audio tour segments, videos, and additional contextual information. The interactive map in ArtLens app used iBeacon technology to help guide visitors and find works of art with additional content nearby (see Figure 3).

Figure 3. Left: A visitor at the Cleveland Museum of Art uses ArtLens' augmented reality scanning feature to learn more about an artwork. Right: ArtLens using iBeacons throughout the museum and outside to improve accuracy and eliminate the need for paper maps[17].

Some museums, like the Royal Ontario Museum allow visitors to experience the past by using augmented reality.

Streetmuseum[18], augmented reality application created by The Museum of London, applied in an outdoor mobile cultural fruition, was providing visitors with the possibility to *move around* the physical spaces of a city, viewing detailed contents and 3D images overlapped with contemporary buildings and places. The real vision was enriched with the picture of the place as it was like in the past showing *the way it was like* compared to *the way it is like*. The application is not, currently, available for developing work to upgrade the application.

Finally, we conclude the section by presenting a game-based application. *Capture the Museum* is a game-based application presented by the National Museum of Scotland. The application uses a gamification element to encourage visitors to learn more about history.

The application provides a physical team game, in which visitors with their own smartphones, explore galleries of the museum to solve puzzles and scan into territories using their device's camera, in order to beat the other team.

The game can accommodate up to 50 players at the time and a map shows in real time which team is winning the challenges concerning to the different galleries of the museum[19].

[17] https://mw17.mwconf.org/glami/artlens-app/
[18] https://www.museumoflondon.org.uk/discover/museum-london-apps
[19] http://www.capturethemuseum.com/press/

2.3 EXTENDED REALITY (XR): APPLICATION IN THE CH DOMAIN

Extended Reality (XR) refers to technologies that allow overlaying digital content and behaviors mapped onto tangible and analog spaces and objects. The deployment of XR provides digital immersive and interactive environments. XR includes mixed reality (MR), augmented reality (AR), and virtual reality (VR) [22] [54].

In this research project, XR has been taken into account and analyzed as a possible approach to support the enhancement of maritime cultural heritage. It is included in this state-of-the-art since it shares features with the technology, we adopted in terms of enabling an interactive experience, and thus represents an approach that can be used for comparison and for identification of common strategies for user engagement.

These technologies are used in the cultural heritage domain for different purposes, including education, exhibition enhancement, exploration, reconstruction and virtual museums. [55]

XR-enabled interactive environments provide user-centered experience and make users more aware of their actions [56].

The potentials of these technologies in creating innovative immersive and interactive experiences make them more affordable and widespread tools in the cultural heritage domain.

XR technologies together with enhanced affordances of mobile technology go beyond physical barriers, and enable dynamic and effective means in museums. There are several functional and recreational approaches that are used before, during and after a visit to the museum [57].

The virtual world can be visual and/or auditory. In order to achieve an immersive experience, users need to either wear a headset (head-mounted displays or VR goggles) or enter a specially designed space with large-scale projections (while usually wearing VR goggles for 3D vision). In AR it has become common to use mobile devices with integrated video cameras which enable exploration of the environment with mobile or “handheld AR” [22].

The widespread adoption of these novel technologies by cultural heritage institutions can stimulate learning and provide audiences with entertaining and meaningful experiences. Moreover, XR technologies enrich the museum's communicative facilities towards its visitors and enhance the learning process by means of dialogic approaches, which can encourage social interaction among museum visitors [57].

Virtual Reality (VR)

Reality (VR) refers to computer-generated 3D environments that replicate places, presence of people and objects, providing sensory immersion experience in the 3D world [41] [58]. VR aims at enhancing the user's presence and interaction with a computer-generated environment without a means to interact with or see the real world [55].

The authors in [59] emphasized the immersion and interaction aspect of a VR experience and defined VR as a complex technology that enables users an interactive environment within which they feel completely immersed.

First Life, at the Natural History Museum[20], was a virtual reality experience. The exhibition allows visitors to explore the world's ancient oceans, using Samsung Gear VR headsets and look around and see three-dimensionally reconstructed sea creatures that existed 500 million years ago. The experience was enriched by narration, helping people to discover the ancient natural world.

The British Museum is one of the museums that incorporate VR technology into a learning program. In 2015, the museum held a VR experiment, in which, visitors were able to explore a *Bronze Age* site and interact with 3D scans of objects placed in their original setting. Using a headset and touchpad, visitors were able to look around, move and navigate within the environment. The results of the experiment confirmed the visitors' enthusiasm and showed the positive impact of this experience on visitors' understanding of the historic collection [60].

Figure 4. Explore Dali's painting "Archaeological Reminiscence of Millet's Angelus", the visitor can virtually walk through the painting and explore it.

[20] https://www.nhm.ac.uk/

"Dreams of Dali"[21], is a virtual reality experience at the Salvador Dali Museum. In this experience, visitors, transported inside the original painting, can explore Dali's painting "*Archaeological Reminiscence of Millet's Angelus" in a* multi-sensory three-dimensional environment of moving image and soundscapes (see Figure 4).

Augmented Reality (AR)

Augmented Reality (AR) is defined as a system that enhances our view of the real world by overlaying virtual and computer-generated elements onto a view of the real world. Unlike VR, AR does not replace the real world and only alters the view by virtual information. In general, augmented reality aims to enhance the user's perception of and interaction with the real environment [22] [55].

The Dali Museum uses Dalí Museum App to offers a new way to experience art. The AR application superimposes digital images and information onto the visitor's real word view of the works and brings the paintings to life on personal mobile devices. The AR experience helps visitors to get a deeper understanding of the meanings behind Dali's works[22]. ReBlink was an AR application offered by the Art Gallery of Ontario, which allowed visitors to view the museum's collection overlaid with three-dimensional images and videos. Using their own devices, smartphones or tablets, visitors were able to see the subjects of the paintings come alive and be transported to 21st-century reality.

Figure 5. Skin & Bones; a tool created to engage visitors to the Bone Hall at the Smithsonian's National Museum of Natural History with animal anatomy and evolution.

[21] https://thedali.org/dreams-of-dali-2/

[22] https://thedali.org/exhibit/masterworks-augmented-reality/

Skin & Bones[23] application, introduced by the Smithsonian's National Museum of Natural History, enables visitors to bring animal skeletons to life through 3D imagery (see Figure 5). The application offers an object-based AR experience with skeletons in the Bone Hall, triggering the augmented content. The skeletons are superimposed with 3D models and animations to show animals' fleshed appearance and highlight their specific features or particularities of the functional anatomy [61].

Mixed Reality (MR)

Mixed Reality (MR) indicates a more complex model that covers the continuum from AR to AV. MR aims at overlaying the real and virtual environments through providing interconnection between digital and physical points of interaction. Mixed reality is an environment where real and virtual content coexist and interact in real-time [22] [55].

Figure 6. Birdly full-body flight simulator: The experience allows one to see the city through a bird's eye-view. You get to capture the flying experience of a bald eagle—feeling the air, hearing the wind and the sounds of your wings flapping.

Birdly[24] is a full-body flight simulator that enables users to experience flying like a bird, using an HMD and the Birdly motion base. The Tech Museum of Innovation was one of the first museums that installed Birdly. In the museum, visitors experience flying through the Manhattan skyscrapers or soar above the clouds (see Figure 6).

Visitors have a multisensory experience (i.e., feeling the wind on their face) and can interact with the MR environment (i.e., control their speed by flapping their wings)[25].

[23] https://naturalhistory.si.edu/exhibits/bone-hall
[24] https://birdly.com/
[25] https://www.thetech.org/birdly

HoloLens technology developed by Microsoft is used by the Kyoto National Museum to create a MR experience for visitors to the oldest Zen temple in Japan. The museum applied a mixed reality experience to an important and sacred painting-*The Folding Screen of Funin and Raijin*. The experience provides an interactive, dynamic and holographic narrative, through which, temple visitors can better understand the painting[26].

2.4 THE INTERNET OF THINGS (IOT) AND ITS APPLICATION TO THE CH DOMAIN

The Internet of Things (IoT)

The Internet of Things (IoT) concept was introduced by Kevin Ashton in 1999 to provide optimization support to his company's supply chain via Radio-Frequency Identification (RFID) [75]. He used RFID tags and detection devices along with the Internet to track and count the supply of goods without human intervention.

The Internet of Things (IoT) becomes more popular and is deployed in different areas in everyday life and industry. Besides, the number of different things and devices that get interconnected increases exponentially.

The variety in the area of application and the increasing number and heterogeneous set of objects used in these applications make various and multifaceted perspectives to IoT. This makes it difficult to provide a single definition of the Internet of Things [76].

Atzori et al. [77] discuss the definition of this paradigm in three different perspectives. The first vision is "Internet oriented", in which the focus is on the characteristics of the interconnection between physical objects. The definition presented by K. Patel and S. Patel [78] well explains this perspective:

> "*Internet of Things is a network of physical objects. The internet is not only a network of computers, but it has evolved into a network of device of all type and sizes, […] all connected, all communicating and sharing information based on stipulated protocols […]". [78, p. 1]*

[26] https://news.microsoft.com/apac/features/mixed-reality-museum-kyoto-unique-insight-centuries-old-japanese-artwork/

The second perspective is "Things oriented", in which the definition is based on the objects themselves that get integrated into a common framework. In this perspective, the definitions depart from considering objects as uniquely identified entities that are embedded into the system network. The definition of Bassi et al. in [79] can be considered as an example of this vision:

> *"Things that have identities and virtual personalities, operating in smart spaces using intelligent interfaces to connect and communicate within social, environment, and user contexts". [79, p. 4]*

Finally, the third one is called the "Semantic oriented". This vision is attributed to the subjects such as object unique addressing, the representation and storing of the exchanged information.

The vision in the definition presented by authors in [80] is enough obvious, when they define the IoT concept as:

> *“Group of infrastructures interconnecting connected objects and allowing their management, data mining and the access to the data they generate”. [80, p. 73]*

Furthermore, Atzori et al. in their latter article [81] discussed a fourth perspective called “Social oriented", which aims to integrate the world of social networks with that of the IoT. According to the authors, this perspective can support novel applications that enable more effective and efficient networking services for the IoT. In the Social Internet of Things (SIoT), objects can be related to each other in different ways and to establish social links as humans do [81][82].

K. Patel and S. Patel [78], instead, identify three different perspectives through which the IoT can be defined. Their approach in presenting an IoT definition emphasizes mainly the interaction of “Things”; People to people, People to machine /things, and Things /machine to things /machine.

The authors’ definition of IoT concept, however, is based on the interaction of these three things through the Internet and state:

> *“Internet of Things (IoT) is a concept and a paradigm that considers pervasive presence in the environment of a variety of things/objects that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things/objects to create new applications/services and reach common goals.” [78, page 6122]*

Application in the Cultural Heritage Domain

Cultural heritage sites and museums deploy digital technologies to create new engaging means to attract and retain more visitors. Technology can support different forms of interaction, both on-site and on-line, to engage visitors in new and interesting ways such as mobile apps, tangible interactions, interactive screens and tables.

However, the deployment of IoT technologies in the cultural heritage domain offers a huge potential to extend the innovative ways of technology use to promote the interaction possibilities that can be offered to visitors [83].

The IoT application provides the CH domain specific ranging from interactive museum experiences, content delivery, visit personalization, visitor generated data analytics, monitoring and management of heritage sites, distributed museums and heritage sites, and providing pre- and post-visit experiences [83][84].

In the following, we discuss some of these IoT application areas reviewing the research and implemented projects.

IoT-based Interactive Experiences

Engagement with material things is recognized as a fundamental building block of the museum visitor's experience, which provides visitors powerful experience through enabling them to understand and empathize with the story's objects [85]. This has encouraged museums to develop tangible interaction experiences and allow visitors to interact with physical-digital interfaces to access digital content.

As an example, at Museon in Den Haag visitors can interact with an IoT-enabled exhibition. The exhibition provides the tangible interaction through combined NFC reader, embedded Raspberry Pi and a bespoke communication. Besides, the exhibition offers a logging system and an online post-visit experience [86].

The meSch project is another example of IoT application in order to enhance the museum physical experience. The meSch platform enables heritage professionals to create tangible smart exhibits by composing physical artefacts and enriching them by digital contents. The platform does not require any specialized technical knowledge and the authoring toolkit of the platforms enables the users to

construct ad-hoc physical smart exhibits, composing physical/digital narratives that map on interactive artefacts embedded into a multi-sensor digital platform [87].

Content Delivery

There have been different research and implementations of IoT enabled content delivery, mostly based on proximity with different technical approaches in implementation.

The authors in [88] designed and implemented an IoT-enabled application that allows visitors to receive multimedia content about the near-by exhibit on their mobile device. Actually, the application is based on proximity and when a user during their visit passes across the surrounding artwork area, the content is delivered. The application received positive feedback from users and the evaluation results indicated that the system could improve the user's cultural heritage experiences and enhance the cultural heritage transmission [88].

Authors in [89] proposed a similar IoT-enable delivery system designed for museums. The system automatically provides the users with content related to the observed artworks, relying on Bluetooth Low Energy (BLE) beacons proximity and localization capabilities [89].

Using IoT for Visit Personalization

Due to the huge amount of information to present, the development of personalized experiences is growing in the field of cultural heritage to enable the individual user to easily access this information [90]. However, the Internet of Things can allow such experiences allowing personalization through dynamically altering delivered content to specific users.

An inclusive personalization framework is presented in [91] to support complex scenarios of a visit, including the physical, the digital, and the social dimensions of a visit. The framework provides an IoT- enabled interaction environment in which visitors can receive personalized information and experience tangible interaction with smart objects.

The authors in [92] proposed an IoT-aware architecture to improve the cultural experience of the user. The proposed architecture enables users to monitor indoor localization, capture and process images from visitor's points of view, receive customized cultural content on mobile and wearable devices, and share multimedia data in cloud.

Data Analytics for Heritage Sites

Moreover, IoT technologies can provide means to gather useful data about visitors during their museum visit and analyze the aspects that attract the most interest. Gathering and analyzing data about the duration of visitors' interaction with specific parts of the exhibition, the flow of visitors in different parts of the museum, and whether or not visitors are repeating the visits can create very useful information that contribute to the exhibition optimization [83].

The authors in [93] suggested an IoT framework to gather and process visitor generated data inside a museum in order to create adaptive and engaging museum experiences. The gathered data, through a network of sensors, was processed based on subject proximity to study the patterns of visitor attention in the context of a curated exhibition. The research results were encouraging and showed that, using the numerical proxies for people's attention inside the museum provided by the IoT framework, the museum curators and professionals could generate more engaging museum interactions [93].

Monitoring and Management

Moreover, related to the cultural heritage domain, there is some research in the area of monitoring and management using the Internet of Things (IoT) paradigm. Sensing technologies together with wireless sensor networks allow for remote monitoring and management of objects in an efficient way [89] [94] [95]. This can be used, for example, to detect structural changes in materials, track environmental conditions, and alert anomalous presence in specific areas. However, such application of the IoT paradigm in the cultural heritage domain can improve preservation, tutelage and access of heritage [96].

For example, the controlled heritage spaces (e.g., museums) can be monitored with a sensing infrastructure that collects and processes data in real time to trigger alarms or control of environmental parameters (e.g., temperature and humidity) or to perform a continuous analysis of the state of perishable assets [84].

2.5 INTERACTIVE DIGITAL STORYTELLING (IDS)

Storytelling is a potential means to attract and engage the audiences of museums and other cultural heritage sites [62]. Bedford [63] discusses the importance of storytelling in generating a visitor's

personal connection with a collection of content and believes that storytelling allows them to create their own experience.

Villaseñor [64] defines storytelling as the production of a narrative that communicates experiences, but Johnsson [65] believes that storytelling is also an experience in itself. However, storytelling is per se an interactive performance, in which the teller and audience interact with each other (e.g., face-to-face communication, physical movements and gestures) [66].

Moreover, storytelling can involve the audience's emotions to catch the audience's attention and engage them along the narration, which contributes to creating a moving story, making it memorable [67] [68].

Storytelling, as the first and most essential form of learning [69], is deeply embedded in human learning and provides them with new experiences and knowledge [70].

Nowadays, museums are increasingly seen as places of *experience* and *communication*. Accordingly, museums are storytellers [63] that share stories and experiences with their audience.

During the 90s, the use of computers opened a new field called digital storytelling. Digital storytelling, which combines traditional storytelling with rich digital content, allows many of the elements of traditional storytelling to be integrated and provides effective innovative and interactive means to create meaningful experiences in museums.

Bedford [63], concerning the essence of museums in relation to storytelling, argued the foundation of museums may be seen as the act of making visitors believe that there was a story worth telling. The story that must be told again and again to pass it to the future generation. According to Bedford, storytelling is the "real work" of museums.

Additionally, Roussou et al. [97] discuss the evolution of museum storytelling alongside museums themselves.

In the 19th century, museum storytelling was based on labelling and on the sequential disposition of museum objects. However, in the 20th century it transformed into spatial thematic narratives arranged in different points of views.

Digital storytelling is a resource that museums adopt to leverage appropriate technological media in the context of the museum's physical space.

The term “storytelling”, according to a dictionary, may be defined as: “storytelling is the act of telling stories”.

The literature does not provide a definition for museum storytelling,

Fontana [98] finds this definition intrinsic to the essence of museums and discusses how storytelling is defined in subject literature. According to Fontana if we review the subject literature, we may incur the following definition for this term:

“[…] storytelling is defined as the activity of creating representations that can be textual, visual, sonorous and perceptual and that are able to engage emotionally an audience.”

The definition incurred by literature involves the act of creating representations and aims to engage emotionally an audience.

According to Fontana, storytelling is a communication device made up of a set of strategies, skills and techniques that allow communicating effectively through stories. Stories, as perceptual representation-systems, produce a reality containing fictional, emotional and symbolic elements.

Coblence and Sabatier [99] identify museum storytelling as a cultural innovation that enables museum institutions to design experiences, implement new representations of collections, and support new aesthetic and symbolic approaches.

The application of digital technologies enabled the creation of dynamic narratives with which the visitors can interact. Interactive digital storytelling is becoming a popular choice for information transmission in different cultural heritage fields. Interactive digital storytelling enables the user to influence the flow and even the content of the story.

Interactive storytelling is a promising way to improve interaction at museums [71]. It makes museums a dynamic environment [72], which provides the audience with playful learning, active engagement and *edutainment experience* [73]. Storytelling, as a means to communicate experiences [64], can take advantage of different technologies such as virtual reality, mobile augmented reality, mixed reality, multi-modality and liquid interfaces, with the aim to enhance the story (narration) and interactivity.

The CHESS[27] project was interdisciplinary research with the purpose of enriching the museum visit through personalized interactive storytelling experiences. CHESS aimed to provide a dynamically personalizing and adapting information about museum artefacts to museum visitors, and inject the sense of discovery and wonder in the visitor's experience.

The project employed different technology and techniques like mixed reality (MR), augmented reality (AR) and pervasive games techniques. The project evaluations resulted in positive and promising feedback from both visitors and museum staff. The current interactive visit at the Acropolis Museum is based on this system designed and implemented by the CHESS project and visitors can enjoy a personalized interactive storytelling experience using their mobile devices [62] [74].

Other EU-funded projects, EMOTIVE[28] and iMareCulture[29], are examples of interactive storytelling. The first one offers dramatic, emotionally engaging stories that can be experienced while at a cultural site or remotely. Wherever visitors are, they can follow characters, look for clues and explore environments alone or with family and friends. Actually, EMOTIVE provides a storytelling engine and a set of rich digital media assets that can be used to create detailed characters and narratives featuring archaeological sites or collections of artefacts.

The latter one, instead, using virtual and augmented reality technologies allows the public to explore the archeological remains through immersive and personalized experiences (e.g., choosing a specific artefacts or serious game) offering additional information through storytelling.

However, due to the importance of the topic in this research project we need to have an insight into the potentials, characteristics and limits of storytelling.

[27] *http://www.chessexperience.eu/*

[28] *https://emotiveproject.eu/*

[29] *https://imareculture.eu*

2.6 STORYTELLING: DEFINITION AND CHARACTERISTICS

2.6.1 STORYTELLING A TOOL FOR HUMAN COMMUNICATION

Storytelling is considered as a universal characteristic of humans across culture and history [100]. They have always told and listened to stories since prehistoric times through cave paintings or gatherings around the fire to describe hunts and heroic stories [101]. The stories have always evoked humans' emotions and have been a resource of inspiration, which helped them to learn morals and interpret values to enrich their culture [101] [100].

> *"Indeed, storytelling is one of the most human of activities. In fact, an individual's history, their persona, their very identity is the sum of the stories they tell about themselves and others tell about them. Everyone, inherently, is a storyteller and there are few things people love more than to hear a great story and pass it on to others." [100, page 80]*

According to the philosopher Roland Barthes stories are categories of knowledge that allow us to understand and order the world; never existed people without narration [102]

Narration enabled man to regain his/her past experiences and contribute to defining the common feelings of the society in which he/she lives [102]. Narration is, therefore, a cognitive and communicative act that occurs in two moments: first, one regains experiences through the attribution of meaning to facts; and, then, shares the acquired knowledge [102]. In fact, storytelling is the most natural way of communication and reflects humans' way of thinking and understanding [98] [104].

Sturm [105] studied the experience state of people listening to a story and discussed it referring to "storytelling trance". He identified six characteristics of this state through which:

- the participants undergo a profound change in their experience with reality and feel that the story is very real (Realism);
- the normal state of consciousness changes, radically, as the story transports itself to a new dimension (Lack of awareness);
- multiple communication channels e.g., visual, auditory, kinesthetic and emotional are engaged when a participant listens to a story (Engaged receptive channels);
- control over the "trance" process (Lack or loss of control);

This alteration of the state of consciousness has been studied in many disciplines: psychology, anthropology, hypnosis, medicine and religion. However, studies have shown that the states of alteration are generally characterized by a variation in the characteristics of mental functions by making participants empathize and identify with the storyteller, providing them a larger vision and sense of purpose [100] [98].

Storytelling has been used by great leaders to manage the listeners' feelings and commit their visions [100]. As Fontana discussed, storytelling is an efficient tool to enhance a sense of belonging and provide the audience with a degree of emotional engagement [98]. Moreover, one can express him/herself easily, helps to be remembered, and speeds of the information transfer, all which makes storytelling to be considered also as a great potential for education [106] [107].

The neuroscientific research referred to by Ramachandra et. al [108], provides a scientific explanation for the potentials discovered through research conducted on storytelling. As the authors mentioned, the findings show that the human neural network system is activated by performing an activity or experiencing an emotion, the same activation in the neural system happens when one sees another person is performing the activity and experiences an emotion. However, the case can be extended to the sense of hearing a story can evoke emotions to recognize and empathize what other people feel. Accordingly, a story that is told makes the listeners connect the storyteller and empathize with him/her [108].

The human brain does not elaborate a fiction as real; however, the brain, through neural coupling, turns the received story into recipient's own ideas and experiences [109]. Barraza and Zak argued that emotional stories trigger the neurotransmitter oxytocin and increase empathy and cooperation and affect human behavior [110].

The above-mentioned characteristics show how effective communication tools can be storytelling. Storytelling can be used to evoke emotions and feelings, to make the recipient feel empathy, to influence the audience behavior, to inspire and commit the recipient, to share knowledge in a more comprehensive and memorable way. Therefore, storytelling is used in different fields of education, management and marketing as a tool of communication to transmit visions and shape the strategies, and influence behaviors [100].

2.6.2 TECHNOLOGY MEDIATED STORYTELLING

Stories are what men have always used to make sense out of the world [111]. The stories over the centuries have been used as a tool for: socializing individuals in the community, passing on knowledge and beliefs, and teaching myths.

Furthermore, listening to a story can engage the human brain differently than the situations one is doing an activity with attention e.g., listening to a lesson.

The goal of a lesson, in fact, is to explain an idea in detail and to make the communicated meanings correspond, with certainty, to those perceived. When a story is told, however, the goal is not to show an idea or concept in all its meanings but rather to connect the experience of what is communicated to the experience of the recipient of the narration [112].

Narrating, therefore, means sharing, co-producing, transforming imaginaries, even at a higher level than the media. In summary, the creation of a story reconfigures the medium, the environment and even ourselves [113]. In this regard, as we shall see later, Murray [114] argues that every story is a Virtual Reality.

The ability to narrate is an anthropological feature of the human being that always existed. However, not all narratives are the same and, in addition to the themes, the transmitted emotions and meanings, they also differ in the media through which they are communicated. The experience of the story is, in fact, always mediated, so it passes through models that shape the stories. Every revolution in the media has therefore also brought about a change in the way of narrating: writing, printing, cinema and now ICT.

It is also interesting to point out that each achievement of a new media took decades for the narratives to adapt to the new modalities imposed by the media. The way of making cinema has evolved together with the progress of cinematographic means, as it had happened centuries before with the printing and the period of the incunabula - a Latin term that indicates the published books, between the invention of printing in 1455 and 1500, which were the result of still an immature technology30.

[30] *https://www.treccani.it*

According to Murray, since precise ways of telling stories through ICT have not yet been defined, therefore, the storytelling carried out through ICT i.e., Interactive and Digital Storytelling (IDN) must still be considered in the period of incunabula [114].

However, although the IDN is still in the initial period of its history, the relationship between ICT and narratives generates strong reactions, both positive and negative. On the one hand, in fact, ICTs are considered the salvation and future of humanity, on the other, their destruction. For Murray, this ambivalence is well represented by the stories concerning ICT, which see on the one hand the stories of Orwell, Bradbury and Huxley and on the other, the positive epic of Star Wars and Star Trek. The two visions summarize the fears and hopes that one has towards ICT, but according to the author it is always necessary to remember that stories serve to give meaning to the world and therefore the use of technology can be positive or negative in relation to the sense of the world you want to communicate [114].

Since the 1930s, with the emergence of ICT, this type of technology mediated with success and impressed both storytellers and the public. According to Bobbitt [115], every media and technology turns out to be an expansion of mankind in terms of visions and awareness of the world. In this sense, ICTs have huge and continuously growing potential (instant communications, enormous quantities of information available in a few seconds, etc. ...), However, as their borders are constantly growing, they cause more ambivalent attitudes in humans, as mentioned before.

Concerning the IDN, it is important to notice that, although no shared characteristics have yet been defined, some common elements of the narratives through ICT are evident and need to be analyzed more in depth.

- **Non-linearity of the stories**

The most evident element in the IDN is the non-linearity of the stories from which the participatory character of the recipient derives. Frank Rose in his book, The Art of Immersion [116], argues that the emergence of the web and non-sequential reading systems has led to the emergence of a new model of empathy, based on the emotional involvement of the recipient and on his/her identification with the transmitter of the narrative itself up to the threshold of substantial indistinction. In a non-linear narrative, the reader is transformed into a prosumer, and the spectator into a participating observer.

To describe this type of narration, Murray uses the term multiform story indicating a story that has a single situation or plot but in different versions, which in an ordinary experience would be mutually exclusive to each other.

It is important to underline that the multiform stories are not necessarily linked to ICT. In literature, in fact, there are famous examples of this type of narration, such as Borges' The Garden of Forking Paths [117] or Calvino's Invisible Cities [118].

The multiform stories provide different versions that may not seem real in different aspects but are real in the emotional dimension, a famous example of this characteristic is the film Groundhog Day, in which the protagonist of the story finds himself living the same day for the duration of the feature film.

During the second half of the twentieth century, the examples of multiform stories are constantly increasing. In this regard, it is important to underline that in liquid society [119], the individual cannot identify him/herself in a defined social order, space and time stop to be absolute realities and a sense of disorientation is created. In this situation, the individual is motivated to individually seek a sense of being in the world, through the relationship with others and the search for stories with which to identify him/herself [120].

According to Murray, therefore, the end of the twentieth century places the individual in front of the evidence that one's life is full of paths and to cope with this situation a book or a film is not enough, but a computer is necessary.

- **The role of the public**

Furthermore, as mentioned previously, the consequence of having non-linear stories is the transformation of the role of the audience, which becomes more active. Contemporary stories continually highlight the presence of the narrator and invite the recipient of the story to guess the choices he will make. The postmodernist narrative "*If on a winter's night a traveler" by* Calvino [121], is a well-known example of this aspect. The novel begins with a direct address to the reader, where "you" is the same as the "you" who is actually reading.

Although media such as TV series or movie sagas supported these aspects, however, the emergence of the Internet enhanced this process. Thanks to the Internet, readers and fans are able to comment on the story and the characters on the web and hypothesize the evolution of the story, and, sometimes, even influence the writers themselves.

Furthermore, the digital dimension allows fans to create real alternative narratives as happened in the case of Star Trek or Star Wars, where fans of the two movie sagas have created real narrative worlds.

This phenomenon is called *textual poaching*[31], which describes how fans go through the mass media, e.g., favorite television shows and engage with the parts that they are interested in. In this process, fans feel the right to own and use the images of their heroes as they like. Interestingly, textual poaching recalls epic narratives of the past, which were created by bards by taking shared narrative elements and reinventing them [122].

It is through the parallelism between the epic narratives of the past and the predisposition to textual poaching on the part of today's fans that Murray hopes for the creation of the figure of the *cyberbard* [114] [123], highlighting again that when you want to tell a story the medium does not matter as much as the type of narrative to be created.

A further phenomenon linked to the process of audience participation are role-playing games, which combine the pleasure of participation with that of creating the plot. According to Murray (2017), RPGs are hologram experiences without technology and demonstrate that VR, AR and MR are following a line, already, drawn by narrative needs and are not technological innovations for their own sake.

From the participatory characteristic of digital stories, originates also the procedural way of their creation. Respectively, a great change brought about by Interactive and Digital Storytelling is related to the authorial control. In such storytelling approaches, the authors give a part of their authorial control to users (players and interlocutors), which enables the authors to act as designers of expressive potential instead of creators of single versions [124].

[31] The term Textual Poaching (Jenkins, 1992) must be distinguished from Fan Fiction, as the first indicates the attitude of fans towards the story, which can be considered real “Text Poachers” ready to grasp every nuance of the narrative world and explore it with their own narrative tools. Fan Fiction, on the other hand, can be defined as a product of the fans' Textual Poaching approach.

Murry believes that digital authors must be procedural authors and likens their task to a kaleidoscope, within which all the possible roles of the recipient of the narration, and also the range of possibilities that the recipient can act, are defined.

As mentioned previously, it may seem that the characteristics of the IDN present a strong discontinuity with the past, however, it is not absolutely the case. Indeed, in epic literature it was important to define the boundaries of the narrative world within which the narrator could move, rather than the story itself [122]. This is also another reason why Murray (2017) and other IDN scholars [125] define the digital author as a CyberBard.

According to Koenitz, the cyberbard is a "system designer" who, unlike a traditional author, sits back and watches with amazement what the audience will do with the narrative [126].

In summary, therefore, the participatory and procedural characteristics of digital media results in the emergence of a third fundamental one, namely *interactivity*. Procedural design and participatory design create, in fact, the interactivity of the medium, which indicates the relationship between the behavior of the computer in relation to the behavior of the human being, user.

- **The interactivity of digital stories**

The interactivity of digital media is one of the most powerful sources of attraction of the IDN, since the use of the computer pushes the user to behave in a new and often unrelated way to his/her usual daily actions.

Furthermore, an additional feature of digital media arises from interactivity, namely spatiality. The new digital media, in fact, are characterized by the property of creating navigable spaces. Linear media, such as books and films, can describe spaces but only digital media can create spaces in which to move. It is a property of digital media that appeared in the 1970s which had numerous experiments, including the most famous: PACMAN.

It is important to underline that spatiality is intrinsic in digital media and is directly linked to the interactive feature of the navigation process. In this regard, the challenge for the future is to create

digital media that bring interaction into increasingly expressive and narrative viewpoints with increasingly liquid interfaces [126]. It is a challenge to which this research will try to respond with an innovative proposal, as will be presented later.

- **Immersion in the story**

In this paragraph we want to emphasize the last two characteristics of Interactive and Digital Storytelling.

One of the specific characteristics of ICT, compared to other media, is the users' higher expectation towards multiform stories. Computers, in fact, are devices to store and manage data which lead us to have an expectation when we interface with them. From this expectation and the spatial nature of digital, emerges the last characteristic of the IDN: *immersion in the medium*.

Similar to the aforementioned expectation, the immersive character of multiform stories is not an exclusive characteristic of this kind of narration. In this regard, an extreme example is Don Quixote, who reads the stories being convinced that he lives in a world where chivalry still exists.

According to Murray, in fact, every engaging narrative can be seen as a kind of virtual reality because human brains are programmed to tune into stories with such intensity that they erase the world around us. However, the ancient desire to make a fiction real seems, in some cases, to be fulfilled thanks to digital media.

Murray discusses that the experience of immersion in a simulated environment is a pleasure in itself and regardless of the type of story. The experience of detaching oneself from the usual world, discovering new feelings, and learning from this experience is enjoyable. As digital environments, enable a user to interact and learn new practices, such as navigating during the Middle Ages.

In digital media the narration is a threshold experience, however, it is necessary to introduce the concept of *transitional objects*, defined by the pediatrician Winnicott, as those objects towards which children embody their feelings and find comfort through these objects that have a physical presence independent of the children's imagination [127].

A story, effectively told, does the same thing for adults as it can in fact evoke the greatest fears and desires in the recipient. According to Winnicott [128], the power of transitional experiences is to make something real that is not present. To achieve the immersive character of the stories it is,

therefore, necessary to create a situation that could seem paradoxical, keeping the virtual world “real” and at the same time keeping it “not present” [129]. In other words, it is necessary to position oneself on the threshold in a way not to disturb the balance of it.

However, since the threshold is by definition fragile, all forms of storytelling have developed ways to maintain it.

In designing a participatory narrative, together with maintaining this threshold experience, there are some important issues to explore whether an imaginary action has a real result. Actually, the ways used to manage these issues may be different in every design and is related to how the participation is structured in a virtual environment.

To structure the participation, Murray suggests adopting the visiting paradigm, thus clearly defining the boundaries between the narrative world and the real world. From this point of view, a visit can be completely immersive, while maintaining its "essence" of a guided tour.

Murray (2017), suggests applying the visiting paradigm in structuring the participation, thus defining clearly the boundaries between the narrative world and the real world. This approach can provide an immersive visit experience, maintaining its essence of a guided tour. In museum environments, in which the interactive experience and museum exhibition are closely linked, the paradigm of the visit is considered in the design.

In a museum, in which the objects are available to be interacted by visitors, the visitors are supposed to follow the interaction rules and indications provided by the museum. Instead, a museum with not structured exhibition visits leaves too many spaces for the visitors to explore that in some cases can be boring and even can create a feeling of disorientation.

2.6.3 MUSEUM STORYTELLING

As discussed in Chapter 1, museums have significantly changed in different aspects e.g., mission and contents. Storytelling has been a subject that discussed in museum context that there were stories worth telling and repeating to deliver them to the future generations [62].

Storytelling is considered as a powerful medium through which modern learning passes [130], a new way of learning and making people more involved.

During the last few years, a very interesting line of studies has been launched which analyze storytelling, not only as a technique, but as a real means of learning, both pedagogical and sociological.

According to Weick, stories are a fundamental part of human life, which are used every day as a meaning in the expression of ourselves and to find a way to give meaning to life. Storytelling facilitates learning, because through the use of stories you can create various meanings and even this is the best way to create a bridge with your personal experiences [131].

In other words, storytelling is an active process that connects individual experiences through reflection to make us arrive at a meaning that we call knowledge. However, when we tell stories and analyze them, using reflective dialogues, we create the condition and the possibility to generate changes, in ourselves and in others [132], the potentials that museums can exploit.

In the 19th century, museum storytelling was mainly based on labeling and on the sequential disposition of objects. Afterwards, in the 20th century the museums started telling the thematic stories through spatial narratives. However, the 21st century has been the era of technology that transformed information more important than the museum objects [97].

The new technologies and media, as discussed previously, provide further tools to tell the stories and broaden the horizons of the experts who manage exhibitions to achieve the objectives of museums. Museums, anyway, continue to tell the stories involving their audiences.

3. METHODOLOGY

3.1 PROBLEM STATEMENT AND RESEARCH APPROACH

At the beginning of Chapter 1, we discussed the evolving definition and nature of museums. Museums as public assets play an important role in depicting the character and memory of a community and provide a better understanding of the past and the present to shape the future [2].

The narration of cultural heritage is fundamental for the construction of meaningful connections that transform the past, present and future into a single story [133].

Regardless of which media is used to tell a story, the narrative nature of an exhibition is an important component of museum experience. In a study conducted in an exhibition, with the aim of evaluating the learning of between visitors with and without the help a guide, the results showed how the visitors in an unguided tour hardly remembered the exhibited artefacts; instead, those with a guided tour remarkably remembered the artefacts that had been presented by the guide [134].

Furthermore, this result can be considered even more evident in the case of ethnographic museums or cultural museums, where artefacts are mostly exhibited behind glass cases. These kinds of exhibitions only present the appearance and are not able to convey the context in which the artefacts were constructed, or in other words, the display of artefacts in this way removes them off most of their meanings [135].

In order to transmit the meanings, museums can employ digital technologies to avoid telling fixed and unchangeable stories to passive visitors. However, museums, thanks to Interactive and Digital Storytelling, can create new museum experiences in which visitors are co-creators of stories [136].

In this regard, the following issues have been identified in the literature and are addressed in this research:

3.1.1 PROBLEM FORMULATION

A. Using museum artefacts as tangible interfaces in interactive storytelling

Museum exhibitions based on this type of technology are able to place museum artifacts in their context of origin, adequately communicating their meaning. However, this type of exhibition works only partially for ethnographic and cultural museums, which aim to communicate cultural practices that are often unknown and difficult to understand by visitors, as they are abstracted from their original context and inserted within a museum exhibition

The main problem of interactive installations based exclusively on the digital dimension is that they often do not consider how to activate the imagination of visitors in order to connect them with different cultures and knowledge [137]. In fact, cultural artifacts possess a narrative potential relating to their use, which is in turn linked to people and the context in which their use was made, which are elements of a cultural memory that can and must be transmitted to visitors [138]. Interaction with artefacts and the resulting narrative can therefore be an effective tool for imagining different perspectives, exploring the boundaries of different times and places. Through the interactive narration of the artefacts, it is possible to virtually connect to another person or to a culture, which may not even be reached in reality due to the distance in time or space.

Holmquist et al. [151] discussed the use of technology enhanced physical objects in interactive narratives that enables users to explore other aspects of the narrative events. According to them, the sense of involvement based on these objects embody meaning to the story and foster engagement.

In parallel, Mazalek et al. [150] discussed this approach from different viewpoints considering the cooperative and social aspects in interactive experiences. According to the authors, the use of physical objects in a collaborative system, in which users are able to interact and modify a non-linear narrative in a shared space, fosters engagement and can bridge the physical with the digital world.

The use of tangible objects is studied, also, in the context of non-linear narratives. Tanenbaum et al. [152] presented an interactive system that bounds a digital narrative to physical objects. They discussed physical objects, alongside with other components of a story, can help make sense of the story and enable users to feel like they are involved in the story.

Tek-Jin & Kim [153] discussed that a narrative to be meaningful should allow tangible interaction, providing objects with ludic value to discover the story through manipulation.

Moreover, Harley et al. in [154] present a framework for tangible interactive storytelling systems, considering ways in which a narrative can be enhanced by tangible interaction. They identified seven categories that reflect narrative possibilities or constraints in creating and communicating a narrative. One of these categories is related to the tangible object used in narratives and considers whether the tangible object is diegetic.

A tangible interactive storytelling allows the audience to interact with the narration through tangible interfaces, which can be a simple button or an augmented object embedded in a complex system.

Fishkin [156] proposed two axes taxonomy for tangible interaction, in which describes *tangibility*, the way an object is manipulated, in terms of a spectrum from *embodiment* to *metaphor*. The embodiment axis refers to the distance between the input and the output; instead, the metaphor axis describes how the actions of the user are analogues to the real world. For example, in a tangible interactive system the further from the origin, the more tangible the system is.

In parallel, Valli [157] discussed the relationship between human and objects enhanced by technology, framing it in the context of *natural interaction*. He claimed that technology should become invisible and provide people with interfaces close to the real world. Natural interaction is defined in terms of real-life experience, through which people are able to communicate naturally through gestures, movements, expressions, and so forth. The interfaces are easy to understand and use and the user interactions are spontaneous like in real life.

Ulmer and Ishii define Tangible User Interfaces (TUIs) as systems that use physical artifacts for representing and controlling digital information. According to the authors, tangible interfaces explore the conceptual gap between input and output [158].

The physical characteristics of TUIs facilitate the mapping between actions and effects [159]. TUIs are assumed to be more natural and intuitive (e.g., in compassion to GUIs) to communicate meanings through their physical affordances [160]. TUIs are employed to represent digital information to users and enable them to interact with this information [161].

TUIs tend to require little skills and experience to be used, and can function as both input and output mediums [162]. Furthermore, they require multimodal ways of human perception to explore the interface and discover their meaning, which facilitates information recall in learning context [163].

The integration of TUIs in museum exhibitions can attract visitors and increase their interest. The Austrian Technical Museum in Vienna developed different hands-on exhibitions using tangible objects e.g., a digitally augmented abacus used as a tangible input to guide visitors through calculation examples by providing feedback and instructions on a screen [164].

The ethnographic museum displays therefore have the aim of activating the imaginative power of visitors but often encounter difficulties in achieving this goal because, as previously mentioned, the artefacts are abstracted from their cultural and experiential context. The display of a cultural artefact behind a display case without the possibility of interaction will hardly be effective in conveying its meaning to the visitor [139]. In this regard, Dudley [140] has criticized museum exhibits for being largely vision based, without offering sensory involvement directly with the artefacts. However, as we will see later, a museum experience designed with interactive moments has the possibility of offering visitors an engaging emotional encounter with cultural artifacts and allowing visitors to appreciate the cultural context in which they are inserted.

B. Designing a dynamic interactive storytelling system in which the functions of integrated artefacts are considered in relation to other artefacts

Several projects have been developed using TUIs, however they usually employ objects focused on a specific function, not a system of objects aimed to perform a complex function, with the interaction of the user therein involved. In the following, I first describe some related works which will be used to outline the problem we aim to address.

Ullmer and Ishii [158] proposed a TUI classification to form a system of physical objects based on how multiple objects are interpreted. Spatial systems interpret the spatial configuration and orientation of physical artifacts within common reference frames to define the state of the tangibles. In relational systems, the sequence, adjacencies, or other logical relationships between systems of multiple tangibles are mapped to computational interpretations. Constructive systems refer to the constructive assembly of modular interface elements, often connected together

mechanically in fashions analogous (and sometimes quite literal). Finally, in associative systems tangibles are individually associated with digital information and do not reference other objects to derive meaning.

Virtex (VIRTual EXhibit) is an approach to museum storytelling, based on a tangible interface, which enables visitors to freely touch small-scale replicated statues. The system maps the visitors' input, received by the physical replica, and shows the corresponding on-screen visualization [165].

The mesch project developed a book-like tangible device used during an outdoor heritage environment visit. Visitors carry this location-based device and can receive auditory information when a bookmark is placed on a selected page [166].

Marshall et al. [86] also designed tangible user interfaces using smart replicas of historical objects e.g., mugs. These 3D replicas are used to trigger multimedia narrative content on museum display cases. The authors in [167] designed tangible interfaces using plaster. By touching different parts of these augmented tangible busts museum visitors are delivered different multimedia information.

The City Mouse is another example of TUIs, where people could interact with a stone sphere, representing the globe on a water fountain, and rotate a 3D model of the Earth visualized on a screen next to the landmark [168].

In these examples, among others, the installations employ TUIs to deliver content to their users. The designed systems map information based on input actions received from a single object and mostly the story spans over the same object (e.g., manipulating a replica statute to receive information about it), in other word, the objects are not used to tell a story that includes more objects.

In tangible interaction design using artefacts (or replicas), for example in an interactive storytelling, the objects allow users to experience physical interaction with the object when they reach the right time in the storyline. However, referring to the abovementioned relational approach, the function of the object is considered out of context - disregarding the functions of other objects, and usually the story follows a line developed by asynchronous contribution of the objects.

This approach in designing interactive storytelling may be useful for objects that have a single function or multiple functions applicable, mostly, in a linear narrative system. Instead, in an interactive storytelling with a non-linear narrative, the objects can accomplish different functions

and play a dynamic role depending on the functions being fulfilled by other objects integrated in the narrative system.

Accordingly, in an interactive storytelling system that tells a story including more objects, the dynamic relations and functions of the integrated objects requires discussions to design and deliver content in such a dynamic story.

3.1.2 Proposed Approach

Considering the high-level research goal presented in the introduction and the problems identified in the section above, the approach proposed and investigated in this research is an innovative application of Tangible Narrative and the Web of Things paradigm applied to the field of cultural heritage.

Tangible Narrative: an instrument to design tangible interaction with cultural artefacts

In the previous section, point A outlined the risks of creating installations that are mostly focused on their digital dimension. According to Hornecker [141], the risk in a completely digital narrative experience, visitors' attention is attracted by the digital environment rather than by the real content of the artifact. This may require visitors to spend their energies to learn how to manage the interface rather than to reflection and acquisition of a true understanding of the artifact and its use [141].

The approach pursued in this research is employing the narrativity potentials of cultural artefacts combined with the physical dimension. The studies concerning Interactive and Digital Storytelling have, in recent years, developed a new discussion in the field: the Tangible Narrative (TN), a type of IDN not yet clearly defined in the literature, however, is expanding very fast [142].

Due to this lack of definition, in the literature, the term TN can be used to indicate different aspects or even can be replaced by other terms. The expression Tangible Narrative, in fact, can indicate the tangible interaction with an object or the design of an interface, which can be tangible platforms [143] [144], environments [145] or simply tangible interfaces that support digital and interactive narratives [146] [150] [147].

"Tangible interaction technology is understood as a necessary component of the narrative or its construction and […] the resulting narrative will include at least one of the following: plot, character, or setting." Daniel Harley [154].

The definition provided by Harley can be supplemented by a system vision [148] meaning the Tangible Narrative as tangible and embodied narrative systems based less on computational modeling of the story and focused more on the free creation of the story or the game. A Tangible Narrative system, in fact, should ideally combine the opportunities of both modes, namely the possibility of a concrete physical interaction and the enjoyment of a good story [148].

Accordingly, Tangible Narratives can be defined as hybrid interactive experiences that aim to create a structured sequence of events representing a story, which digitally combines one or more artifacts and physical environments and maps their narrative content [142].

TNs emerges as a new paradigm of interaction used to design and improve different scenarios, interaction and digital storytelling from different points of views. However, the use of TN still presents many challenges and unexplored issues, especially with regards to theoretical aspects [149].

In a Tangible Narrative design, there are several factors that need to be considered. Harley [154], discusses a series of the elements that must be analyzed such as: Users, narration, media, objects, etc. These factors show both the richness and complexity of the Tangible Narrative systems. Therefore, in this research, in the design of the storytelling system, we employed the TNs using the aspects presented by Harley to enrich the theoretical part of the project. Instead, concerning the technological part of the research, the Web of Things (WoT) paradigm has been employed in the design of the storytelling system.

THE WEB OF THINGS (WOT): A PARADIGM TO DESIGN AND INTEGRATE THE ARTEFACTS' FUNCTIONS

Point B of Problem Formulation in section 3.1.1 outlined the lack in the literature of Tangible Narrative systems composed of objects playing different roles in the interaction with the user. However, this seems necessary in order to communicate and let users experience complex realities and cultural practices. To address this issue, in this research project we propose and investigate the use of the Web of Things paradigm, as explained in the following.

The increasing use of the Internet of Things (IoT) in everyday life leads to connecting an increasing number of objects, devices and systems — "things"— over the internet. Indeed, in classical IoT

projects a variety of *heterogeneous* network and connection *technologies* (e.g., communication protocols, data models for payload data exchange, and security requirements) is utilized, which creates challenging issues for IoT developers to face, for example, in terms of data integration and reuse.

As argued in the literature, this problem can be tackled through a unique and global ecosystem of *things* that communicate perfectly with each other. In this regard, Dominique Guinard and Vlda Trifa[32], during their doctorate, in 2007, proposed the innovative idea of the Web of Things, i.e., using the World Wide Web infrastructure as "*lingua franca*" among IoT objects to create an ecosystem for the IoT applications. The IoT objects in this ecosystem are interconnected through the Internet by the IP address that is allocated to each one. The connected objects are able to exchange data among them at the network level; however, the end-to-end interoperability can be supported by the application protocols, including HTTP, in particular.

According to Guinard and Trifa, the Web of Things enables anything in the physical world by using and adapting Web protocols to be connected and present on the World Wide Web.

> *"The Web of Things is a refinement of the Internet of Things by integrating smart things not only into the Internet (network), but into the Web Architecture (application)"*[33].

The Internet of Things can be defined as an extension of the Internet connectivity to physical objects and devices—things, in addition to human users. IoT supports the integration of different technologies, computing systems and services, making them networked [77]. However, the Web of Things (WoT) enables IoT objects and devices to be accessible via standard and well-supported Web technologies [200].

The Web of Things aims to provide facilities to maximize existing and emerging tools and techniques used on the Web and apply them to the development of Internet of Things scenarios.

The idea of maximizing existing and emerging tools and techniques used on the web and applying them to the development of Internet of Things scenarios is therefore the ultimate goal of the Web of Things.

[32] *https://webofthings.org/about/*
[33] *https://webofthings.org/2017/04/08/what-is-the-web-of-things/*

In WoT, devices and their services are integrated into the Web by using the same standards and techniques as traditional web applications, which enables the interaction with embedded devices in the same way that one interacts with any other web services using web *API*s (Application Program Interface), especially *RESTful* (Representational State Transfer) architectures.

REST refers to a set of architectural principles for the design and implementation of interfaces for accessing distributed services and applications, and is the basis on which the modern web is founded. The key concept that characterizes REST is the creation of services that can be easily reused, made available using URI, HTTP and other standardized media types.

In practice, this means that one can start interacting with objects via a web browser and explore the Web of Things in the same way as one browses the net (via links to other related objects). The data collected in real time by the distributed sensors can also be easily retrieved, processed, and displayed on web pages using HTML, CSS and JavaScript.

Web of Things (WoT) is a general term that refers to the different approaches by which objects of the physical world connect to the World Wide Web. Several alternative approaches have been proposed for using Web standards, among which the *World Wide Web Consortium (W3C) WoT*.

In fact, in 2015, the *Web of Things Interest Group* was created within the W3C, with the aim of reaching the definition of standards (Recommendations) for the WoT. The W3C WoT provides standards that describe *Things* as the basis for interoperability and semantic discovery and that simplify application development through a common interaction model independent of the underlying protocols.

At the time of writing this thesis, the latest version of released Recommendation in April 2020[34], and the latest editors' draft in December 2021 are available.

One of the first proposals that the Web of Things Interest Group worked on is a document published in 2015 (revised in 2017) entitled *Web Thing Model*.

This document proposes the basis of a common model for describing the virtual counterpart of physical objects in the Web of Things. It defines a model and a web API for objects, which anyone who wants to create a product, a device, a service or an application for the WoT must follow. This document considers the Web of Things as an application layer of the IoT. The proposed model and

[34] *https://www.w3.org/TR/2020/REC-wot-architecture-20200409/*

protocols aim to make the interaction among IoT objects accessible through Web standards, to facilitate the implementation of Web applications that use or retrieve data from real-world objects.

In the recent Recommendation proposed by the W3C, WoT encompasses: the *Web of Things (WoT) Thing Description*, and the *Web of Things (WoT) Architecture*, published in April 2020.

The Web of Things (WoT) Thing Description describes a formal model and common representation for describing a Thing. A Thing Description describes the metadata and interfaces of the Thing, which is an abstraction of a physical or virtual entity that provides interactions and participates in the WoT ecosystem. Thing Descriptions provide a set of interactions based on a small vocabulary that makes it possible to integrate different devices as well as interoperability of different applications. These descriptions, by default, are encoded in a JSON format that also allows JSON-LD processing, functional to the representation of knowledge about the Thing in a *machine-understandable* way.

A WoT Thing Description instance can be contained by the same Thing or placed externally when the Thing has limited resources (for example, little memory space) or when a WoT compatible device is updated with a Thing Description.

An instance has four main components: *textual metadata* about the Thing, a set of *Interaction Affordances* indicating how the Thing can be used, *schemas* for the data exchanged with the Thing for machine-understandability, and finally, *Web links* to express all formal or informal relationships with other Things or documents on the web.

The Interaction Model provided by the W3C WoT defines three types of Interaction Affordances:

- ***Properties*** (PropertyAffordance class), exposes the state of the Thing and are used for the detection and control of parameters, such as obtaining the current value or setting an operating state;
- ***Actions*** (ActionAffordance class) allows to invoke a function of the Thing. An Action *may* manipulate state in Properties. Besides, Invoking an Action *may* also trigger a process on the Thing that manipulates state (including physical state through actuators) over time; and
- ***Events*** (EventAffordance class) are used to push event data, where notifications, discrete events or streams of values are sent asynchronously to the receiver - *consumer*. [Consumer is an entity that can process WoT Thing Descriptions (including its JSON-based representation format) and interact with Things (i.e., consume Things).]

A Thing can be implemented by a *Servient*, which is a software stack that contains a representation of a Thing - *Exposed Thing*. A servient makes available the WoT interface of Things to their Consumers. On the other hand, since a Consumer must be able to process the Thing Description (TD) of a Thing, therefore, Consumers are always implemented by Servients. A servient, in a Consumer, provides a representation of a Thing called *Consumed Thing*, in a way that the running applications on the Servient can process TD to interact with Thing (see Figure 7).

Figure 7. High-level architecture of Consumer – Thing interaction.

In Chapter 4, the application of the Web of Things to the WoTEdu interactive storytelling system according to the Interaction Affordances defined by the W3C WoT paradigm is discussed.

3.2 RESEARCH OUTLINE

The rich resources of the Ligurian region related to the maritime cultural heritage, on the one hand, and the identified gaps in the literature, from the other, encouraged me to orient the research to address these gaps in the maritime cultural heritage domain.

The idea, in broad terms, was to enhance heritage artefacts to intermediate the history, enabling visitors to interact with physical artefacts. In order to be able to answer the general research question introduced in Chapter 1, taking into account the museum missions, we identified different objectives for this research.

The challenge was to guide the research in a way to encompass all the objectives and answer the high-level question of the research. To this end, the research presents a tangible interactive storytelling system, incorporated with museum artefacts. In this storytelling system, audiences are provided with entertaining and learning experience to play an active role and discover the story by interacting with the artefacts.

3.2.1 RESEARCH GOAL AND METHODS

In this chapter, we recap and detail the research outline and the methods used in this study.

3.2.1.1. GOAL

This research aims to study the integration of museum artefacts in a maritime museum. The high-level goal is to investigate the potential of using integrated and tangible storytelling to engage visitors and promote cultural heritage, with a specific focus on the communication of maritime practices in the past.

3.2.1.2 APPROACH

To achieve this goal, the study investigated the application of the following approach and methods that are currently scarcely explored in the literature, as discussed in Section 3.1:

A. *Using museum artefacts as tangible interfaces in interactive storytelling*
B. *Designing a dynamic interactive storytelling system in which the functions of integrated artefacts are considered in relation to other artefacts*

In order to experiment and test the approach we ***designed a CASE STUDY PROJECT.***

Motivation: based on the result in the controlled scenario of the use case, we can analyze the effectiveness and limits of the approach, in order to start the investigation of the potential of using tangible narratives to engage visitors and promote cultural heritage to communicate complex practices, for future research.

3.2.1.3 RESEARCH QUESTION

We identified a main Research Question for the case study project in relation to the high-level goal of the research and the problem statement:

We want to **investigate to what extent; the proposed application succeeds in**:

> *Engaging the visitor in the museum experience through interaction with artefacts that play different roles in order to communicate a maritime practice, intended as a complex practice that pertains cultural heritage.*

3.2.2 METHODOLOGY FOR THE CASE STUDY PROJECT

The used in this research, basically, fall under the Human Computer Interaction (HCI) domain. Due to the visitor's central role in a museum experience, the approach used in this study is User-Centered Design (UCD), which is a multidisciplinary approach derived from HCI.

UCD is an iterative design approach that entails the focus on the user in each phase of the process. The user involvement in this approach, improves the understanding of users, task requirements as well as the iteration of design and evaluation [169].

In UCD, "users" can contribute to the design as *informants*, from whom we can gather requirements, needs and wishes, as well as *targets* who will use the designed output [22].

The iteration initially is related to a holistic understanding of task requirements, user characteristics, and usage context. Then, based on this, design concepts are developed, which over time turn into complex prototypes. The developed concepts and prototypes are evaluated during this iterative process, and the results determine how concepts and prototypes should be improved or even, referring to knowledge gaps, can give rise to further investigations [22].

We have employed mixed quantitative and qualitative methods, in different phases of the research, in order to gather and analyze data. Besides, a mix of qualitative methods such as focus groups, surveys and semi-structured interviews are used in different phases of the design process.

We managed the research within a four-phase iterative process: study, Design, Prototype, and Test. In Figure 8, we illustrate these four phases of the research process.

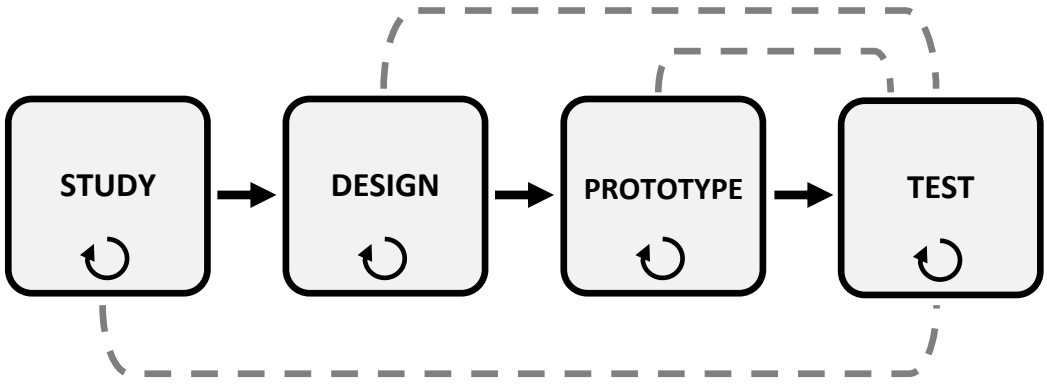


Figure 8. Research four-phase iterative process.

In the following sections, we describe the function of each phase and its contribution to the research process.

3.2.2.1 STUDY

This phase includes different stages and mainly focuses on the identification of the research problem and determines the initial research objectives.

Literature review: A Secondary Research

Secondary research refers to research that uses already existing (or secondary) sources of data, for example census or archive data. Most research projects include secondary research to establish and evaluate the types of data that have been gathered in previous research projects in the research area as part of literature review [170].

Related Work Review: EU-funded Projects

Since this PhD is a European-Union funded research, this stage is considered as an introduction to the literature review. In this part of the review, we examined the recent EU-funded research in the cultural heritage domain to obtain a better understanding regarding the objectives and approaches defined by the European Union for this area.

The review provided an insight into common key factors and concepts (i.e., objectives and approaches) among these projects, which guided me to align the research with the objectives defined by the European Union in its research and innovation program- H2020.

The nature of these research and innovative projects endowed me a clear vision to refer to the most related literature in the cultural heritage domain. Moreover, the review helped me to extract some useful keywords and key-phrases that were used in the later literature review: “engagement”, “education”, “entertainment”, “interactive museum experience”, “digital storytelling”.

Although all the stages in the Study phase have contributed to identifying the objectives of this research, however, in defining these objectives we are significantly inspired by the objectives defined in the EU Research and Innovation program.

Critical Review: Definitions and Applications

We provided a critical review of literature, relating to a museum definition and the application of technology, within the field of cultural heritage.

In this review, we focused, mainly, on how cultural heritage institutions, especially museums, could achieve their goals deploying digital technologies, in general and interactive storytelling, in particular.

The review was to examine the existing technologies used to leverage the museum edutainment experience, which provided me with elements to enrich the research with supplementary objectives.

This part of the review aimed to identify the existing gap in the literature, which led me to formalize the research question. The identified gaps and the research question required me to employ the case study approach, which consequently necessitated primary research.

Field study: A Primary Research

Primary research generally refers to original data gathered through self-conducted research methods for a particular project, for example using methods such as questionnaires or interviews [170].

Field study can include contextual inquiry, on-site interviews, and simple observations, during which a researcher visits end users in their own environments.

The study gives a better understanding of the user's environment and context surrounding as well as context that cannot be captured or replicated in a lab environment. Field studies can be conducted at any point of a product development lifecycle, but they are most beneficial during the conceptual stage [171].

Field study is the initial part of this iterative User-Centered Design process, which aimed to collect data to obtain insight into

- **Stakeholder interview:** provides an in-depth knowledge regarding their needs and requirements;
- **User profiles:** target groups interested in museum visit, characteristics of the user, their needs, tasks, goals and motivations; and
- **Scenario of use:** scenarios that describe how users can interact with a system to achieve a goal under specified conditions and constraints (e.g., mock-up storyboard).

The information provided by this primary research in conjunction with knowledge and insights from the literature contributes to the design concept of a meaningful museum experience.

3.2.2.2 DESIGN

In this phase, using the information collected in the previous phases, we created iterative designs. We followed and repeated the following steps:

- **Creating a design concept** – refers to the presentation of the core idea of the product, which is explained through low-fidelity prototypes (e.g., a collection of sketches, images, and a written statement).

  We designed an incremental mock-up storyboard to present and evaluate an overall concept of a tangible and interactive storytelling system.

- **Evaluating the design concept** – refers to formative evaluations that in this phase included evaluations and execution of activities to get the user requirements, such as focus groups, interviews, card sorts, etc. [171] We conducted a formative evaluation on the prepared design concept using questionnaire as the method for quantitative and qualitative data collection.

3.2.2.3 PROTOTYPE

A Prototype is a concrete representation of an interactive system that allows designers to envision the final appearance and functionality of the system [172] [173]. It also enables designers to reason about the potential ways to fulfill tasks and meet the requirements established for a given project.

Therefore, this phase of the iterative design aimed to develop a working prototype, integrating the physical artefacts into the storytelling, in order to provide a tangible interactive storytelling system.

The phase, in this research, encompasses two stages of development and evaluation

Development – includes the following components:

- Developing the system architecture,
- Defining the task of each artefact integrated to the narration, and
- Augmenting the physical artefacts to embody them into the interactive storytelling system.

Formative Evaluation – in this stage, the prototype was evaluated through a pilot study on user engagement employing different methods for collecting data; quantitative, observation, and qualitative. The collected data and feedback are used to revise and refine the prototype.

3.2.2.4 TEST

This phase of design is related to the evaluations that are conducted during the iterative process in order to correct the design errors and improve the prototype. We employed formative evaluations and a final user study using different methods, to fulfill and improve the design concept and the prototype.

The formative evaluation in this phase aims to check that a design concept continues to meet users' needs and helps to "form" the design. Formative evaluation covers a broad range of design processes, from the development of early sketches and prototypes through to tweaking and perfecting an almost finished design [174].

This evaluation is often employed iteratively and according to the evaluation feedback, the designs and prototypes may be modified and subsequently evaluated.

A formative evaluation on the storyboard mock-up was conducted in the second phase of the research in order to identify the most obvious usability problems of the design concept. Besides, the collected data consults, critiques, and comments in this evaluation provided understanding about if the users' requirements were correctly embodied in their designs appropriately.

Another formative evaluation was conducted in the third phase to evaluate the almost finished design. In this evaluation, a pilot study was conducted on user engagement to detect and eliminate the usability problems. The feedback collected from this evaluation provided helpful indications to refine the prototype.

Finally, a usability evaluation of the prototype was conducted to evaluate whether the prototype achieved the research objectives.

The usability evaluation employed mixed quantitative and qualitative methods. The evaluation was conducted with museum visitors, asking them to participate in an interactive museum experience using the tangible interactive storytelling system prototype. The data and feedback are collected through observation, survey and semi-structured interviews.

4. CASE STUDY

In this chapter, we present the case study project through which the iterative research phases of the research were completed.

> *"The essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result."* [175: Schramm, 1971, p. 6]

Schramm defines a case study as a research strategy, which enables a researcher to make a set of decisions in order to fulfill their research. However, another alternative definition was developed by ethnographers, focusing on participant-observation, defining a case study as a technique used for data collection [176] [177].

Yin in [178] defined a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." [Yin, 1989, p. 23]

Platt [179] explained that according to Yin the case study strategy in a fieldwork could be defined as a logic of design, which is preferred to be applied "when circumstances and research problems are appropriate rather than an ideological commitment to be followed whatever the circumstances." [179: Platt, 1992a, p. 46]

The case study assisted this research in order to identify the requirements and to design and prototype an interactive storytelling system, moreover it offered the possibility to evaluate the system with target audiences.

After presenting the case study- the Galata Museum, the iterative research process is detailed referring to the case. The chapter includes the primary study of the research, the design and prototype phases and the related evaluations conducted during the iteration process.

4.1 THE GALATA MUSEUM

The *Galata - Museo del Mare* was opened to the public in 2004. The Galata, being the largest maritime museum in the Mediterranean area, preserves 4,300 original objects and welcomes more than 200,000 visitors every year.

The museum exhibition is divided into 31 rooms that trace the evolution of the port and the city from the Early Middle Ages to the mid-twentieth century. The museum is located in the Darsena district, where galleys were built in the Republic of Genoa era and includes four floors, the terrace and the outdoor area [180].

On the ground floor there are the rooms dedicated to the Port of Genoa in the past and to the history of Christopher Columbus. In the *Armory of the Darsena*, a life-size reconstruction in which cold weapons, armor and helmets of the military department are exhibited [181]. Related to the history of sailing and boats used in the past, the *Galley* (la Galea), a faithful reproduction of a Genoese boat of the seventeenth century, forty meters long and nine at the stern is exhibited. Visitors can get on the galley and interact with multimedia content in order to discover the on-board life of slaves, convicts and volunteers who made up the crew [182].

On the first floor, there are globes, virtually reproduced atlases, and original maps of the sixteenth and seventeenth centuries, which make it possible to consult them interactively. Another room dedicated to the theme of storms and shipwrecks, allows the visitor to experience a storm on board of a lifeboat thanks to a 4D installation.

On the third floor, there is the MEM room - Memory and Migration, in which the story of Italian emigration by sea and the most recent immigration to Italy is told through more than forty multimedia stations - many of which are interactive [183]. An installed ship simulator enables the visitors to try the experience of piloting a ship inside the port of Genoa, and there is also the *Sala degli Armatori*, which tells the story of Genoa and its port from the ship owners' viewpoint.

Finally, on the fourth floor, the structure ends with two terraces, called Coeclerici and Mirador. The Coeclerici hall displays the collection "Navigare nell'arte" sixty paintings selected out of 250 belonging to the Maritime Collection of Paolo Clerici Foundation. The exhibition has expanded the museum's exhibition spaces with a new section that introduces a new subject among the ones already on display. The exhibition represents the biggest Italian private collection and one of the

most preeminent in Europe. Passing through the Clerici Hall, one can reach the Mirador panoramic terrace and the roof garden on the fourth floor [184].

The Galata, in addition to traditional exhibitions and collections, already has a strong interactive and, in a certain sense, digital component. The museum represents an important resource for creating and maintaining identity, belonging and citizenship values.

Mu.Ma – *Istituzione Musei del Mare e delle Migrazioni*

Galata Museo del Mare, Commenda di Prè, Naval Museum of Pegli and the Monumental Complex of the Lanterna are the four museums united in a single strategic structure of the Municipality of Genoa. The Mu.MA - Institution of the Sea and Migration Museums, born in 2005 on Mayor Giuseppe Pericu's initiative: a cultural center linked to the themes of the sea, travel and dialogue between peoples, knowledge and religions with the following strategic objectives:

- Guarantee greater recognition and visibility by enhancing and qualifying the artistic, cultural and historical heritage,
- Strengthen and enhance marketing, communication and promotion strategies and actions,
- Improve the customer experience and ensure a high number of visitors,
- Guarantee sustainability (economic, social and environmental), maintaining a high qualitative standard, and
- Guarantee organizational models for the management of innovative services.

The Mu.Ma through a distinct management between public, private and private-social, over the years has focused on guidelines that identify unity and purpose, becoming the cultural soul of a sea system to be enhanced also through collaboration with similar institutional, economic, touristic and cultural realities [185].

4.2 STUDY: A PRIMARY RESEARCH AT THE GALATA MUSEUM FOR REQUIREMENTS IDENTIFICATION

This section is the complementary part of the study phase, which helps to determine the project and its requirements. Here, we present the results of our visits to the Galata Museum as a case study and the information gathered from interviews with the curator of the Galata Museum.

During our visit to the Galata a guided visit was provided by the museum curator, and the didactic operator of the Cooperative Solidarity and Work that manages the entire package of services to the public.

During our visit to all the rooms in each floor, the guides provided me with useful information about the museum rooms, artefacts, history, the museum design, the museum visitors, and the objectives of the museum.

The visit concluded by a semi-structured interview. The interview questions were formulated to gather information about helpful means to address the research objectives: educational content, entertaining activities, and interactive artefacts.

Besides, it aimed to gain insights into the museum objectives and possibilities for new projects to promote history and artefacts exhibited in the Galata.

Concerning the questions about educational content, the curator was asked about the materials and content that may be worth to highlight in a maritime museum visit, or may be interesting for the museum visitors. The curator indicated some historical events such as the voyages of Christopher Columbus, the Genoese colony in Tabarca, and the story of the Ottoman naval commander at the coasts of Liguria. These historical events as cultural and historical resources of the territory can foster the identity and the feeling of belonging in the region [1].

The second group of questions oriented towards entertainment and interactive artefacts. The curator, referring to some interactive artefacts available in the museum (e.g., the replicas of the navigation instruments such as the rudder, the oars, and the faithful reproduction of galley), confirmed that the museum visitors enjoy artefacts that are permitted to be touched and practiced.

Regarding the artefacts that have the potential to be highlighted, the curator indicated astrolabe and quadrant explaining their functions. According to the museum curator, the navigation

instruments have a rather simple practical use but a more difficult conceptual basis to understand and the interaction with digitally augmented instruments could improve the learning process.

According to the museum curator, visitors attend in small groups such as families with their children and they spend, approximately, an average of two hours and half in the museum. The technical nature of the navigation instruments and artefacts makes them complicated to be explained during a traditional museum visit and sometimes educational videos, provided by standalone kiosks, related to the functions of these instruments are not efficient enough. They added that some instruments (e.g., astrolabe) require hands-on practices to be understood (see Figure 9).

Figure 9. The celestial and terrestrial surveying instruments.

The curator also indicated that the visitors show great interest in interactive visits and they can spend around 20 minutes[35] of their visit to such experiences for example, the interactive map of Genoa in the 15th century, with various interactive points which tells the story of buildings by clicking on them (see Figure 10).

However, the sounds generated by a video playing on an adjacent kiosk in the room can be distracting and may cause the visitors to lose the will to continue their interactive experience.

[35] The thesis just reports the curator's personal experience as a component of stakeholder in the process of the design and prototyping process which is the main field of this work. This work is not judging the stakeholder's opinion and expectations.

Figure 10. The interactive map of genoa in the 15th century installed on the ground floor.

During our visit, we noticed that some replicas of artefacts could be touched and practiced by the visitors. The visitors, especially children, seemed very interested in touching and trying the replicas. The curator, also, confirmed that visitors are usually interested in replicas that allow them to touch and discover their function by doing (see Figure 11).

Figure 11. The replicas of a Genoese Galley's oars: allow the visitors to practice and experience a galley slave or a convicted criminal sentenced to work at the oar.

In the room dedicated to Christopher Columbus, located on the ground floor, a huge illustrative map shows the routes of voyages of Christopher Columbus to America and indicating the related timelines (see Figure 12).

The curator, referring to this map, explained that Christopher Columbus' in his voyages tried to avoid the *Horse Latitudes*, which refers to either of two belts or regions near 30 degrees north or 30 degrees south; characterized by calms and light-baffling winds and very little precipitation. According to the curator, the Horse Latitudes were worth to be indicated when a sailing story across the Atlantic Ocean is told.

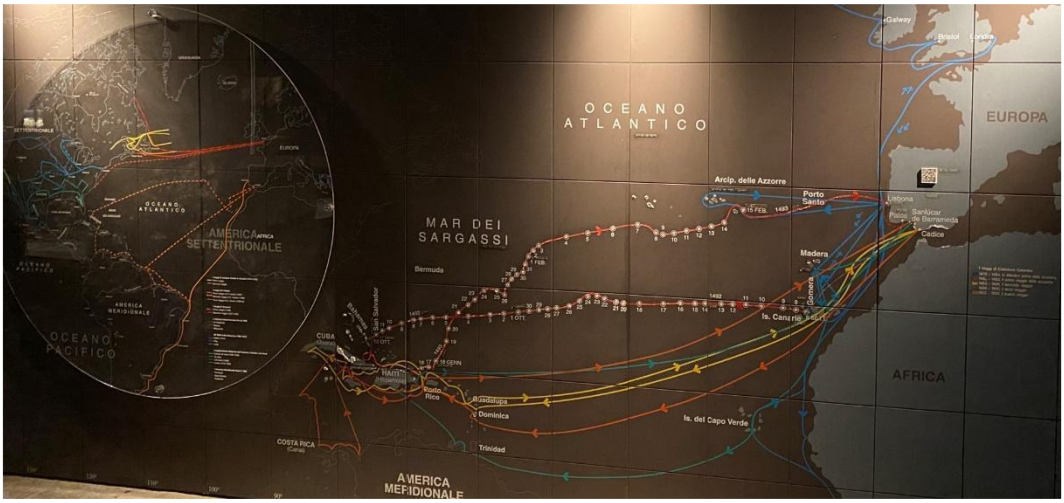


Figure 12. The map illustrating the routes and timelines of christopher columbus' voyages.

The visits to the museum contributed to the research in two aspects; the first one helped to gain an insight knowledge about the needs of the museum curators and the expectations of the museum visitors as reported by the curators, and the second aspect dealt with identifying content and artefacts to be promoted.

This primary research at the Galata Museum, together with the first part of the study phase, i.e., the literature review, complemented the requirements elicitation and resulted in seven requirements (R1-R7) as follows:

> **R1.** Delivering contents through rich interactive media — since many navigation instruments exposed in the museum have complicated functions and visitors, even using explanation videos, hardly understand their use in traditional visits.

R2. Physical interaction with real museum artefacts — the use of the artefacts to provide the visitors with a physical interaction supports the experiential learning that helps visitors to understand how the instruments work.

R3. Objects and tasks selection for the tangible interaction — integrating museum real objects/replicas (i.e., astrolabe) and enabling the visitors to have a free-choice tangible interaction by selecting an object and performing related tasks.

R4. Small groups as targets, especially families — to make collaborative activities possible.

R5. Augmentation of the museum artefacts — some navigation tools have a practical use with a difficult conceptual base, thus augmented digital affordances can enhance the learning process by providing contextual and cultural perspective and interaction feedback.

R6. Pace of interaction along the story flow — keeping visitors focused on the activities increases engagement and better understanding of the content, avoiding distraction.

R7. Usability of the application — the novelty and the application of augmented artefacts could determine some issues such as usability and complexity of the interaction, which need to be tackled.

Constraint: the interaction duration must be shorter than 20 minutes — since a visit at Galata usually takes around two hours and half, thus the visitors cannot spend too much time for a single installation, as suggested by the museum curator.

4.3 DESIGN: WOTEDU FOR INTERACTIVE STORYTELLING

This chapter presents the design concept and evaluation of WoTEdu, a tangible and interactive storytelling system mock-up about Christopher Columbus' voyages. The focus of this storytelling system, despite the relevance of the character and the story of Christopher, is on the art of navigation in the past.

According to the curator of the Galata Museum, communicating the old sailing skills to visitors has always been a challenging task in museum exhibitions. The problem lies in the different worldviews of old and modern people and differences in perception.

Today, a sailor can easily access the information of a position using routing applications. However, the task was not so convenient for the sailors in the past, as they had to observe stars and go through complicated calculations using different instruments. Thus, understanding, for example, how an astrolabe works is quite hard for a museum visitor and may require multiple presentations and hands-on practices.

Accordingly, following the visits to the Galata Museum and identifying the requirements specification, the next step was to ideate and design a system to include and satisfy all these requirements. The idea was to create a digital interactive storytelling system employing smart physical objects- museum artefacts augmented with sensors that can be interacted.

Due, on the one hand, to the application of the technological infrastructure based on the W3C Web of Thing (**WoT**) architecture to augment and integrate the museum artefacts into the storytelling system, and the objectives of the research to enhance visitors' education and entertainment (**Edu**tainment) experience, on the other hand, the research project is entitled as **WoTEdu**.

Goal specification and story design

Based on the research question and objectives, the research goal was defined to create a tangible interactive storytelling installation aimed to provide museum visitors with an engaging experience to understand the challenges that had to be undergone to travel across the Atlantic Ocean in the past. This engaging experience aimed to support comprehension and learning of (i) the context in which Columbus traveled, and (ii) ancient navigational practices and tools, in the spirit of edutainment [186].

To this end, the voyage of Christopher Columbus was chosen as the theme for the interactive story design, entitled *"Sail with Columbus"*. The story is in line with the H2020 Framework and contributes to the public awareness of European identity by focusing on maritime cultural heritage [5].

The story proceeds based on participant's interaction and collaboration. It is designed to create a dynamic environment in the museum [72] and provide a playful learning through participant's active engagement [73]. To do so, different museum objects, related to the story context, have been incorporated into the story, which act as tangible interfaces to interact with the story.

During the story, participants receive multimedia content about historical events (i.e., Columbus' first voyage) and the function of objects (e.g., astrolabe), which support education through the cultural heritage resources [8].

Games have been recognized as potential learning tools in education [187], and have been strongly employed in the CH domains [188]. Moreover, games and storytelling are among the most used tools to engage museum visitors [189]. Accordingly, different ludic elements such as quizzes, puzzles, and practicing navigation instruments to calculate certain values have been integrated in *"Sail with Columbus"*[36].

Referring to Figure 13, the designed story can be reviewed as follows:

- A group of visitors selects the story from an interactive display.
- They are told a brief story about Columbus' first voyage.
- Then, they are asked to accompany Columbus in this voyage and they are asked to select the instruments that they would need during their journey. The instrument selection is presented as a quiz where each correct answer gives the visitors a score. In case of wrong answers, the visitors can see the correct answers with their functions explained[37].

[36] This part of the research was conducted by my colleague, Luca Ciotoli, on his thesis titled: "SAIL WITH COLUMBUS": UN PROGETTO DI TANGIBLE NARRATIVE APPLICATO AL PATRIMONIO NAUTICO LIGURE.

[37] The quiz is enough simple that an adult can have an idea about the choices presented. It is about just selecting the artefacts and if the user is wrong, they will be presented by the right answer with a brief explanation that can be read or ignored by the user. In other words, the quizzes try to attract and intrigue the users.

- The departure time of the fleet is determined to be at the sunrise time and the visitors are asked to practice and calculate the sunrise time after a brief instruction. This part of the story includes learning, interactive, collaborative, and ludic aspects.

- Afterwards, they are asked to divide the roles in the group by choosing the navigation tools (e.g., oars and rudder).

- The visitors raise the anchor and start the voyage and set sail to the New World traveling across the Atlantic Ocean. On their journey, they are asked to visit different checkpoints that have historical or geographical values in the story (e.g., the Canary Islands, the Sargasso Sea). At each point, they face challenges that require to be tackled through answering quizzes (e. in the Canary Islands) or using the navigation tools (e.g., getting across the Horse Latitude where they need to oars faster to leave the area).

- Once they arrive at the New World, they are asked to lower the anchor and, as the last challenge, to calculate the latitude of the position using a quadrant.

WoTEdu: Components and Architecture

One of the issues discussed with the museum curator was the need of highlighting the functionalities of navigation instruments and artefacts exposed in the museum. Some of these objects have complicated structure and functionalities that cannot be understood through a traditional museum visit and require to be enriched in terms of educational objects and interactive capabilities to enhance learning and entertainment experiences.

Astrolabe, quadrant, oars, rudder and anchor were of the components determined to be augmented and integrated into the WoT-enabled storytelling system. The high-level architecture of the storytelling system is displayed in Figure 13 and includes the following three main parts:

i. the **Story and Interaction Managing System (SIM)**, which is in charge of managing the interaction logic, the storytelling flow and content delivery,

ii. the **WoT-enhanced real-world artefacts** in the museum, equipped with sensors and communication capabilities that allow the interaction with other artefacts and with users, and

iii. the **Interactive display**, that is used for the digital storytelling and for some input tasks such as selecting options on the map or inserting some data when needed.

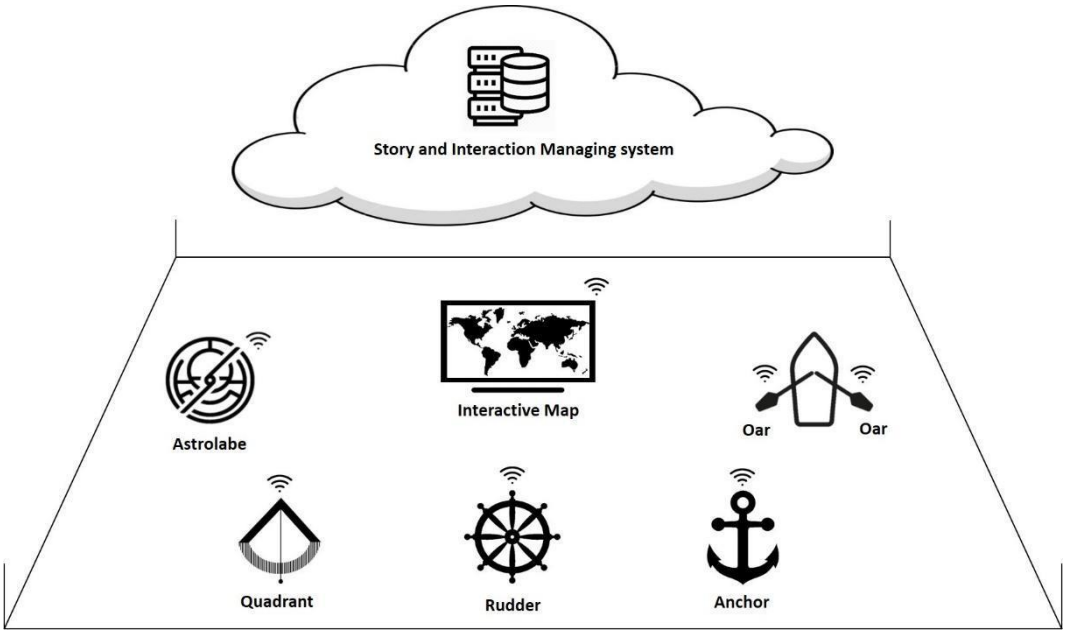


Figure 13. High level WoTEdu architecture, which includes WoT-enhanced real-world artefacts, an interactive digital display and the SIM system.

The storyteller enables visitors to participate in the construction of narratives. Each participant takes a task to engage in active problem solving through interacting with the augmented museum artefacts, and to reflect on narrative experience.

Participants and Tasks

The number of participant groups can vary from three to eight (preferably, but not necessarily, young adults like the target of escape rooms). The lower limit of participants was considered to address the collaborative nature of the experience (e.g., a group of oarsmen in a galley), and the upper limit was due to the simultaneous interaction with the WoT-enabled artefacts.

Relating to the tasks, in a four-participant group, for example, one can participate as captain and others play as oarsmen. In this case, the tasks were split into two categories: specific and shared tasks (see Table 1).

Table 1. Participants' specific and shared tasks during the collaborative storytelling experience.

		Participants	
		Captain	Oarsmen
Task	Specific	*Rudder*	*Oar*
	shared	*Astrolabe, quadrant, anchor, interactive map, ...*	

The specific tasks are special roles assigned to participants to perform during the experience, while the shared tasks are the ones that can be accomplished by each participant, regardless of his/her specific role. For example, when, during the narration, a latitude calculation needs to be done by using a quadrant or an option must be selected on the interactive map, each of the participants can fulfill these tasks depending on his/her position or availability.

Scenario

The participants of the group engaged in the WoTEdu interactive storytelling perform the following steps:

- Participants select the adventure that they want to experience on the interactive display;
- WoTEdu starts telling the story and involves the participants in different tasks in order to proceed with the narration.

All the tasks determined to be performed during the storytelling experience are fulfilled through two types of interaction provided by WoTEdu: *user-artefact interaction*, where participants interact with the augmented museum artefacts, and *artefact-artefact interaction*, where the WoT-enhanced artefacts can access and update each other's state.

Below is sketched how an interaction with the system begins (see Table 2), while Figure 14 shows a portion of the WoTEdu interaction flow and related storytelling.

Table 2. Digital storytelling and interaction flow user-artefact, artefact-artefact.

Choosing a story:	Participants choose a story from the interactive display; e.g., exploration, trading , battle, chasing, ...
Forming a galley crew:	Each participant takes a role in the crew; e.g., captain, oarsmen, ...
Positioning:	The galley crew is engaged in the interaction with artefacts—rudder, oar, astrolabe —to get the position and start navigating, ...

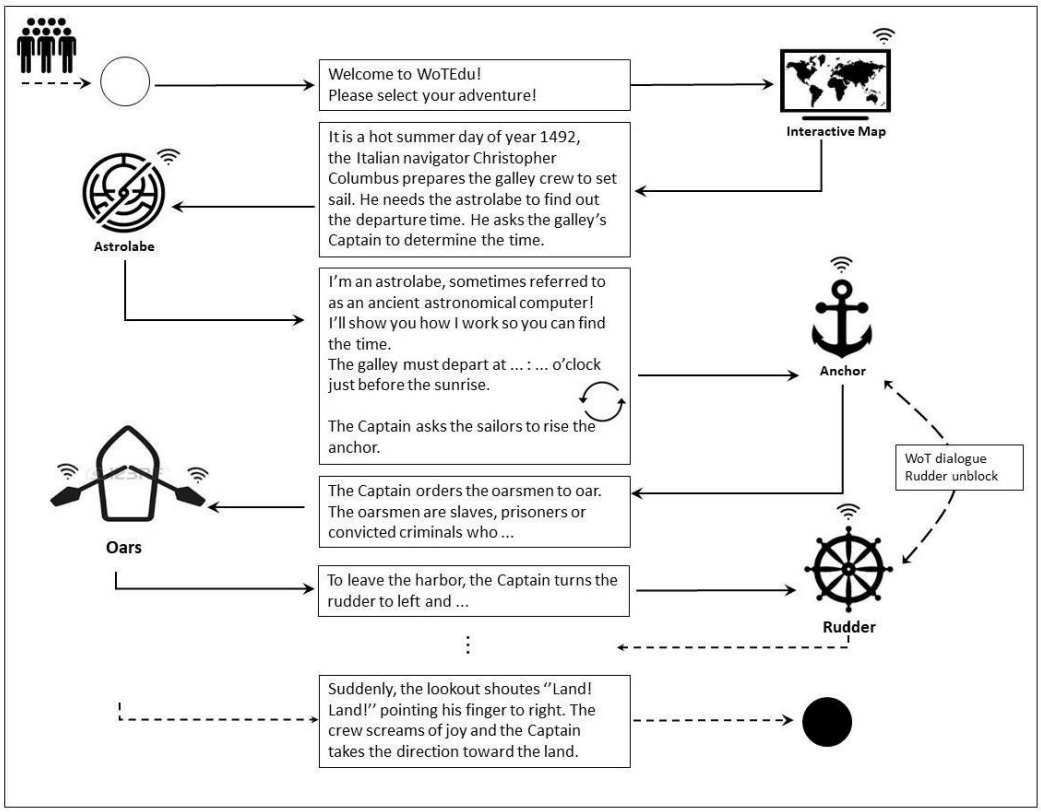


Figure 14. Digital storytelling and interaction flow user-artefact, artefact-artefact.

The figure shows the WoT-enabled artefacts (astrolabe, anchor, oars, and rudder) at the sides, while the central part of the figure sketches the digital storytelling and the task required to be fulfilled by the participants.

Each interaction, regardless of being user-artefact or artefact-artefact, triggers some actions in the storytelling system that can include instructive information about the use of an instrument, sending feedback to the user or to other artefacts in order to make the story proceed.

4.3.1 PRELIMINARY EVALUATION

According to the iterative process presented in the methodology, a user study was conducted to test if the presented design concept satisfies the requirement specifications. The evaluation results and feedback gained from the users would contribute to correct and enrich the design.

Mock-up Design

To represent the complex relations among narrative elements, functionalities, interactivity, feedback, appearance, and spatial structure involving users, tangible and intangible objects we used the design tool of the *mock-up storyboard*[38]. To test the technical feasibility, we used an evolutionary prototyping approach, by building demonstrators that implement specific features and that would be integrated in the high-fidelity prototype; details will be provided below in this section.

The storyboard, entitled *"Sail with Columbus"*, was designed to provide participants with an engaging experience to understand the challenges that had to be undergone to travel across the Atlantic Ocean in the past. This engaging experience aimed to support comprehension and learning of (i) the context in which Columbus traveled, and (ii) ancient navigational practices and tools, in the spirit of edutainment [186].

The storyboard was expected to represent a *tangible narrative (TN)* system and address the requirements. TN is characterized by the use of digitally enhanced physical objects to tell stories. However, despite this common feature, which makes TNs a medium with identifiable characteristics [154], TNs are various implementations as discussed in [190].

The Tangible and Embodied Narrative Framework (TENF) is a framework proposed by Chu and Mazalek [191] that is used as a conceptual model for the design of Sail with Columbus. The TENF framework is based on three components named spectra that refers to their continuum spaces:

i. The *physical engagement* determines the physical modality of interaction with the objects, *diegetic or non-diegetic*. The former happens when the user, through the interaction with the objects, can physically situate her/himself within the story, immersing herself/himself in the context (time and place) of the story. The latter happens when the user interacts with the story through symbolic objects resulting in a less intense immersion in the story world;

ii. The *narrative role* determines the role of the user in the story, which can be *internal*, if the user immerses his/her point of view in the story world, or *external*, if there is not any connection between the user and the context of the story.

[38] The storyboard video presented in *https://drive.google.com/file/d/1cTW_wQbqB_8-UWxtFCxwyt5FcYQ0-nwt/view?usp=sharing*

iii. The *narrative consequences*, refers to the third spectrum is between *ontological* and exploratory narrative consequences, and refers to the evolving of the storyline. In the ontological narrative consequences, the user is able to make decisions that change the story world. In the exploratory narrative consequences, the story world is defined and the user can live his/her adventure without changing the structural elements of the story.

The TENF framework fitted the project requirements because it considers tangible narratives from a holistic point of view and it is a valid tool to design a tangible and interactive story. However, using this framework to design our tangible narrative, enabled the "Sail with Columbus" to introduce some interesting novelties from TENF, such as a more complex storyline in comparison to other projects [192] [193] and the interaction with different kinds of objects during the same experience.

Designing the Interactive Story

The mock-up interactive story is designed to engage the participants with the story in order to satisfy the first, second and the fifth requirements (R1, R2, and R5) enabling them to interact with specific tools and instruments in order to convey the context of ancient navigational practice through experiential and collaborative activities (R4). The design involves the physical engagement with specific navigation instruments (R3), which raises different challenges in the flow of the story.

In order to interact with objects, the participants need to learn about their functions, which is a critical issue that can cause museum fatigue. To address this issue the "Sail with Columbus" storyline was divided into two kinds of moments with different functions, according to TENF (see Figure 15).

- *Non-diegetic moments:* the users explore the storyworld through the interaction with non-diegetic objects (e.g., keyboard and a caravel shaped joystick). In these moments, the narrative contents are outside of the objects, so the users can relax exploring the storyworld and have fun facing small challenges, like answering simple quizzes.
- *Diegetic moments:* in these steps, the objects become the protagonist of the story. The users have to understand how to use navigational tools and resolve challenges using them. The succession between diegetic and non-diegetic moments characterizes the storyline and influences the pacing of the story (R6), increasing the engagement during the tasks most focused on learning content, and involving diegetic objects.

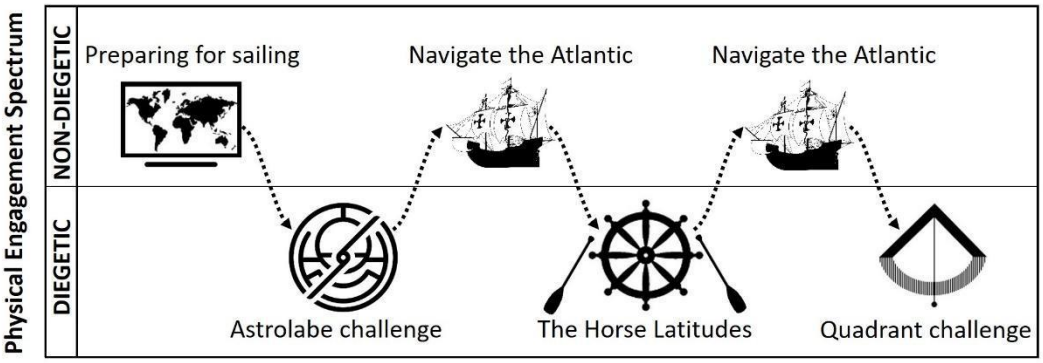


Figure 15. The storyline flow altering diegetic and non-diegetic moments.

Augmented Objects and Tasks

If we analyze the interactive story from the TENF point of view, the main difference among the augmented objects included in "Sail with Columbus" is the diegetic level of the physical engagement (see Figure 16), which influences the way to imagine and experience the narrative world [191].

The motion along the spectrum enables the mock-up to meet the requirements of having a good pacing in the storyline, and also to achieve the two above-mentioned learning goals. Therefore, to achieve the first goal we chose to enrich the story with challenges characterized by slow pacing and objects with low diegetic level. Accordingly, the interactions with the caravel model and the interactive map do not require a completely immersive experience. Thus, while participants interact with the caravel model, they can learn stories in the context thanks to the multimedia storytelling and challenges at checkpoints along the way.

Relating to the second goal, two immersive moments were created in which the participants can experience the use of the ancient navigation tools, quadrant, astrolabe, rudder and oars, and their context of use. The first was the "Horse Latitudes" step aiming to make the users understand the difficulties related to sailing across the Ocean. The second was about the navigation skills, which a sailor must have had in the past. These are shown by the use of the quadrant and its explanation through videos.

Tasks in diegetic moments were designed to be collaborative activities (R4), as these require all members of the group to participate, aiming to raise co-experiential knowledge construction [194]. However, tasks in non-diegetic moments do not require collaborative activities.

From the narrative role (on the TENF spectrum from internal to external) viewpoint, participants act and have a role in the story, in both diegetic and non-diegetic moments. For example, in order to make the participants get into the experience of navigation, like sailors in Columbus' crew, participants undertake an internal role in the story.

However, participants are not completely free to act in the story. In this respect the narrative consequences of the interaction are exploratory (on the TENF spectrum from ontological to exploratory), which means that participants are not able to change the storyline in depth and they only influence the order in which tasks and multimedia materials are experienced. This decision in the storyboard design was taken to avoid the participants going through further complexity of the interaction (see Figure 16).

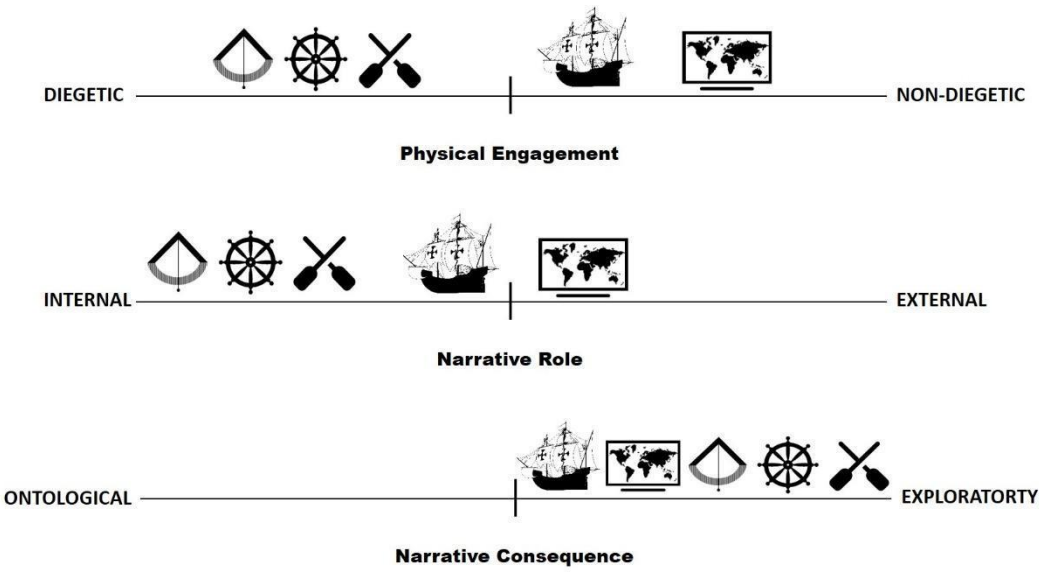


Figure 16. Classification of the augmented objects in the "Sail with Columbus" according to the TENF.

WoTEdu Audience Experience

In order to support engagement and education, the audience experience enhancement was considered as the guiding principle in WoTEdu design. Accordingly, different dimensions of the user experience needed to be determined to evaluate the designed interactive storytelling system in the context of edutainment.

The literature relating edutainment in museum context do not provide one single model that could fit the requirements of the WoTEdu application context. However, the combination of two models- in the context of education and entertainment- turned out to be useful to identify the relevant dimensions for WoTEdu design.

The *Educational Digital Storytelling Environments (EDSE)* model [195], including 16 dimensions based on the *constructivist* paradigm of learning, and the *Interactive Digital Narrative (IDN)* model [196], including 12 dimensions of user experience based on the *Entertainment Theory*, have been combined to form the model employed in the WoTEdu preliminary evaluation. The dimensions, as shown in

Table 3, were identified as *Education* and *Entertainment* respectively.

Table 3. Dimensions for WoTEdu audience experience design, focused on Education and Entertainment goals and split in dimensions mostly dependent on the Task and Story (TSD) and dimensions that are more related to the user's Personal Features (PFD).

		WoTEdu Affordance	
		TSD dimensions	**PFD dimensions**
Edutainment	**Education**	*Collaborative Learning* *Creativity and Innovation* *Multiple Representations* *Motivation* *Gender Equality* *Cognitive Effort* *Feedback* *Learner Control* *Flexibility* *Learner Activity* *Sharply-Focused Goal Orientation* *Experiential Value*	*Cultural Sensitivity* *Value of Previous Knowledge* *Knowledge Organization* *Metacognition*
	Entertainme	*Usability* *Effectance* *Autonomy* *Presence* *Suspense* *Flow*	*Believability* *Role-identification* *Eudaimonic appreciation* *Affect positive vs negative* *Enjoyment*

The two columns distinguish, among such dimensions, those which are mostly related with the Task and the Story (TSD dimensions) and those more dependent on participant's Personal Features (PFD

dimensions). The further information regarding the dimensions and detailed explanations regarding how these dimensions and their application to the WoTEdu system, were provided in Appendix A.

Since, the PFD dimensions are highly related to audiences' feelings and emotions (e.g., cultural sensitivity, believability, etc.), so their evaluations were mostly performed through participant observation and interview, while TSD features are mostly based on the objective features of the task and the story. Moreover, the usability evaluation was particularly critical, especially with respect to the augmented physical objects that show both traditional and enhanced digital behaviors [197] [198].

Evaluation

To evaluate how the mock-up satisfied the predetermined requirements, a mixed quantitative and qualitative method was employed for data collection using a questionnaire. The questionnaire is prepared to obtain feedback for each Requirement (R). The table presented in Appendix B, reports details about the applied markers and the related questions.

The prepared set of questions to address each requirement (R) was mapped onto the dimensions presented in the IDN (Interactive Digital Narrative) and EDSE (Educational Digital Storytelling Environments) models. Consequently, seven sets of questions - markers, were obtained as: R1: Multiple Representations (EDSE), R2: Experiential Value (EDSE), R3: Learner activity (EDSE), R4: Collaborative Learning (EDSE), R5: Focused Goal Orientation (EDSE), R6: Flow (IDN), and R7: Usability (IDN).

The selection of these markers was based on their suitability to be tested in a mock-up storyboard. The excluded markers are best suited for experimental tests and observation methods (i.e., motivation, cultural sensitivity, value of previous knowledge, etc.). It is also important to underline that the goal of this first testing phase was not to analyze all of the project aspects but evaluate the core ideas and the potential to reach the goals. In this respect, despite the small number of markers, this design concept evaluation took into account the most important aspects of the tangible narratives [199] related to the edutainment aspect of the design.

Participants and task description

Due to interdisciplinary considerations taken into account in the design, the evaluation needed to be conducted with participants that had some expertise in the field of both human-computer interaction and digital edutainment. On this basis, researchers and last year PhD students in Digital Humanities of University of Genoa were asked to take part in this evaluation. Fourteen participants ranging in age from 27 to 41 were recruited and asked to watch the video version of the mock-up storyboard twice. In the first view, they had to try to imagine themselves as museum visitors, while in the second view they had to observe the mock-up as digital edutainment experts.

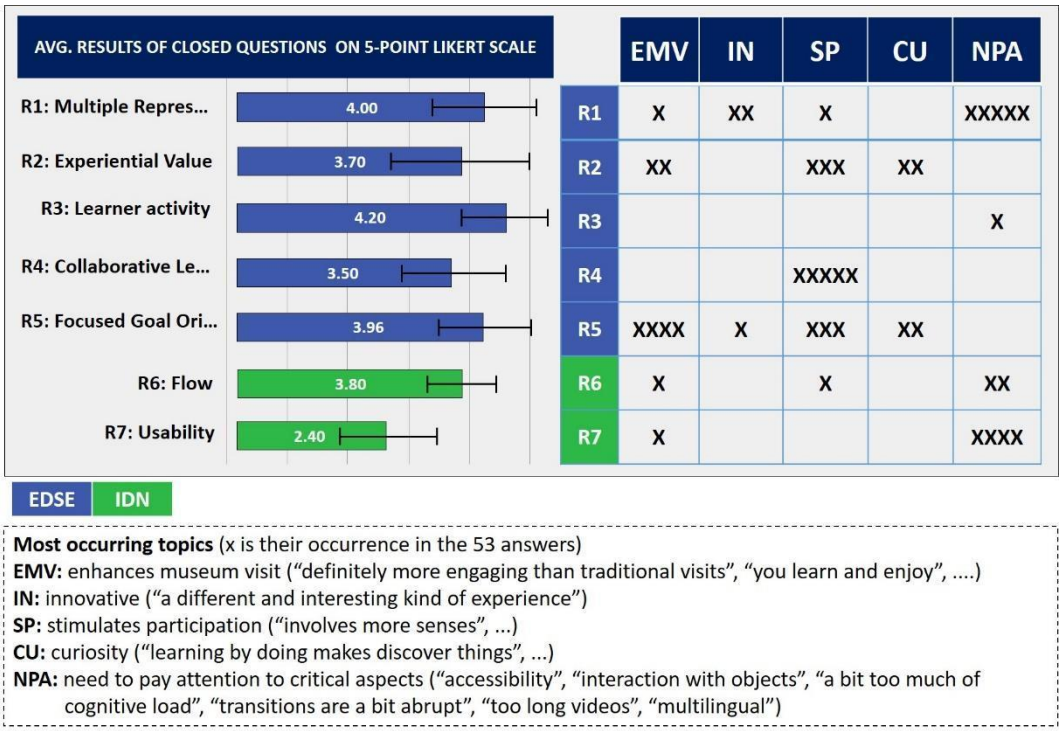
Subsequently, they were asked to fill out a survey consisting of a set of closed and open-ended questions related to each of the aforementioned markers. In order to catch all the details, the participants were asked to feel free to watch the mock-up video again, go back and forward, as many times as they wanted.

Results and Analysis

The results showed that all the markers related to education and sense making had gained good responses, which highlighted an expected effective communication of the learning objectives. The quantitative analysis in Figure 17 (left) shows that the Focused goal orientation marker obtained (Avg. 4.0; Std. Dev. 0.9) on a 5-points Likert scale and Learner activity (Avg. 3.9; Std. Dev. 0.76). They are followed by Experiential value (Avg. 3.7; Std. Dev. 1.1), which was intended to measure the potential positive effect of interacting with objects to enhance learning. The highest value had been obtained by the Multiple representations' marker (Avg. 4.20; Std. Dev. 1.09), highlighting that the combination of different media was evaluated as effective toward the learning goal. The last marker related to education, Collaborative learning (Avg. 3.50; Std. Dev. 1), was again well-above the mean, but slightly below the other markers. Good rating had been achieved also by the IDN Flow marker (Avg. 3.80; Std. Dev. 0.57), showing that the narrative flow had been perceived as potentially engaging for visitors. The qualitative analysis mostly confirmed the above results. In particular, it is worth noting that, even though no questions asked for a comparison with traditional visits, a good 23% out of 53 open answers commented on that, mentioning the positive impact on engagement and experiential learning. However, the free text opinions of participants about the role played by the augmented objects with respect to the narrative flow was not homogeneous and raised issues that required attention and further investigation. This was in line with the results of the Usability

marker, that obtained the worst score, Avg. 2.40 (5-points Likert scale, Std. Dev. 0.80). The quadrant had been judged as the most difficult object to use (Avg. 3.1; Std. Dev. 0.8), while the caravel model had been considered the easiest one (Avg. 2.3; Std. Dev. 0.8). This was an issue to pay great attention in the next design iterations and evaluations.

The analysis of open answers was highly relevant in this kind of evaluation since it provided detailed feedback and might also highlight more general opinions.



	EMV	IN	SP	CU	NPA
R1	X	XX	X		XXXXX
R2	XX		XXX	XX	
R3					X
R4			XXXXX		
R5	XXXX	X	XXX	XX	
R6	X		X		XX
R7	X				XXXX

Most occurring topics (x is their occurrence in the 53 answers)
EMV: enhances museum visit ("definitely more engaging than traditional visits", "you learn and enjoy", ...)
IN: innovative ("a different and interesting kind of experience")
SP: stimulates participation ("involves more senses", ...)
CU: curiosity ("learning by doing makes discover things", ...)
NPA: need to pay attention to critical aspects ("accessibility", "interaction with objects", "a bit too much of cognitive load", "transitions are a bit abrupt", "too long videos", "multilingual")

Figure 17. Evaluation results on quantitative data (left side) and open answers (right side).

An overview is provided in Figure 17 (right), which presents the most occurring topics bound to each marker (table rows) and overall (columns) for the project. Museum visit enhancement (EMV) and stimulus to participation (SP) are the topics most frequently occurring and include extensive and interesting comments and details. Besides, the other most occurring topic concerns issues to pay attention to (NPA), as reported in the figure, among which the accessibility issue was indicated.

In most cases, NPA comments were about Usability requirements (R7) and multiple representations (R1). In this respect, very often, participants noted that a physical prototype would be needed to test in depth the satisfaction of requirements, even though the expectations are on average good.

This was indeed planned as the next step of the iterative design process, through using developed demonstrators and focusing on the NPA points emerged in this evaluation.

Discussion

In this section we presented a mock-up storyboard, “Sail with Columbus”, which had been used in the Design iteration of the project to present the design concept and related preliminary evaluation.

The findings in this evaluation showed that “Sail with Columbus” had the potential to achieve the goal defined for the project. However, the preliminary evaluation had also highlighted some challenges to be faced. First, the need to understand how much *distracting/engaging/time demanding* the interactions were, and subsequently, to modulate their presence in our storyline. The evaluation in this phase of design was encouraging enough about the possibility of getting good results from the interaction with WoT-augmented objects. The results, also, revealed the necessity of using a high-fidelity prototype to test all the aspects through experiments and observations. Finally, this part of the iterative design offered the opportunity to extend the project to the aspects bound to accessibility that would be considered in the prototype (see Section 4.4.3).

In the following section, we present another iteration of the design, which deals with the construction of a high-fidelity prototype and the related evaluation conducted to test how the prototype could satisfy the project requirements.

4.4 PROTOTYPE

This section presents the process of the WoTEdu prototype implementation. Due to the incorporated artefacts into the storytelling system and the interactions provided by these artefacts - user-artefact and artefact-artefact interaction-, the Web of Things (WoT) paradigm was exploited to prototype the tangible interactive storytelling system.

The section provides an introduction about the Web of Things paradigm and the specifications provided by the W3C WoT paradigm that offered facilities to the prototyped system. Afterwards, the application of the W3C WoT’s specifications in relation to the designed interactions and contents of WoTEdu storytelling system is discussed. Finally, the section is concluded with the pilot study on prototype user engagement.

4.4.1 THE APPLICATION OF THE W3C WOT TO THE WOTEDU PROTOTYPE

In this section, we present the design process for modeling the WoTEdu storytelling system through diagrams that provide interaction among WoT-augmented Things according to the W3C WoT Interaction Affordances.

The system is implemented by the *WebThing* framework proposed by Mozilla, and allows communications among objects employing the Thing Descriptions of Things.

The Thing Descriptions in this architecture enables the Things to be exposed and consumed. The Things are accessible through a unique URI, and can be interacted according to the *actions* and *events*.

For example, considering the case of "Sail with Columbus" presented in Chapter 3, a part of the story includes the interaction between a physical anchor and a rudder. This interaction can be summarized as:

a. Anchor lowered => Rudder locked
b. Anchor raised => Rudder unlocked
c. On the event arriving in some location or at destination => need to consult the state of the rudder and, if unlocked, lock it, and afterwards the anchor is lowered.

The corresponding implementation of this interaction scenario according to the W3C WoT can be represented as in Figure 18.

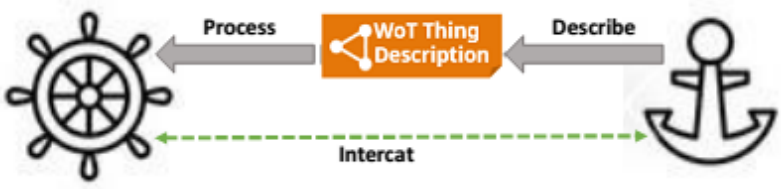


Figure 18. High-level architecture of Anchor – Rudder interaction.

The anchor, as an Exposed Thing, describes the metadata and interfaces through its Thing Description, and the rudder, as a consumer, generates a Consumed Thing instance by parsing and

processing the anchor's Thing Description document. The interactions between the anchor and the rudder are performed by the *Consumed Thing* and the *Exposed Thing* exchanging messages over a direct network connection between them.

The application of the Web of Things paradigm facilitates the deployment of RESTful web services [201] for integrating the WoT-enabled artefacts and establishing communication among them. Moreover, it allowed managing the storytelling content delivery, and establishing an interactive screen to visualize the interaction feedback through a web application.

Moreover, there was another motivating feature of the W3C WoT that was considered to be helpful in the future studies to provide the museum visitors with learning experience in the Cultural Heritage domain.

The increasing application of the IoT paradigm in the Cultural Heritage domain discussed in (Section 2.3.6). However, the heterogeneous data generated by diverse types of these IoT entities require to be managed in an efficient and effective way [202]. The Web of Things is an emerging paradigm that seeks to counter the fragmentation of the IoT systems through wider adoption of the Web principles, standardized Thing Description, metadata and semantic web technologies [203].

In this regard, the employment of Semantic Web Technologies (SWT) in Thing description (TD), as in the standard proposed W3C WoT, extends the TD context based on existing ontologies e.g., the RDF Schema or OWL [203]. This approach enables WoT applications i.e., in the Cultural Heritage domain to integrate WoT-enabled institutions to provide the visitors with rich content and information (e.g., artefact's story, function and so forth through associating them to external ontologies).

INTERACTION FLOW

Before presenting the considerations taken into account in the deployment of the WoT in the prototype, overall passages applied in the WoTEdu structure are as:

Participants make an enrollment to the WoTEdu experience by inserting a name for their team as crew name. To collect data for the future evaluations, participants are asked to insert some personal data such as gender, age, the number of participants and so forth.

- To address the educational objectives of the experience, a short narrative *cutscene*[39], introduces some fundamental historical concepts. Afterword, the edutainment element comes into action.
- When the narrative part ends, a call-to-action is displayed on the screen inviting the user to take action. Specifically, participants are asked to select the instruments that would help them to find the route in the Ocean during the expedition.
- After the selection phase, another educational moment takes place and chosen objects are marked as correct or wrong, and in the case of an error, the reason is briefly. For each correct choice, some bonus points are awarded. This *reward* strategy encourages the user to think carefully and choose carefully, based on historical facts.
- After another narrative moment, participants arrive at the first interaction with a physical object. Participants are assisted by a short video that explains how to use the objects inside the room. For example, in order to calculate the sunrise time which is necessary before the sailing, participants use an astrolabe to find it.
- The experience structure is based on different mini-games. When participants start their voyage and set sail across the Ocean, they are faced with an unexpected event, namely a storm that sends them off course in the Horse Latitudes. In order to fix the situation, they are asked to use oars to exit from this area.
- During the experience, participants are invited to answer quizzes designed for some specific areas on the Ocean that contain scientific or historical information. For example, when participants visit the Canary Islands, they are asked to answer a quiz about the first inhabitants of the island.
- Once participants arrive at the destination, as the last challenge, they are asked to calculate and insert the latitude of the position by using a quadrant. After a cutscene about quadrant use, they learn how to calculate the asked value.

[39] A cutscene is a non-interactive animated section that intersperses purely interactive moments within a video game. It serves to convey and communicate the exclusively narrative contents of the game, since its function is primarily explanatory. It also has a reward function, as it “rewards” the player for his progress and allows him to advance in the game [103].

- Upon completion of the experience, the total time spent by participants to complete the experience and their obtained overall score (considering the time spent and bonuses obtained by them).

CONSIDERATIONS IN WOTEDU IMPLEMENTATION: CONSTRAINTS AND ASSUMPTIONS

The WoTEdu interactive storytelling system employs the Mozilla *WebThing* framework to implement the following *Things* used in the story:

- An interactive map to recognize the direction and position of the galley on the voyage route displayed on the screen.
- A WoT-augmented rudder used to determine the direction by user.
- Two WoT-augmented oars to manage movement and direction of the galley.
- A keypad integrated in the WoTEdu system is used to insert the time of sunrise and check if the inserted time is correct.
- A keypad integrated in the WoTEdu system is used to insert the value of the position using the quadrant and check if the inserted time is correct.
- An anchor, which is used for raising and lowering the anchor.

The flowchart model depicted in Figure 19 shows an overall representation of interaction among the Things incorporated in the WoTEdu interactive storytelling.

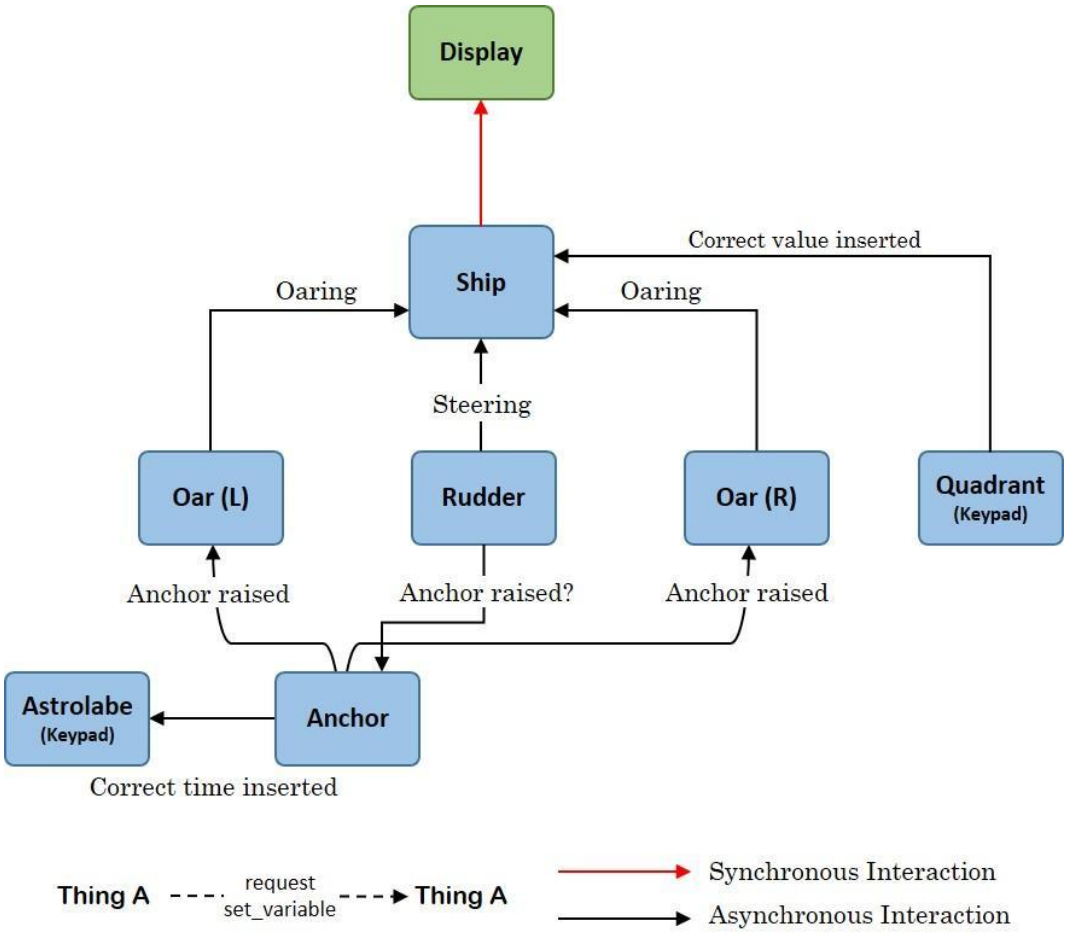


Figure 19. Representation of interactions among WoTEdu Things.

As indicated in Figure 19, at the beginning of the story the state of the anchor determines those of the rudder and the oars, which is managed by synchronous communication with the oars and asynchronous with the rudder. The rudder and oars were implemented by using rotaries. *Arduino Integrated Development Environment (IDE)* was used to develop the WoTEdu system, besides; *JavaScript (JS)* was used to manage the interactive map.

WoTEdu Museum Things

Based on the W3C WoT specifications the museum objects integrated in the story, referring to the story flow were augmented as shown in Figure 20.

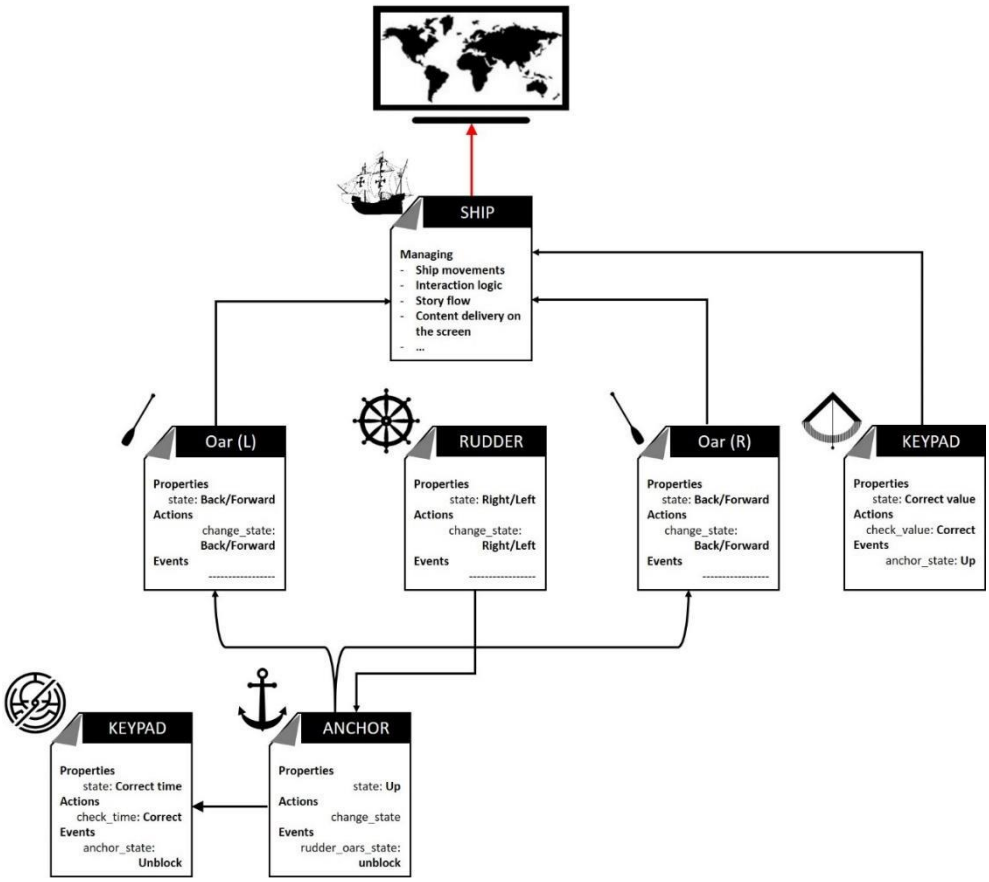


Figure 20. The WoTEdu storytelling Things implemented based on the W3C WoT.

Astrolabe Thing

The sunrise time calculated using the astrolabe is designed to be inserted using *Astrolabe Thing*, represented by a keypad. The *Properties* affordance of the Thing, defined in the TD, contains: *state* that exposes the state of the time (i.e., correct/incorrect), the *actions* include *check_time* that enables the Thing to check the inserted value, and the Events affordance contains *anchor_state*, which enables the Astrolabe Thing to block/unblock the *Anchor Thing*.

Anchor Thing

The Anchor Thing can be interacted with, once the inserted time is correct. The *Properties* affordance of anchor exposes the *state* of the anchor i.e. *Up/Down*; the *Actions* affordance,

change_state enables the Things state to be modified; and the *Events* affordance, *rudder_oars_state* is used to *block/unblock* the rudder and the oars.

Oar Things

The oars (both right and left) become unblocked and ready to use once the state of the Anchor Thing is *Up*. The Oar Things, together with the Rudder Thing, are used to allow the ship to move along its direction. *Properties* with *state*: *back/forward* expose the ongoing state of each oar to the managing system and enable the logic system to calculate the speed and direction together with the data received from the Rudder Thing. The *Actions* affordance, *change_state*, allows the Things to modify their states.

Quadrant Thing

The Quadrant Thing is represented by a keypad and is used to insert the calculated value of the latitude of the destination. The Thing contains *Properties*, *state* to expose the state of the calculated value (i.e., *correct/incorrect*), and the *Actions* affordance, *check_value*, allows the state modification.

Ship Thing

The Ship Thing enables to coordinate and regulate all the information that is generated by other Things, their communications and their use. Moreover, it also allows the management of the interactive screen, the events of the Things and the movement of the ship on the map.

Appendix C provides details regarding the structural design of the WoTEdu interactive storytelling system: *Use Case Diagram*, *Class Diagram*, *Object Diagram*, *Dynamic Model*, *State Machine Diagram*, and *Activity Diagram* of the WoTEdu system.

Moreover, Appendix DAppendix D: Things and Methods used in the WoTEdu project contains the link to access the project codes, namely *Ancora*; for anchor, *Barca*; for galley, which deals with system and content delivery management, *Keypad*; deals with time insertion and validity control, *Remo_dx*; manages the right oar, *Remo_sx;* manages the left oar, *Timone*; for the rudder. Furthermore, the appendix presents a description of all the methods used within each program contained in the WoTEdu project.

4.4.2 WoTEdu: Multimodal Interactions and Accessibility

Given the results of the evaluation described in Section 4.3.1, since the interactions with the WoTEdu system requires physical interactions with WoT-augmented museum artefacts (i.e. Anchor, ruder, oars), multiple interaction modalities were considered to provide alternative input channels to allow users with motor impairment to interact with physical objects during their WoTEdu experience.

In this regard, deploying the voice modality to enable museum visitors to fulfill their tasks, without touching objects integrated in the storytelling system, turns out to be a useful option to support users with motor impairment, but also to support safe contactless interactions for health reasons.

Interactions with the WoTEdu system are fulfilled in multiple modalities implemented for the input and output channels. Figure 21 presents a general architecture of multimodal interaction provided by the WoTEdu system indicating the modalities and devices used in each channel.

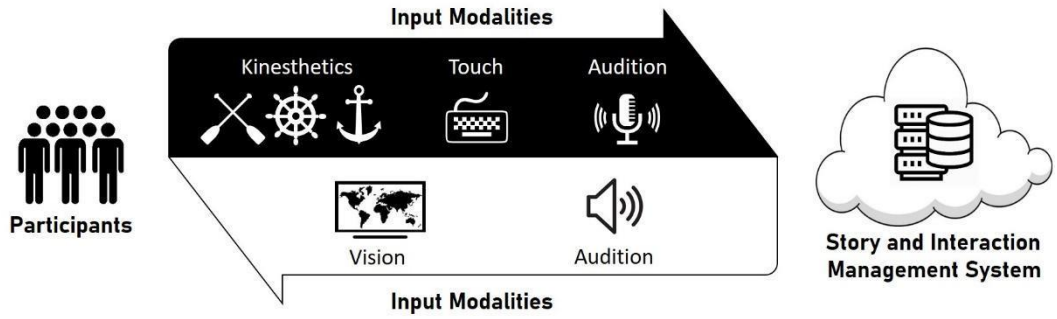


Figure 21. General architecture of multimodal interaction with modalities used for the input and output channel.

The input/output modalities provided by WoTEdu, as shown in Figure 21, can be described according to the taxonomy proposed by Augstein and Neumayr [204] shown in Table 4.

Table 4. Input/output modalities of the WoTEdu system.

	Modalities	Sources
Input	Kinesthetics: Kinematics	WoT-enabled artefacts: Anchor, rudder, oars
	Touch: Tactility	Keyboard to insert data
	Audition	Voice command
Output	Vision	Interactive display: visual narration content, multimedia content, movement and position of the galley
	Audition	audio narration content, notification, task requests

The input channel includes three modalities, *Kinesthetics*, *Touch*, and *Audition* to interact with WoTEd:

- *Kinematics* is a subcategory of *"kinesthetics"* interaction modalities presented in the taxonomy of modalities. In the story of "Set Sail with Columbus", used in the WoTEdu prototype, when participants are required to set sail and begin navigating across the Ocean to experience the Columbus' voyage, they need to interact physically will WoT-enhanced museum artefacts (i.e. anchor, oars, and rudder). These artefacts, equipped with sensors and actuators, have the communication capabilities to act as input sources to collect and communicate data to the system.
- *Tactility* refers to a device's ability to sense the physical contact of an agent. During the WoTEdu experience, participants are asked to use different sailing instruments to calculate some asked values are to be communicated to the Story and Interaction Management System to proceed with the story. The participants can communicate the calculated values by using a keyboard (e.g., before starting to set sail and navigate in the Ocean, the participants are required to use an astrolabe and calculate the sunrise tie which is determined as the departure time in the story flow. Once the participants find the right time then they use the keyboard to insert the time value).

- *Audition* refers to sound-based interaction and is an optional choice provided by the system to participants. The participants, depending on their preferences and choices, can fulfill tasks by interacting with the system through voice commands. For example, the task of enrolling to the system requires participants to insert some personal data (e.g., gender, age), fulfilling choice options (e.g., choosing quiz answers), and using voice navigation commands (e.g., moving the galley on the interactive map).

The output channel, instead, employs two modalities, *Vision* and *Audition* to fulfill the WoTEdu presentation and delivery tasks:

- *Vision* is a modality employed to present visual narration content (e.g., games, quizzes, notifications), multimedia content (e.g., instructive videos to teach how to use instruments like quadrant and astrolabe), movement and current position of the galley on the interactive map.
- *Audition* is modality used to deliver audio narration content, sound notifications to inform participants about a specific event or error (e.g., alerting the participants about an imminent storm), requests to participants about tasks they have to fulfill to proceed with the narration.

In accordance with the W3C WoT specifications, as discussed in the previous chapter, *Things* are consumed through different *Interaction Affordances* (properties, actions, and events) described in a *Thing Description (TD)*. WoTEdu uses these affordances to manage the interactions between the *Things* and with the Story and Interaction Management system.

Accessibility was addressed in the WoTEdu storytelling system and thanks to WoT different behaviors of the *Things* integrated into the system were designed according to the user preferences and futures. Together with manual modalities, WoTEdu was designed to provide speech-based modalities to facilitate interactions with WoTEdu system for users with motor impairment. For example, in case of raising/lowering the anchor, users are free to choose the modality of their interaction with WoTEdu system-using manual modes, or employing voice commands as input channel.

In order to give a better understanding of this facility of the system, a simplified diagram in Figure 22 illustrates how the WoT affordances allow managing the interaction with the anchor *Thing*.

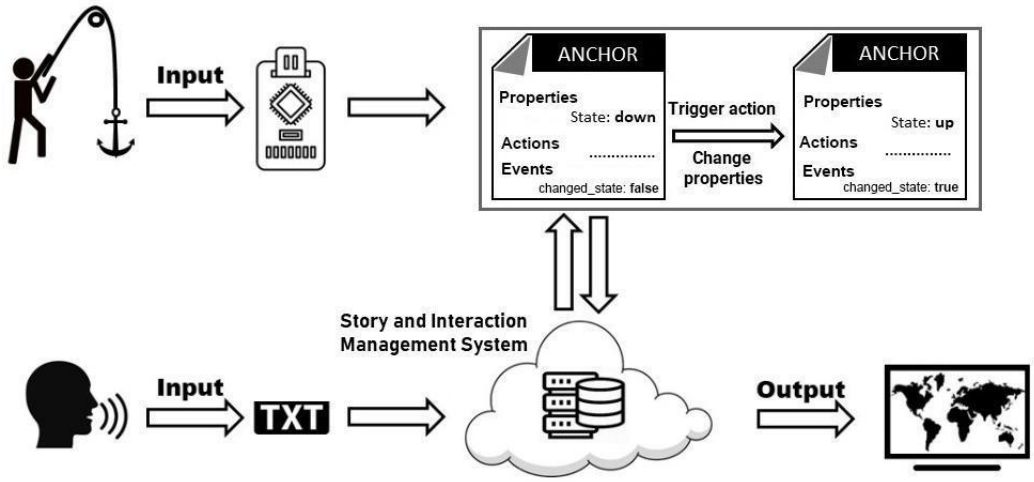


Figure 22. Simplified diagram showing the WoT affordances for managing the interaction with the anchor Thing.

The upper part of the figure shows how the anchor is used as an interaction input. In this *kinematic* interaction, when the anchor is raised, for example, the raising movement is triggered to modify the state *property* of the anchor *Thing*. This event is notified to the Story and Interaction Management system that, consequently, generates an output on the screen and takes actions for the story to progress.

The Story and Interaction Management System, implemented as a web application, is in charge of managing the interaction logic and the storytelling flow (e.g., handling the game progress and the user preferences, receiving notifications and invoking actions on the Wot-enabled artefacts, handling the responses and the interaction modality).

The lower part of Figure 22 illustrates the case in which the participant uses the *audition* modality to interact with the anchor. In this case, the speech input is recognized by a speech-to-text application and converts it into text. Similarly, the command invokes the action that changes the state of the anchor *Things*.

Both in the case of manual and voice command, the web application is notified with the *changed_state* event to take actions. In order to manage the interaction with the artefacts in the

speech-based modality, the properties of the *Things* need to be writable in order to modify them through actions (e.g., raise the anchor).

4.4.3 PILOT STUDY ON USER ENGAGEMENT

In this section, we present a pilot study on user engagement on the WoTEdu prototype conducted with master students in Human-Computer Interaction in Uppsala University.

Gaining user engagement is our overall goal of the project since it is related with higher involvement of the users and active participation, which is one of the requirements aimed to make the ancient sailing practice to be shared and acquired

The evaluation used an exploratory mixed quantitative and qualitative approach to collect data. The evaluation employed a User Engagement Scale, observation and semi-structured interviews, respectively, in quantitative and qualitative methods for data gathering.

Note……..

Due to the COVID-19 Pandemic, the Swedish government announced restrictions and measures that banned all meetings and group-based activities in the university during the 2020-2021 academic year. These restrictions proved to be impossible to plan the pilot study of the WoTEdu prototype in the way envisioned.

Since, the prototype included WoT-enabled tangible artefacts to be interacted during the storytelling experience, it seemed to be inevitable to apply some modifications to the prototype in a way that all physical interactions to be experienced and perceived by the participants during the evaluation.

This unexpected issue, despite requiring further efforts, was tackled by substituting these artefacts with their digital counterparts with corresponding interaction models as shown in Table 5. The solution resulted in an on-line version of the WoTEdu system and provided the possibility to conduct a remote pilot study with the participant group.

Table 5. Digitally implemented artefacts with corresponding interactions for an on-line version of the WoTEdu prototype.

artefact	Interaction
Anchor	*Using a click speed game to lower/raise*
Rudder	*Using keyboard arrows (←↑↓→) to move the galley on the map*
Oars	
Astrolabe	*Using a digitally implemented interactive astrolabe with possibility to turn it back and front, and move its rete and alidade.*
Quadrant	*Using a digitally implemented interactive quadrant with possibility to move and line it up with the North star and read the pending index arm*

The detailed WoTEdu storyboard attached in Appendix EAppendix E: Storyboard for online WoTEdu experience illustrates the digital counterparts used in the on-line version of the WoTEdu interactive storytelling prototype.

……

In the context of User-Centered Design (USD), usability testing is essential to determine whether a given designed system is usable [171]. Usability, as a part of term User Experience (UX), has been a principal aspect in a system development process, which helps to improve system facilities to address users' needs [205]. Usability is used as a degree to measure if specified users, in a particular environment, can achieve the specified goals with effectiveness, efficiency, and satisfaction and in an acceptable way [206].

Moreover, despite the traditional usability engineering, UX takes into account users' emotions evoked by a system. UX considering users' feelings, motivations and values extends the usability concept beyond effectiveness, efficiency, and satisfaction [207] [208].

User engagement (UE), as a quality of UX, has been of increasing interest in human-computer interaction (HCI) and different tools have been developed and employed in a variety of digital domains to measure this quality [209].

O'Brien et al. [209] have conducted a study, the User Engagement Scale (UES), focused on the challenges of measuring UE used in design and evaluation. Their work resulted in a 31-item experiential questionnaire (see Appendix F) that encompassed six factors or dimensions as shown in Table 6.

Table 6. The dimensions included in the User Engagement Scale (UES) proposed by O'Brien et al.

Focused attention (FA)		*feeling absorbed in the interaction and losing track of time (7 items).*
Perceived usability (PU)		*negative affect experienced as a result of the interaction and the degree of control and effort expended (8 items).*
Aesthetic appeal (AE)		*the attractiveness and visual appeal of the interface (5 items).*
Reward (RW)	**Endurability (EN)**	*the overall success of the interaction and users' willingness to recommend an application to others or engage with it in future (5 items).*
	Novelty (NO)	*curiosity and interest in the interactive task (3 items).*
	Felt involvement (FI)	*the sense of being "drawn in" and having fun (3 items).*

The widespread use of the UES in different HCI domains and the way that it had been implemented in studies, encouraged the authors to revise the USE to develop a briefer and more effective version of the USE. To this end, the authors proposed and validated the shorter version of the USE[40].

In this new version the Endurability (EN), Novelty (NO), and Felt involvement (FI) dimensions were grouped into a single dimension called Reward factor (RW).

The short form (SF) of the USE- called USE-SF, however, includes the four dimensions of the former version: Focused attention, Perceived usability, Aesthetic appeal, and Reward factor.

As the authors validated the UES-FS, which is a 12-item questionnaire that looks closely at the dimensions of the UES, still can capture the core concepts represented in the full form (in Appendix G the UES-FS questionnaire items are presented).

In the following we will describe the Pilot Evaluation we performed by using the User Engagement Scale (UES) short form (SF).

[40] The authors in their original work the UES consisted of 31-items and purported to measure six dimensions of engagement: aesthetic appeal, focused attention, novelty, perceived usability, felt involvement, and endurability. A recent synthesis of the literature questioned the original six-factors. Further, the ways in which the UES has been implemented in studies suggests there may be a need for a briefer version of the questionnaire and more effective documentation to guide its use and analysis. This research investigated and verified a four-factor structure of the UES and proposed a Short Form (SF). We employed contemporary statistical tools that were unavailable during the UES 'development to re-analyze the original data, consisting of 427 and 779 valid responses across two studies, and examined new data (N = 344) gathered as part of a three-year digital library project.

Main goals of the study

The pilot study on engagement aimed to (i) investigating the interaction between the users and the interactive installation (interactive objects screen, quizzes, and multimedia materials), looking carefully at the dynamics among participants, (ii) analyze the engagement level and its development during the experience, looking especially at the differences between diegetic and non-diegetic interactions. The study employed mixed quantitative and qualitative methods to collect data from the participants.

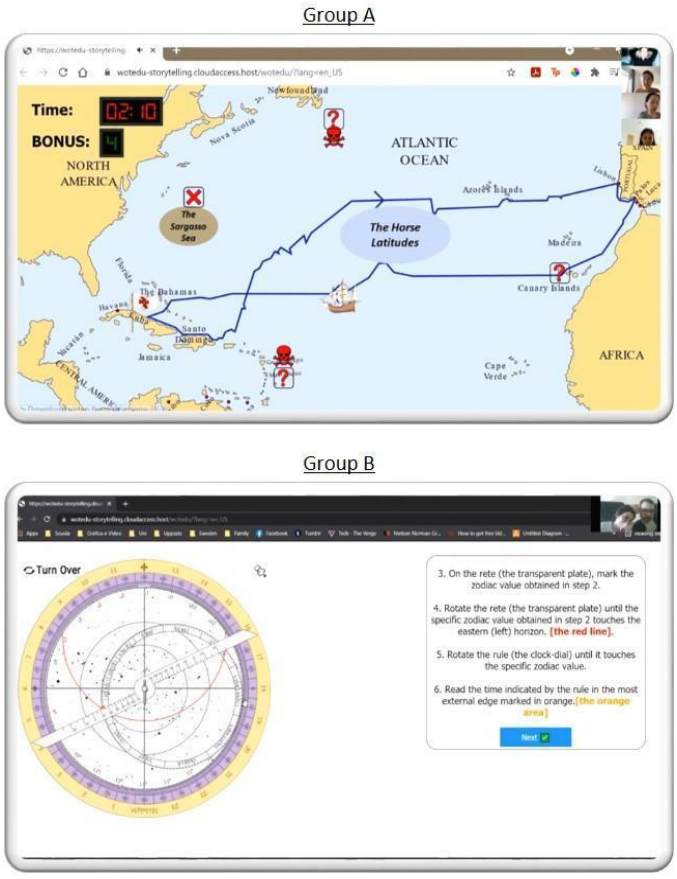


Figure 23. Online pilot study on WoTEdu User ENGAGEMENT: Four participants in Group A are sailing on the map, two participants in Group B are interacting with astrolabe.

Evaluation Procedure

In order to recruit volunteer participants, an announcement email was shared with the Department of Informatics and Media- Uppsala University. The email contained a brief introduction about the WoTEdu system and the modality of the study. The participants were asked to act as museum

visitors and play an on-line museum game for 15-20 minutes and then participate in an online survey and finally have an interview (about 20-30 min). The mail also included the Zoom meeting link (see Figure 23).

The volunteers had been offered a very flexible time schedule with the possibility to register in a group or individually. We received registrations from six candidates that were interested in the study.

Participants

In this study, six participants (5 females and 1 male) acted as participants and tested the on-line version of the WoTEdu system. The participants participated in two groups of four and two people[41]. The participants were master's candidates in Human-Computer Interaction at the Department of Informatics and Media.

All the participants, with the age ranging from 22 to 30, came from different cultural backgrounds and nationalities (Chinese, Myanmarese, Swedish, Italian and Bulgarian). Most of them frequently play computer games and five out six had experience and experties in game designing e.g., interactive fitting room game using Kinect and Unity, and interactive game app for the natural history museum.

In order to access the study details, the participants were asked to confirm the recording consent form (see Appendix H) at the beginning of the session. During the evaluation sessions, one of the participants was asked to access the game link and share the screen with his/her teammates.

In order to enhance the spirit of teamwork and collaboration, the participants were encouraged to talk and guide their partner that was playing the game. They were free to search on Google to find the answers of the quizzes.

After the WoTEdu storytelling experience, the participants participated in an online survey based on UES-SF with the following five-point rating scale:

[41] The minimum of 3 participants was defined for the users who participate in an interactive system with physical objects. As explained previously, due to the Pandemic restrictions we had to establish an online version of this experience in order to make the most of our time, since it was unknown how long the restrictive situation would last. However, the online version of the interaction enabled us to have,also, two participants.

Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly agree*
1	2	3	4	5

Finally, the participants in a semi-structured interview shared their experience relating to the WoTEdu storytelling system. The semi-structured questions are available in Appendix I.

Results and Analysis

The pilot study on WotEdu user engagement showed encouraging results in most dimensions relating user's absorption and control in interaction with museum artefacts and their satisfaction from the experience. According to the users, the installation contains elements to attract the user's curiosity to try and provides learning experience through playful interactions. However, results concerning some aesthetic aspects such as quality of multimedia content and visual aspects of the interface, showed that the participants were not satisfied enough and they were expecting more high-quality videos and graphic design of the web application. In the following, the data collected through different methods; quantitative, observation and qualitative are discussed.

Quantitative data

The overall User Engagement of the WoTEdu is 4 out of 5, which is an acceptable result. Figure 24 illustrates the overall scores gained from participants for each dimension. The scores, in descending order, are as Reward factor (4.75), Focused attention (4.00), Perceived usability (3.95), and Aesthetic appeal (3.16).

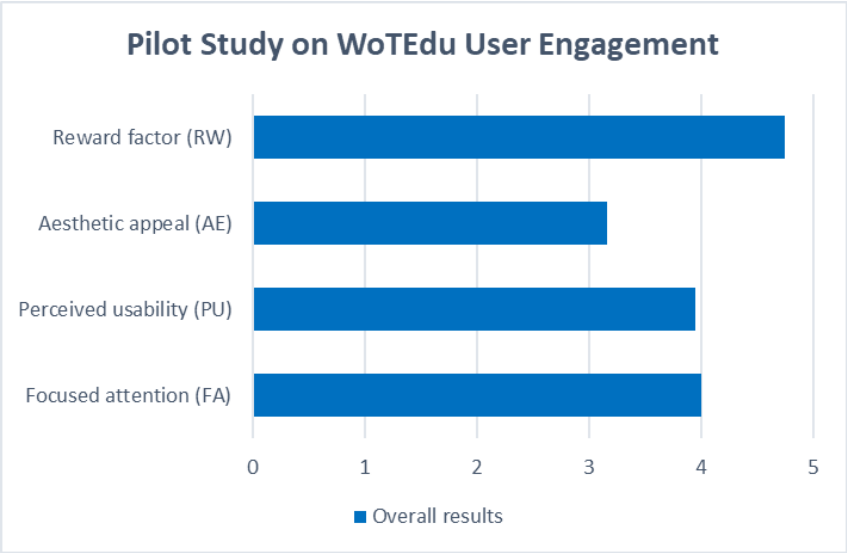


Figure 24. Pilot study results on WoTEdu User Engagement.

Reward factor (RW), indicates the users' willingness and curiosity to interact with WoTEdu and can be interpreted that the participants have had an enjoyable experience and would recommend the WoTEd experience to others.

Focused attention (FA), can be considered the most important factor in the WoTEdu prototype evaluation, however, the high overall score gained by this factor means that the participants were immersed in the experience and having their feelings absorbed in the interaction.

Perceived usability (PU), as the third in the overall score order, gained a high score that indicates that the participants managed the experience with a high degree of control on fulfilling interactive tasks.

Finally, the last dimension in the order, Aesthetic appeal (AE) indicates that the visual representation of the prototype (e.g., interface and videos) must be improved to be more appealing for users.

Qualitative observation data

Due to the limitations caused by on-line evaluation, the participants were not able to be sufficiently active and collaborative. Actually, the interactions with the interface were being performed by a single participation and others were helping their teammate to follow through the interactions. The

idea of enabling them to feel free to use Google for answers of the quizzes in predefined checkpoints turned out to be helpful to leverage the engagement through *collaborative dialogue*[42].

This lack of collaboration was noticed more in the crowded team, group A. However, active collaboration and the establishment of continuous dialogue between less crowded group, group B, seemed to be more achievable.

Moreover, all the participants in both groups seemed very interested in the experience and in some cases (e.g., the video that explains the use of astrolabe and quadrant); they were sharing their comments on how they should calculate the asked values.

Qualitative data and interview

- *Enjoyment*

The results obtained from the semi-structured were also interesting and could help more to understand the participant' impression and collect their comments. The participants, mostly, found the experience enjoyable and impressive as participant A1 stated: *"… I really liked playing with different objects. Especially the last one [quadrant] that I didn't know what it is used for."* Similarly, participant A2 adds *"I would like to try and travel and do the things again because it is funny and I am kind of missing it. That sounds great!"* or as the participants B1 and B2 stated *"The whole set is pretty cool! … with this installation you can feel yourself as a part of the museum."*, *"The created set was very cool, it worked very well, actually!"* all can refer to the enjoyment and engagement that aimed to reach with the project. According to participant B1, *"there are a lot of museum installations with digital solutions like touch screens, but having some physical component has really potential to increase user involvement and enjoyment during the experience*."

- *Engagement*

The participants found the WoTEdu system surprising and capable of engaging the participants with unexpected events. The participant B1 stated *"Honestly. I didn't know what to expect during the game ... using an instrument to solve some kind of mathematical problems was very cool and surprising!"* According to participant A1, *"There were some surprising up and down moments and*

[42] Collaborative dialogue has been defined as dialogue in which speakers are engaged in problem solving and knowledge building [156].

when we are traveling around the map and reaching some destination, the game unexpectedly stops. We are surprised at what we should do now." The participant B2 confirmed, *"Having the possibility to interact with instruments digitally was unexpected*." In addition, the participant A2 referring to a video before a quiz found it unexpected and *"pretty humorous"*. The statements can apparently confirm that the objective to make the participants engage and relax is accomplished through the distribution of the diegetic and non-diegetic moments in the storyline, which influence the pacing of the story. Moreover, they can be interpreted as the *curiosity*, *interest* and the *willingness* of the participants to continue to discover the story and interact with the system.

- *Education*

Concerning the learning and educational aspects of the system, the interview revealed that the storytelling system is well matched to communicate helpful information in different fields such as history, geography, and sailing techniques and instruments that can enhance the participants' general culture. Especially, providing visitors with *learning-by-doing* was an interesting aspect of the storytelling system. In this regard the participant A3 added, *"If we use the physical objects, it could be clearer and we could learn more and in depth."*

As stated by participant B2 *"actually the context is about learning, and interacting with instruments (quadrant) was nice to learn how it works…. I learned about the magnetic deviation, astrolabe, and what a 'caravel' means."* He continues, *"I wish I had the chance to experience such a museum installation when I was a child [smiles], because I couldn't touch anything when my parents took me to a museum visit"*. Accordingly, participant B1 adds, *"Actually, it is not enough to listen and watch the video and you learn when you use the astrolabe to solve the problem."*

- *Collaboration*

According to the participants, the WoTEdu experience can enhance the collaboration among museum visitors. As discussed, the participant B2, *"The collaborative point in the game brings people together to discuss and choose the correct answer…"* He continues referring to his experience as *"we asked each other when we didn't know the answer and if you have more people around you can just have a discussion*." However, the participants A1, A2 and A4 highlighted that WOTEdu can encourage communication among friends, in some ways, when they discuss the answers, especially in the museum environment with real objects. The participant A2 discussed that the experience

demands an organization in the group and the participants need to share and divide the tasks among them, which leverages the sense of collaboration.

We received some comments and suggestions to improve the system that were mostly about the aesthetic concept in implementation, offering rewards to encourage the users to be more active and engage themselves more in the experience.

5. TEST: USER STUDY

In this chapter, we present the user engagement evaluation with end users, the final iteration of the User-Centered Design process applied in WoTEdu. It evaluates the visitors' interaction with the WoTEdu system in the museum environment to validate or invalidate the usability of the WoTEdu system, applying the previously used User Engagement (UE) dimensions. This chapter includes the evaluation procedure and related obtained results.

5.1 EVALUATION PROCEDURE

In order to evaluate the end users' interaction with the prototyped system, considering the volunteer user availability to participate in the study, the study was conducted in the *MuSel*-Archaeological and City Museum in Sestri Levante in the region of Liguria.

The **MuSel** [43]– Archaeological and City Museum in Sestri Levante in the region of Liguria – opened to the public in 2013 with the aim of preserving and enhancing the memory and identity of the territory. During the pandemic, the Musel offered the possibility of visiting museum exhibitions on appointment applying restrictions on the *number* of visitors. This provided the chance to conduct the evaluation in a room accessible in the museum. The room was spacious with a large interactive screen that was well matched to set up the storytelling objects and create the expected exhibition environment for the final user study.

Participants

The participants for this end user study were volunteer museum visitors. In order to tackle the restricted communication issues caused by the pandemic; the participants were recruited by publishing announcements on the museum's social channel and by word of mouth.

[43] http://www.musel.it/musel/

The user study included three groups (families) with overall 11 people composed of five adults and six children. The participant groups and the duration of their experience are detailed in Table 7.

Table 7. Participants' details and the experience duration.

	Adults		Children		Experience duration
	Male (age)	Female (age)	Male (age)	Female (age)	
Group A	1 (35-40 y.o.)	1 (35-40 y.o.)	1 (10 y.o.)		18 min
Group B		2 (35-40 y.o.)	3 (9 y.o.)		22 min
Group C		1 (35-40 y.o.)		2 (12 y.o.)	25 min

Experimental Session

Initially, the participants were provided with brief and general explanations about the concept of the study and what they were going to do. They were asked to feel free to take a look around to familiarize themselves with the prototype, however they were not given any explanation how they could use or interact with the objects. Afterwards, the adult components of the group were asked to sign the prepared consent form (Appendix H).

Figure 25. Participants are interacting with the WoTEdu storytelling system.

In the experimental sessions, the participants interacted with different objects of the storytelling system to experience the “Sail with Columbus”. Figure 25 illustrates objects and moments of the participants' interaction with the prototype.

Each session lasted around 45 minutes; they spent an average of 22 minutes to arrive at the destination and complete the story, and afterwards, they were asked to participate in a survey on UES-SF and interview, which lasted around 25 minutes.

5.2 RESULTS AND ANALYSIS

The user study based on the User Engagement Scale (UES), as a quality of user experience, evaluated different dimensions with museum visitors. The overall results obtained through different methods (i.e., quantitative, observation, and qualitative), showed encouraging results in all four dimensions as detailed in the following.

The scores for each single dimension are around 4 and the average scores of each gained from all three groups are as:

- Reward factor (4.90) that encompasses: Endurability (EN): the overall success of the interaction and users’ willingness to recommend an application to others or engage with it in future, Novelty (NO): curiosity and interest in the interactive task, and Felt involvement (FI): the sense of being “drawn in” and having fun.
- Aesthetic appeal (4.42), the attractiveness and visual appeal of the interface
- Perceived usability (4.13), negative affect experienced as a result of the interaction and the degree of control and effort expended, and
- Focused attention (3.93), feeling absorbed in the interaction and losing track of time

Quantitative data

The User Engagement evaluation applied to WoTEdu prototype shows an encouraging overall result of 4.34 out of 5. Figure 26 shows the scores gained from participant groups for each dimension of UES-SF. The scores for each single dimension are around 4 and the average scores of each gained from all three groups are as; Reward factor (4.90), Aesthetic appeal (4.42), Perceived usability (4.13), and Focused attention (3.93).

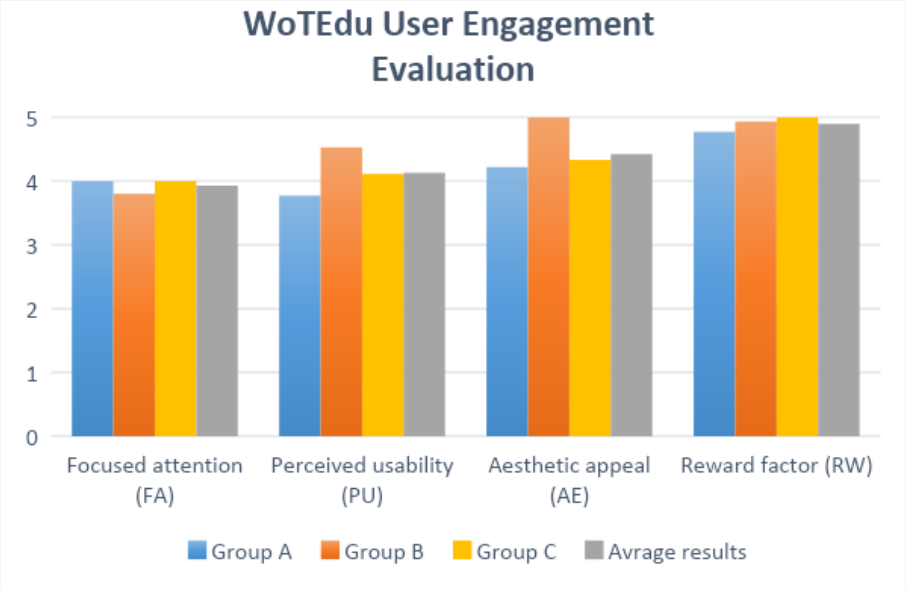


Figure 26. Evaluation results; user engagement based on UES-SF, conducted by museum visitors.

Reward factor (RW), with an overall of 4.90 is the best performing factor and obtained a minimum score of 4.77 from Group A -composed of two adults and one child. The results obtained from Group B and Group C, with three and two children respectively, are around a maximum of 5, which shows the children's high interest in this factor. This is particularly interesting because in this user test the gamification dynamics (such as the countdown and the possibility to gain a final score) were not highlighted, though the result indicates that the intrinsic challenge in the game results the most important factor for achieving a good level of engagement.

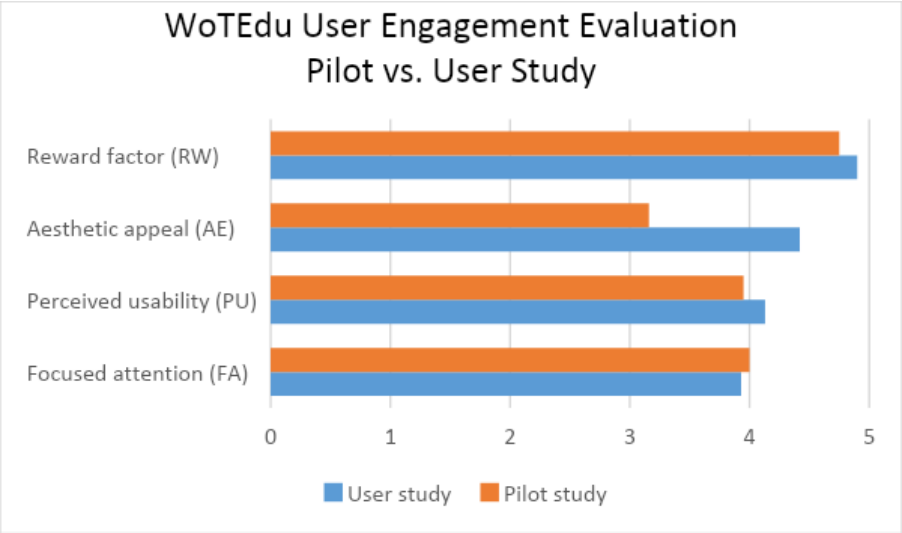


Figure 27. WoTEdu User Engagement Evaluation: Pilot vs. User Study

Figure 27 illustrates the results obtained for each dimension in the present evaluation and the heuristic evaluation conducted by expert evaluators. The figure shows that the scores gained for every single dimension in both evaluations, except Aesthetic appeal (AE), are significantly close.

As discussed previously, the participants in the user engagement pilot study criticized the aesthetic factor in the WoTEdu prototype and accordingly the Aesthetic appeal (AE) factor received a lower score compared to the other dimensions. Although the aesthetic concept was not a primary factor in the prototype level; however, the Aesthetic appeal (AE) factor in USE-FS evaluation comes in second place (4.42). The highest scores are obtained from Group B (4.93) and Group C (4.90). Referring to the child members of these groups, it shows that the prototype was considerably able to be appealing and attract the participants to interact.

Perceived usability (PU) as the third in the overall score order (4.13) indicates that the participants have had a satisfactory degree of control during their interaction with the prototype. It shows that the WoTEdu storytelling system is capable to involve the user in the interactive experience giving them the freedom to control and manage their experience. The highest score for this factor was gained from Group C (4.53) with three children, which shows that the storytelling system offers perceivable interactions that can be easily fulfilled.

Finally, Focused attention (FA) with the overall score of 3.93 comes the last in last in the score order. The scores gained for this factor from Group A and Group C are both 4. The lowest score was gained from the most crowded group, Group B (3.80). The overall result confirms that the storytelling prototype is capable of involving the users and making them feel absorbed in the interaction with the system. However, the single scores obtained from each group shows that the experience could be more engaging for not less crowded groups such as Group A and Group B. The reason might lie in the distracting situations caused by other participants in a group that make participants feel overwhelmed and lose concentration.

Qualitative observation data

The initial cutscene video, with a duration of one minute and twenty seconds, did not have a positive effect on any of the participants in all groups. The video aimed to introduce the participants into the Columbus' story world; however, after a few seconds the participants detached themselves from the screen, beginning to look away, sit down and talk to their co-player. This confirms the quantitative results regarding Focused attention and Perceived usability. The first collaborative moment with the first quiz after the video enhanced Focused attention among the participants. The collaboration took place differently in the groups; in Group A, the adults were trying to help the under-13 participant to understand and solve the quiz, instead, in Group B and C, all under-13 participants had more active collaboration among themselves independently from the adult members of the group. The similar dynamic was observed repeatedly in all the other challenges during the experience.

Despite no reward being promised, the participants were curious and interested in fulfilling their task and finding the correct answer. They were enjoying the challenge and each correct answer gave them satisfaction and stimulated them to continue the experience. This aligns perfectly with the quantitative results obtained for Reward factor (RW) and confirms the aspects of willingness to interact with the system and have fun.

Regarding Aesthetic appeal (AE), considering the aforementioned cutscenes the visual part of the prototype seemed not to be sufficiently satisfactory, however, when the participants made a shift from non-diegetic to diegetic moments the interaction experience was improved. For example, after

the first introduction cutscene the participants were asked to lower the anchor, until that moment the participants had interacted with the interactive screen, which are non-diegetic moments. Although at the beginning few this was to some extent confusing because they were expecting to continue the same steady non-diegetic moments on the screen, however, when they explored that they are required to interact with a physical anchor in the room, they accomplished to make this moment shift from non-diegetic to diegetic.

After this opening to the tangible dimension of the experience, the participants were able to easily understand the movements between these moments and enjoy the interaction with physical objects. Thus, considering the prototype as a whole the high score gained for Aesthetic appeal (AE) in the quantitative results suggests that it can be attributed to the attractiveness of the tangible interactive objects integrated to the prototype.

Qualitative data and interview

The post-experience interview with the participants highlighted collaboration as a main factor that enhances engagement and pushes the participants into the storyline.

The adult participants appreciated the way in which WoTEdu encourages the children to collaborate and share tasks. However, referring to the experience of Group A, composed of two adults and one under-13, in some steps of the experience, where the adult participants try to help the under-13 participant with the astrolabe challenge, collaboration becomes nonreciprocal. This asymmetric collaboration aspect aroused less interest to understand the functions of the augmented navigation tools. This issue is mitigated in the groups with more symmetric distribution of the participants of the same age, Group B and Group C.

Concerning the interaction with augmented real-world objects faced in diegetic moments of the experience, two thirds of the participants found it difficult to manage. This is the well-known affordance problem, which concerns how users perceive what actions affords a given object in a given situation [211]. This was partially expected given the novelty of the application. However, on the one hand, it highlights the important role of *visibility* as discussed Norman:

"The human mind is exquisitely tailored to make sense of the world. Give it the slightest clue and off it goes, providing explanation, rationalization, understanding." [212:P.2]

"Visible affordances provide strong clues to the operations of things." [213: p.13]

On the other hand, it draws attention to the environment of the experiment. It is worth to remind that the environment in which the participants experienced the installation. The WoTEdu system was designed to be installed in the room dedicated to Christopher Columbus at the Galata Museum, however due to the restrictions it was not possible to do so. According to Gibson [211] user's perceptions are guided by the perception of what the environment is offering in terms of action potentialities. Thus, the perceived use of objects depends heavily on the action context in which the object is presented [214].

The participants expressed their pleasure of being able to touch the artefacts to fulfill the task during the experience. They stated that normally in a museum visit it is possible to visit the exhibited artefacts and get some information about what they are and how they are constructed. They added that having the possibility to touch and practice them during the interactive storytelling experience is very helpful to learn how a museum artefact works. The participants expressed that they could continue the experience if there would have been more interactive challenges with physical artefacts and tasks e.g., quizzes to fulfill. This confirms the fact that museum visitors are expecting museums to provide more visitor-centered activities [215] and highlights that people visit museums to have an entertaining and learning experience.

5.2.1 DISCUSSION

Museums are public assets that contribute to cultural sustainability. Museums play an important role in preserving cultural resources and ensure the continuity of cultural values that provides a better understanding of the past and the present to shape the future [2] [216]. Moreover, the educational role of museums aims to intermediate the beliefs and practices, and encourage the development of new community values and attitudes within society [217] [218].

In order to accomplish their mission, museums "must be an active and attractive part of the community by adding value to the heritage and social memory" [219]. In this regard, digital technology enables museums to create an active environment to attract more visitors and interactive storytelling systems used in museums are an important *piece of the puzzle*.

The proposed tangible interactive storytelling system in this research, WoTEdu, aimed to address edutainment experience in a maritime museum.

As discussed in Problem Statement in Chapter 2, the first problem was to manage the integration of the museum artefacts in the storytelling system in a way that they act as tangible interfaces and allow the visitors to interact with the narration. Since in such an interactive system the artefacts can offer multiple functions in relation to the function of other artefact, however, the second problem was to manage the functions of these integrated artefacts in a dynamic system.

The prototype showed that the problems could be tackled by employing the specifications defined by the W3C Web of Things paradigm[44]. The paradigm enables to define each artefact as a *Thing* and enable synchronous and asynchronous communication among these things through the Things descriptions (TDs), describing *properties*, *actions*, and *events* for *Things*.

The WoTEdu final user study showed favorable and promising results. The results indicate that a tangible interactive storytelling system enables museums to create a visitor-centered experience, which allows the visitor to actively control their museum experience. However, in the case of cooperative experience with the system, the control perspective of an interaction shifts to sharing the interaction with other visitors. Sharing the interaction enhances also the verbal communication to share information among the collaborators [220] and Butler [221] discusses the power of language that can constitute action. Therefore, the verbal communication results in collaborative dialogue that is expected to encourage the visitors to engage in problem solving and knowledge building [210].

[44] Although, the the interaction among objects involved in the prototype could be implemented by using the Internet of Things (IoT) paradigm, however, the Web of Things paradigm offers more facilities to define each object that can be reusable in the similar projects and also WoT simplifies the communication among the objects using the Web protocols.

As observed during the user experience evaluation, the participants tend to initiate a dialogue when they face quizzes and physical interactions - especially when an instrument is technically complicated - to share the ideas to find the correct answer.

The integration of diegetic and non-diegetic moments in the storylines turned out to be a delicate approach to engage the visitors in a non-linear story. However, an unelaborated shift design between diegetic and non-diegetic moments can cause confusion for participants during their interaction with the storytelling system. This confusion is related to the affordance problem as discussed Gibson [211] user's perceptions are guided by the perception of what the environment is offering in terms of action potentialities. Thus, the perceived use of objects depends heavily on the action context in which the object is presented [214].

Ellis [222] goes beyond the environment context and discusses the affordance activation of objects in relation to the physical, social, linguistic, and cultural contexts. Borghi [223] discusses multiple action possibilities that can be activated due to different reasons, such as the distance of the object from the user, the situation, the presence of further objects, and active versus passive role of objects. Furthermore, she discusses that the presence of multiple agents can influence perception of affordances and make the situation more complex.

The prototype evaluation also identified certain relationships between the ages of participants in a group and their interactions. In groups composed of participants with different age groups (adults and children), the collaboration among the members resulted to be less reciprocal in the groups with asymmetric distribution of the participants of the same age (e.g., one adult and two children).

The research results show that museum visitors would be interested in tangible interactions based on a non-linear storytelling approach that could enrich interaction. The deployment of physical museum artefacts as a tangible interface to provide the interactive experience in the storytelling system and enables the participant to shift non-diegetic to diegetic moments of the story. These interactive tangible interfaces allow the user to practice, explore, and learn the functions of the artefacts and use them to proceed with the story.

Moreover, the collected user feedback for the aesthetic factor of the prototype from the end user, in comparison to that of the pilot study on the user engagement shows a considerable improvement. The result can be attributed to the application of physical artefacts in the final user

study rather than digital counterparts. However, as components of the interactive storytelling system, the physical artefacts can contribute to the aesthetic enrichment of the system (see Chapter 5, Figure 27).

The study aimed to achieve the research objectives through different evaluations. The preliminary to evaluate the conceptual design showed the potentials of the research approach in communicating the maritime cultural heritage through edutainment experience. The results obtained from the pilot study on user engagement with the storytelling prototype highlighted the importance of visitor's active role in museum experience, which creates enjoyment and enhances the sense of collaboration among visitors to stimulate them to discuss and share their knowledge on related subjects during the experience. Finally, the user study on engagement revealed that interacting with museum objects encourages the visitors to practice and discover the function of objects. Accordingly, it can be claimed that the objectives set for this research to some extent were achieved.

6. CONCLUSION

In line with the European research and innovation framework program Horizon 2020 aimed to support initiatives for preserving, reconstructing and promoting cultural heritage [5]; And the importance of visitors' active role in museum, on the one hand, and the growing and indispensable presence of technology in cultural heritage domain on the other hand, shaped the research origin to enhance heritage artefacts to intermediate the history, enabling visitors to be involved in the museum experience during their visit.

Accordingly, this thesis presented the study and design for an interactive storytelling installation for a maritime museum. The installation is designed to integrate different museum artefacts into the storytelling system to enrich the visitors experience through tangible storytelling.

> *The high-level goal of this research is to investigate the potential of using integrated and tangible storytelling to engage visitors and promote cultural heritage, with a specific focus* on *the communication of maritime practices in the past*.

Given the high-level goal of communicating maritime practices, the following objectives were identified to address it:

- *Enhancing the visitors' active role in their museum visit*
- *Creating an enjoyable museum experience through interaction with the artefacts*

To achieve this goal, the study investigated the application of the following approach and methods that are currently scarcely explored in the literature, as discussed in Section 3.1:

A. *Using museum artefacts as tangible interfaces in interactive storytelling*
B. *Designing a dynamic interactive storytelling system in which the functions of integrated artefacts are considered in relation to other artefacts*

The former statement addressed the use of real museum objects (or replicas) as tangible interfaces in interactive storytelling to investigate the related possibilities and challenges that are scarce in the area of interactive storytelling. However, the latter investigated the dynamic functions of the

objects, in a tangible interactive system with a non-linear narrative, in relation to the functions of other objects.

Considering the high-level research goal and the identified problems, the approach proposed and investigated an innovative application of Tangible Narrative and the Web of Things paradigm applied to the field of cultural heritage. The proposed approach employed the narrativity potentials of cultural artefacts combined with the physical dimension.
Therefore, WoTEdu, a case study project, was designed to experiment and analyze the effectiveness and limits of the approach based on the result in the controlled scenario of the use case to investigate the research question formulated as:

To **what extent; the proposed application succeeds in**:

> *Engaging the visitor in the museum experience through interaction with artefacts that play different roles in order to communicate a maritime practice, intended as a complex practice that pertains cultural heritage.*

The research project was framed within a four-phase iterative process: study, Design, Prototype, and Test. The iteration began with literature and related work review together with a field study at the Galata Maritime Museum. In the design iteration, a design concept of a tangible interactive storytelling system was created and evaluated. The tangible storytelling prototype, based on the Web of Things paradigm, was developed and a pilot evaluation was applied in collaboration with master students in Human-Computer Interaction in Uppsala University. Finally, in the last iteration of the design process the user study was conducted with museum visitors.

Other than the limitations taken into account during the design, the COVID-19 Pandemic restrictions caused serious limitations on the evaluation process of the WoTEdu system. The issue for the pilot study on user engagement was tackled through an online version of the project to make it available for the participants to conduct a remote pilot study with the participant group. Related to the user study still due to the restrictions we had to conducted the evaluation with limited number of the participants groups.

However, the results obtained are promising for how digital narratives can be enriched with the tangible dimension and thanks to this dimension can enable to communicate stories and knowledge of the past that are very complex, such as the art of navigating in the past.

The proposed WoTEdu approach, thanks to the Web of Things (WoT) paradigm, accomplished to employ the museum artefacts as pieces of the puzzle that tell their own stories to encourage the visitors to learn and practice the use of them to explore more.

Though, WoTEdu promisingly provides a better understanding of the past [2] [216] through creating an active environment to attract visitors and intermediate the old sailing practices to address the educational and entertainment aims of the museum [217].

The research encouraged to consider the potential of the proposed approach in designing complex practices to create diegetic and non-diegetic moments to simulate the art of navigating the past. The interactions designed for diegetic moments employing the artifacts identical to the ancient navigation tools allowed the participants to immerse themselves in the narrative world. The interactions designed for non-diegetic moments (i.e., interaction with the interactive map and the checkpoints contained in it), on the other hand, allowed the participants to have an overview of the era in which Columbus made his sea voyages.

The collaborative dynamics can be considered an excellent element for the transmission of information [277]. The approach presented a promising ability also in creating collaborative dynamics among participants. The elements of collaboration and cooperation within the group showed that the installation would be able to achieve the objectives of the research to create an engaging and enjoyable museum visit.

Moreover, According to Butler the power of language that can constitute action [221]. The collaborative characteristic of the project during the user study, especially in shifts between diegetic and non-diegetic moments, referred to the capability of the system to enhance also the verbal communication to share information among the participants [220].

Although the prototype was tested in a specially set up museum room, the technology used has the potential to be applied throughout the museum set-up, providing the possibility for a museum to make the whole set up interactive, a hypothesis that the participants rated it positively.

The proposed approach, on the one hand, enabled us to develop a project with different potential and, on the other, paved a way for a useful opportunity to deepen the study related to digital and tangible narratives. However, considering limitations and imposed restrictions during the user

study, further studies must be conducted to apply statistics over a large number of participants in order to have more precise and deterministic results to confirm the results.

6.1 LIMITATIONS

This section briefly reports some of the limitations of this research work that can be indicated as follows:

- The need for multimodality for the purposes of accessibility is a feature that was added as an output of the iterative evolution. This requirement was addressed in the prototype design and as explained in Section 4.4.3, it enables the users with physical impairments to interact with the storytelling system through voice commands. However, due to the limited time planned for the research to arrange an evaluation with users with disabilities, there was not the opportunity to conduct an evaluation on this aspect of the prototype.
- The user's comprehension and learning were partially evaluated through the qualitative analysis of the user study; however, it could be an interesting to perform a more specific evaluation on the effect of the tangible interactive storytelling system on learnability during the visit and the post-visit memorability to evaluate if f the embodiment has also a long-time effect. Such study would be useful to support learning in the Cultural Heritage domain.
- Concerning the final goal of promoting cultural heritage about maritime instruments and practice in the past, the research should be expanded to create novel access models, enhance users satisfaction, improve knowledge transmission [88] and the public awareness about cultural heritage e.g. i-MareCulture [11], familiarize them with unpopular cultural heritage resources [224], and connect existing digital historical resources, locations, people, artefacts and concepts e.g. CrossCult H2020 Project[45] [225].
- The research project was conducted in the H2020 framework aiming at the EU identity, belonging, and citizenship values focusing on the regional cultural resource, however, the content used in the storytelling was mainly related to the region of Liguria.

[45] http://www.crosscult.eu/

- Due to the limited access to museums and end users, concerning the restrictions caused by the COVID-19 Pandemic, the usability evaluation was conducted with a limited number of users. Similarly, the pilot evaluation for the prototype was not fulfilled in the way envisioned and required to prepare an on-line evaluation substituting the physical artefacts with their digital counterparts.
- Being the W3C WoT a recent standard, we could find very limited implemented projects based on the W3C WoT, especially in the CH domain. Therefore, literature supporting the research project in the phase of review was in short supply.

6.2 CONTRIBUTIONS

Contributions made by this research can be evaluated from various dimensions as follows:

a. The research opens new discussion to the application of the Web of Things paradigm proposed by the World Wide Web Consortium (W3C). The research shows the potentials of the paradigm in augmenting museum objects, managing interactions and content delivery.

   For example, a new approach can be the deployment of the Web of Things together with the Semantic Web[46] in the domain of cultural heritage, especially, in museums.

   The application of the Semantic Web in museums is not limited to a single collection but spans over other related collections in other museums. The network of semantic associations can be extended to contents of other types in other organizations, as well. It is advisable to publish digitized cultural heritage collections using semantic portals [226].

   However, in an interactive storytelling experience with WoT-enabled objects of museums, the connection of the storytelling system to the collection semantic network of other museums enables them to access information regarding heterogeneous museum collections.

[46] The term "Semantic Web" refers to W3C's vision of the Web of linked data. Semantic Web technologies enable people to create data stores on the Web, build vocabularies, and write rules for handling data [*https://www.w3.org/standards/semanticweb/*]

b. The research addresses the scarce studies in the field of tangible storytelling systems using real museum objects (replicas). The research provides an innovative study relating to the use of museum objects as interfaces to enhance the museum learning and entertainment experience.

c. The research presents an integrated model to evaluate educational and narrative aspects of the interactive storytelling system using Educational Digital Storytelling Environments (EDSE) and Interactive Digital Narrative (IDN)[47].

d. The research provides a novel application of proposed Tangible and Embodied Narrative Framework (TENF) to design physical engagement during the storytelling experience.

Moreover, the study can provide inspiration for other researchers to study the further application of the W3C WoT paradigm in the Cultural Heritage domain, for example, creating integrated systems in museums, especially museums united in a single strategic structure.

Furthermore, the study can inspire researchers in different fields to employ the idea of the research into different contexts, for example, the integration of interactive storytelling systems, like WoTEdu, into Extended Reality (XR) can be another User Experience (UX) research topic in the fields of Human-Computer Interaction and Cultural Heritage.

[47] Educational Digital Storytelling Environments (EDSE) and Interactive Digital Narrative (IDN).

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APPENDIX

APPENDIX A: DIMENSIONS FOR WOTEDU AUDIENCE EXPERIENCE DESIGN

Dimension	Dimension Description (from EDSE model)	WoTEdu Application
Collaborative Learning	Collaborative learning refers to instructional methods in which learners work together in pairs or small groups to accomplish shared goals.	*Galley crew collaboration to achieve a shared goal (arriving to destination).*
Creativity and Innovation	Creativity and innovation refers to the phenomenon whereby a person creates something new (a product, a solution, a work of art etc.)	*Each action creates an interaction with the museum artefacts; this can change the narration sequence.*
Multiple Representations	The capability to incorporate text, pictures, video, voice, graphs, diagrams into the digital story.	*WoTEdu narratives are mostly based on videos, while hints and feedback are provided using text and audio messages. Moreover, it uses an interactive map as a component of the story and to show the progress of the narration.*
Motivation	Motivation is a key factor for achieving educational goals. There are two main types of motivation: intrinsic and extrinsic. Digital Storytelling gives another dimension to learning, making students striving for learning because the material is interesting in itself.	*Intrinsic motivation in WoTEdu concerns fulfilling the task and arriving to destination* *The design of the narratives using the museum artefacts is aimed to give the further motivation of interest. In addition, extrinsic motivation might be some kind of rewards for groups who win.*
Cultural Sensitivity	The level of learners' cultural diversity adapted into the system.	*WoTEdu narratives are designed to be historically accurate and to make cultural*

		diversity not relevant in this respect. Moreover, we plan to offer narratives in different languages.
Gender Equality	Educational DST environments offer equal treatment to both genders.	*Both male and female participants can experience WoTEdu equally.*
Cognitive Effort	The environment should be as simple and understandable as possible, so that visitors can get the appropriate educational objectives.	*Using objects that are real museum artefacts should help visitors understand how to interact with them, however the combination of physical and digital features could disorient them and require more cognitive effort. This is a challenge when designing smart physical objects.*
Feedback	Feedback can be provided by the system during the story construction, warning participants when they are not following the instructions given or when they have forgotten a part of the construction of the digital story	*Both the WoTEdu storyteller and museum artefacts are designed to give feedback.*
Learner Control	Users could influence the story flow and outcome.	*Participants are provided with control so to influence the story through WoTEdu interaction affordances.*
Flexibility	How far the application is able to adapt to learners' individual preferences and background?	*Participants can freely choose their favorite stories and characters. Moreover, the behavior of objects changes depending on the user action (for example if it asks for more or less information or instructions).*
Learner Activity	The dominance of participants' active roles compared to instructor in affecting learning experience.	*Participants play an active role in the progress of the story, even though it is guided by the*

		Story and Interaction Manager, that acts as an instructor.
Value of Previous Knowledge	Cumulative previous material aid participants' understanding.	*Prior knowledge about artefacts can help to perform a rapid and correct interaction, but the goal is to limit its relevance.*
Sharply-Focused Goal Orientation	The definition of learning goals is present.	*The learning goals of WoTEdu are already defined and the whole story and the interactive map with hints are oriented toward them.*
Experiential Value	Is the process of learning through experience, and is more specifically defined as "learning through reflection on doing".	*In order to accomplish the tasks, participants have to interact with the artefacts, use them, understand what they say and what they ask for. This is aimed to foster reflection and learning by doing.*
Knowledge Organization	Knowledge organization is a domain concerned with the structuring of what is known. Concept maps and story grammars can be an effective approach for developing learner-centered storytelling tools.	*Learning goals have been designed by means of concept maps, then evolved into a graph of prerequisites and finally into the storytelling flow. Therefore, knowledge organization of concepts is the core of WoTEdu design and an educational goal as well.*
Metacognition	Metacognition is defined as knowing about knowing.	*WoTEdu is designed to make participants aware of the acquired knowledge throughout in the course of the story, when they need to use the acquired knowledge to make the story go on. This is aimed to make them aware of the value of the experience and to have an effect on satisfaction and memory.*

Dimension	Dimension Description (from IDN model)	WoTEdu Application
Usability	System usability refers to the interface design of a given application. Usability is a precondition for any enjoyable user experience. System usability is crucial for the interaction experience and therefore assumed to influence perceived effectance, autonomy and satisfaction of user expectations.	*The interaction involves digital and physical objects, some of them equipped with enhanced digital capabilities. This makes usability a challenge with regard to affordances of smart physical objects and with regard to the interaction with the whole system.*
Effectance	Effectance is about the effect a chosen action has, e.g. how meaningful it is for the narrative progression.	*Interactions performed by participants are designed to be meaningful because of natural response to actions and feedback from the system.*
Autonomy	Autonomy is regarded as a basic need of human beings that drives intrinsic motivation: we want to be free to choose.	*Participants have some freedom with regard to choosing the story, the character to experience and the artefacts to explore.*
Flow	Interactors experiencing flow are strongly engaged in their activity and succeed in blocking out any external input that could distract them.	*The tasks are designed to provide engaging narrative and interface while giving the right amount of control, so to focus on the story and its progression to the final destination.*
Presence	The concept of presence describes the sense of being present in a mediated (story-) world, which implies being engaged, absorbed by content and feeling as if transported to the story world.	*We are optimistic about the sense of presence, due to the sea museum environment and to the interaction with real museum artefacts .*
[character]Believability	For Interactive Storytelling applications this means that users will judge fictional characters on an affective level, by showing empathy, and on a	*Characters are core parts of the design since one of the learning goals of WoTEdu is making visitors discover and learn about jobs, tasks, roles and life*

	cognitive level by assessing the actions of the characters in relation to the themes and messages of the narrative	*of people in the crew, paying attention to historical accuracy and believability.*
Role-identification	By identifying with a virtual character, an interactor can feel like a hero, a rock star, or a powerful decision maker. Fulfilling the desire to be in some else's shoes can generate positive emotions such as pride, self-esteem, and self-efficacy.	*WoTEdu is designed to make participants identify with a character within a crew, thus, in addition to role-identification, also team building is a dimension aimed to generate positive emotions and engagement.*
Curiosity	In IDN curiosity may refer to progress, but also to the interactor's actionable possibilities ("What will happen if I do this?"). Curiosity is an innate basic emotion that activates uncertainty-relieving perceptions as well as quests for knowledge, which can be stored in symbolic responses. Be curious regarding the consequences of their actions.	*Since participants receive feedback and hints in response to their actions from WoTEdu, this could increase participants' curiosity and push them to try different actions to experience different reactions.*
Suspense	The concept of suspense is related to curiosity. Both experiences are rooted in a state of uncertainty. However, suspense is also fueled by aversive emotional components, such as anxiety or empathic concern (e.g. fearing the defeat of a liked protagonist)	*Since WoTEdu mainly tells challenging adventure stories, it can create feelings like anxiety, fear, and suspense.*
Eudaimonic Appreciation	Visual and auditive presentation and the particular way it engages with our personality. This kind of appreciation is derived from a combination of the prerequisites of a given artefact (design, aesthetics) and its pleasurable experience, which manifests itself for instance in sensory delight, evoked by beautiful	*This dimension is the result of many factors, some of them related to the design of the interactive storytelling and of the environmental setting, while others depending on the users' personal traits and past experience, that lead to the construction of personal*

	images, music, camera angles, narrative style, and the narrative content (character development, character fate).	*meaning from the story and the experience.*
Positive and Negative Affect	Different narratives can evoke diverse affective states in interactors. They can range from horrid to joyful, from calm to excited. While positive affect is obviously connected to enjoyment (e.g. feelings of empowerment, excitement, and pride), it is more complex for negative affect.	*WoTEdu is not designed as a single experience but as a group experience, therefore positive and negative affect can be also influenced by this condition in addition to the narratives and the goal of reaching the final destination.*
Enjoyment	Enjoyment is the most general experiential category underlying entertainment. In comparison to affect (and it more fine-grained measurements of different states of arousal), it describes a more broad experience of pleasure.	*WoTEdu aims to enjoy participants but also to foster learning and cultural heritage, which is a difficult combination, though, and the final goal of edutainment.*

APPENDIX B: QUESTIONNAIRE USED IN MOCK-UP EVALUATION

QUESTIONS for quantitative data collection (5-point Likert scale)

R1	Multiple Representations (EDSE)
	- To what extent interactive objects enhance the story's meanings? - Does the presence of different multimedia materials stimulate the user to go on with the story? - How much do you think video stories, actions and messages are harmonized to communicate the same narrative world?
R2	Experiential Value (EDSE)
	- To what extent the request of doing things increases understanding? - How much the interaction with the objects stimulates to get into the story?
R3	Learner activity (EDSE)
	- To what extent the required activities with the museum artefacts support the immersion in the narrative flow? (Model Caravel, Rudder, oars and quadrant)
R4	Collaborative Learning (EDSE)
	- To what extent the narrative flow and the required activities foster the collaboration with the other members of the group to solve the game's tasks?
R5	Sharply Focused Goal Orientation (EDSE)
	- To what extent this experience may result in knowledge acquisition about Columbus voyage and navigational instruments of the past?
R6	Flow (IDN)
	- How much do you think this interactive story can engage the user? - To what extent do you think the interaction with different objects may avoid distraction from the narrative flow? - To what extent do you think the game dynamics (e.g. game goal; challenge to gain extra time; etc…) help stay focused on the flow? - To what extent the actions required to the user are perceived as non relevant with respect to the game?
R7	Usability (IDN)
	- To what extent do you think the interaction modalities of this novel application may be difficult to understand for users?

	- About the interaction with the objects, how much do you think it may be difficult for the users? - Do you think error messages are clear and helpful? - Do you think the help icon is visible and placed in a good position?

QUESTIONS for qualitative data collection

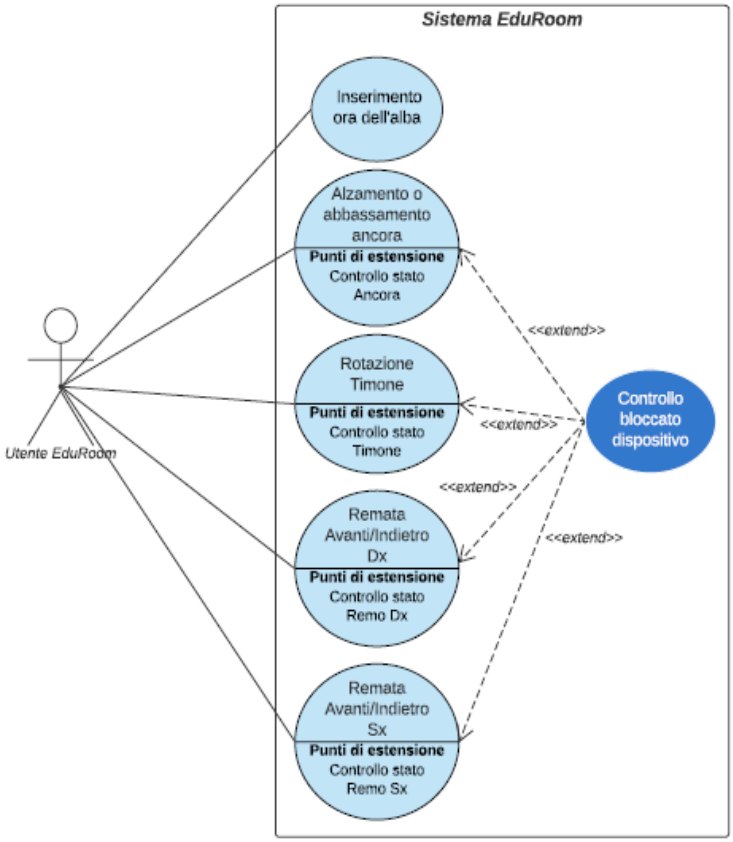
R1	Multiple Representations (EDSE)
	- Do you have comment about the question "Do interactive objects enhance the story's meanings?" - Do you have comment about the question "Does the presence of different multimedia materials stimulate the user to go on with the story?" - Do you have comment about the question "How much do you think video stories, actions and messages are harmonized to communicate the same narrative world?"
R2	Experiential Value (EDSE)
	- Do you have comment about the question "To what extent the request of doing things increases understanding?" - Do you have comment about the question "How much the interaction with the objects stimulates to get into the story?"
R3	Learner activity (EDSE)
	- Do you have comment about the question "To what extent the required activities with the museum artefacts support the immersion in the narrative flow? (Model Caravel, Rudder, oars and quadrant)"
R4	Collaborative Learning (EDSE)
	- Do you have comment about the question "To what extent the narrative flow and the required activities foster the collaboration with the other members of the group to solve the game's tasks?"
R5	Sharply Focused Goal Orientation (EDSE)
	- Do you have comment about the question "To what extent this experience may result in knowledge acquisition about Columbus voyage and navigational instruments of the past?"
R6	Flow (IDN)

	- Do you have comment about the question “How much do you think this interactive story can engage the user?” - Do you have comment about the question “To what extent do you think the interaction with different objects may avoid distraction from the narrative flow?” - Do you have comment about the question “To what extent do you think the game dynamics (e.g. game goal; challenge to gain extra time; etc…) help stay focused on the flow?” - Do you have comment about the question “To what extent the actions required to the user are perceived as non relevant with respect to the game?”
R7	Usability (IDN)
	- Do you have comment about the question “To what extent do you think the interaction modalities of this novel application may be difficult to understand for users?” - Do you have comment about the question “About the interaction with the objects, how much do you think it may be difficult for the users?” - Do you have comment about the question “Do you think error messages are clear and helpful?” - Do you have comment about the question “Do you think the help icon is visible and placed in a good position?”
The story	- The story is useful to learn more on …..? Columbus' story, ways to sail in the past and navigation tools, Colonialism, or other topics? Please explain why.
Overall	- Do you have any general comments on the mock-up?

APPENDIX C: STRUCTURAL DESIGN OF WOTEDU

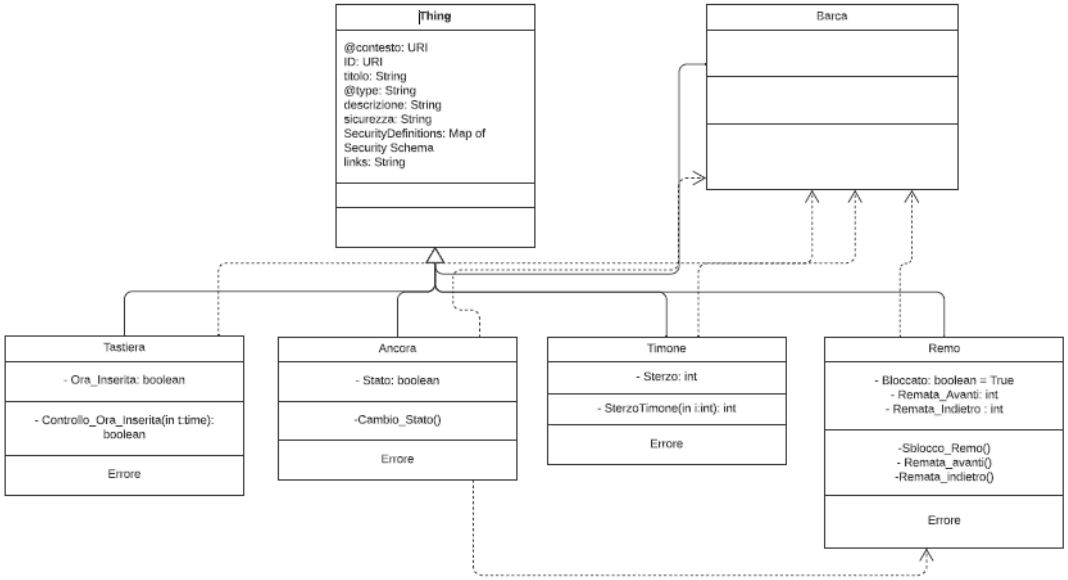
APPENDIX C1: WOTEDO USE CASE DIAGRAM

The WoTEdo Use Case Diagram, based on the interaction flow represented in Chapter 4, Figure 19, depicts all system functions and user's possible interactions with the WoTEdu Interactive storytelling system.



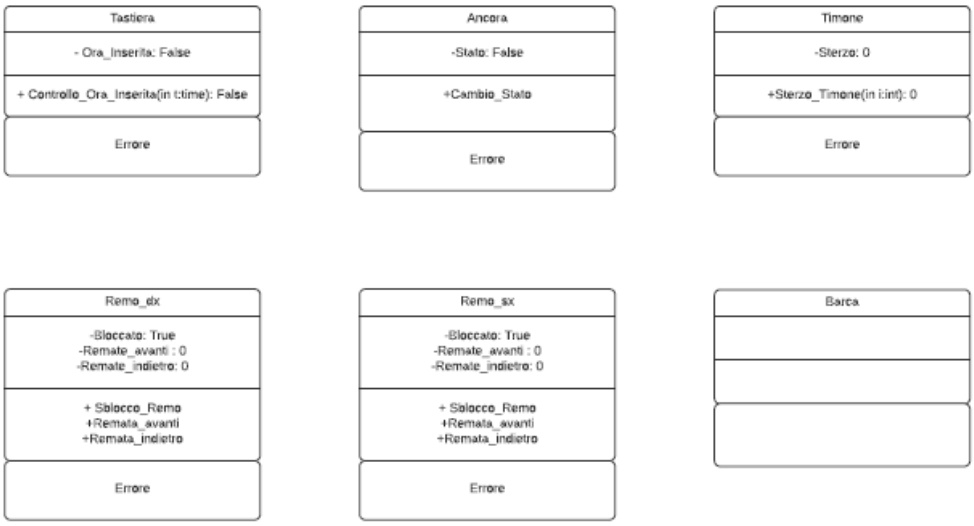
WoTEdo Use Case Diagram.

APPENDIX C2: WOTEDU CLASS DIAGRAM

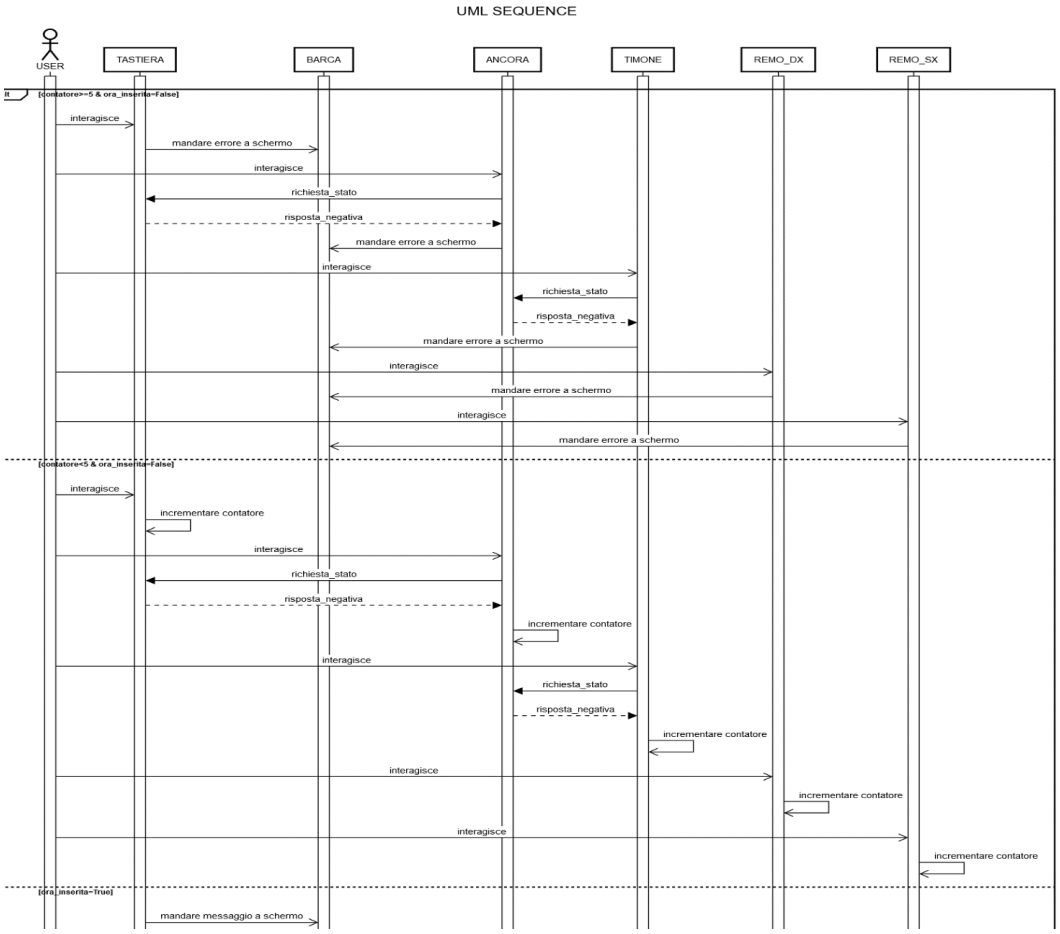


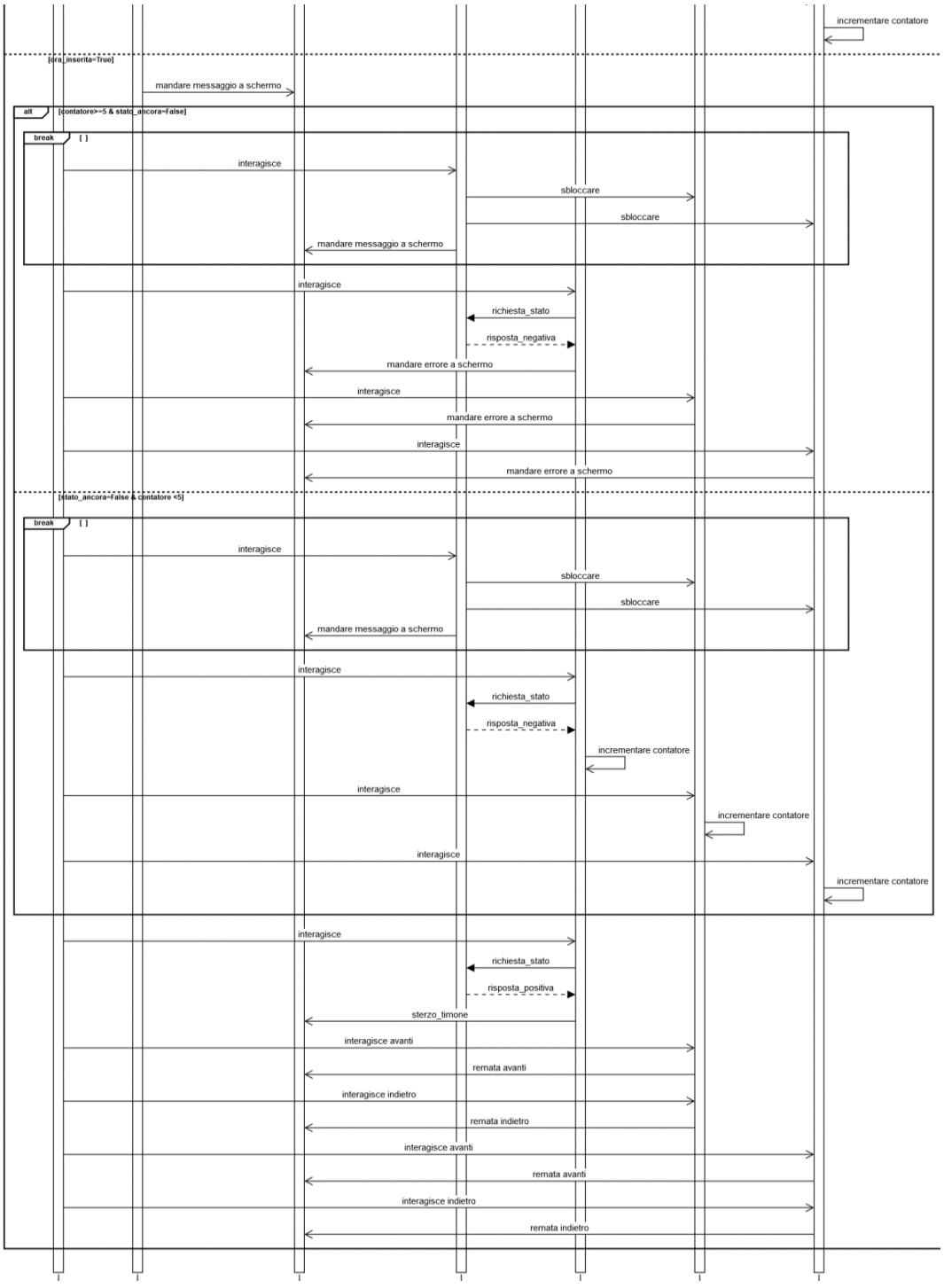
In the UML diagram of the classes shown in Appendix C2, the starting point is the superClass Thing, which defines all the main properties that each Thing requires in order to be defined. These are a URI for defining the context and ID, strings for defining the title, type, links, description and security protocol adopted and a mapping of the security scheme. All the subclasses inherit these fields, they also have their own, which can be easily deduced from the names and values indicated in the diagram itself.

APPENDIX C3: WOTEDU OBJECT DIAGRAM

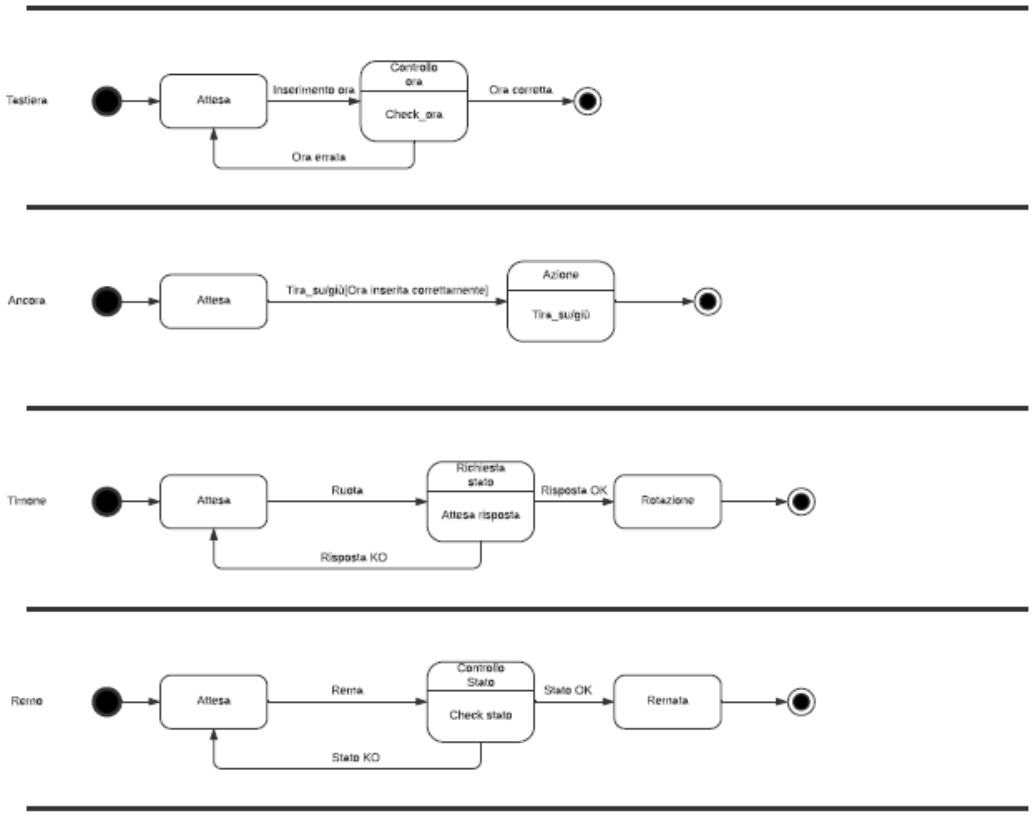


APPENDIX C4: WOTEDU DYNAMIC MODEL: SEQUENCE DIAGRAM

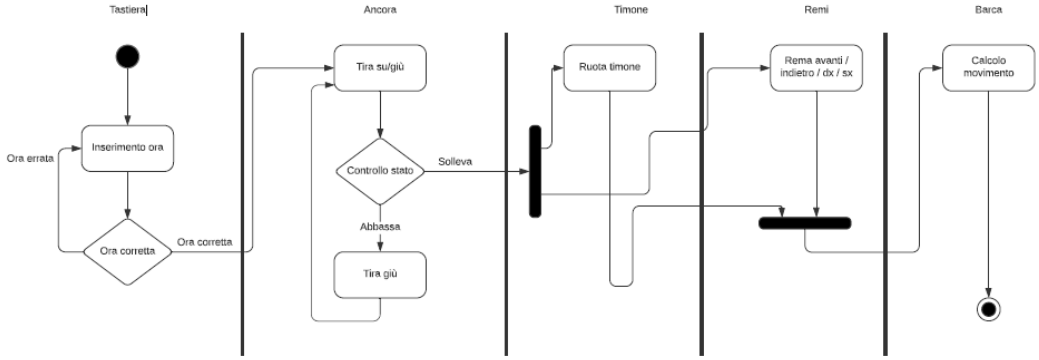



incrementare contatore
[ora_inserita=True]
mandare messaggio a schermo
alt
[contatore>=5 & stato_ancora=False]
break
[ ]
interagisce
sbloccare
sbloccare
mandare messaggio a schermo
interagisce
richiesta_stato
risposta_negativa
mandare errore a schermo
interagisce
mandare errore a schermo
interagisce
mandare errore a schermo
[stato_ancora=False & contatore <5]
break
[ ]
interagisce
sbloccare
sbloccare
mandare messaggio a schermo
interagisce
richiesta_stato
risposta_negativa
incrementare contatore
interagisce
incrementare contatore
interagisce
incrementare contatore
interagisce
richiesta_stato
risposta_positiva
sterzo_timone
interagisce avanti
remata avanti
interagisce indietro
remata indietro
interagisce avanti
remata avanti
interagisce indietro
remata indietro

APPENDIX C5: WOTEDU STATE MACHINE DIAGRAM



APPENDIX C6: WOTEDU ACTIVITY DIAGRAM



APPENDIX D: THINGS AND METHODS USED IN THE WOTEDU PROJECT

Note: The WoTEdu project codes are available in the following link:

https://drive.google.com/drive/folders/1mtJwsaJtHXI-WNlEbgKekxnvJzZWHbFc?usp=sharing

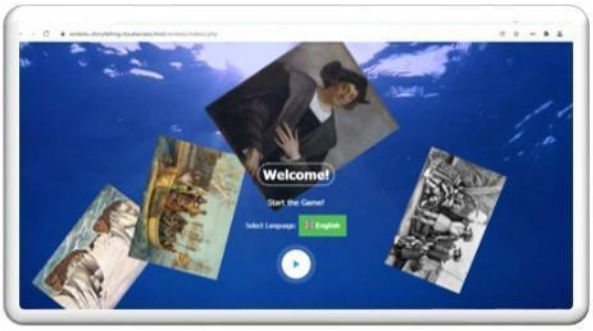
Things	Implementation details
Keypad.ino	The numeric keypad has the function of allowing the use of other *Things* once the sunrise time is correctly inserted, however it must have the correct time memorized and check the time validity once the user inserts it. - *Keypad.getKey*: returns the whole number pressed on a KeyBoard device connected via USB.
Ancora.ino	The anchor has the function of allowing the use of other *Things* once is raised, note that this can only be used after the correct sunrise time inserted correctly. In addition, the anchor manages the unlocking of the oars (via http post) and the rudder. The behavior of the anchor was simulated through the use of a button.
Remo dx/sx.ino	The oars (both right and left) are used to allow the boat to move, in particular to translate, along its course. The two oars can be used only after correct use of the *Keypad* and A*nchor*. The movement of the oars is combined with the rotation of the rudder to allow the user to implement the movement of the boat in a free and coherent way. The behavior of the oars was simulated through the use of a rotary for each oar, in particular an oaring movement is counted every time the rotary makes (approximately) 40 clicks in the same direction. The oaring forward or backward is implemented with a *Boolean* value (false = rowed back, true = rowed forward), and the behavior of both oars is identical.
Timone.ino	The rudder allows the boat to rotate and, therefore change its direction. The rudder can only be used after inserting the correct time and raising the anchor. The behavior of the rudder is simulated thanks to the use of a rotary (functioning in the same way as the oars). The movements made by the rudder are communicated to the boat via a post-type http call. The rudder acts in conjunction with the movement of the oars to allow the boat to sail as desired.
Barca.ino	The boat is used to coordinate and regulate all the information that is generated by Things, their communications and their use. In particular. Barca.ino is the Thing that also allows the management of the interactive screen, the events of the Things and the movement of the cursor on the map - that represents the boat movement. In fact, there is an array of 5 values (associated with the 5 Things previously illustrated) for managing events: whenever an event is triggered relating to errors in the execution of the *actions* in the correct order, the value

	corresponding to the Thing is changed in the array (it is set = 1). In the case of particular events such as that of the anchor, the value is set to -1 to allow to send the right message on the screen. The movement function allows user to manage the use of the oars and the rudder, converting each physical movement into its correspondent on the map. The boat also has an html file that must be launched on the processor file system to allow the map content to be displayed. - *SPIFFS.begin*: this method allows to launch the file system and returns true or false depending on the success or failure of this operation. - *SPIFFS.open* (path, mode): opens the file declared in the path in the manner described in mode. Input: path: the path of the file to open, mode: opening mode (r = read, w = write etc ...). - *Request-> send* (fs, path, contentType, download, processor_callback): allows to make requests to the file indicated in the filesystem. Input: fs: the file system address, path: the path to which to make the call, contentType: the type of content to pass in the call). - *Request-> hasParam* (param, value): allows to know if a certain parameter to which the call will be made has a certain value. Input: param: the parameter to check the value, value: the value that can be assumed by the param
Index.html	The Index.html file in the data folder located at the Barca.ino file, because the file will subsequently be loaded on the file system of the processor that deals with the boat. The index.html file manages the display of the dynamic map, shows the events that are triggered during the execution of the system and manages the arrival on the lands and in the places of interest that involved the first voyage of Columbus towards the America. The file contains the various css classes, the svg map with all its components and finally the part dedicated to JavaScript. The latter in particular allows to manage all aspects of movement within a *setInterval* function which obtains the coordinates (inscribed in a rectangle) of all the important places and then makes a comparison with the position (current or future) of the cursor and therefore decide whether to show popups on the screen. Pop-ups are divided into different categories: there are *text-only* popups, those with *text and video*. The text-only popups do not block navigation and those that have text and video and block the possibility of moving along the route for predetermined time. There are other functions for blocking the movement, managed thanks to a timeout and the *toggle_visibility* function that allows to exchange the visibility attributes of two different objects.

APPENDIX E: STORYBOARD FOR ONLINE WOTEDU EXPERIENCE

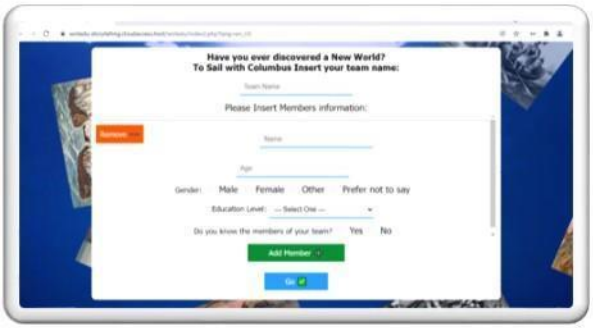
Note: The on-line WoTEdu experience prepared for USE-SF heuristic evaluation is available in

https://wotedu-storytelling.cloudaccess.host/wotedu/index.php

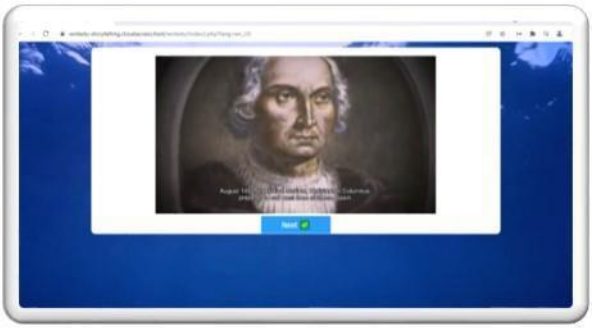


1 Select the language of the experience.

2 Giving some general information about the WoTEdu system.



3 Participants' registration page. The insert a group name and some personal data.

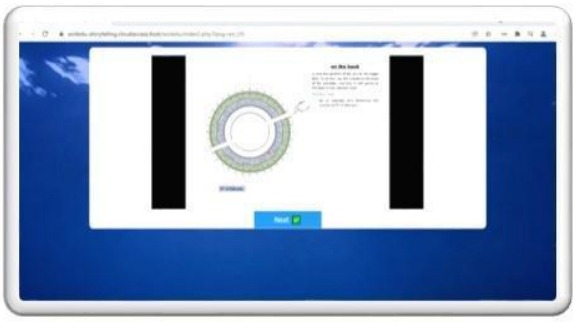


4 An introduction video about the Columbus' voyages.

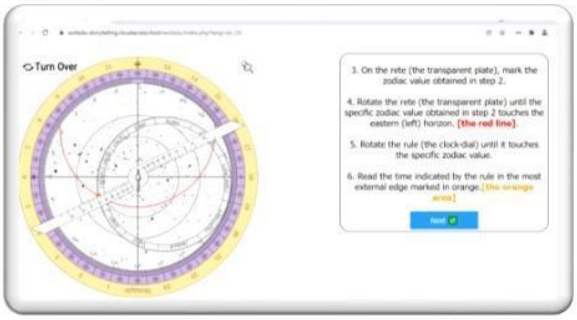
5 The first challenge before start to sail. Participants need to select instruments that they may need during their voyage.

6 If they select correct options they can gain some bonuses that would be added to their final score.

7 Participants are told to find the sunrise time, departure time, by using an astrolabe.



8 A video explains what is an atrolabe and how can be used.

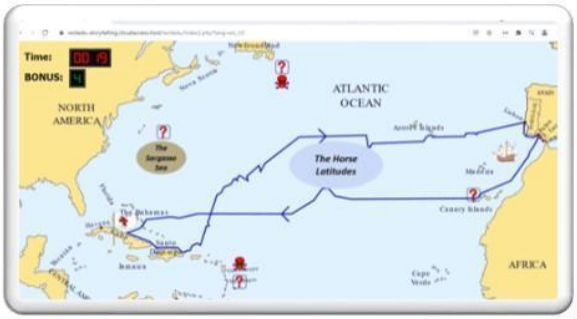


9 Participants can use a digitally implemented interactive astrolabe.

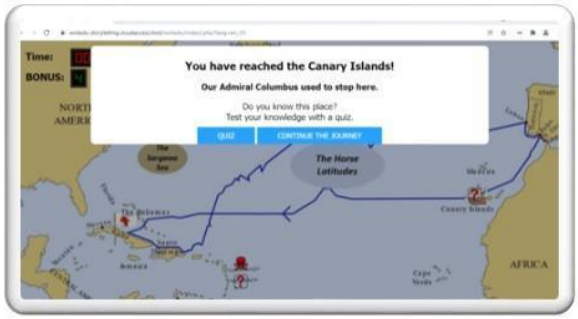
10 They have three attempts to insert the correct sunrise time to gain a bonus.

11 Before starting the sailing, they need to raise the anchor. They can fulfil this task by playing a click-speed game.

12 Participants are asked to use the keyboard arrows to move on the galley Ocean.



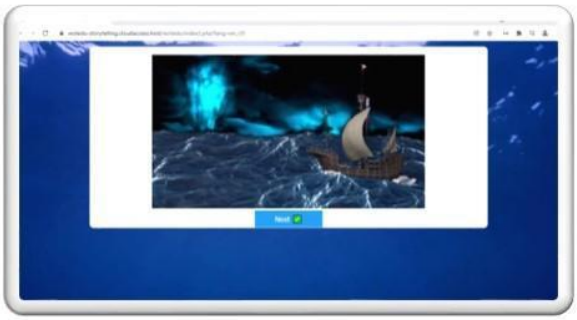
13 Participants start to sail from Spain and can move on the map by using keyboard arrows (←↑↓→) .



14 The first challenge on the map that participants undertake is a quiz to answer when they arrive the Canary Islands.

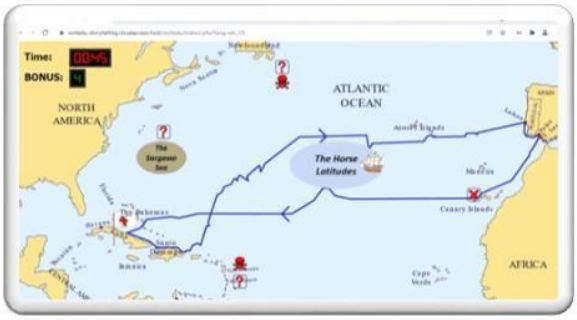
15 Participants answer a multiple choice quiz on the Canary Islands.

16 An unexpected storm is faced after leaving the Canary Islands.

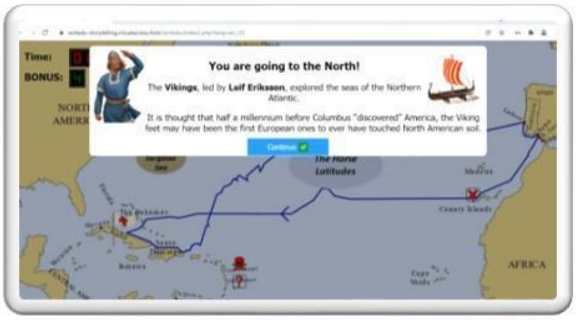


17 A video illustrates the galley in the stormy Ocean that conveys the situation.

18 After the storym participants are informed that they are driven to the Horse Latitude.



19 Participans find the galley in the Horse Latitudde area and need to oar faster to leave this area.

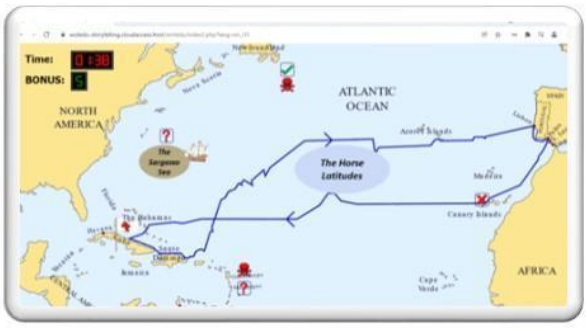


20 When the galley goes towards the North, a pup-up indicates a brief history about the Vikings exploration of the Nwe World.

21 There is another checkpoint in the North that participants need to visit.

22 When participants arrive the checkpoint, a video shows the galley among the icebergs. The galley strikes an icberg and gets broken.

23 To repair the galley, participants are asked to play a puzzle game to put all parts of the galley together.

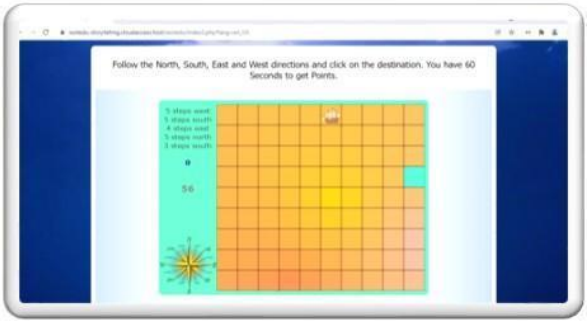


24 Participans face another quiz in the Sargasso Sea.

25 Participants answer another historical fact in the quiz about the Sargasso Sea.

26 In the southern part of the map, there is another checkpoint to visit.

27 Participants answer a quiz in the South about the magnetic deviation that affects the function of a compass.



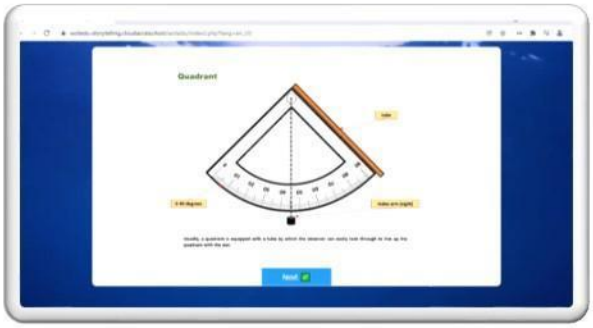
28 After the game participants play a compass game.

29 After visiting all of the checkpoints, participants reach the destination.

30 Participants are asked to lower the anchor in the position.

31 Participants lower the ancher playing a click-speed game.

32 Participants are invited to take part in the last challenge, which is calculating the latitude of the destination.



33 A video explains what a quadrant is and how it works.

34 Participants can work with an interactive quadrant to calculate the latitude of their position.

35 After calculatin the latitude, participants insert the value.

36 The experience terminated with inserting the correct answer and participants can see details about their score and experience time.

APPENDIX F: USER ENGAGEMENT SCALE LONG FORM (UES-LF)

FA.1 I lost myself in this experience.

FA.2 I was so involved in this experience that I lost track of time.

FA.3 I blocked out things around me when I was using Application X.

FA.4 When I was using Application X, I lost track of the world around me.

FA.5 The time I spent using Application X just slipped away.

FA.6 I was absorbed in this experience.

FA.7 During this experience I let myself go.

PU.1 I felt frustrated while using this Application X.

PU.2 I found this Application X confusing to use.

PU.3 I felt annoyed while using Application X.

PU.4 I felt discouraged while using this Application X.

PU.5 Using this Application X was taxing

PU.6 This experience was demanding.

PU.7 I felt in control while using this Application X.

PU.8 I could not do some of the things I needed to do while using Application X.

AE.1 This Application X was attractive AE.2 This Application X was aesthestically appealing

AE.3 I liked the graphics and images of Application X.

AE.4 Application X appealed to be visual senses.

AE.5 The screen layout of Application X was visually pleasing.

RW.1 Using Application X was worthwhile.

RW.2 I consider my experience a success.

RW.3 This experience did not work out the way I had planned.

RW.4 My experience was rewarding.

RW.5 I would recommend Application X to my family and friends

RW.6 I continued to use Application X out of curiosity.

RW.7 The content of Application X incited my curiosity.

RW.8 I was really drawn into this experience.

RW.9 I felt involved in this experience.

RW.10 This experience was fun.

APPENDIX G: USER ENGAGEMENT SCALE SHORT FORM (UES-SF) QUESTIONNAIRE

FA-S.1 I lost myself in this experience.

FA-S.2 The time I spent using Application X just slipped away.

FA-S.3 I was absorbed in this experience.

PU-S.1 I felt frustrated while using this Application X.

PU-S.2 I found this Application X confusing to use.

PU-S.3 Using this Application X was taxing.

AE-S.1 This Application X was attractive.

AE-S.2 This Application X was aesthetically appealing.

AE-S.3 This Application X appealed to my senses.

RW-S.1 Using Application X was worthwhile.

RW-S.2 My experience was rewarding.

RW-S.3 I felt interested in this experience.

APPENDIX H: RESEARCH INFORMED CONSENT FORM

Dear participants,

Thank you for your time. The researcher requests your consent for participation in a study about the WoT-enabled installation designed for the Galata-the Maritime Museum of Genoa in Italy.

You will be participating in an online simulation of an experience that is intended to be installed in the museum with some of the using physical elements such as oars and anchor.

- This consent form asks you to allow the researcher to record and view your participation, the interview and to use your comments to evaluate the designed installation. The form also asks your permission to use related observations, images or posts as data in this study.

- The data gathering process will consist of recording our discussion on Zoom. The data will be treated in accordance with GDPR. The data will be transcribed and anonymized.

- Footages and images might be used in publications, but if so no names will be used and images will be blurred so that participants cannot be identified. If this will not be possible, we will contact you for a specific permission.

- If you at any point feel uncomfortable, you have the right to withdraw your consent. If in the future, you would want to know more about the progress of the project or withdraw your consent you can contact the researcher via email.

Mortaza Alinam

PhD Candidate, University of Genoa

m_alinam@yahoo.com

APPENDIX I: SEMI-STRUCTURED QUESTIONS FOR PROTOTYPE EVALUATION

Q1: What impressions did the experience leave you?

Q2: What have you learned?

Q3: Were you bored during the experience?

Q4: Did you find it difficult to carry out the challenges posed by "Sail with Columbus"?

Q5: Would “Sail with Columbus” affect your visit to the museum?

Q6: Did you collaborate with the other participants during the experience?